



8TH INTERNATIONAL ANATOLIAN AGRICULTURE FOOD, ENVIRONMENT AND BIOLOGY CONGRESS

11-12 Haziran 2026

Sinop - TÜRKİYE

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PREFACE

Dear Colleagues...

The " 8th International Anatolian Agriculture, Food, Environment and Biology Congress (TARGID 2026) " has been held in Sinop/Türkiye on 11-12 June 2026, with the participation of scientists working in agriculture and related sciences, with the aim of sharing scientific developments, proposing scientific solutions to international problems, increasing cooperation and creating scientific outputs that will benefit humanity by using international resources economically.

A total of 296 papers from 37 countries were presented to our congress. Of these papers, 158 came from foreign countries and 138 came from Türkiye. The countries of the participants who submitted papers to the congress and the number of incoming papers are as follows: Algeria (5), Azerbaijan (5), Bangladesh (15), Benin (4), Bosnia and Herzegovina (1), Bulgaria (1), Chad (1), China (4), Côte d'Ivoire (1), Ethiopia (3), Ghana (4), Hungary (3), India (0), Iraq (1), Iran (11), Italy (5), Kazakhstan (5), Kenya (1), Malaysia (4), Moldova (1), Morocco (1), Nepal (5), Niger (3), Nigeria (25), Pakistan (18), Philippines (1), Poland (4), Somalia (2), Spain (1), Sri Lanka (7), Sudan (4), Tanzania (1), Tunisia (5), Uganda (2), Ukraine (1), United States (2), Zimbabwe (1), and Türkiye (138). The rate of international papers was 53.4%, while papers from Türkiye accounted for 46.6% of the total.

At the congress; participants discussed such topics as animal production, crop production, aquaculture, food science and technologies, agricultural technologies, soil science, sustainable agricultural systems, agricultural economics, genetics, biology, agricultural ecology, landscape architecture and agricultural environment issues related to original, advanced technology on agriculture and natural life.

During the organization and congress phases of TARGID 2026, Assoc. Prof. Dr. Burak Şen, Prof. Dr. Cem Baltacıoğlu, Assoc. Prof. Dr. Hande Baltacıoğlu, Assist. Prof. Dr. Mustafa Duman, Assist. Prof. Dr. Mutlu Bulut, Assist. Prof. Dr. Ali Kaan Yetik, Assist. Prof. Dr. Mehmet Yetişen, Ahmet Akyol, Furkan Baş, Muhammet Talha İnce, and Ulrich Sosthène Hodonou took on important responsibilities in the congress secretariat.

We would like to express our gratitude to all our stakeholders who supported the successful realization of our congress and all the scientists who participated and supported us with their papers.

Kind regards





ÖNSÖZ

Değerli Meslektaşlarımız,

Tarım ve ilgili bilim alanlarında çalışan bilim insanlarının katılımıyla gerçekleştirilen "8. Uluslararası Anadolu Tarım, Gıda, Çevre ve Biyoloji Kongresi (TARGID 2026)", bilimsel gelişmelerin paylaşılması, uluslararası sorunlara bilimsel çözümler sunulması, iş birliğinin artırılması ve uluslararası kaynakların ekonomik ve etkin bir şekilde kullanılması yoluyla insanlığa fayda sağlayacak bilimsel çıktılar oluşturulması amacıyla 11–12 Haziran 2026 tarihlerinde Sinop/Türkiye’de gerçekleştirilmiştir.

Kongremize 37 ülkeden toplam 296 bildiri sunulmuştur. Bu bildirilerin 158’i yabancı ülkelerden, 138’i ise Türkiye’den gelmiştir. Kongremize bildiri gönderen katılımcıların ülkeleri ve gönderilen bildiri sayıları şu şekildedir: Cezayir (5), Azerbaycan (5), Bangladeş (15), Benin (4), Bosna-Hersek (1), Bulgaristan (1), Çad (1), Çin (4), Fildişi Sahili (1), Etiyopya (3), Gana (4), Macaristan (3), Hindistan (0), Irak (1), İran (11), İtalya (5), Kazakistan (5), Kenya (1), Malezya (4), Moldova (1), Fas (1), Nepal (5), Nijer (3), Nijerya (25), Pakistan (18), Filipinler (1), Polonya (4), Somali (2), İspanya (1), Sri Lanka (7), Sudan (4), Tanzanya (1), Tunus (5), Uganda (2), Ukrayna (1), Amerika Birleşik Devletleri (2), Zimbabve (1) ve Türkiye (138). Uluslararası bildirilerin toplam bildiriler içerisindeki oranı %53,4, Türkiye’den sunulan bildirilerin oranı ise %46,6 olarak gerçekleşmiştir.

Kongrede; hayvansal üretim, bitkisel üretim, su ürünleri yetiştiriciliği, gıda bilimi ve teknolojileri, tarımsal teknolojiler, toprak bilimi, sürdürülebilir tarım sistemleri, tarım ekonomisi, genetik, biyoloji, tarımsal ekoloji, peyzaj mimarlığı ve tarımsal çevre konularının yanı sıra tarım ve doğal yaşamla ilişkili özgün ve ileri teknoloji uygulamaları ele alınmış ve tartışılmıştır.

TARGID 2026’nın organizasyon ve kongre süreçlerinde; Doç. Dr. Burak Şen, Prof. Dr. Cem Baltacıoğlu, Doç. Dr. Hande Baltacıoğlu, Dr. Öğr. Üyesi Mustafa Duman, Dr. Öğr. Üyesi Mutlu Bulut, Dr. Öğr. Üyesi Ali Kaan Yetik, Dr. Öğr. Üyesi Mehmet Yetişen, Ahmet Akyol, Furkan Baş, Muhammet Talha İnce ve Ulrich Sosthène Hodonou kongre sekreteryasında önemli görevler üstlenmişlerdir.

Kongremizin başarıyla gerçekleştirilmesine katkı sağlayan tüm paydaşlarımıza ve bilimsel çalışmalarıyla kongremize katılım göstererek bizleri destekleyen tüm bilim insanlarına teşekkürlerimizi sunarız.

Saygılarımızla





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Yayın Ve Düzenlemede Görevlendirilmiş Akademisyen Temsilci

11–12 Haziran 2026 tarihinde Sinop/Türkiye’de “8. Uluslararası Tarım, Gıda, Çevre ve Biyoloji Kongresi (TARGID 2026)” gerçekleştirilmesinde, Niğde Ömer Halisdemir Üniversitesi Rektörlüğü’nün 04/02/2026-777021 sayısı olurları ile aşağıda isimleri verilen akademisyenlere **yayın ve düzenlemede akademik temsilci** olarak yer almalarına izin verilmiştir.

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Arş. Gör. Ahmet AKYOL
Arş. Gör. Furkan BAŞ
Arş. Gör. Muhammet Talha İNCE





ULUSLAR ARASI KONGRE ÖZELLİKLERİ

1. Ülkelere göre bildiri sayıları

No.	Ülke	Bildiri sayısı
1	Algeria	5
2	Azerbaijan	5
3	Bangladesh	15
4	Benin	4
5	Bosnia and Herzegovina	1
6	Bulgaria	1
7	Chad	1
8	China	4
9	Côte d'Ivoire	1
10	Ethiopia	3
11	Ghana	4
12	Hungary	3
13	Iran	11
14	Iraq	1
15	Italy	5
16	Kazakhstan	5
17	Kenya	1
18	Malaysia	4
19	Moldova	1
20	Morocco	1
21	Nepal	5
22	Niger	3
23	Nigeria	25
24	Pakistan	18
25	Philippines	1
26	Poland	4
27	Sri Lanka	7
28	Somalia	2
29	Spain	1
30	Sudan	4
31	Tanzania	1
32	Tunisia	5
33	Türkiye	138
34	Uganda	2
35	Ukraine	1
36	USA	2
37	Zimbabwe	1





2. Bilim Kurulunda Yer Alan Yabancı Akademisyenler

(Toplam: 11 yabancı akademisyen, 8 farklı ülke)

Sıra	Unvan	Ad Soyad	Kurum	Ülke
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11	Dr. Öğr. Üyesi	Muhammad Habib-ur-RAHMAN	Georg-August-University of Göttingen	Almanya

3. Yurt dışı katılım oranı

Group	Number of countries	Participation	Percentage
Türkiye	1	138	46.62%
Yurt dışı	36	158	53.38%
Total	37	296	100.00%

Yukarıda verilen bilgiler çerçevesinde, 11-12 Haziran 2026 tarihinde Sinop/Türkiye’de “ 8. Uluslararası Tarım, Gıda, Çevre ve Biyoloji Kongresi (TARGID 2026) ”, uluslararası kongre niteliği taşımakta, akademik teşvik kriterleri ve UAK Doçentlik başvuru koşullarını **sağlamıştır**.





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Study of Some Biozootechnical and Hereditary Characteristics of Black-and-White Dairy Cattle

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Abstract

The article investigates certain biozootechnical and hereditary characteristics of Azerbaijani Black-and-White cattle. The research was conducted on Black-and-White cattle raised in private farms located in the Samukh and Shamkir districts. **Problem and objective:** The study focuses on important productive and biological traits of this breed, particularly the relationship between live body weight and milk productivity. Another characteristic feature is the high milking rate during machine milking, expressed as milk yield per minute, which is of practical importance in dairy production systems. **Methods:** Through long-term selection, a reduction in calf birth weight has been achieved, which has helped to prevent difficult calving in the population. Under Azerbaijani conditions, animals of this breed reach approximately 340 kg live weight at 18–20 months of age, attain sexual maturity, and are inseminated. By 29–30 months of age, they enter the production cycle, allowing them to calve twice. Their service period and dry period remain within acceptable zootechnical standards. The average calving interval is 352 days, which ensures the production of approximately one calf per year under normal management conditions. **Result:** Research findings indicate that an increase in live body weight does not negatively affect milk production; on the contrary, it has a stimulating effect. Crossbreeding with local cattle breeds resulted in hybrid animals showing 25–30% higher levels of total protein, total globulins, and gamma globulins compared to purebred Black-and-White cattle. This demonstrates improved immune response and higher adaptive capacity, inherited from local breeds. **Conclusion:** The milk productivity index of Black-and-White cows raised in Azerbaijan is close to European standards of this breed. The results suggest that farmers should prioritize animals with higher body weight and better milk productivity. Scientifically based breeding programs that consider genetic and zootechnical characteristics contribute to higher efficiency and improved productivity in dairy farming systems.

Keywords: Black-and-White breed, milk productivity, milk fat content, live body weight, hereditary characteristics.

Introduction

In our republic, the population's demand for raw milk and dairy products is mainly met through cattle breeding. Therefore, in order to increase milk production in the country, priority should be given to improving the milk yield and quality of cattle. Accordingly, the heads of specialized dairy farms should focus on keeping cows of the Black-and-White breed, which has proven effective in global cattle breeding, is well adapted to the climate of our republic, and has a sufficiently developed breeding base in the country, as well as high productivity potential. In livestock production, the main products obtained are milk, meat, and hides and skins. The most valuable product of cattle breeding is milk and its derivatives, such as butter, cheese, sour cream, yogurt, cottage cheese, and others. Beef is highly nutritious and, at the same time, is cheaper compared to the meat of other animal species. High-quality footwear leather is produced exclusively from cattle hides [1,2].

Cattle herds in the country consist of 46.5% purebred and improved animals. Among them, 19.9% are purebred cattle, while 26.6% are crossbred (genetically improved) livestock. In the republic, 24.9% of the animals belong to the Brown Caucasian breed, 21.6% to the Black-and-White breed, 11.8% to the Holstein-Friesian breed, 6.2% to the Simmental breed, and 5% to the Swiss breed. The highest concentration of cattle in the country is found in the Sabirabad and Jalilabad districts. In Sabirabad district, there are 109,716 head of cattle (including 54,483 cows and buffaloes), while in Jalilabad district there are 98,968 head of cattle (including 49,969 cows and buffaloes). Overall, 38.7% of the national cow population is concentrated in the farms of the Aran economic region [3,4].

The selective breeding and maintenance of dairy types within Black-and-White cattle breeds is beneficial from both zootechnical and economic perspectives. In addition, in order to increase milk productivity and improve the economic efficiency of milk production in dairy cattle farms, special attention should be paid to the following zootechnical factors [5].



Materials and Methods

In order to meet the increasing demand of the population for milk and dairy products at a high level, large-scale importation of the world's most valuable dairy cattle breed, the Black-and-White cattle, was initiated into the country. Over the past 30–35 years, this breed has become the leading cattle breed in the republic. During this period, the breed has been developed in the country through two main approaches: pure breeding and crossbreeding. In the latter method, offspring of local and imported breeds have been crossed with Black-and-White sires. The resulting third-generation crossbreds have been bred “within themselves” over the last 10 years. It should also be noted that, at present, cattle farms belonging to farmers, private owners, and state breeding enterprises in the republic are largely composed of cattle imported from Europe. In these farms, purebred Black-and-White cattle, fully adapted to local conditions and obtained under domestic management, are being raised. Currently, the share of this breed in the national cattle population exceeds 60%.

In the last 10 years, the Black-and-White cattle breed has been successfully raised in practically all regions of the republic. The rapid dissemination of this breed across all regions is explained by its possession of a number of biological, genetic, zootechnical, and technological characteristics, many of which have already become hereditarily fixed traits.

For example, milk fat content was increased in England from 3.63% to 3.86% over a 30-year period (by 0.23%), in the United States from 3.73% by 0.38% over 40–45 years, in Switzerland to 4.01% over 70 years (by 0.63%), and in Poland to 3.87% over 23 years (by 0.53%). Although the milk fat content of this breed under Russian conditions ranges between 3.2% and 3.6%, in the Republic of Azerbaijan this indicator reaches 3.9–4.21% and higher levels. One of the biological and economic advantages of the Black-and-White breed is that, alongside increased milk productivity, the fat content of milk also rises. Looking at the history of the breed, it can be seen that the milk yield of Dutch Black-and-White cattle increased from 4,001 kg in 1905 to 5,297 kg in 1976, accompanied by an increase in milk fat content from 3.17% to 4.23%. In Germany, the milk yield of this cattle breed increased from 4,158 kg in 1950 to 5,233 kg in 1976, while milk fat content rose from 3.45% to 4.03%. In the United States, over a 51-year period, milk productivity increased by 2,445 kg, while milk fat content increased by 0.38%. This positive relationship between milk productivity and milk fat content has been observed not only in Dutch Black-and-White cattle but also in more than 35 of its global derivatives.

Results and Discussion

One of the valuable characteristics of this breed is the positive correlation between live body weight and milk productivity. This trait also has a strong hereditary basis. In other cattle breeds, an increase in live weight above 450–500 kg often leads to a decrease in milk yield; however, in Dutch Black-and-White cattle and all its derivatives, an increase in live weight of cows up to 700 kg is accompanied by a corresponding increase in milk productivity. It is suggested that this characteristic is associated with the specialization of metabolic processes toward milk synthesis, resulting in the preferential utilization of nutrients from feed for milk production.

In addition to all these positive traits, Black-and-White cows are also characterized by a high milk flow rate during machine milking (the amount of milk obtained per minute). Another valuable feature of this breed is that, through long-term selection, a reduction in calf birth weight has been achieved, thereby preventing difficult calving in this cattle population. It should also be noted that calves born with a low live weight (18–20 kg) exhibit intensive growth after birth. Therefore, at 18 months of age, heifers reach about 70% of their mothers' live weight and, as a rule, attain 320–340 kg at 18–19 months of age. All these positive characteristics are also observed in Black-and-White cattle kept in peasant (farmer), private, and state farms of the Republic of Azerbaijan. Thus, this breed fully expresses all the advantageous traits it acquired in its country of origin under local conditions.

In connection with all the above, the generalized results of our long-term research conducted on Black-and-White cattle in farms located in different regions of the republic are presented in Table 1 below.

Table 1. Characteristics of reproductive ability of black-and-white female cattle

№	Indicators	On average M±m	Hesitation
1	Age at first conception (months)	19,5±2,26	18,3-20,8
2	Live weight at fertilization (kg)	340±3,34	325-355
3	Live weight at first birth (kg)	450±4,48	435-470
4	Duration of labor in hours	9±0,75	7,5-40
5	End of postpartum period (time of fall of the umbilical cord around the baby), in hours	3,2±0,09	2,8-3,6
6	Service period in I lactation, days	65±2,46	60-71
7	Drying period, days	60±2,67	56-64
8	Intercalation time, days	352±4,6	345-361
9	Factor of utilization of reproductive capacity of female calves, %	92,4±4,26	88-100



From the analysis of the figures presented in Table 1, it can be seen that the black-and-white Dutch cattle and its derivatives, which have gained fame all over the world, can also show their useful biological, genetic and zootechnical potential in our conditions. Thus, animals of this breed, even in Azerbaijani conditions, reach the age of 18-20 months, reach 340 kg of live weight, become fertile, and enter the production cycle by giving birth twice at 29-30 months. Also, their service period and drying period are within the zootechnical norm. The average intercalation period in this cattle is 352 days, which ensures that one calf is obtained from them per year. Most importantly, the coefficient of utilization of the reproductive capacity of female calves in cattle of this breed is high (92.4-100%).

The milk yield of those animals was as shown in Table 2, for the example of a collective farm in the Samukh region.

As can be seen from the figures in Table 2, black-and-white cows of Dutch origin, raised in the Ismayilli region of the republic under conditions of good and abundant feeding, are able to use their productive potential at a high level. Thus, the milk yield of the breed in middle-aged cows (III lactation) has reached a fairly high level for our republic (4260 kg). At the same time, the fat content of their milk is at the level of the fat content of the milk of Dutch cows, close to the level of local cattle breeds of Azerbaijan. It should also be noted that both in this farm where we conducted the research and in the black-and-white cattle herds in other intensive dairy farming zones of the republic, the weight of cow groups with milk productivity reaching 4500-5000 kg and milk fat content of 4.3-4.6% is quite high. On their basis, breeding groups and breeding centers are created, and selection work is aimed at increasing the number of their offspring and further improving the quality of breeding productivity. It should be noted that the milk index or milk yield coefficient of black-and-white cows bred in Azerbaijan is close to the corresponding indicator of the types of the breed bred in Europe.

Table 2. Milk yield of cows by lactation

Lactations	Milking days	Milk yield in lactation, kg	Milk fat content, %	Milk fat content, kg	Live weight, kg	Milk yield index, kg
I	297±3,61	3000±8,43	3,89±0,31	116±2,53	450±5,62	664±8,14
II	303±3,56	3510±7,56	3,96±0,19	139±2,18	503±6,12	691±9,26
III	305±3,59	4260±7,32	4,12±0,23	179±2,23	559±5,22	761±9,54

The milk yield of cows during machine milking on the farm is also quite high (2.5-2.95 kg/min), which corresponds to the breed standard. There is no doubt that targeted selection work carried out in the herds of this breed will increase productivity indicators in the near future. As we have shown above, one of the most valuable biozootechnical characteristics of this breed is that, unlike other breeds, the increase in live weight to the maximum limit does not have a slowing effect on milk production, but rather stimulates it. This is also evidenced by the results of our studies given in Table 3 below.

Table 3. Relationship between milk yield and live weight of black-and-white cattle

No	Cow groups by live weight	Milk yield per lactation, kg	Maximum-minimum	Milk fat content, %
1	451-480 kq	2700±6,18	2600-2900	3,82 ±0,31
2	481-510 kq	2850 ±6,25	2790-3700	3,86 ±0,28
3	511-540 kq	3200± 6,43	3100-3300	3,86± 0,31
4	541-570 kq	3360 ±6,51	3310-3400	3,88±0,27
5	571-600 kq	3600 ±7,11	3500-3710	3,89± 0,23
6	601-630 kq	3800± 6,83	2700-3850	4,00±0,26
7	631-660 kq	3980± 6,83	3860-3990	4,08 ±0,31
8	661-690 kq	4200 ±6,46	4000-4400	4,14 ±0,36
9	691-720 kg and above	4500 ±5,86	4400-4615	4,22 ±0,34

The drying period (the last month of calving) also plays a major role in increasing milk yield in cows. Thus, 2 months before calving, the cow is not milked, but is dried. At this time, the mother's body spends its strength and energy on the growth of the calf, the next calving and the favorable lactation. The normal and favorable drying period for the cattle of the breed we studied is on average between 55-65 days for our republic.

Conclusion

The results of our studies clearly show that the total protein globulin, including gamma globulin, in the blood of hybrids obtained from crossing black-and-white cattle with local breeds of cattle is 25-30% higher than in purebred black-and-white cattle. This trait is due to the fact that the hybrid black-and-white cattle have crossed with local breeds, and they have high resistance.





Relative traits such as high milk yield of black-and-white cattle, intensive growth rate in young animals, and milk yield rate have high heritability, and the heritability coefficient (h^2) for these indicators in their crossbreeding with local cattle is between 0.65-0.78%. The positive correlation between the live weight of black-and-white cattle and milk yield is also highly transmitted to the crossbreeds of black-and-white breed and local cattle. Of course, this was achieved through the scientific selection work carried out by specialists over many years. Summarizing all the above, it can be said that further improvement of feeding conditions in the conditions of the Republic of Azerbaijan and greater attention to selection work than at present will allow creating highly productive herds of Azerbaijani black-and-white cattle in the near future.

Declarations

Ethical Approval Certificate

Not applicable.

Author Contribution Statement

Ramil Mammadov: Conceptualization, methodology, data collection, formal analysis, writing – original draft, review & editing.

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Conflict of Interest

The author declares no conflict of interest.

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Comparative Limnological Characterization and Environmental Risk Assessment of Two Strategic Wetland Ecosystems in the Marmara Basin

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Abstract

The protected wetlands situated within the Marmara Basin represent indispensable ecosystems for regional biodiversity and critical migratory corridors. Despite their high conservation status, these shallow lake systems are increasingly vulnerable to surrounding industrial, agricultural, and domestic stressors. This research focuses on a comparative limnological evaluation of Manyas and Uluabat Lakes to quantify the extent of anthropogenic degradation. During a systematic monitoring campaign in the winter of 2025, water samples were analyzed for a comprehensive suite of parameters, including physicochemical variables (pH, EC, TDS, salinity, turbidity, SS) and organic/inorganic indicators (DO, O₂ saturation, NO₂-N, PO₄-P, and COD). The analytical results revealed distinct hydrochemical signatures for each system; Uluabat Lake was characterized by a more alkaline nature and superior dissolved oxygen levels, whereas Manyas Lake exhibited a profound organic pollution burden. These findings suggest that Manyas Lake is subject to more intensive allochthonous organic inputs and physical disturbances. This study underscores the necessity of implementing site-specific restoration protocols and integrated basin management to safeguard the ecological functionality of these vital aquatic habitats against escalating environmental pressures.

Keywords: Wetland Management, Hydrochemistry, Manyas Lake, Uluabat Lake, Comparative Limnology, Marmara Basin

Introduction

In the past century, industrial activities, agricultural practices, and the excessive exploitation of natural resources have significantly contributed to environmental degradation, adversely impacting all components of our biosphere. Freshwater contamination profoundly affects aquatic life, disrupting natural ecosystems and causing numerous ecological and health issues, including biodiversity loss (Mia et al., 2023; Tokatlı et al., 2023; Yüksel et al., 2025; Muhammad et al., 2024; 2025). Excessive contaminants, particularly nutrients from agricultural runoff and wastewater, induce algal blooms, especially in lentic ecosystems (Atıcı et al., 2018; Jannat et al., 2022; Mutlu et al., 2023; Tokatlı et al., 2024; Din et al., 2024). These pollutants accumulate in aquatic organisms, bioaccumulating toxins that ascend the food chain, potentially affecting larger predators and humans (Howarth et al., 2011; Borrell et al., 2019; Tokatlı and Varol, 2021; Ustaoglu et al., 2022; Yazman et al., 2024). Parameters such as oxygenation, turbidity, salinity, and nitrogen-phosphorus compounds are crucial for the functioning of aquatic ecosystems; however, their imbalanced concentrations can lead to significant challenges (Isiuku and Enyoh, 2020; Varol et al., 2022; Varol and Tokatlı, 2023; 2024).

Manyas Lake is situated in the Bandırma region of western Türkiye. This nutrient-rich freshwater lake, with an average depth of 3 meters, is fed by groundwater and four streams, making extensive marshes and reed beds. It is a crucial habitat for breeding and wintering waterbirds, including the vulnerable Dalmatian pelican, and is also a Ramsar site. Uluabat Lake is a shallow freshwater lake with a surface area that fluctuates between 135 and 160 km², depending on water levels, and a maximum depth of 3 meters. It receives water from the Mustafakemalpaşa River and drains into the Marmara Sea via the Susurluk River. The lake is designated as a Ramsar Wetland of International Importance, supporting extensive white water lily beds and significant populations of endangered pygmy cormorants. Both lakes are threatened by substantial pollution from agricultural runoff, domestic and industrial discharges, and waste from poultry farms and slaughterhouses. Pollutants such as nitrogenous and phosphorous compounds, low dissolved oxygen levels and salinization significantly degrade water quality and threaten the biodiversity of these lakes. Therefore, it is crucial to implement urgent measures to mitigate pollution and protect these essential ecosystems ([https:// www.livinglakes.org/](https://www.livinglakes.org/); <https:// www.marmara.gov.tr/>; Tokatlı et al., 2025). This study undertook a comparative hydrochemical assessment of the water quality in Manyas Lake (ML) and Uluabat Lake (UL).



Materials and Methods

Selected locations and water collection

Figure 1 shows the map of the investigated lakes and the selected sampling locations. Water samples were gathered during the winter of 2025. Subsurface samples were collected using a telescopic water sampler, approximately 2.5 to 3 meters from the shore, and stored in 500 mL polyethylene bottles at 4°C (APHA, 2017). These samples were then transported to Trakya University for further chemical analysis.

Chemical analysis

Electrical Conductivity (EC), Total Dissolved Solids (TDS), salinity, Dissolved Oxygen (DO), O₂ saturation, pH, and turbidity were measured on-site in the field (APHA, 1998, 2017) using a multiparameter device (Hach Lange – HQ40D) and a turbidimeter (Hach Lange – 2100Q). In the laboratory, Suspended Solids (SS), nitrite nitrogen (NO₂-N), phosphate phosphorus (PO₄-P), and Chemical Oxygen Demand (COD) levels were determined in filtered samples (using a 0.45 µm cellulose nitrate filter) (APHA, 1998) with a colorimeter (Hach Lange – DR890) and a spectrophotometer (Hach Lange – DR3900).

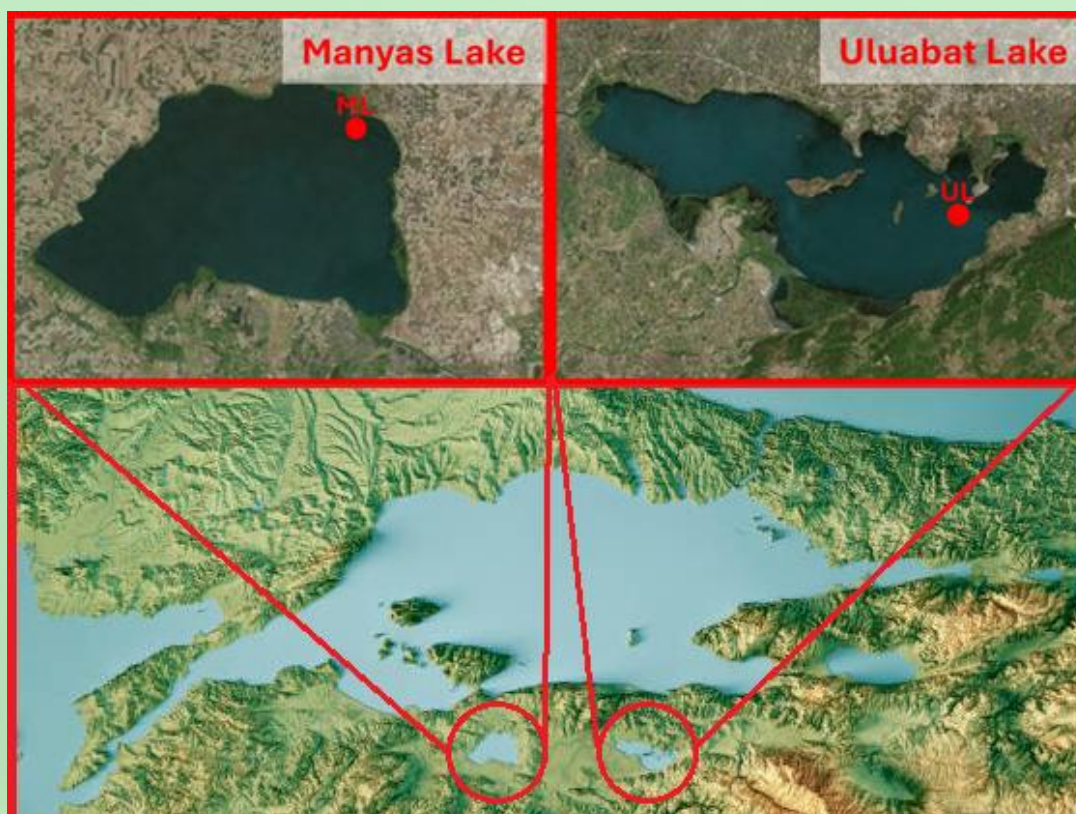


Figure 1. Study area and selected stations

Results and Discussion

The data for measured water quality parameters of UL and ML are given in Figure 2. Results showed that the water of UL (pH: 8.46) exhibited a more alkaline character than ML (pH: 7.80). Also, oxygen content of UL (DO: 9.82 mg/L; O₂ saturation: 110.1 %) is higher than those in ML (DO: 8.76 mg/L; O₂ saturation: 98.1 %). Although salinity parameters were slightly higher in UL (EC: 518 µS/cm; TDS: 251 mg/L; salinity: 0.25 ‰) than those in ML (EC: 472 µS/cm; TDS: 228 mg/L; salinity: 0.23 ‰), water of ML exhibited significantly elevated levels of organic pollution (NO₂-N: 0.021 mg/L; PO₄-P: 0.401 mg/L) compared to water of UL (NO₂-N: 0.001 mg/L; PO₄-P: 0.091 mg/L). In addition, the turbidity, SS and COD values detected in water of ML (turbidity: 29.1 NTU; SS: 59 mg/L; COD: 49.5 mg/L) were recorded as 12, 4 and 3 times higher than detected in water of UL (turbidity: 2.36 NTU; and SS: 14 mg/L; COD: 15.6 mg/L), respectively.

The investigated lacustrine habitats have 1st class water quality (wq) in terms of pH (6–9) DO (> 8 mg/L) values, while they have 2nd class wq in terms of EC (400–1000 µS/cm) values (TSWQR, 2021). The water of UL was classified as 1st class wq based NO₂-N (< 0.01 mg/L) and COD (< 15 mg/L) values and 2nd class wq based PO₄-P (0.05 – 0.16 mg/L) values, while ML was classified as 2nd class wq based NO₂-N (0.01 – 0.06 mg/L) and COD (25 – 50 mg/L) values and 3rd class wq based PO₄-P (> 0.16 mg/L) values (TSWQR, 2021).





Figure 2. Limnologic variables detected in water of UL and ML

Conclusions

In this research, water qualities of Uluabat Lake (UL) and Manyas Lake (ML) two of significant Ramsar lakes of Türkiye were investigated. In conclusion, the water quality of UL is superior to that of ML. The water in UL is more alkaline, has higher oxygen content, and shows lower levels of organic pollution. Additionally, UL's water has lower turbidity, suspended solids, and chemical oxygen demand values. These data indicate that UL's water quality is cleaner and healthier compared to ML. To improve the water quality of ML, it is essential to reduce organic pollution through stricter regulations and monitoring, enhance wastewater treatment facilities for better contaminant removal, promote sustainable agricultural practices to minimize fertilizer and pesticide use, establish vegetative buffer zones to filter pollutants, and raise public awareness about water conservation and pollution prevention.



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Assessment of Eutrophication Risks in Strategic Stagnant Ecosystems of the Marmara Basin via Modified Biodegradable Pollution Indices

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Abstract

Lentic and enclosed aquatic systems are inherently vulnerable to organic enrichment and accelerated eutrophication due to their limited flushing capacities. Manyas and Uluabat Lakes, two ecologically significant freshwater resources in Northwestern Türkiye, serve as vital habitats and migratory corridors for diverse avian populations. Despite their high conservation status, these ecosystems face mounting pressures from intensified agricultural runoff, industrial effluents, and domestic wastewater. This research evaluates the eutrophication potential and organic pollution levels of Manyas Lake and Uluabat Lake utilizing a suite of Modified Biodegradable Contamination Indices (MBCI) based on regional environmental standards. During the winter of 2025, critical limnological parameters were measured to calculate the index values. The analytical outcomes revealed a significant divergence in the ecological health of the two systems; Manyas Lake demonstrated a substantially higher eutrophication risk compared to Uluabat Lake. According to the applied MBCI results, Manyas Lake was characterized as highly polluted with an advanced eutrophic status, whereas Uluabat Lake exhibited moderate pollution levels and a non-eutrophic character. These findings emphasize the urgent necessity for targeted management strategies to mitigate organic loading and preserve the ecological resilience of these strategic wetland habitats.

Keywords: Eutrophication Index, Organic Pollution, Manyas Lake, Uluabat Lake, Nutrient Enrichment, Marmara Basin

Introduction

Organic contaminants, including nutrients from agricultural runoff and wastewater, induce algal blooms in lacustrine habitats (Atıcı et al., 2018; Ustaoglu et al., 2022; Tokatlı et al., 2023; 2024; Muhammad et al., 2025). These blooms, marked by rapid algal growth, disrupt aquatic ecosystems by depleting oxygen, blocking sunlight, and altering food webs. Additionally, organic contamination contributes to hypoxic zones with significantly reduced oxygen levels. Such hypertrophic and hypoxic conditions severely challenge the survival of aquatic organisms, leading to mass mortality among fish and invertebrates (Howarth et al., 2011; Borrell et al., 2019; Mia et al., 2023). Evaluating organic contaminants is crucial to understand their cumulative impacts on aquatic biodiversity, water quality, and ecosystem health (Isiuku and Enyoh, 2020; Varol and Tokatlı, 2023; 2024; Yazman et al., 2024; Yüksel et al., 2025). Holistic approaches provide a comprehensive understanding of aquatic ecosystem health and inform effective management strategies. Practical indicators for assessing eutrophication risks and the synergistic effects of organic contamination include the nutrient pollution index (NPI), organic pollution index (OPI), and eutrophication index (EI) (Tokatlı and Varol, 2021; Varol et al., 2022; Muhammad et al., 2024).

Uluabat Lake, located near Bursa Province of Türkiye, is a shallow freshwater lake with a surface area ranging from 135 to 160 km², depending on water levels, and a maximum depth of 3 meters. It is fed by the Mustafakemalpaşa River and drains into the Marmara Sea via the Susurluk River. The lake is recognized as a Ramsar Wetland of International Importance and supports extensive white water lily beds and significant populations of endangered pygmy cormorants. Manyas Lake is also known as Bird Lake and this nutrient-rich freshwater lake, with an average depth of 3 meters, is fed by groundwater and four streams, forming extensive marshes and reed beds. It is a crucial site for breeding and wintering waterbirds, including the vulnerable Dalmatian pelican, and is designated as a Ramsar site. These significant lakes face significant pollution risks and key pollutants include nitrogenous and phosphorous compounds. Therefore, both lakes require urgent measures to mitigate pollution and protect their ecosystems ([https:// www.livinglakes.org/](https://www.livinglakes.org/); <https:// www.marmara.gov.tr/>; Tokatlı et al., 2025). This study evaluated and compared the eutrophication threat for the Manyas Lake (ML) and Uluabat Lake (UL) by means of some modified biodegradable contamination indices (MBCI) using Turkish Standards.



Materials and Methods

Selected locations and water collection

The map of the investigated lakes and selected sampling locations is presented in Figure 1. Water samples were collected during the winter season of 2025. Subsurface samples were taken using a telescopic water sampler, approximately 2.5 to 3 meters from the bank, and stored in 500 mL polyethylene bottles at 4°C (APHA, 2017). These samples were then transported to Trakya University for further chemical analysis.

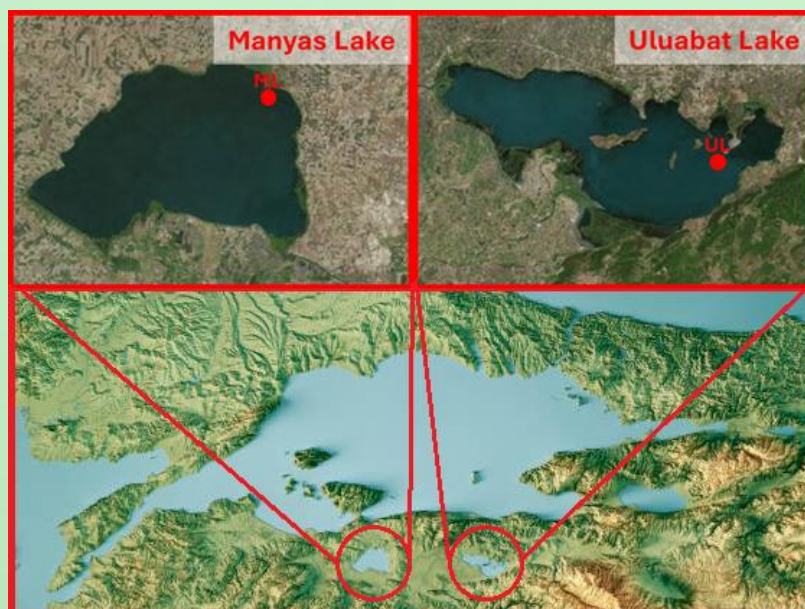


Figure 1. Study area and selected stations

Chemical analysis

Dissolved Oxygen (DO) was measured on-site in the field (APHA, 1998, 2017) using a multiparameter device (Hach Lange – HQ40D). In the laboratory, nitrite nitrogen ($\text{NO}_2\text{-N}$), phosphate phosphorus ($\text{PO}_4\text{-P}$), and Chemical Oxygen Demand (COD) levels were determined in filtered samples (using a 0.45 μm cellulose nitrate filter) (APHA, 1998) with a spectrophotometer (Hach Lange – DR3900).

Ecological indices

The details of the formulas and computation techniques of applied modified biodegradable contamination indices (MBCI) using Turkish Standards (TSWQR, 2021) are shown in Table 1 (Tokatlı et al., 2025).

Table 1. Methods of applied modified organic pollution risk assessment indices

Index	Calculation	Formula Explanations	Rating of Water Quality
NPI	$NPI = (C_N/MAC_N) + (C_P/MAC_P)$	C_N : The levels of $\text{NO}_2\text{-N}$ in water sample C_P : The levels of $\text{PO}_4\text{-P}$ in water sample MAC_N : The maximum limit of $\text{NO}_2\text{-N}$ MAC_P : The maximum limit of $\text{PO}_4\text{-P}$	<1: No polluted 1-3: Moderate polluted 3-6: Considerable polluted >6: Very high polluted
OPI	$OPI = (COD/COD_s) + (NO_2\text{-N}/NO_2\text{-N}_s) + (PO_4\text{-P}/PO_4\text{-P}_s) - (DO/DO_s)$	COD: The chemical oxygen demand DO: Dissolved oxygen ...s: Standard levels of variables	<0: Excellent water quality 0-1: Good water quality 1-2: Beginning to be polluted 2-3: Lightly polluted 3-4: Moderately polluted >4: Heavily polluted
EI	$EI = \frac{COD \times NO_2 - N \times PO_4 - P}{COD_s \times NO_2 - N_s \times PO_4 - P_s}$	COD: The chemical oxygen demand ...s: Standard levels of variables	$EI > 1$: Water quality is regarded as eutrophic



Results and Discussion

The data for calculated modified biodegradable contamination indices (MBCI) for water of UL and ML are given in Figure 2. Results showed that among the investigated natural stagnant water bodies, ML exhibits a much higher potential eutrophication risk compared to UL. According to the applied MBPI results, it was determined that the water of ML was highly polluted (NPI: 10.12 – Very high polluted; OPI: 11 – Heavily polluted) and had an eutrophic character (EI: 33.3 – Water quality is regarded as eutrophic), while the water of UL was moderately polluted (NPI: 1.82 – Moderate polluted; OPI: 1.3 – Beginning to be polluted) and had a non-eutrophic character (EI: 0.11 – Water quality is regarded as non-eutrophic).

Chemical fertilizers containing large amounts of nitrogenous and phosphorous compounds are being widely used in agricultural lands. These fertilizers and the organic pollutants they contain may be carried to the streams and rivers by irrigation, precipitation, and soil erosion (Jannat et al., 2022; Mutlu et al., 2023; Din et al., 2024). It is thought that the agricultural lands around the lakes and the domestic wastewater coming from the settlements are the main reasons for the calculated quite high ecological risk index results and eutrophication indicators.

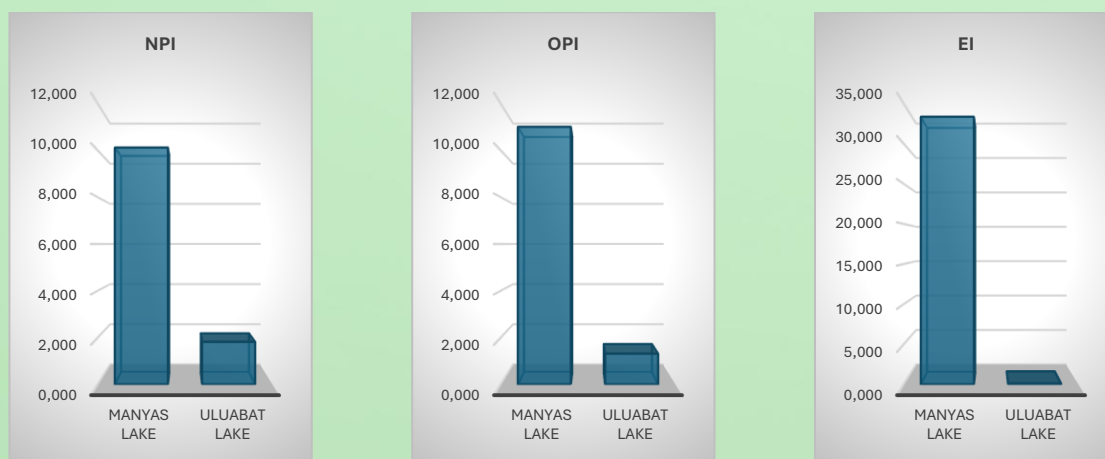


Figure 2. Results of applied MBCI in water of UL and ML

Conclusions

In this research, eutrophication threat for the Manyas Lake (ML) and Uluabat Lake (UL) were compared and evaluated by means of some modified biodegradable contamination indices (MBCI) using Turkish Standards. In conclusion, the data indicates that ML has a significantly higher potential for eutrophication and is more heavily polluted compared to UL. ML's water is classified as highly polluted and eutrophic, with very high pollution indices (NPI: 10.12, OPI: 11, EI: 33.3). In contrast, UL's water is moderately polluted and non-eutrophic, with much lower pollution indices (NPI: 1.82, OPI: 1.3, EI: 0.11). To mitigate the high eutrophication risk and pollution levels in ML, it is crucial to implement stricter pollution control measures, enhance wastewater treatment processes, reduce nutrient runoff from agricultural activities, and restore natural vegetation around the water body to act as a buffer. Additionally, promoting community awareness and involvement in pollution prevention efforts can help maintain and improve water quality over time.

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Spatial Assessment of Organic Pollution in Three Major Lakes of Türkiye: A Comparative Analysis of BOD and COD Levels in Manyas, Uluabat, and İznik Lakes

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Abstract

This study investigates the spatial distribution and comparative water quality status of Manyas, Uluabat, and İznik Lakes using Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) as key indicators of organic pollution. Water samples collected in spring 2025 were analysed, and GIS-based mapping approaches was applied to reveal spatial variability and pollution patterns. Results showed that Uluabat Lake generally exhibited good water quality with low organic load, İznik Lake reflected mostly moderate conditions with localized impacts, while Manyas Lake displayed considerably higher BOD and COD values, indicating stronger organic pollution pressure. According to the Turkish Water Pollution Control Regulation, Manyas Lake was classified at higher pollution classes in several stations, whereas the other two lakes remained largely within lower classes. Overall, the findings highlight clear differences in anthropogenic pressure among the studied lakes and emphasize the importance of continuous monitoring and effective watershed management to protect these ecologically and economically significant freshwater systems.

Keywords: *Manyas Lake, Uluabat Lake, İznik Lake, BOD, COD, water quality, GIS*

Introduction

Freshwater contamination has become one of the most severe environmental problems, with wide-ranging impacts on aquatic ecosystems, biodiversity, and human well-being (Tokatlı et al., 2017; Helvacıoğlu et al., 2025; Haq et al., 2023; Din et al., 2023). Lakes, as key components of inland water resources, play a fundamental role in drinking water supply, irrigation, fisheries, and ecological stability. However, increasing human-induced pressures such as agricultural drainage, industrial effluent discharge, and the input of untreated domestic wastewater have significantly contributed to the deterioration of lake water quality in many regions (Tokatlı, 2019; 2020a; 2020b; Çiçek et al., 2014; Köse et al., 2020; Varol et al., 2022; Ustaoglu et al., 2022; Yüksel et al., 2024). These pressures not only alter the physicochemical structure of aquatic environments but also disrupt ecosystem functioning and reduce the resilience of freshwater systems.

Freshwater ecosystems are particularly sensitive to organic pollution, which is commonly evaluated using Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). These two parameters are widely recognized indicators that reflect biodegradable organic matter and total oxidizable substances in water, respectively. Their combined assessment provides a comprehensive understanding of organic pollution dynamics and ecosystem health. In many lake systems, elevated BOD and COD levels are closely associated with nutrient enrichment, microbial activity, and oxygen depletion, which may ultimately lead to ecosystem degradation. Therefore, analyzing spatial and temporal variations in these parameters is essential for identifying pollution hotspots, understanding contaminant pathways, and evaluating the ecological response of aquatic environments to anthropogenic stressors (Muhammad et al., 2024; 2025; Tokatlı et al., 2025).

Within this context, Manyas Lake, Uluabat Lake, and İznik Lake represent three ecologically and socioeconomically important freshwater systems in northwestern Türkiye. These lakes differ in terms of hydrological characteristics, surrounding land use patterns, and the intensity of human activities within their catchments, resulting in variable levels of environmental pressure. This study aims to evaluate the spatial distribution and comparative water quality status of these three lakes based on BOD and COD parameters. By integrating GIS-based spatial analysis with statistical evaluation, the research identifies spatial variability in organic pollution levels and classifies water quality according to the Turkish Water Pollution Control Regulation. The outcomes are expected to contribute to a better understanding of anthropogenic impacts on these lake ecosystems and to provide a scientific basis for effective and sustainable water resource management strategies.



Materials and Methods

Selected locations and sample collection

Figure 1 presents the map of the studied lakes together with the selected sampling sites. Water samples were collected in spring 2025. Subsurface samples were obtained using a telescopic water sampler from approximately 2.5–3 m offshore and transferred into 500 mL polyethylene bottles. All samples were preserved at 4 °C in accordance with APHA (2017) guidelines and subsequently transported to Trakya University for laboratory analyses.



Figure 1. Marmara Basin, investigated lakes and selected sampling stations

BOD – COD analysis

Biochemical Oxygen Demand (BOD) was determined using a Hach BOD Trak II system based on the standard 5-day incubation method (BOD_5), which measures the amount of oxygen consumed by microorganisms during the degradation of biodegradable organic matter. Chemical Oxygen Demand (COD) was analysed using a Hach DR3900 spectrophotometer, based on the dichromate digestion method, which quantifies the total amount of oxidizable substances present in the samples. All analyses were conducted in accordance with APHA standard methods (1998), and appropriate quality control procedures were applied to ensure the accuracy and reliability of the results.

Results and Discussion

The spatial distribution of BOD and COD values obtained in this study is presented as GIS-based maps in Figure 2 and as graphical representations in Figure 3, allowing a clear visualization of both spatial variability and comparative trends among the studied lakes.



Biochemical Oxygen Demand (BOD) values show clear differences among the three lakes when evaluated according to the Turkish Water Pollution Control Regulation. In Uluabat Lake, BOD concentrations ranged between 1.6 and 3.1 mg/L, with a mean of 2.28 mg/L, indicating that all stations fall within the 1st class water quality category (<4 mg/L) (TSWQR, 2021). This suggests low levels of biodegradable organic matter and relatively good ecological conditions. In contrast, Manyas Lake exhibited substantially higher BOD levels (2.4–11.0 mg/L; mean: 6.14 mg/L), corresponding to 2nd (4–8 mg/L) and 3rd (>8 mg/L) class water quality (TSWQR, 2021). Particularly, stations M3 and M4 exceeded 8 mg/L, indicating significant organic pollution and increased microbial oxygen consumption. İznik Lake displayed intermediate conditions, with BOD values ranging from 1.7 to 6.3 mg/L (mean: 2.77 mg/L). Most stations were classified as 1st class, while a few (e.g., İ1) reached 2nd class levels, reflecting localized organic inputs (TSWQR, 2021). Overall, BOD results indicate that Uluabat Lake maintains high water quality, İznik Lake is generally good with minor localized impacts, and Manyas Lake is under more pronounced organic pollution pressure.

Chemical Oxygen Demand (COD) results further support these findings and reveal differences in both biodegradable and non-biodegradable organic loads. Uluabat Lake showed COD values between 11.9 and 18.3 mg/L (mean: 15.7 mg/L), consistently within the 1st class category (<25 mg/L), indicating low overall organic pollution. In Manyas Lake, COD concentrations were markedly elevated, ranging from 39.5 to 65.1 mg/L with a mean of 56.3 mg/L, corresponding predominantly to 3rd class water quality (>50 mg/L) (TSWQR, 2021). These high values suggest substantial inputs of oxidizable substances, including more resistant organic compounds, likely linked to intensive anthropogenic activities. İznik Lake exhibited COD values between 18.5 and 25.6 mg/L (mean: 21.5 mg/L), placing most stations in the 1st class, with a few measurements approaching or slightly exceeding the threshold into 2nd class (25–50 mg/L) (TSWQR, 2021). This indicates generally good water quality with occasional moderate pollution signals. Collectively, COD data confirm that Manyas Lake is the most impacted system, while Uluabat and İznik lakes exhibit comparatively lower levels of organic contamination.

Elevated BOD and COD levels can accelerate eutrophication, a process in which excessive nutrient and organic matter inputs stimulate algal blooms, ultimately leading to oxygen depletion and disruptions in the aquatic food web. In natural lake systems, increased BOD and COD concentrations are commonly associated with external inputs such as agricultural runoff and untreated or partially treated wastewater discharges. Agricultural activities contribute substantial amounts of organic matter and nutrients through fertilizers, animal waste, and soil erosion, while domestic and industrial effluents further intensify the organic and chemical load (Mutlu et al., 2021a; 2021b; Tokatlı et al., 2023; 2024). These combined pressures enhance microbial activity, increasing oxygen consumption and potentially resulting in hypoxic conditions, which can negatively affect aquatic organisms and overall ecosystem health. In this context, the relatively high BOD and COD values observed in Manyas Lake are likely linked to intensive agricultural practices in the surrounding basin, together with domestic wastewater inputs from nearby settlements. Such conditions indicate a substantial organic pollution burden and suggest that the lake is vulnerable to ongoing eutrophication processes if these pressures persist.

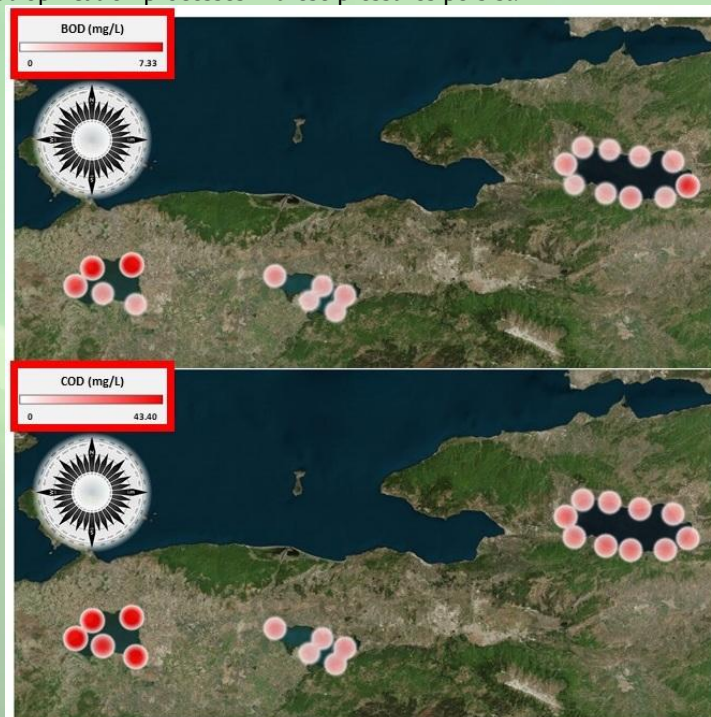


Figure 2. GIS-based BOD-COD distribution maps



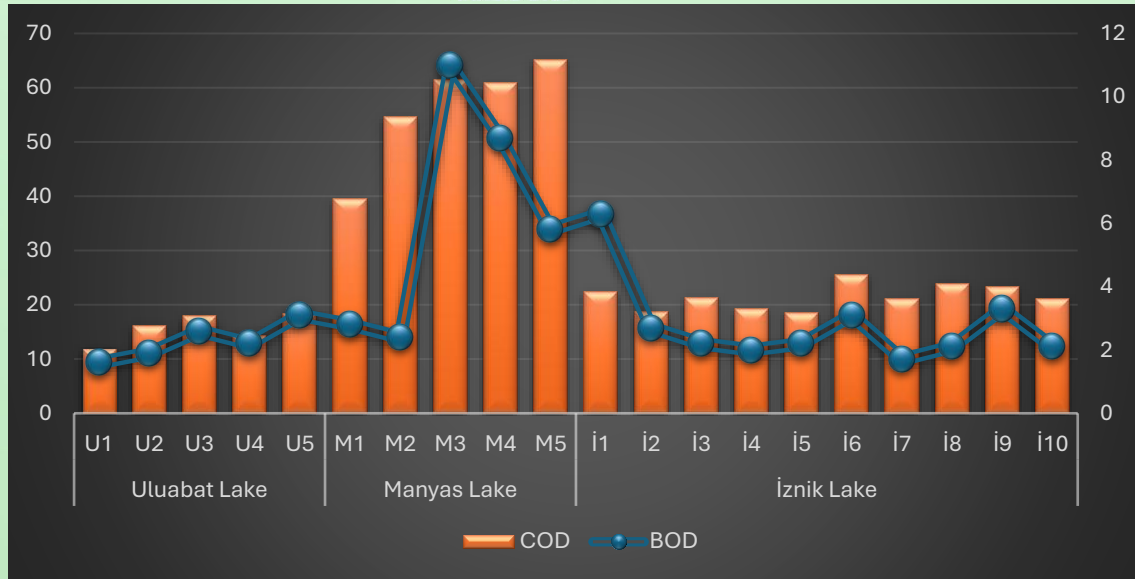


Figure 3. BOD-COD concentrations in water of investigated lakes

Conclusions

Overall, the combined evaluation of BOD and COD results demonstrates a distinct gradient of organic pollution among the lakes. Uluabat Lake consistently exhibits low BOD and COD levels, corresponding to 1st class water quality, indicating limited organic loading and relatively stable ecological conditions. İznik Lake generally reflects good water quality, with most stations classified as 1st class and only minor deviations toward 2nd class, suggesting localized and moderate anthropogenic influences. In contrast, Manyas Lake shows markedly elevated BOD and COD values, frequently falling into 2nd and 3rd class categories, which points to significant organic pollution and potential ecological stress. These findings indicate that while Uluabat and İznik lakes largely maintain acceptable water quality, Manyas Lake is under considerable pressure from organic inputs. The spatial patterns observed in the GIS maps and the trends illustrated in the graphs further emphasize the influence of site-specific pollution sources and highlight the need for targeted management strategies, particularly for Manyas Lake, to improve and sustain water quality.

Acknowledgment

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Spatiotemporal Dynamics of BOD and COD as Organic Pollution Indicators in Porsuk Dam Lake, Türkiye

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Abstract

This study evaluates the spatiotemporal distribution of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) as primary indicators of organic pollution in Porsuk Dam Lake, Türkiye. Monitoring was conducted during the winter and spring seasons of 2025 across multiple stations. Pearson Correlation Index (PCI) was applied to the dataset to identify the relationship between BOD and COD. Results revealed a significant increase in both parameters during the spring, with the highest levels recorded at station P1. This station, located at the inflow of the Porsuk Stream, is subject to intensive domestic and industrial discharges from Kütahya Province. The near-perfect correlation between BOD and COD confirms a shared origin, primarily linked to municipal and agricultural wastewaters. Conversely, a gradual improvement in water quality was observed toward the dam outlet; stations P4 and P5, located near the dam gates, exhibited significantly lower organic loads, consistent with the natural self-purification processes of the reservoir. Ultimately, these findings underscore that organic pollution is driven by anthropogenic activities, particularly concentrated at the river-lake interface.

Keywords: Porsuk Dam Lake, BOD, COD, Pearson Correlation Index, water quality

Introduction

Freshwater degradation remains a critical global environmental challenge, exerting profound consequences on aquatic biodiversity, ecosystem integrity, and public health (Tokatlı et al., 2017; Helvacıoğlu et al., 2025; Haq et al., 2023; Din et al., 2023). As indispensable components of continental water systems, lakes and reservoirs are vital for maintaining ecological balance while supporting essential services such as potable water supply, agricultural irrigation, and fisheries. Nevertheless, the quality of these inland waters is increasingly compromised by anthropogenic stressors. The discharge of untreated municipal effluents, industrial wastes, and nutrient-rich agricultural runoff has led to widespread deterioration in water quality across various geographic regions (Tokatlı, 2019; 2020a; 2020b; Çiçek et al., 2014; Köse et al., 2020; Varol et al., 2022; Ustaoglu et al., 2022; Yüksel et al., 2024). Such persistent pressures modify the physicochemical characteristics of water bodies, ultimately undermining the resilience and functional capacity of aquatic ecosystems.

A primary concern in the management of freshwater systems is organic enrichment, typically monitored through Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). As fundamental metrics, these parameters quantify the biodegradable organic fraction and the total chemically oxidizable substances, respectively. Evaluating the synergy between BOD and COD is crucial for a holistic assessment of organic pollution and overall ecosystem health. In reservoir environments, elevated levels of these indicators are frequently linked to accelerated nutrient cycling, intense microbial respiration, and subsequent dissolved oxygen depletion, which can trigger severe ecological decline. Consequently, investigating the spatiotemporal fluctuations of these parameters is imperative for pinpointing contamination hotspots, tracing pollutant transport pathways, and assessing how aquatic systems respond to human-induced stress (Muhammad et al., 2024; 2025; Tokatlı et al., 2025).

Within this framework, Porsuk Dam Lake stands out as a socioeconomically vital reservoir on the Porsuk Stream in northwestern Türkiye. Constructed in 1947 and expanded by 1972, this concrete gravity dam (storage capacity: 431 hm³) provides irrigation for 41,020 hectares and supplies 206 hm³ of potable water annually. Geographically, the dam is situated in Eskişehir, while its reservoir body extends into Kütahya, receiving inflows from the Porsuk and Felent Streams that are subject to intensive urbanization and industrial pressures from the Kütahya Plain (Köse et al., 2020). This study aims to evaluate the spatiotemporal distribution of BOD and COD levels to characterize organic contaminant variability and classify water quality according to the Turkish Water Pollution Control Regulation. By integrating seasonal monitoring with statistical analysis, the research clarifies anthropogenic impacts—particularly at the river-lake interface—providing a scientific basis for sustainable water management strategies.



Materials and Methods

Selected locations and sample collection

The geographic layout of Porsuk Dam Lake and the strategic locations of the sampling stations are illustrated in Figure 1. Fieldwork was conducted during the winter and spring seasons of 2025. Subsurface water samples were collected at a distance of approximately 2.5–3 m from the shoreline using a telescopic sampler and stored in 500 mL high-density polyethylene bottles. Following collection, all samples were immediately preserved at 4 °C in chilled containers, adhering to APHA (2017) protocols, and transported to the laboratories at Trakya University for further physicochemical analysis.



Figure 1. Porsuk Dam Lake and selected sampling stations

BOD – COD analysis

Biochemical Oxygen Demand (BOD) was determined following the 5-day incubation protocol (BOD₅) utilizing the Hach BOD Trak II respirometric system. This method quantifies the oxygen consumption of microorganisms during the biological degradation of organic matter. Chemical Oxygen Demand (COD) was measured via the dichromate digestion method using a Hach DR3900 spectrophotometer, providing a comprehensive quantification of total oxidizable substances. All analytical procedures were executed in strict adherence to APHA (1998) standard methods. To verify the accuracy and precision of the dataset, rigorous quality control measures, including blank samples and replicate analyses, were systematically applied.

Results and Discussion

The spatiotemporal fluctuations of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) concentrations recorded throughout the study period are illustrated in Figures 2 and 3, respectively. These graphical representations facilitate a comprehensive visualization of the spatial heterogeneity and comparative seasonal trends observed across the Porsuk Dam Lake monitoring stations. When evaluated according to the Turkish Surface Water Quality Regulation (TSWQR, 2021), the results revealed a concerning degree of organic pollution, particularly concentrated at the inflow zone. At station P1, BOD concentrations were recorded at 12.7 mg/L in winter and surged to 22.0 mg/L in spring, representing a dramatic 73.23% increase. These levels far exceed the threshold for 4th class water quality (>20 mg/L) in spring, reflecting a severe biodegradable organic load. Similarly, COD concentrations at P1 showed markedly elevated levels, increasing from 29.2 mg/L in winter to 44.9 mg/L in spring—a percent exchange of 53.77%. While the remaining stations (P2–P5) generally maintained 1st class (<4 mg/L for BOD; <25 mg/L for COD) or 2nd class categories, the persistent high values at P1 identify the river-lake interface as a critical pollution hotspot.



The marked seasonal increase at P1 suggests an intensified influx of municipal and industrial effluents from the Kütahya region, likely exacerbated by seasonal runoff and increased flow rates that mobilize contaminants from the catchment area. Conversely, the transition from high concentrations at P1 to significantly lower values toward the dam outlet—where BOD reached 2.5 mg/L and COD dropped to 14.8 mg/L at P5—underscores the reservoir's robust capacity for natural self-purification and attenuation through sedimentation and dilution processes. These elevated levels of BOD and COD serve as critical precursors to the acceleration of eutrophication, a process where excessive organic enrichment stimulates algal blooms, ultimately leading to oxygen depletion and profound disruptions in the aquatic food web. In Porsuk Dam Lake, these concentrations are intrinsically linked to external terrestrial inputs, including agricultural runoff and the discharge of untreated or partially treated wastewaters. Agricultural activities in the Kütahya Plain introduce significant organic matter via fertilizers and animal waste, while domestic and industrial effluents further intensify the chemical load (Mutlu et al., 2021a; 2021b; Tokatlı et al., 2023; 2024).

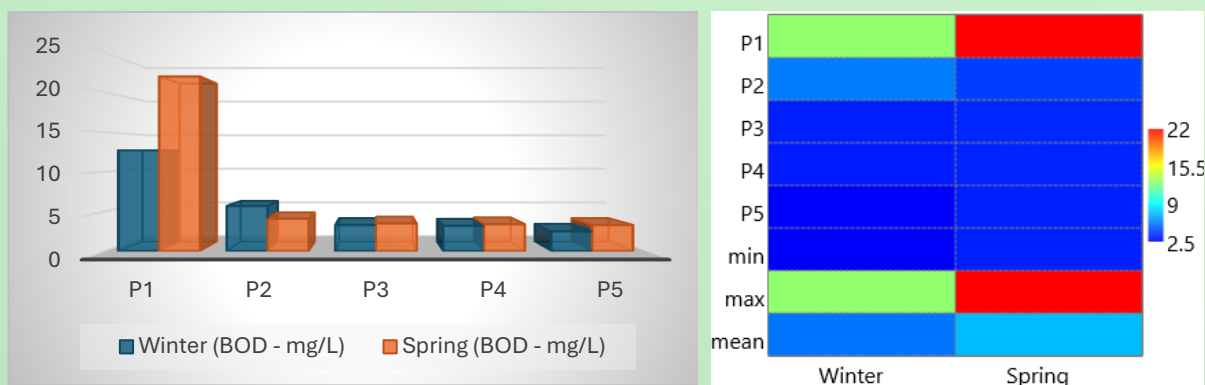


Figure 2. Spatio – temporal BOD distributions on the Porsuk Dam Lake

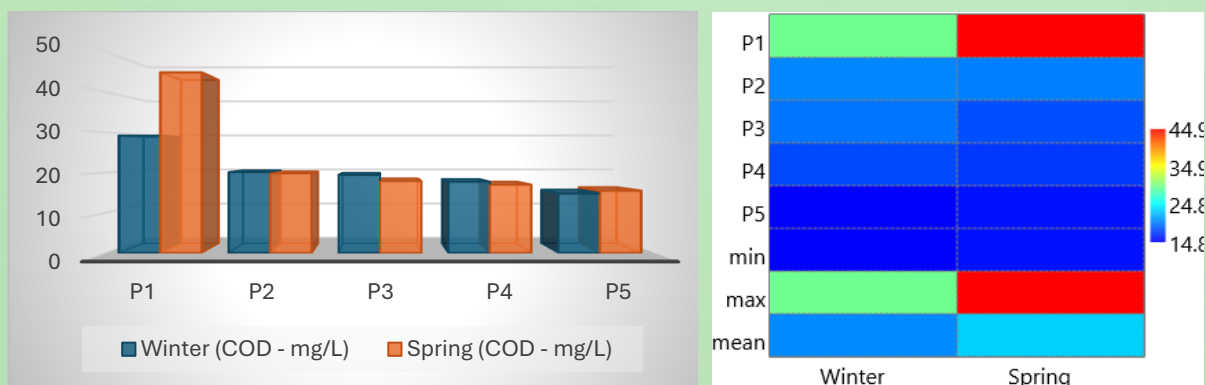


Figure 3. Spatio – temporal COD distributions on the Porsuk Dam Lake

These cumulative pressures enhance microbial respiration, thereby escalating oxygen consumption and potentially inducing hypoxic conditions that jeopardize aquatic biodiversity. The near-perfect correlation between BOD and COD data further confirms a shared anthropogenic origin for these pollutants. While the main body of the reservoir (P3–P5) currently maintains a relatively good ecological status, the extreme organic burden at the inflow zone highlights a significant vulnerability to ongoing degradation. Overall, the findings underscore that organic pollution is strongly influenced by human activities, especially domestic, industrial, and agricultural inputs at the river inflow zone. Persistent monitoring and the implementation of advanced wastewater treatment strategies are essential to mitigate these anthropogenic pressures and ensure the long-term ecological resilience of this vital water resource.

Conclusions

This study highlights a clear spatiotemporal gradient in Porsuk Dam Lake, where severe organic pollution at the Porsuk Stream inflow (P1) progressively diminishes toward the dam outlet (P4–P5). The significant surge in BOD and COD levels during the spring, reaching 4th class water quality at the inflow, underscores the intensified impact of municipal, industrial, and agricultural discharges from the Kütahya region. While the near-perfect correlation between these parameters confirms a shared anthropogenic origin, the sharp decline in organic loads toward the downstream sections demonstrates the reservoir's robust natural self-purification capacity. Although



the main water body maintains relatively good ecological status, the extreme organic burden at the inflow necessitates urgent management interventions. Ultimately, implementing advanced wastewater treatment and continuous monitoring within the catchment area is imperative to mitigate eutrophication risks and ensure the long-term sustainability of this vital freshwater resource for irrigation and potable use.

Acknowledgment

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A meta-Analysis of Effects of Green Light Stimulation During Incubation on Hatching Traits in Broiler Chickens

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Abstract

Green light stimulation during incubation has gained increasing attention as a potential strategy for improving hatching traits in broiler chickens. However, findings among studies remain inconsistent. Therefore, this meta-analysis evaluated the effects of green light exposure during incubation on hatchability of set eggs, hatchability of fertile eggs, chick length, and chick weight in broiler chickens. A comprehensive literature search was conducted in PubMed, Web of Science, and Scopus for studies published up to 26 January 2026, following Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines. A total of 3660 records were identified, of which 23 studies met the inclusion criteria for qualitative synthesis, while eligible outcomes were included in quantitative meta-analysis. Random-effects models were applied to estimate pooled standardized mean differences with 95% confidence intervals. The meta-analysis demonstrated that green light exposure during incubation significantly improved hatchability of set eggs (standardized mean difference = 1.83, 95% confidence interval: 0.53-3.12; $p = 0.0058$) and chick length (standardized mean difference = 0.64, 95% confidence interval: 0.02-1.26; $p = 0.042$). In contrast, no significant effects were observed for hatchability of fertile eggs (standardized mean difference = 0.78, 95% confidence interval: -0.33-1.88; $p = 0.167$) or chick weight (standardized mean difference = 0.58, 95% confidence interval: -0.50-1.67; $p = 0.293$). Considerable heterogeneity was detected for hatchability of set and fertile eggs, and chick weight, whereas chick length showed negligible heterogeneity. Sensitivity analyses confirmed the robustness and stability of the pooled estimates. Funnel plot assessment and Egger's regression test indicated no significant publication bias for chick weight outcomes ($p = 0.055$). Overall, the findings suggest that green light stimulation during incubation may positively influence hatchability set eggs and chick length in broiler chickens, although its effects on hatchability of fertile eggs and chick weight remain inconsistent. Further standardized studies are needed to determine the optimal light intensity, photoperiod, and incubation stage for green light application in commercial broiler production.

Keywords: Broiler chickens, chick quality, green light, hatchability, incubation, meta-analysis



Determination of Some Properties of a Kombucha Beverage Produced with Bitter Orange Peel and Bergamot

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Abstract

In recent years, awareness of the role of diet in maintaining human well-being and health has increased. Consumers expect food products not only to provide essential nutrients but also to serve as sources of biologically active compounds that may benefit health. Kombucha is a fermented beverage produced under aerobic conditions through the addition of a symbiotic culture of bacteria and yeast (SCOBY). In this study, a novel kombucha beverage was developed by fermenting green tea with equal amounts of bitter orange peel and bergamot peel. Green tea was used for kombucha production. Sixty grams of organic brown sugar was added to 1 L of water and boiled. Then, 3.3 g of green tea, 34.3 g of bergamot peel, and 34.3 g of bitter orange peel were added to the boiled water and allowed to steep for 15 min. After cooling to 24–25 °C, 10% kombucha culture was added, and the mixture was allowed to ferment. The pH, titratable acidity (g/L), °Brix, dry matter (%), and color values of the green tea kombucha produced with bitter orange and bergamot peels were 3.27, 0.42 g/L, 6.5, 6.56%, 25.14 (L*), –0.64 (a*), and 0.17 (b*), respectively. In addition, microbiological and antioxidant activity analyses were performed. Sensory evaluation showed that the kombucha containing bitter orange and bergamot peels was generally more highly appreciated in terms of taste than the green tea control group.

Keywords: Kombucha, Bergamot, Bitter Orange Peel, Green Tea, Fermentation

Turunç Kabuğu ve Bergamot ile Yapılan Kombucha İçeceğinin Bazı Özelliklerinin Belirlenmesi

Özet

Son günlerde, insanların refahı ve sağlığı korumada diyetin rolü hakkındaki farkındalığı artmıştır. İnsanlar, ürünlerin kendilerine yalnızca gerekli besinleri sağlamasını değil, aynı zamanda sağlıkları için yararlı olan biyolojik olarak aktif maddelerin kaynağı olmasını da beklemektedir. Kombü çayı kültürü (SCOBY) ilavesiyle aerobik koşullarda fermentasyon yoluyla üretilen bir içecektir. Bu çalışmada aynı miktarda turunç kabuğu ve bergamot ilave edilerek yeşil çayın fermentasyonu ile yeni bir Kombucha içeceği geliştirilmiştir. Kombucha üretiminde yeşil çay kullanılmıştır. 1 lt. suya 60 gr organik esmer şeker eklenerek kaynatılmıştır. Kaynamış suya 3,3 gr yeşil çay ilave edilmiş ve 34,3 gr bergamot kabuğu ve 34,3 gr turunç kabuğu ilave edilerek 15 dk demlenmeye bırakılmıştır. 24-25 °C soğuduktan sonra (%10) kombucha kültürü ilave edilerek fermentasyona bırakılmıştır. Turunç kabuğu ve bergamot ot ile yapılan yeşil çay kombucha çayının pH, titrasyon asitliği (g/L), briks, kurumadde (%) ve renk değerleri sırasıyla 3.27, 0.42 (g/L), 6.5, 6.56, 25.14 (L*), -0.64 (a*), 0.17 (b*) olarak bulunmuştur. Bunun yanında mikrobiyolojik ve antioksidan aktivite testleri yapılmıştır. Duyusal olarak turunç kabuğu ve bergamot ile yapılan kombuchanın tadı kontrol grubu yeşil çaya göre genel olarak daha çok beğenilmiştir.

Anahtar Kelimeler: Kombucha, Bergamot, Turunç kabuğu

Giriş

Ülkemizde üretilen meyveler içinde turunçgiller (portakal, limon, mandarin, bergamut, greyluft vb.) önemli bir paya sahiptir. *Citrus bergamia* Risso et Poiteau bitkisinin ortak adı olan ve Rutaceae familyasına ait olan bergamot, sarı bir kabuğa sahip portakal büyüklüğünde bit meyvedir (Perna vd., 2019). Esas vatani Batı Hindistan olan bergamot günümüzde İran, Güney Amerika (Arjantin ve Brezilya), Fildişi Sahilleri ve Akdeniz bölgesinde (Fas, Kefalonya ve Güney İtalya) yetişmektedir (Ballistreri vd., 2021). Bergamot ve diğer turunçgillerin sağlık üzerine faydaları çeşitli araştırmaların konusu olmasını sağlamıştır.

Fermente ürünlerden “Kombucha”, maya ve asetik asit bakterilerinin simbiyotik birleşiminin şekerli çayın fermentasyonu ile elde edilen bir içecek olup ve kelime olarak Japonca *Laminaria japonica* adındaki geniş yapraklı bir deniz yosununu tanımlayan ‘Kombu’ ile çay anlamına gelen ‘Cha’ kelimelerinin birleşiminden oluşmaktadır (Giritlioğlu vd., 2020).



Fermente edilmiş çayın ilk tüketimi M.Ö. 220’de Manchuria bölgesinde olmuştur. Daha sonra Rusya ve Almanya’da kullanılmış ve son zamanlarda ABD’de kullanımı yaygınlaşmıştır. Bu popülerite onun düşük etanol içeriği nedeniyle hayat verici ve canlandırıcı gücüyle ilişkilidir (Şafak vd., 2003).

Kombucha çayı tatlı bir ortamda, genellikle siyah çayda asit bakterileri (AAB; *Komagataeibacter*, *Gluconobacter* ve *Acetobacter* türleri), laktik asit bakterileri (LAB; *Lactobacillus Lactococcus*) ve mayalar (*Schizosaccharomyces pombe*, *Saccharomycodes*) *ludwigii*, *Kloeckera apiculata*, *Saccharomyces cerevisiae*, *Zygosaccharomyces bailii*, *Torulaspora delbrueckii*, *Brettanomyces bruxellensis*) simbiyotik bir asetik kültürden elde edilir. Fermantasyon süreci ayrıca belirli AAB suşlarının aktivitesi nedeniyle büyüme ortamının yüzeyinde yüzen bir biyofilm oluşumuna da yol açar. Mevcut ana asitler asetik, glukonik, tartarik, malik ve daha az oranda sitrik asittir. Tüm bu asitler, karakteristik ekşi tadından sorumludur. Tüketici bilinciyle birlikte, minimum işlenmiş, katkı maddesi içermeyen, besin değeri yüksek ve sağlık yararları olan ürünlere yönelik gerçek gıda eğilimleri artmıştır. Bu bağlamda geleneksel Kombucha çayı, probiyotik özelliklerinden dolayı son zamanlarda araştırmacıların ve tüketicilerin dikkatini çekmiştir. Ancak üretim teknolojisi, mikrobiyotası, yan ürünleri ve fizikokimyasal özellikleri endüstriyel üretim için dikkate alınması gereken önemli gerçeklerdir. İzlenen metabolik yola bağlı olarak çeşitli fermantasyon türleri ve elde edilen ürünler vardır. Kombucha fermantasyonu üçünün bir kombinasyonudur: alkollü, laktik ve asetik olan, bunun nedeni besiyerinde bir arada bulunan birkaç maya ve bakterinin varlığıdır. Osmotolerant mikroorganizmalar tarafından başlatılmakta ve sonuçta aside toleranslı türler hâkim olmaktadır. Birkaç yazar, Kombucha çayının faydalarını inceledi; ancak aktif bileşenlerinin karakterizasyonu, fermantasyon sırasındaki evrimleri ve farmakolojik aktiviteleri hakkında çok az bilgi vardır. Ayrıca, fermenterlerin, substratların, metabolitlerin etkisi ve bunların organoleptik nitelikler ve fermantasyon kinetiği üzerindeki gelişmeleri de değerlendirilmelidir (Villarreal-Soto vd., 2022).

Kombucha, Combuchu ya da mantar çayı genellikle Asya’da tüketilen geleneksel bir içecek olduğu bilinmektedir. Aynı zamanda Rusya ve Almanya’da da tüketilmektedir. Çayın kökeninin Çin olduğu ve M.Ö. 221 yıllarında üretildiği tahmin edilmektedir. Hafif asitli, karbonatlı ve tatlı bir tada sahip olan çay çoğunlukla evde hazırlanıp tüketilmektedir (Akarca ve Tomar, 2018).

Bu çayın kökeninin MÖ 221 yılı Çin’ine dayandığını anlatılır: Ona, ‘Ölümsüzlük İlacı’ adı verilmiştir (Kutluer, 2009). MS 414 yılında Koreli Dr. Kombu, Japon İmparatoru Inkyo’yu tedavi için bu iksiri Japonya’ya getirmiştir. Daha sonra kombu çayın kullanımı, Rusya, Hindistan ve Avrupa’ya yayılmıştır. Bakteri ve maya simbiyotik kültürüyle şekerli çayın fermentasyonunu içeren içecektir (Sirisa-ard vd., 2015).

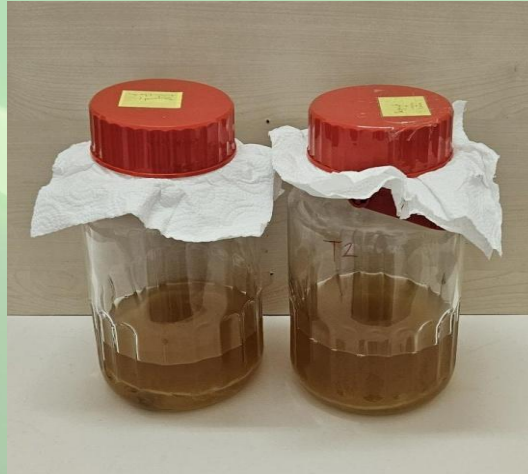
Materyal ve Metot

Materyal

Çalışmada organik esmer kamışı şekeri (Alnatura, Rahrohr Zucker), organik ÇAYKUR zümrüt yeşil çayı (*Camellia sinensis*) kullanılmıştır. Kombuchanın üretimi ve malzemeleri Antalya’dan alınmış ve analizleri ise Süleyman Demirel Üniversitesi Gıda Mühendisliği bölümü laboratuvarında yapılmıştır.

Kombucha Üretimi

Kombucha üretiminde yeşil çay kullanılmıştır. 1000 ml suya 60 gr organik esmer şeker eklenerek kaynatılmıştır. Kaynamış suya 3,3 gr yeşil çay ilave edilmiş ve 34,3 gr bergamot kabuğu ve 34,3 gr turunc kabuğu ilave edilerek 15 dk demlenmeye bırakılmıştır. 24-25 °C soğuduktan sonra (%10) kombucha kültürü ilave edilerek fermantasyona bırakılmıştır.



Şekil 1. Turunc kabuğu ve bergamot ile yapılan kombucha örnekleri



Fizikokimyasal ve Kimyasal Analizler

Briks değeri (Bellingham Stanley Limit 60/70 Refractometer, UK), toplam titre edilebilir asitlik (% laktik asit) ve pH (Schott instruments, pH-meter lab 850, USA) değeri analizleri AOAC (1992)'ye uygun olarak gerçekleştirilmiştir.

Mikrobiyolojik Analizler

Mikrobiyolojik analizlerde klasik yayma yöntemi tercih edilmiş ve toplam aerobik mezofilik canlı bakterilerin sayımı için Plate Count Agar besiyeri, toplam maya sayımı için Patato Dextrose Agar ve Lactobacillus türlerinin sayımı için De Man Rogosa and Sharpe agar, Laktik Streptokokların sayımı için M17 agar besiyerleri kullanılmıştır (Leite vd., 2013).

Renk Değerleri

Utoiu ve arkadaşları tarafından yapılan çalışmada turunc kabuğu ve bergamot kullanılarak yapılan kombucha örneklerinin rengi Konica Minolta Chroma Meter CR-5 renk ölçüm cihazı kullanılarak yapılmış olup, sonuçlar L*, a* ve b* değerleri olarak verilmiştir. Renk değerleri ölçülecek 3 örneğin cihazın ürüne uygun olan (sıvı ürün) haznesi seçilerek, kolorimetrenin cihazının içerisine yerleştirilip cihazın renk değeri okumaları gerçekleştirilmiştir. L*,a*,b* renk koordinat sisteminde L* değeri renk parlaklığını/aydınlığını göstermekte ve değer aralığı 0-100 arasında değişmektedir. Renk koordinat düzlemindeki a* değeri (+) ise kırmızı, (-) ise yeşil rengi ifade ederken değeri -120 ile 120 arasındadır. b* değeri ise renk koordinat düzleminde bulunmasına rağmen değer aralığı yoktur (+) ise sarı, (-) olduğunda ise mavi rengi göstermektedir. Analizler üç paralel olarak gerçekleştirilmiştir (Pekcan, 2022).

DPPH Serbest Radikal Süpürme Aktivitesi

Kambucha çay örneklerinden 0,025 ml alınarak 4 mL metanolde (0.0625 mg / mL) çözündürüldü. Daha sonra 0.5 mL metanolik bir α, α -diphenyl- β -picrylhydrazyl (DPPH) (1 mM) çözeltisi ile karıştırıldı ve oda sıcaklığında 30 dakika beklemeye bırakıldı. Ardından karışımın optik yoğunluğu spektrofotometre ile (Hitachi U-2000) 517 nm'de ölçüldü (Chu ve Chen, 2006).

Kombucha çaylarının serbest radikal giderme aktivitesi aşağıdaki denklemle hesaplandı.

$$\text{Süpürme Kapasitesi (\%)} = [1 - (\text{As} - \text{Ab}) / (\text{Ac} - \text{Ab})] \cdot 100$$

As: Örneklerin Absorbans değeri

Ab: Kör Numune

Ac: Kontrol Numunesi

Toplam Fenolik Madde İçeriğinin Belirlenmesi

Kombucha çay örneklerinden 0.05 ml' alınarak üzerine 2 ml % 2'lik sodyum karbonat eklenmiştir. 2 dakika bekledikten sonra sonra, yukarıdaki çözelti ile 0.1 ml Folin-Ciocalteu reaktifi karıştırıldı, 30 dk bekletildikten sonra spektrofotometre ile (Hitachi U-2000) 750 nm' de absorbans ölçüldü. Toplam fenolik madde içeriği, kalibrasyon eğrisinden gallik asit eşdeğerleri (GAE, mM) olarak ifade edildi (Chu ve Chen, 2006).

Duyusal Analiz

Yapılan duyusal analiz Bodyfelt vd., 1998 göre yapılmış üretilen kombucha örnekleri ferahlık hissi, buruk tat, gazlı yapı, renk, meyvemsi tat, koku, ekşilik, lezzet, tatlılık, görünüş ve genel beğeni özelliklerine göre 1-5 (1: en az, 2: az, 3: orta, 4: iyi, 5: en iyi) arasında değerlendirilmiştir. Panelistler: lisans, lisansüstü öğrenciler ve akademik personelden oluşmaktadır.

Araştırma Sonuçları ve Değerlendirme

Osiripun, ve Apisittiwong (2021) yapmış olduğu çalışmada siyah çay, yeşil çay ve oolong çayından yapılan elma suyu, nar suyu ve ananas suyu ile hazırladığı 10 gün fermentasyon sonucunda oluşan kombucha çaylarının titrasyon asitliğini 3,4-9,2 (g/L) arasında olarak bulmuştur.

Depolamanın 1, 7, 14 ve 21. günlerinde yapılan analizlerde; kombu çayı örneklerinin pH ve titrasyon asitliği değerleri birbiri ile ters orantılı olarak değiştiği gözlenmiştir. Tüm ürünlerde depolama süresi boyunca ve ürünler arasındaki pH ve asitlik değişimleri önemli ($p < 0,05$) bulunmuşken, kontrol grubunda depolama süresi boyunca asitlikteki değişim önemsiz ($p > 0,05$) bulunmuştur. Örneklerin pH'sı 2,61 ile 3,25 arasında, asitlikleri (% asetik asit cinsinden) ise 2,14 ile 4,14 arasında belirlenmiştir. Asitlikteki artış pH'nın düşmesiyle birlikte beklenen bir sonuç olmuşken fermentasyon sırasında meydana gelen organik asitler (asetik asit, glukonik, glukoronik, laktik asit vb.) asitliğin artmasındaki en temel etken olduğu tespit edilmiştir (Açıkel, 2024).



Tablo 1. Kombucha ve çay örneklerinin kimyasal ve fizikokimyasal analiz sonuçları

Ürün	pH	%KM	Briks	L*	a*	b*	Titrasyon Asitliği (g/L)
Çay	6.19 ±0.01 ^a	6.68±0.75 ^a	6.50±0.00 ^a	25.69± 0.02 ^a	-0.60 ± 0.05 ^a	0.55± 0.03 ^a	0.072±0.00 ^b
Kombucha	3.27±0.04 ^b	6.56±0.11 ^a	6.50± 0.00 ^a	25.14±0.06 ^b	-0.64 ±0.07 ^a	-0.17±0.11 ^b	0.42±0.05 ^a

Örneklerin istatistiksel analizi için Mann-Whitney U testi uygulanmıştır. Aynı sütunda belirtilen farklı harfler, istatistiksel olarak anlamlı (P<0.05) olduğunu belirtir., Çay: Yeşil çay (*Camellia sinensis*); Kombucha: Turunc kabuğu ve bergamot ilaveli kombucha çayını ifade etmektedir.

Tablo 2. Kombucha örneklerinin mikrobiyolojik analiz sonucu (Log CFU/mL)

Mikroorganizma	Mikrobiyal Sayım Sonucu (Log CFU/mL)
Lactobacilli spp.	4 <
Lactococci spp.	4 <
Mayalar	5.95 ±0.01
Toplam Aerobik Mezofilik Bakteri Sayısı	5.45 ± 0.11

Tablo 3. Kombucha örneklerinin antioksidan aktivitesi

Antioksidan Aktivitesi	Kombucha İçeceği
Toplam fenolik içeriği (mg GAE/L)	634.54±12.23
DPPH (% İnhibisyon)	82.04±0.79

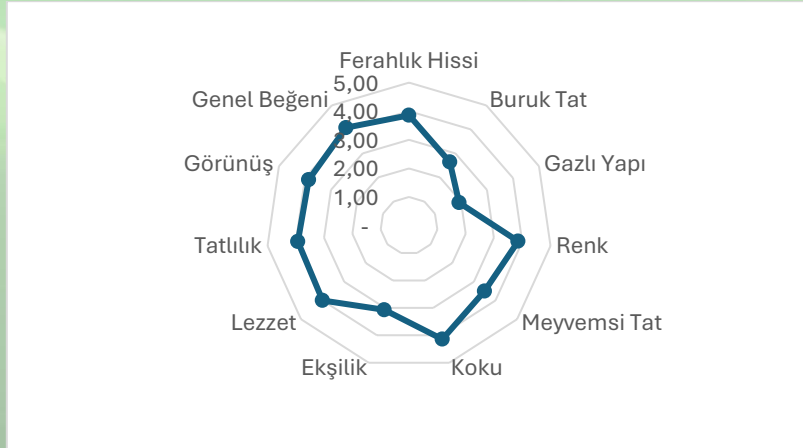
Kombucha içeceklerinin fermentasyon süresince AAB ve maya sayıları, KA örneklerinde sırasıyla 3.08-6.15 ve 3.30-6.21 log KOB/mL aralığında, KI örneklerinde sırasıyla 3.74-6.02 ve 3.85-6.85 log KOB/mL aralığında ve KK örneklerinde sırasıyla 3.63-6.13 ve 3.86-6.70 log KOB/mL aralığında belirlenmiştir. Depolanmanın sonunda (4°C'de 120 gün), örneklerin AAB ve maya sayılarının genellikle başlangıça kıyasla daha düşük olduğu, bununla birlikte KA ve KI örneklerinin AAB sayılarının KK örneklerine kıyasla daha yüksek olduğu tespit edilmiştir (Kılıç, 2023).

Kombucha, mor fesleğen, %50 ve %75 karışımlarının 1, 10, 20 ve 30 günlük depolanmasından elde edilen DPPH radikal temizleme aktivitesi değerleri 57,96-68,09 arasında değiştiği tespit edilmiştir (Yıkılmış ve Tuğgüm, 2019).

Çalışmamızda yaygın olarak tüketilmeye başlanan kombucha çayına, sarı halile bitkisi eklenilerek fenolik bileşik içeriği yüksek, antibakteriyel ve antioksidan fonksiyonel yeni bir ürün elde edilerek fizikokimyasal özellikleri tespit edilmiştir (Ulutaş, 2025).

Fenolik madde miktarı ve antioksidan aktivitesine bağlı olarak gerçekleştirilen analizler sonucunda, değerlendirmelere göre; fermentasyonun ve zamanın, fenolik madde miktarı ve antioksidan aktivitesi değişiminde önemli bir etkisinin olduğu tespit edilmiştir (P<0,01). Örneklerin fenolik madde miktarı değişimi ve antioksidan aktivitesi günlere bağlı düzenli bir değişim göstermemiştir. Buna rağmen sakkaroz şekeri haricinde genellikle fermentasyonu tamamlanan Kombucha örneklerinin antioksidan kapasitesi ve fenolik madde miktarının, 0. günde belirlenen değerlerden daha yüksek olduğu bulunmuştur. Sakkaroz şekerinde ise fermentasyonu tamamlanan çaylara ait antioksidan aktivitenin, başlangıça oranla daha fazla olduğu gözlenmiştir (Tarhan, 2017).

Yapılan çalışma, siyah çay, yeşil çay, oolong çayı ile birleştirilen biyoaktif bileşenlerce zengin Trabzon hurmasının substrat olarak kullanımının, içeceklerin antioksidan aktivitelerini arttırdığı tespit edilmiştir. Trabzon hurmasının fonksiyonel fermente içecekler üretmek için alternatif substrat olduğu ve kombucha içeceklerinin kabul edilebilirliğini arttırdığı bulunmuştur (Savan, 2023).



Şekil 2. Duyusal test analiz sonuçları



Bazı meyve suları ile hazırlanan kombu çaylarının özellikleri üzerine yapılan bir çalışmada, kombu çayı örnekleri renk, tat/lezzet, yapı/kıvam, asitlik ve genel izlenim açısından depolamanın 1. ve 7.gününde değerlendirilmiş olup depolamanın 7. gününde ürünlerin asitlik açısından değerlendirme sonuçları önemli ($p<0,05$) bulunurken diğer tüm parametreler depolamanın 1. ve 7. Gününde ve ürünler arası önemsiz ($p>0,05$) bulunmuştur (Açıkel, 2024).

Sonuç

Depolama sırasında pH değerleri düşerken, toplam asitlik değeri arttığı gözlenmiştir. Mor fesleğen, tüm depolama sürelerinde diğer örneklerle göre daha yüksek toplam fenolik içeriğe sahip olduğu tespit edilmiştir. Çalışmanın sonunda, mor fesleğendeki toplam fenolik bileşik ve flavonoid miktarının diğer örneklerle kıyasla oldukça korunduğu sonucuna varılmıştır. 30. günde belirlenen antioksidan değerleri, mor fesleğenli kombucha içeceğinde en yüksek DPPH (radikal temizleme aktivitesi) (%64,19) değerlerini gösterdiği bulunmuştur. Renk değerleri incelendiğinde, tüm örneklerde genel depolama sürecinde istatistiksel olarak anlamlı farklılıklar olduğu bulundu. Depolama süreciyle birlikte kıvam, koku, tat ve genel kabulde önemli bir değişiklik olmadı. Sonuç olarak, 30 günlük depolama süresinin %100 mor fesleğenli kombucha çayı için daha başarılı ve elverişli olduğu tespit edilmiştir (Yıkılmış ve Tuğgüm, 2019).

Turunç kabuğu ve bergamot ile yapılan kombucha yeşil çayın kontrol grubu yeşil çaya göre titrasyon asitliğinin daha yüksek olduğu gözlenmiştir ($P<0.05$). Aynı şekilde pH, titrasyon asitliğine ters oranlı olduğu bulunmuştur. Turunç kabuğu ve bergamot ile yapılan kombucha ile kontrol grubu yeşil çay arasında briks değerinde ve % kurumadde değerleri arasındaki fark önemli bulunmazken renk değerleri b^* değeri arasındaki fark göze çarpmaktadır ($P<0.05$).

Yapılan mikrobiyolojik ve antioksidan aktivite testleri yoruma açık olduğu gibi diğer yapılan çalışmalara benzer sonuçlar bulunmuştur. Duyusal olarak kombuchanın beğenilmesi endüstriyel olarak alternatiflerinin çok olduğunu akla getirmektedir. Bu çalışma kombucha ile ilgili literatüre katkı sağlayacağı ve yeni fikirlerin oluşması açısından önemlidir.

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Effect of Plant Protein-Based Microencapsulation on Antioxidant Capacity in Probiotic Systems

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Abstract

The protection of bioactive compounds against environmental stress factors is of paramount importance in the development of functional food ingredients. This study was conducted to determine the effectiveness of microencapsulation systems based on rice protein, a plant-derived protein, and inulin, a prebiotic polysaccharide, using conjugation and physical mixing methods, and to evaluate their impact on the antioxidant capacity of systems containing different probiotic strains (*Lactobacillus reuteri* and *Lactobacillus acidophilus*). In the research, conjugate structures prepared through covalent modification of rice protein and inulin, as well as traditional physical mixtures, were utilized as wall materials. The total phenolic content of the microcapsules was analyzed using the Folin-Ciocalteu method, and their radical scavenging activities were determined by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay. The findings indicated that the total phenolic content of the microcapsules ranged from 275.94 to 291.56 milligrams of gallic acid equivalent per gram (mg GAE/g), while radical scavenging activities ranged between 157.36 and 227.54 milligrams of ascorbic acid equivalent per gram (mg AAE/g). The highest phenolic content and antioxidant potential were identified in the formulation containing *Lactobacillus acidophilus* prepared with the rice protein-inulin conjugate matrix (LAPC). The results of the study revealed that the covalent conjugation of rice protein and inulin strengthened molecular interactions with phenolic compounds through modifications induced in the protein structure and created a more resilient protective barrier compared to physical mixtures. These findings demonstrate that plant protein-based conjugate systems offer a superior encapsulation strategy for enhancing the oxidative stability of bioactive components in food formulations containing probiotics.

Keywords: Plant protein, Rice protein, Microencapsulation, Probiotic, Antioxidant capacity.

Introduction

In recent years, microencapsulation has proven effective in protecting bioactive compounds when exposed to an unfavorable food processing environment and the human gut. Among the different coating matrices, food-grade polymers such as milk proteins, plant proteins, and polysaccharides have been extensively investigated as wall materials for the encapsulation of bioactive substances. However, protein-based delivery systems, in addition to their precipitation and aggregation disadvantages (pH and ionic strength effects), show limited stability against digestive enzymes in the gastrointestinal tract and undergo degradation, leading to the burst release of encapsulated bioactive compounds in the gastric environment instead of the intestine (Marson et al., 2020; Nooshkam & Varidi, 2020). Moreover, the application of chemicals as crosslinkers is a limiting factor due to health concerns (Li & Huang, 2015).

To overcome these challenges, protein-carbohydrate conjugation/complexation based on the Maillard reaction has rapidly expanded and proved to be excellent candidates for the encapsulation and delivery of bioactive components in food and pharmaceutical fields (Cao et al., 2022; Sun et al., 2022). This is mainly because of their outstanding characteristics, such as good solubility and emulsifying capacity, stability over a wide range of pH values, temperatures, and ionic strengths, and the ability to promote a thicker, continuous, viscoelastic, and shear-resistant layer surrounding bioactive components (Khan et al., 2021). In this study, the total phenolic content (TPC) and DPPH radical scavenging activities of the obtained encapsulated samples were comparatively analyzed across different combinations including physical mixtures (LRPP and LAPP) and conjugate formulations (LRPC and LAPC) prepared with *Lactobacillus reuteri* and *Lactobacillus acidophilus*. This study aims to pave the way for increased utilization of plant proteins not only to provide a protective barrier in food formulations but also as functional ingredients that optimize antioxidant capacity.

Materials and Methods

Determination of DPPH (2,2-Diphenyl-1-picrylhydrazyl) Scavenging Activity

The DPPH free radical scavenging activity was determined by modifying the method reported by Du et al. (2023). The method is based on the principle of lightening the dark purple color as a result of the reduction of the DPPH radical by antioxidant substances. The decrease in absorbance is measured at 517 nm. Within the scope of the analysis, 3.9 mL of DPPH solution (0.05 mM prepared in 70% ethanol) was added onto 0.1 mL of extract, and



the mixture was vortexed for 30 s. After 30 min of incubation in the dark and at room temperature, the samples were centrifuged (4 °C, 8965 × g, 5 min). After collecting the supernatant, absorbance values were measured at 517 nm with a spectrophotometer. The % DPPH scavenging activity of the samples was determined according to Formula 1:

$$\% \text{ DPPH scavenging} = \left(1 - \frac{A_{\text{sample}}}{A_{\text{control}}}\right) \times 100 \quad (1)$$

(A_{control} : expresses DPPH solution + solvent; A_{sample} : expresses DPPH solution + extract.)

Ascorbic acid was used as the antioxidant standard, and a standard curve was prepared in the concentration range of 20–500 µg/mL. Using Equation 2 created over the % inhibition values, the results were expressed as mg ascorbic acid equivalent (AAE) / g sample.

$$y = 0,0513x + 2,1835 \quad R^2=0,9643 \quad (2)$$

Determination of Total Phenolic Content

The total phenolic content (TPC) was determined using the Folin-Ciocalteu reagent (FCR) according to the method reported by Singleton and Rossi (1965). In the analytical procedure, pre-diluted Folin-Ciocalteu reagent (2.5 mL) was added onto 0.5 mL of extract, and the mixture was kept at room temperature for 5 min. Then, 2 mL of sodium carbonate (Na_2CO_3) solution (20% w/v) was added to the mixture, and the samples were incubated for 60 min at room temperature in the dark. The absorbance values of the samples were measured at 765 nm using a UV-Vis spectrophotometer. Gallic acid was used as the phenolic compound standard, and serial dilutions of gallic acid (20–100 µg/mL) were prepared for this purpose. Using the standard curve equation (Equation 3), the TPC of the samples was expressed as mg gallic acid equivalent (GAE) / g sample.

$$y = 0,0016x + 0,2707 \quad R^2=0,9606 \quad (3)$$

Results

DPPH Radical Scavenging Activity

The DPPH analysis results, conducted to determine the free radical scavenging capacities of the microcapsule samples, were calculated in terms of mg AAE/g. The antioxidant activities of the samples ranged between 157.36 and 227.54 mg AAE/g (Table 1), and the differences among the formulations were found to be statistically significant ($p < 0.05$, Table 1).

In parallel with the TPC results, the highest radical scavenging activity was observed in the LAPC sample (227.54 ± 4.05 mg AAE/g), which was significantly different from all other samples ($p < 0.05$). This demonstrates that the LAPC formulation is the most effective combination, not only in terms of total phenolic content but also regarding the biological activity capacity (radical scavenging) of these phenolics. The prebiotic effect of inulin and the structural integrity of rice protein enhanced the stability of antioxidant metabolites, thereby enabling the achievement of higher activity values.

Total Phenolic Content (TPC)

The total phenolic contents of the samples are presented in Table 1. According to the analysis results, the TPC values of the microcapsules varied between 275.94 and 291.56 mg GAE/g. The highest phenolic content was detected in the sample coded LAPC (291.56 ± 2.64 mg GAE/g), followed by LAPP (288.44 ± 1.98 mg GAE/g), showing no statistically significant difference between these two specific formulations ($p > 0.05$). However, both conjugate structures (LAPC and LRPC) exhibited significantly higher TPC values compared to their respective physical mixture counterparts (LRPP and LAPP) ($p < 0.05$). The high phenolic content in the samples prepared with the combination of rice protein and inulin is associated with the capacity of the wall materials to protect antioxidant components and the release efficiency during methanol extraction.

Table 1. Total phenolic content (TPC) and DPPH radical scavenging activities of the encapsulated probiotic microcapsules.

Sample Code	DPPH (mg AAE/g)	TPC (mg GAE / g sample)
LRPP	$157,36 \pm 2.14^d$	$275,94 \pm 3.12^c$
LRPC	$161,26 \pm 1.85^c$	$285,44 \pm 2.45^b$
LAPP	$188,56 \pm 3.22^b$	$288,44 \pm 1.98^{ab}$
LAPC	$227,54 \pm 4.05^a$	$291,56 \pm 2.64^a$

*Values are expressed as mean ± standard deviation. Different superscript letters (a–d) within the same column indicate statistically significant differences ($p < 0.05$).; *LRPP: L. reuteri + Rice Protein + Inulin Physical Mixture; LRPC: L. reuteri + Rice Protein-Inulin Conjugate; LAPP: L. acidophilus + Rice Protein + Inulin Physical Mixture; LAPC: L. acidophilus + Rice Protein-Inulin Conjugate.



Discussion

When the total phenolic content (TPC) and DPPH radical scavenging activity values of the samples are examined, it is observed that the protein-inulin conjugate matrices (PC) provide a distinct superiority in protecting the antioxidant properties of rutin and related bioactive components compared to physical mixtures (PP). The highest phenolic content and radical scavenging activity were detected in the sample coded LAPC (291.56 mg GAE/g and 227.54 mg AAE/g), whereas the lowest antioxidant and phenolic compound values were determined in the LRPP sample (157.36 mg AAE/g and 275.94 mg GAE/g), which is a physical mixture formulation. This clearly demonstrates that the conjugate structures prepared via the Maillard reaction significantly increase the preservation of antioxidant properties. Statistically, the transition from physical mixtures to conjugate matrices (from LRPP to LRPC, and LAPP to LAPC) resulted in a significant upward shift in both parameters ($p < 0.05$), confirming that the covalent bonding matrix offers a predictable and mathematically validated protective performance over simple blending.

The high success obtained in the conjugate samples (LAPC and LRPC) is directly related to the capacity of covalent modification to enhance antioxidant stability. In the literature, it is reported that the conjugation of proteins with polysaccharides, such as inulin, provides higher protection in preserving the antioxidant capacities of bioactive components compared to native proteins or physical mixtures (Yi et al., 2016). The conjugation process creates a tighter and more resilient protective barrier around phenolic compounds through modifications induced in the protein framework. These structural alterations and the increase in antioxidant power can be attributed to the presence of high molecular weight (HMW) melanoidins formed during the Maillard reaction, which are well-known for their superior antioxidant properties (Nooshkam et al., 2019). Conversely, in physical mixtures (LRPP and LAPP), since this molecular protective network remains weaker, the phenolic components become more open to environmental effects, and subsequent decreases have been observed in both TPC and DPPH values.

Furthermore, the protective role of encapsulation technology on the structural integrity of bioactive substances is of critical importance in preventing the adverse conditions to which free or poorly protected components are exposed (Babazadeh et al., 2017). In our study, the emergence of the LAPC sample, which possesses a conjugate matrix, as the most effective combination proves that the prebiotic effect of inulin, combined with the dense network integrity formed by the conjugated protein structure, synergistically enhances the stability of antioxidant metabolites. The capacity of conjugated systems to hold phenolic compounds more stably within the matrix and manage the release profile more efficiently is in perfect agreement with literature findings showing that conjugated structures (e.g., pectin-chitosan conjugates) are far more efficient in protecting the antioxidant potential of bioactive substances compared to non-conjugated systems (Shishir et al., 2019). Consequently, plant protein and inulin conjugation represents a superior encapsulation strategy for preserving bioactive components and developing functional products with high antioxidant potential in probiotic systems.

Conclusion

This study demonstrates that the conjugation of rice protein and inulin is a far more effective strategy for enhancing the antioxidant stability of probiotic-containing microcapsules compared to physical mixtures. The obtained findings prove that the conjugated matrices prepared particularly with the *Lactobacillus acidophilus* strain (LAPC) exhibit the highest total phenolic content and radical scavenging activity. It was determined that the protein-polysaccharide network structure, strengthened by the conjugation process, protects bioactive components against oxidative degradation. In future studies, it is recommended to investigate the storage stability of these conjugated systems in different food matrices and their release mechanisms in the gastrointestinal tract using in vivo methods.

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Carcass and Meat Quality Characteristics of Reciprocal Crosses between Anatolian-T and Commercial Broilers

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Abstract

This study evaluated carcass characteristics and meat quality of Anadolu-T chickens and reciprocal crosses with commercial broiler parent stocks. Four genotypes (AA, CC, AC, and CA) were evaluated using four replicates, with 24 chicks per replicate. A total of 96 birds were processed after a 12-h feed withdrawal period. Genotype and sex significantly affected carcass and cut-up part weights. Commercial broiler genotypes, particularly CC and AC, showed the highest carcass and cut-up weights, whereas AA showed the lowest values. Males generally had higher carcass and cut-up weights than females. Relative carcass yields were largely stable, although breast and thigh proportions varied among genotypes and sexes. Back fat was affected by genotype and sex, while relative abdominal fat differed among genotypes and sexes. Water-holding capacity and pH were mainly influenced by genotype and carcass region, whereas meat color was primarily affected by carcass region and sex. Overall, reciprocal crossing with commercial broiler genetics improved carcass performance and influenced selected meat quality traits. Genotype and sex significantly influenced absolute carcass traits, with Commercial Broiler genotypes (CC and AC) exhibiting the highest hot and cold carcass weights and marketed cut-up part weights, while AA birds showed the lowest values. Males consistently had higher carcass and cut-up part weights than females across all genotypes. In contrast, carcass proportions relative to live body weight were generally stable, with only breast and thigh proportions showing genotype- and sex-dependent variations. Back fat weight was significantly affected by genotype and sex, whereas abdominal fat was primarily influenced when expressed relative to cold carcass weight. These findings highlight differential fat deposition patterns associated with genetic background and sex. Meat quality analysis revealed that water-holding capacity and pH were largely influenced by genotype and carcass region, with sex showing minimal effect. Hue angle, chroma, and total color difference indicated that meat color traits were primarily shaped by carcass region and sex, while genotype had a limited impact, particularly on color tone (H°). Overall, genetic background and sex predominantly affected absolute carcass traits, fat deposition, and selected meat quality parameters, whereas proportional carcass yields were relatively stable. Reciprocal crossing, particularly with commercial broiler genetics, may improve carcass performance and selected meat quality traits in broiler production.

Keywords: Anadolu-T chickens, Reciprocal crosses, Carcass characteristics, Meat quality, Commercial broiler genetics.

Introduction

Since the mid-20th century, meat-type (broiler) chickens have undergone intensive genetic selection targeting early growth rate, feed conversion efficiency, and body composition, complemented by management practices aimed at optimizing production (Tallentire et al., 2016; Muth & Zarate, 2017; Hartcher & Lum, 2020). These breeding programs have profoundly transformed broiler production, resulting in accelerated growth, increased meat yield, reduced slaughter age, and improved feed and energy efficiency. Importantly, the persistence of additive genetic variation in modern broiler populations ensures continued responsiveness to selection, providing insights applicable to other agricultural animal species.

Hybrid breeding strategies aim to exploit heterosis by controlled crossing of genetically distinct parental lines. F₁ offspring often exhibit superior growth performance, carcass traits, and viability compared with their pure-line parents (Türkoğlu & Sarıca, 2018; Paril et al., 2024). These programs emphasize improving general combining ability within pure lines and evaluating specific combining ability across multiple crossbreeding schemes, facilitating the identification of optimal parental combinations for efficient hybrid production (van Grevenhof & Van der Werf, 2015; Calus et al., 2019; Peters et al., 2026).

In commercial broiler breeding, rapid growth remains a key selection objective, and males from both dam and sire lines are preferentially selected based on elevated body weight (BW), which exhibits moderate heritability (0.29–0.40) and positively correlates with progeny performance (Leeson & Summers, 2010; Chu et al., 2020;



Sarıca et al., 2021; Uçar et al., 2025). Long-term selection has significantly increased growth rate and final live weight in modern broilers compared to historical strains (Havenstein, Ferket, & Qureshi, 2003), while substantial genetic variation for BW persists, allowing continued selection response.

Accordingly, this study aimed to evaluate carcass characteristics and meat quality of reciprocal cross hybrids between Anatolian-T and Commercial Broiler parent stocks, with particular emphasis on parental combinations, carcass yield, fat deposition, and meat quality traits.

Material and Methods

Research Location and Animal Material

The study was conducted at the broiler research and development facility of the Animal Production Application and Research Center, Kahramanmaraş Sütçü İmam University. The animal material consisted of broiler chicks from four distinct genotypes, all sourced from parent flocks of the same age. The crossbreeding combinations of the hybrids used are presented in Table 1.

Table 1. The crossbreeding combinations of the hybrids

Genotype	Sire Line (♂)	Dam Line (♀)
Genotype 1 (AA)	Anadolu-T	Anadolu-T
Genotype 2 (CC)	Commercial Broiler	Commercial Broiler
Genotype 3 (AC)	Anadolu-T	Commercial Broiler
Genotype 4 (CA)	Commercial Broiler	Anadolu-T

Experimental Design and Housing Conditions

The experiment comprised four primary treatment groups, each representing a different genotype. Each group included four replicates, with 24 chicks assigned to each replicate pen, totaling 380 chicks (4 genotypes × 4 replicates × 28 chicks). The experiment was conducted using a completely randomized design, in which replicates were randomly assigned to the experimental treatments.

Birds were housed in a fully environmentally controlled closed poultry house measuring 7 m × 19 m. They were placed in pens measuring 2 m × 1.5 m (3 m²), separated by wire mesh partitions. Stocking density was maintained at 8 birds per m² throughout the trial. The floor was covered with pine wood shavings to a depth of 7–8 cm as litter material.

Feeding and Management Program

Birds were provided a three-phase feeding program consisting of commercial broiler starter, grower, and finisher diets obtained from a commercial feed company. The nutritional composition of the diets is presented in Table 2.

Table 2. Feed types and nutrient composition provided to chicks at different ages

Ingredients, %	0-21 days	22-35 days	36-84 days
Dry matter %	89.63	89.42	89.26
Metabolizable enerji MJ/kg	12.20	12.56	13.08
Crude Protein %	22.00	20.50	19.50

Slaughter, Defeathering, and Evisceration

A total of 96 birds, following a 12-hour feed withdrawal period with *ad libitum* access to water, were processed. Slaughter was performed without stunning in accordance with standard Turkish slaughter regulations and under the approval of the institutional ethics committee (2019/07). The procedure was conducted in a local organic processing facility. Slaughter was performed manually using killing funnels by severing the throat and major cervical blood vessels. Carcasses were then scalded in water at 54°C for 30 seconds and mechanically defeathered. To minimize bacterial proliferation and ensure cleanliness, carcasses were immersed in 22°C water for 20 minutes prior to evisceration via an abdominal incision. Hot carcass weight was recorded, followed by individual weighing of edible internal organs (liver, heart, gizzard).

Carcass Cutting Procedure

Following evisceration, carcasses were chilled at +4°C for 24 hours. After chilling, excess surface moisture was removed. Heads, feet, and visceral organs (excluding previously weighed edible organs) were removed prior to dissection.



Weighing and Calculations

All carcass parts and fat depots were weighed using a digital balance with 0.01 g precision. The yield of each part was calculated as a percentage of cold carcass weight using the following formula:

$$\text{Part Yield (\%)} = (\text{Part Weight} / \text{Cold Carcass Weight}) \times 100 \quad (1)$$

Cold carcass weight was recorded after the 24-hour chilling period.

pH and Color Measurements

- **pH:** Muscle pH was determined using a Hanna HI2211 pH meter. The probe was inserted directly into the muscle tissue. For analytical reliability, three measurements were taken from each breast and thigh muscle.
- **Color:** Color characteristics were measured using a HunterLab ColorFlex spectrophotometer (or insert brand/model if different) under standardized D65 daylight conditions with a 10° viewing angle. Color coordinates (L^* : lightness, a^* : redness/greenness, b^* : yellowness/blueness) were determined based on the CIE $L^*a^*b^*$ color space system. Color difference (ΔE), chroma (C), and hue angle (h°) were calculated using the following formulas:

$$\Delta E^* = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^2)} \quad (2)$$

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (3)$$

$$h^\circ = \tan^{-1}(b^*/a^*) \quad (4)$$

During cutting, three samples (approximately 1-2 g each) were taken from the breast and thigh of the right side of each carcass for color analysis.

Water-Holding Capacity (WHC)

Water-holding capacity (WHC) was determined using the method proposed by Hamm (1972) and later modified by Zayas and Lin (1988, 1989). A 300 mg sample obtained from skinless breast and thigh meat was placed on Whatman filter paper and subjected to a pressure of 1 kg for 20 minutes. Subsequently, scaled images of the filter papers were captured using a Canon EOS 60D equipped with an 18–135 mm lens, mounted on a tripod at a fixed height. The water spreading area (T) and meat spreading area (E) were determined using Adobe Photoshop (Eleroglu et al., 2016).

The calculation of WHC was based on the formula developed by Hofmann (1982), which has been widely applied in previous studies (Hofmann et al., 1982; Reuter, 1982; Honikel and Hamm, 1983; Honikel and Kim, 1986; Honkavaara, 1989) and was also reported by Öztan and Vural (1983). Accordingly, WHC was calculated (Eq 5) as the ratio of meat spreading area (E) to water spreading area (T).

$$\text{WHC} = E/T \quad (5)$$

Statistical Analysis

Data were analyzed using univariate statistical analysis to evaluate the effects of genotype and sex on the measured traits, while carcass part was additionally included as a fixed effect for water-holding capacity (WHC) and pH. The interaction between genotype and sex was also included in the model. Following ANOVA, Duncan's multiple range test was used as a post hoc test to determine significant differences among the groups. Statistical significance was declared at $P < 0.05$. Results are presented as means $\pm$ standard error of the mean (SEM).

Statistical model:

$$Y_{ij} = \mu + G_i + S_j + (G \times S)_{ij} + e_{ij} \quad (6)$$

Where

Y_{ij} = observed value,

μ = overall mean,

G_i = effect of genotype,

S_j = effect of sex,

$(G \times S)_{ij}$ = interaction effect,

e_{ij} = random error.



Result and Discussion

The effects of genotype and sex on carcass traits and their proportions relative to cold carcass weight (%) are summarized in Table 2.

Genotype and sex had significant effects on absolute carcass traits, whereas their effects on the relative proportions of carcass parts to cold carcass weight (%) were more limited. Regarding carcass weights (g), genotype significantly affected hot carcass, cold carcass, and edible internal organ weights ($p < 0.05$). Among genotypes, the CC group exhibited the highest hot and cold carcass weights, followed by AC and CA genotypes, while the AA genotype showed the lowest values ($p < 0.05$). This pattern was consistent for both hot and cold carcass weights, indicating a strong genetic influence on growth and carcass yield. Edible internal organ weight was also significantly influenced by genotype, with CC birds presenting higher values than the other genotypes.

Sex had a significant effect on hot and cold carcass weights ($p < 0.001$), with males consistently showing higher carcass weights than females across all genotypes. However, sex did not significantly affect edible internal organ weight ($p > 0.05$). Moreover, the genotype $\times$ sex interaction was not significant for any of the evaluated carcass traits, suggesting that the effect of sex on carcass weight was consistent across genotypes.

When carcass traits were expressed as proportions of live body weight (%), genotype and sex had no significant effects on hot or cold carcass yields ($p > 0.05$). In contrast, the proportion of edible internal organs was significantly influenced by both genotype ($p < 0.01$) and sex ($p < 0.001$). Females generally exhibited a higher proportion of edible internal organs compared to males, and the CA genotype showed the highest total edible internal organ proportion, differing significantly from the other genotypes ($p < 0.05$). No significant genotype $\times$ sex interaction was observed for carcass proportions.

Table 2. Effects of genotype and sex on carcass traits and their proportions relative to cold carcass weight (%)

Items		Carcass values (gr)		
Genotype	Sex	Hot carcass $\pm$ SEM	Cold carcass $\pm$ SEM	Edible internal organs $\pm$ SEM
AA	Male	2182.5 $\pm$ 59.69	2158.33 $\pm$ 60.12	85.57 $\pm$ 3.67
	Female	1746.67 $\pm$ 60.59	1718.33 $\pm$ 60.02	85.98 $\pm$ 3.69
	Total	1964.58^c$\pm$61.6	1938.33^c$\pm$61.89	85.77^b$\pm$2.54
CC	Male	2740 $\pm$ 68.52	2709.17 $\pm$ 69.23	94.61 $\pm$ 3.53
	Female	2149.17 $\pm$ 62.18	2127.5 $\pm$ 64.59	94.73 $\pm$ 3.02
	Total	2444.58^a$\pm$76.43	2418.33^a$\pm$76.3	94.67^a$\pm$2.27
AC	Male	2482.5 $\pm$ 61.93	2453.33 $\pm$ 61.27	87.8 $\pm$ 3.59
	Female	2088.33 $\pm$ 66.73	2058.33 $\pm$ 65.88	87.52 $\pm$ 2.71
	Total	2285.42^b$\pm$60.59	2255.83^b$\pm$60.26	87.66^b$\pm$2.2
CA	Male	2393.33 $\pm$ 64.99	2365 $\pm$ 63.71	82.36 $\pm$ 3.15
	Female	1932.5 $\pm$ 53.43	1906.67 $\pm$ 52.5	89.63 $\pm$ 2.35
	Total	2162.92^b$\pm$63.25	2135.83^b$\pm$62.55	85.99^b$\pm$2.07
Source of variation		p value	p value	p value
Genotype (G)		0.001	0.001	0.023
Sex (S)		0.001	0.001	0.416
G $\times$ S		0.433	0.486	0.606
Proportions of carcass parts to cold carcass weight (%)				
Genotype	Sex	Hot carcass $\pm$ SEM	Cold carcass $\pm$ SEM	Edible internal organs $\pm$ SEM
AA	Male	76.88 $\pm$ 0.18	76.02 $\pm$ 0.2	3.94 $\pm$ 0.18
	Female	77.19 $\pm$ 0.14	75.93 $\pm$ 0.12	4.94 $\pm$ 0.18
	Total	77.03 $\pm$ 0.12	75.97 $\pm$ 0.11	4.44^b$\pm$0.16
CC	Male	77.2 $\pm$ 0.12	76.31 $\pm$ 0.13	3.48 $\pm$ 0.16
	Female	76.73 $\pm$ 0.3	75.92 $\pm$ 0.27	4.44 $\pm$ 0.16
	Total	76.96 $\pm$ 0.17	76.12 $\pm$ 0.15	3.96^b$\pm$0.15
AC	Male	77.14 $\pm$ 0.15	76.23 $\pm$ 0.14	3.55 $\pm$ 0.14
	Female	77.4 $\pm$ 0.19	76.29 $\pm$ 0.16	4.24 $\pm$ 0.18
	Total	77.27 $\pm$ 0.12	76.26 $\pm$ 0.1	3.89^b$\pm$0.13
CA	Male	76.94 $\pm$ 0.16	76.04 $\pm$ 0.16	3.46 $\pm$ 0.13
	Female	77.08 $\pm$ 0.15	76.05 $\pm$ 0.17	4.68 $\pm$ 0.18
	Total	77.01 $\pm$ 0.11	76.05 $\pm$ 0.11	4.07^a$\pm$0.17
Source of variation		p value	p value	p value
Genotype (G)		0.349	0.403	0.007
Sex (S)		0.642	0.405	0.000
G $\times$ S		0.137	0.566	0.457

AA: Anadolu – T $\times$ Anadolu – T; CC: Commercial Broiler $\times$ Commercial Broiler; AC: Anadolu – T male $\times$ Commercial Broiler female; CA: Commercial Broiler male $\times$ Anadolu – T female; SEM: Standard error of the mean, Total values within the same column with different superscript letters differ significantly ($p < 0.05$).



The results related to the proportions of carcass parts relative to cold carcass weight (%) are summarized in Table 3.

Genotype and sex had significant effects on the absolute weights of marketed cut-up carcass parts (wing, thigh, breast, and neck) ($p < 0.001$), whereas their effects on the relative proportions of these parts were more limited and trait-dependent.

For carcass part weights (g), genotype significantly influenced all evaluated traits ($p < 0.001$). The CC genotype exhibited the highest wing, thigh, breast, and neck weights, followed by the AC and CA genotypes, while the AA genotype showed the lowest values ($p < 0.05$). These differences reflect the superior growth performance and muscle development associated with the CC genotype. Sex also had a significant effect on all carcass part weights, with males consistently presenting higher values than females across all genotypes ($p < 0.001$). No significant genotype $\times$ sex interaction was observed for any of the carcass part weights, indicating that the sex-related differences were consistent among genotypes.

When expressed as proportions of carcass parts (%), genotype significantly affected thigh and breast proportions ($p < 0.01$), whereas its effects on wing and neck proportions were not significant ($p > 0.05$). In particular, the CC genotype showed the highest breast proportion, differing significantly from the AA genotype ($p < 0.05$). Sex had a significant effect on thigh proportion ($p < 0.05$), with males generally exhibiting higher values, while no significant sex effect was observed for breast, wing, or neck proportions. A significant genotype $\times$ sex interaction was detected only for breast proportion ($p < 0.05$), suggesting that the effect of sex on breast yield varied depending on genotype.

Table 3. Effects of genotype and sex on marketed cut-up carcass traits and their proportions relative to cold carcass weight

Items		Carcass parts (gr)			
Genotype	Sex	Wing $\pm$ SEM	Thigh $\pm$ SEM	Breast $\pm$ SEM	Neck $\pm$ SEM
AA	Male	209.17 $\pm$ 5.83	632.50 $\pm$ 21.15	780.83 $\pm$ 26.27	148.33 $\pm$ 3.86
	Female	169.17 $\pm$ 4.99	485.00 $\pm$ 14.85	646.67 $\pm$ 26.7	120.00 $\pm$ 4.61
	Total	189.17^a$\pm$5.61	558.75^b$\pm$19.9	713.75^c$\pm$23.05	134.17^c$\pm$4.17
CC	Male	250.83 $\pm$ 8.11	746.67 $\pm$ 21.01	1073.33 $\pm$ 28.61	171.67 $\pm$ 6.72
	Female	204.17 $\pm$ 7.12	571.67 $\pm$ 17.83	830.00 $\pm$ 28.47	141.67 $\pm$ 5.75
	Total	227.50^a$\pm$7.18	659.17^a$\pm$22.68	951.67^a$\pm$32.14	156.67^a$\pm$5.34
AC	Male	227.50 $\pm$ 6.17	694.17 $\pm$ 21.41	944.17 $\pm$ 29.53	168.33 $\pm$ 6.13
	Female	194.17 $\pm$ 6.57	579.17 $\pm$ 18.44	781.67 $\pm$ 29.51	129.17 $\pm$ 5.14
	Total	210.83^b$\pm$5.61	636.67^a$\pm$18.29	862.92^b$\pm$26.53	148.75^{ab}$\pm$5.66
CA	Male	225.00 $\pm$ 5.97	668.33 $\pm$ 17.53	908.33 $\pm$ 28.36	154.17 $\pm$ 4.68
	Female	186.67 $\pm$ 4.49	519.17 $\pm$ 14.01	730.00 $\pm$ 20.71	126.67 $\pm$ 4.32
	Total	205.83^b$\pm$5.41	593.75^b$\pm$19.03	819.17^b$\pm$25.31	140.42^{bc}$\pm$4.23
Source of variation		p value	p value	p value	p value
Genotype (G)		0.000	0.000	0.000	0.000
Sex (S)		0.000	0.000	0.000	0.000
G $\times$ S		0.762	0.452	0.241	0.664
Items		Proportions of carcass parts to cold carcass weight (%)			
Genotype	Sex	Wing $\pm$ SEM	Thigh $\pm$ SEM	Breast $\pm$ SEM	Neck $\pm$ SEM
AA	Male	9.71 $\pm$ 0.17	29.27 $\pm$ 0.36	36.15 $\pm$ 0.51	6.90 $\pm$ 0.19
	Female	9.88 $\pm$ 0.16	28.29 $\pm$ 0.27	37.54 $\pm$ 0.34	7.00 $\pm$ 0.21
	Total	9.79^a$\pm$0.12	28.78^a$\pm$0.24	36.85^c$\pm$0.33	6.95^a$\pm$0.14
CC	Male	9.25 $\pm$ 0.14	27.56 $\pm$ 0.35	39.62 $\pm$ 0.32	6.32 $\pm$ 0.15
	Female	9.61 $\pm$ 0.19	26.90 $\pm$ 0.37	38.97 $\pm$ 0.33	6.65 $\pm$ 0.16
	Total	9.43^{ab}$\pm$0.12	27.23^c$\pm$0.26	39.30^a$\pm$0.24	6.49^b$\pm$0.11
AC	Male	9.28 $\pm$ 0.13	28.29 $\pm$ 0.46	38.44 $\pm$ 0.49	6.86 $\pm$ 0.16
	Female	9.46 $\pm$ 0.24	28.18 $\pm$ 0.46	37.93 $\pm$ 0.52	6.29 $\pm$ 0.19
	Total	9.37^b$\pm$0.13	28.24^{ab}$\pm$0.32	38.19^b$\pm$0.36	6.57^{ab}$\pm$0.14
CA	Male	9.53 $\pm$ 0.18	28.28 $\pm$ 0.32	38.38 $\pm$ 0.39	6.56 $\pm$ 0.23
	Female	9.83 $\pm$ 0.23	27.27 $\pm$ 0.41	38.28 $\pm$ 0.18	6.66 $\pm$ 0.19
	Total	9.68^{ab}$\pm$0.14	27.78^{bc}$\pm$0.28	38.33^b$\pm$0.21	6.61^{ab}$\pm$0.14
Source of variation		p value	p value	p value	p value
Genotype (G)		0.068	0.001	0.000	0.069
Sex (S)		0.053	0.012	0.901	0.944
G $\times$ S		0.950	0.609	0.049	0.092

AA: Anadolu – T $\times$ Anadolu – T; CC: Commercial Broiler $\times$ Commercial Broiler; AC: Anadolu – T male $\times$ Commercial Broiler female; CA: Commercial Broiler male $\times$ Anadolu – T female; SEM: Standard error of the mean, Total values within the same column with different superscript letters differ significantly ($p < 0.05$).



The effects of genotype and sex on back and abdominal fat traits, expressed both as absolute weights and as proportions relative to cold carcass weight, are presented in Table 4.

The effects of genotype and sex on abdominal fat traits expressed both as absolute weights and as proportions relative to cold carcass weight were evaluated in this study. The results indicate that absolute abdominal fat weight did not differ significantly among genotypes or between sexes, as evidenced by non-significant genotype ($p = 0.693$) and sex ($p = 0.345$) effects. This finding suggests that total fat deposition in broiler chickens may be relatively stable across genetic backgrounds and between males and females when assessed on an absolute basis, a pattern that has been observed in other broiler populations where total fat weight shows limited divergence among commercial and alternative lines (Petracci et al., 2015; Shim et al., 2012; Becker et al., 1981).

In contrast, when abdominal fat was expressed relative to cold carcass weight, both genotype ($p = 0.034$) and sex ($p = 0.019$) exhibited significant effects. The AA genotype showed the highest relative abdominal fat percentage, whereas the CC genotype displayed the lowest value, indicating genotype-specific differences in fat partitioning relative to overall body size. Additionally, females tended to have higher abdominal fat percentages than males across genotypes. These results highlight that proportional measures are more sensitive than absolute weights in detecting subtle differences in fat deposition, reflecting underlying genetic and physiological variation more clearly. Similar observations have been reported in broiler studies, where relative adipose tissue measures reveal genotype- and sex-linked differences not evident in absolute fat weights (Moreira et al., 2018; Wang et al., 2017).

The lack of a significant genotype $\times$ sex interaction for abdominal fat traits suggests that although both genotype and sex independently influence relative abdominal fat deposition, their combined interaction does not significantly amplify or mitigate this effect. This is consistent with reports in commercial broiler research indicating that sex differences in fat distribution are generally additive and not dependent on specific genotype combinations (López et al., 2011). The higher relative abdominal fat observed in females aligns with established patterns of sexual dimorphism in poultry, where females tend to deposit a greater proportion of adipose tissue relative to carcass mass due to endocrine and metabolic differences (Xie et al., 2026; Chen et al., 2021).

Table 4. Effects of genotype and sex on back and abdominal fat and their proportions relative to cold carcass weight

Items		Carcass parts (gr) and relative to cold carcass weight (%)			
Genotype	Sex	Back (gr) $\pm$ SEM	Back (%) $\pm$ SEM	Abdominal fat (gr) $\pm$ SEM	Abdominal fat (%) $\pm$ SEM
AA	Male	325.83 $\pm$ 10.76	15.1 $\pm$ 0.29	61.67 $\pm$ 4.05	2.87 $\pm$ 0.19
	Female	249.17 $\pm$ 9.08	14.5 $\pm$ 0.17	50 $\pm$ 5.5	2.87 $\pm$ 0.26
	Total	287.5^c$\pm$10.55	14.8 $\pm$ 0.18	55.83 $\pm$ 3.56	2.87^a$\pm$0.16
CC	Male	416.67 $\pm$ 12.87	15.4 $\pm$ 0.34	50 $\pm$ 4.26	1.85 $\pm$ 0.15
	Female	320.83 $\pm$ 11.31	15.09 $\pm$ 0.32	57.5 $\pm$ 4.46	2.71 $\pm$ 0.2
	Total	368.75^a$\pm$13.04	15.25 $\pm$ 0.23	53.75 $\pm$ 3.12	2.28^c$\pm$0.15
AC	Male	358.33 $\pm$ 9.99	14.62 $\pm$ 0.26	60.83 $\pm$ 5.43	2.52 $\pm$ 0.25
	Female	318.33 $\pm$ 12.6	15.46 $\pm$ 0.36	55.83 $\pm$ 4.99	2.67 $\pm$ 0.2
	Total	338.33^b$\pm$8.9	15.04 $\pm$ 0.23	58.33 $\pm$ 3.64	2.6^{ab}$\pm$0.16
CA	Male	354.17 $\pm$ 14.64	14.93 $\pm$ 0.29	55 $\pm$ 2.89	2.32 $\pm$ 0.1
	Female	292.5 $\pm$ 12.56	15.3 $\pm$ 0.38	51.67 $\pm$ 5.05	2.66 $\pm$ 0.22
	Total	323.33^b$\pm$11.42	15.11 $\pm$ 0.24	53.33 $\pm$ 2.87	2.49^{ab}$\pm$0.12
Source of variation		p value	p value	p value	p value
Genotype (G)		0.000	0.540	0.693	0.034
Sex (S)		0.000	0.729	0.345	0.019
G $\times$ S		0.122	0.089	0.231	0.166

AA: Anadolu – T $\times$ Anadolu – T; CC: Commercial Broiler $\times$ Commercial Broiler; AC: Anadolu – T male $\times$ Commercial Broiler female; CA: Commercial Broiler male $\times$ Anadolu – T female; SEM: Standard error of the mean, Total values within the same column with different superscript letters differ significantly ($p < 0.05$).

Effects of genotype and sex on water-holding capacity (WHC) and pH of carcass regions are presented in Table 5.

Analysis of water-holding capacity (WHC) and pH in thigh and breast muscles revealed significant effects of genotype, while sex had no significant influence ($p > 0.05$). The AA genotype (Anadolu-T $\times$ Anadolu-T) consistently exhibited the highest WHC values (0.14 ± 0.01), whereas CC (Commercial Broiler $\times$ Commercial Broiler) and hybrid genotypes (AC and CA) showed lower values (0.10 – 0.11 ± 0.01), indicating that slower-growing Anadolu-T birds maintain superior water retention in the muscle. This is consistent with previous findings demonstrating that WHC is strongly associated with growth rate and muscle fiber characteristics, with fast-growing commercial lines generally showing lower water retention due to rapid muscle accretion (Zuidhof et al., 2014; Shim et al., 2012). No significant genotype $\times$ sex interaction was observed, suggesting that WHC differences are primarily determined by genetic background rather than sex.



Regarding pH, genotype also had a significant effect ($p = 0.000$), with CC and AC birds showing lower mean pH values (5.18–5.23) compared to AA and CA birds (5.32–5.35). Lower pH in fast-growing commercial broilers is indicative of accelerated post-mortem glycolysis, which may affect meat quality attributes such as texture and WHC. Although the effect of carcass region was marginally significant ($p = 0.045$) and a genotype $\times$ region interaction was detected ($p = 0.033$), no sex effect was observed. These findings suggest that pH differences are primarily driven by genotype, with region-specific variation reflecting inherent differences between thigh and breast muscles. Overall, the results indicate that genetic selection for rapid growth influences both WHC and pH, whereas sex has limited impact, and that slower-growing Anadolu-T birds may possess more favorable meat quality traits in terms of water retention and pH stability.

Table 5. Effects of genotype and sex on water-holding capacity (WHC) and pH of carcass regions

Genotype	Sex	Carcass region	n	WHC (mean $\pm$ SEM)	n	pH
AA	Male	Thigh	12	0.15+0.02	36	5.29+0.02
		Breast	12	0.14+0.02	36	5.37+0.03
		Total	24	0.14+0.01	72	5.33+0.02
	Female	Thigh	12	0.14+0.01	36	5.27+0.02
		Breast	12	0.15+0.02	36	5.35+0.03
		Total	24	0.15+0.01	72	5.31+0.02
Total		48	0.14^a+0.01	144	5.32^a+0.01	
CC	Male	Thigh	12	0.11+0.01	36	5.26+0.04
		Breast	12	0.1+0.01	36	5.15+0.04
		Total	24	0.1+0.01	72	5.21+0.03
	Female	Thigh	12	0.09+0.01	36	5.28+0.04
		Breast	12	0.12+0.01	36	5.24+0.05
		Total	24	0.11+0.01	72	5.26+0.03
Total		48	0.11^b+0.01	144	5.23^b+0.02	
AC	Male	Thigh	12	0.09+0.01	36	5.28+0.06
		Breast	12	0.11+0.01	36	5.02+0.15
		Total	24	0.1+0.01	72	5.15+0.08
	Female	Thigh	12	0.12+0.01	36	5.23+0.06
		Breast	12	0.12+0.01	36	5.21+0.04
		Total	24	0.12+0.01	72	5.22+0.03
Total		48	0.11^b+0.01	144	5.18^b+0.04	
CA	Male	Thigh	12	0.09+0.01	36	5.39+0.04
		Breast	12	0.11+0.01	36	5.28+0.04
		Total	24	0.1+0.01	72	5.33+0.03
	Female	Thigh	12	0.09+0.01	36	5.4+0.05
		Breast	12	0.12+0.01	36	5.34+0.05
		Total	24	0.11+0.01	72	5.37+0.03
Total		48	0.1^b+0	144	5.35^a+0.02	
Source of variation			p-value			
Genotype (G)			0.000			
Sex (S)			0.191			
Carcass region (CR)			0.052			
G $\times$ S			0.820			
G $\times$ CR			0.474			
S $\times$ CR			0.449			
G $\times$ S $\times$ CR			0.431			

AA: Anadolu – T $\times$ Anadolu – T; CC: Commercial Broiler $\times$ Commercial Broiler; AC: Anadolu – T male $\times$ Commercial Broiler female; CA: Commercial Broiler male $\times$ Anadolu – T female; SEM: Standard error of the mean, Total values within the same column with different superscript letters differ significantly ($p < 0.05$).

The effects of genotype, sex, and carcass region on meat color parameters (L^* , a^* , and b^*) of thigh and breast meat are presented in Table 6.

Genotype had no significant effect on L^* , a^* , or b^* values ($p > 0.05$), indicating that overall meat color characteristics were not markedly influenced by genetic background. In contrast, sex significantly affected a^* and b^* values ($p < 0.01$), whereas its effect on L^* was not significant ($p > 0.05$). Females generally exhibited higher redness (a^*) and yellowness (b^*) values compared to males.

Carcass region had a significant effect on all color parameters ($p < 0.001$). Breast meat showed higher L^* and b^* values, indicating lighter and more yellow coloration, while thigh meat exhibited higher a^* values, reflecting greater redness. These differences highlight the distinct muscle characteristics between carcass regions.



Significant genotype $\times$ sex interactions were observed for a^* ($p < 0.05$) and b^* ($p < 0.05$), suggesting that sex-related differences in redness and yellowness varied among genotypes. However, no significant genotype $\times$ carcass region, sex $\times$ carcass region, or three-way interactions were detected for any of the color parameters ($p > 0.05$).

The effects of genotype, sex, and carcass region on meat color parameters (H° – hue angle, C – chroma, and ΔE) of thigh and breast meat are presented in Table 7.

Genotype had a significant effect on H° values ($p < 0.01$), while its effects on C^* and ΔE^* were not significant ($p > 0.05$), indicating that genetic background primarily influences overall color tone rather than color intensity or total color variation (Le Bihan-Duval et al., 2008; Sarica et al., 2021). Sex significantly affected both H° and C^* values ($p < 0.001$), with females generally showing higher hue angle and chroma, reflecting brighter and more vivid meat coloration, likely due to differences in muscle fiber distribution, myoglobin content, and lipid deposition (Leeson & Summers, 2010; Erensoy & Sarica, 2023). In contrast, sex did not significantly affect ΔE^* , suggesting that overall color difference is less sensitive to sex than individual color parameters.

Carcass region had a significant effect on C^* ($p < 0.001$) and ΔE^* ($p < 0.01$), with breast meat exhibiting higher chroma and ΔE^* than thigh meat, reflecting more intense color and greater total color difference. H° was not significantly influenced by carcass region. Significant genotype $\times$ sex interactions for H° indicate that the effect of sex on hue angle varies depending on genotype. Additionally, a significant sex $\times$ carcass region interaction for H° suggests that regional differences in color tone are modulated by sex. No other two- or three-way interactions were significant for C^* or ΔE^* , highlighting that these traits are primarily shaped by muscle region rather than genotype or sex.

Table 6. Effects of genotype and sex on meat color parameters (L^* , a^* , b^*) in different carcass regions

Genotype	Sex	Carcass region	n	L^*	a^*	b^*
AA	Male	Thigh	36	43.74+1.02	3.51+0.21	11.56+0.35
		Breast	36	45.33+1.51	2.52+0.25	13.29+0.41
		Total	72	44.54+0.91	3.01+0.17	12.42+0.29
	Female	Thigh	36	46.01+0.9	3.23+0.24	13.43+0.36
		Breast	36	47.79+0.89	2.77+0.22	15.36+0.39
		Total	72	46.9+0.64	3+0.16	14.4+0.29
	Total		144	45.72+0.56	3.01+0.12	13.41+0.22
CC	Male	Thigh	36	45.45+1.21	2.84+0.32	11.88+0.53
		Breast	36	50.41+1.09	1.5+0.24	13.82+0.45
		Total	72	47.93+0.86	2.17+0.21	12.85+0.36
	Female	Thigh	36	43.63+1.5	4.41+1.07	12.56+0.49
		Breast	36	49.58+1.05	2.62+0.19	15.01+0.5
		Total	72	46.6+0.98	3.51+0.55	13.78+0.38
	Total		144	47.27+0.65	2.84+0.3	13.32+0.26
AC	Male	Thigh	36	46.86+0.85	2.88+0.18	12.31+0.48
		Breast	36	49.71+1.24	1.26+0.19	13.5+0.48
		Total	72	48.29+0.77	2.07+0.16	12.91+0.34
	Female	Thigh	36	40.67+0.91	3.29+0.23	12.27+0.41
		Breast	36	61.75+14.02	2.24+0.17	14.47+0.37
		Total	72	51.21+7.09	2.77+0.16	13.37+0.3
	Total		144	49.75+3.55	2.42+0.12	13.14+0.23
CA	Male	Thigh	36	44.87+1.31	2.75+0.19	11.72+0.52
		Breast	36	49.02+1.01	2.4+0.2	14.46+0.47
		Total	72	46.95+0.86	2.58+0.14	13.09+0.38
	Female	Thigh	36	43.16+1.13	3.12+0.23	12.09+0.44
		Breast	36	48.74+0.69	2.71+0.2	14.84+0.29
		Total	72	45.95+0.73	2.91+0.15	13.46+0.31
	Total		144	46.45+0.56	2.75+0.1	13.28+0.25
Source of variation				p-value	p-value	p-value
Genotype (G)				0.434	0.100	0.853
Sex (S)				0.686	0.001	0.000
Carcass region (CR)				0.001	0.000	0.000
G $\times$ S				0.779	0.035	0.040
G $\times$ CR				0.247	0.057	0.332
S $\times$ CR				0.156	0.664	0.325
G $\times$ S $\times$ CR				0.240	0.669	0.867



Table 7. Effects of genotype and sex on meat color parameters (H° , C^* , ΔE) in different carcass regions

Genotype	Sex	Carcass region	n	H°	C*	ΔE
AA	Male	Thigh	36	72.91+1.03	12.14+0.35	45.44+1.02
		Breast	36	69.61+6.5	13.59+0.42	47.52+1.39
		Total	72	71.26+3.27	12.87+0.29	46.48+0.87
	Female	Thigh	36	76.69+0.92	13.87+0.38	48.09+0.92
		Breast	36	79.84+0.8	15.66+0.4	50.33+0.93
		Total	72	78.26+0.63	14.77+0.29	49.21+0.66
CC	Total	144	74.76+1.69	13.82+0.22	47.84+0.55	
	Male	Thigh	36	57.19+8.79	12.32+0.56	47.16+1.25
		Breast	36	54.39+10.76	13.95+0.47	52.34+1.14
		Total	72	55.79+6.9	13.14+0.37	49.75+0.9
	Female	Thigh	36	73.28+1.9	13.9+0.96	46.29+1.36
		Breast	36	79.13+1.6	15.34+0.45	51.94+1.08
Total		72	76.2+1.28	14.62+0.53	49.12+0.93	
AC	Total	144	66+3.6	13.88+0.33	49.43+0.64	
	Male	Thigh	36	76.63+0.85	12.69+0.48	48.61+0.88
		Breast	36	65.29+9.07	13.6+0.49	51.59+1.28
		Total	72	70.96+4.57	13.14+0.34	50.1+0.79
	Female	Thigh	36	74.95+0.93	12.77+0.42	42.68+0.95
		Breast	36	81.34+0.57	14.66+0.38	63.92+13.97
Total		72	78.15+0.66	13.72+0.3	53.3+7.06	
CA	Total	144	74.55+2.32	13.43+0.23	51.7+3.54	
	Male	Thigh	36	76.74+0.88	12.09+0.52	46.54+1.34
		Breast	36	75.8+4.76	14.69+0.49	51.23+1.05
		Total	72	76.27+2.41	13.39+0.39	48.88+0.89
	Female	Thigh	36	75.7+1	12.54+0.45	45+1.16
		Breast	36	79.82+0.71	15.12+0.31	51.05+0.7
Total		72	77.76+0.66	13.83+0.31	48.02+0.76	
Total			144	77.01+1.24	13.61+0.25	48.45+0.59
Source of variation				p-value	p-value	p-value
Genotype (G)				0.005	0.555	0.463
Sex (S)				0.000	0.000	0.544
Carcass region (CR)				0.952	0.000	0.001
G × S				0.033	0.104	0.792
G × CR				0.920	0.298	0.269
S × CR				0.044	0.574	0.166
G × S × CR				0.776	0.836	0.226

Conclusion

This study investigated the effects of genotype and sex on carcass characteristics and meat quality in reciprocal crosses between Anatolian-T and Commercial Broiler parent stocks. Genetic background was the primary determinant of absolute carcass weights and marketed cut-up parts, with Commercial Broiler genotypes (CC and AC) showing superior growth, muscle development, and total carcass mass. Sex significantly influenced absolute weights, with males generally outperforming females, whereas relative carcass yields were largely consistent across genotypes.

Fat deposition patterns were trait-specific: back fat was mainly affected by genotype and sex in absolute terms, while relative abdominal fat differed among genotypes and sexes. Meat quality traits, including water-holding capacity, pH, and color parameters, were mainly influenced by genotype, sex, and muscle region. These findings highlight the importance of considering genetic background, sex, and carcass region when evaluating meat quality in reciprocal cross hybrids.

In summary, reciprocal crosses between Anatolian-T and Commercial Broiler parent stocks can improve carcass traits and influence meat quality. The effects of genotype, sex, and carcass region varied among traits, providing useful information for parental line selection and hybrid breeding programs aimed at improving broiler carcass performance and meat quality.

Declarations

A shortened version of this manuscript has been submitted to TARGID 20026for presentation at the congress

Ethical Approval Certificate

The experimental procedures of this study were approved by the Local Animal Care and Ethics Committee of Animal Experiments of Kahramanmaraş Sütçü İmam University (Approval date: 28 February 2025; Approval number: 2025/02)



Author Contribution Statement

The authors declare that they have contributed equally to the work. Conflict of Interest The authors declare no conflict of interest. Acknowledgments In this study, we would like to thank TAGEM for providing the animal material we used from project number TAGEM/HAYSÜT/G/22/A4/P4/6230

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Evaluation of Welfare Traits in Hybrids Obtained from Reciprocal Crosses between Anadolu-T and Commercial Broiler Parent Stocks

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Abstract

This study aimed to evaluate the effects of genotype, sex, and their interaction on welfare-related traits, morphological characteristics, and developmental stability in reciprocal crosses between Anadolu-T and commercial broiler parent stocks at 3 and 6 weeks of age. Welfare indicators, including tonic immobility (TI) and rectal temperature (RT), were largely unaffected by genotype and genotype $\times$ sex interactions at both ages. At 3 weeks, sex had a significant effect on RT, with males exhibiting slightly higher values, suggesting early metabolic differences; however, this effect was not observed at 6 weeks. These findings indicate that early physiological welfare traits are relatively stable and largely independent of genetic background. Morphological traits, including comb length (CL), comb width (CW), and beak length (BL), were significantly influenced by sex at both ages, with males consistently showing higher values. Genotype effects were not evident at 3 weeks but became significant at 6 weeks, highlighting the increasing influence of genetic background on phenotypic expression as birds approached market age. Reciprocal cross differences suggested potential maternal and sex-linked genetic effects. Fluctuating asymmetry (FA) and relative asymmetry (RA) analyses revealed that developmental instability was generally low and not significantly affected by genotype at 3 weeks. However, at 6 weeks, genotype, sex, and genotype $\times$ sex interactions significantly influenced several traits, particularly in head, tarsometatarsus, and foot measurements. These results indicate that developmental instability increases with age and becomes more sensitive to genetic and physiological factors. Taken together, the findings demonstrate that early-stage traits are relatively stable across genotypes, whereas later developmental stages show increased variability driven by genotype, sex, and their interaction. These results emphasize the importance of considering age-dependent effects in broiler breeding and welfare evaluation.

Keywords: Anadolu-T broiler, commercial broiler, reciprocal crossbreeding, developmental stability, fluctuating asymmetry

Introduction

The global poultry industry has undergone substantial transformation over the past decades, largely driven by intensive genetic selection for rapid growth, improved feed efficiency, and high meat yield. While these advancements have significantly increased production efficiency, they have also raised concerns regarding potential trade-offs with animal welfare, physiological stability, and structural integrity (Scanes, 2015). In modern broiler production systems, understanding how genetic background and biological factors such as sex influence both performance and welfare-related traits is critical for sustainable breeding strategies.

Welfare-related physiological indicators, such as tonic immobility (TI) and rectal temperature (RT), are widely used to assess stress responsiveness and thermoregulatory capacity in poultry. TI is considered a reliable behavioral measure of fearfulness, while RT reflects metabolic activity and heat regulation (Dixon, 2020; Scanes, 2015). Previous research suggests that these physiological traits tend to be relatively stable during early development and may be less influenced by genotype compared to growth and morphological traits (Scanes, 2015). However, sex-related differences, particularly in metabolic rate and thermoregulation, may still be observed, especially during early growth phases.

Morphological traits, including comb length, comb width, and beak length, are important indicators of growth performance and developmental progression. These traits are strongly influenced by endocrine factors, particularly androgens, and often exhibit pronounced sexual dimorphism, with males generally showing greater development (Siegel, 2014; Siegel & Honaker, 2024). While early-stage morphological traits may show limited genotype effects, genetic differences tend to become more evident as birds approach later growth stages due to differential growth rates and metabolic demands (Zuidhof et al., 2014).

In addition to absolute trait measurements, developmental stability is an important aspect of animal performance and welfare. Fluctuating asymmetry (FA) and relative asymmetry (RA) are widely used indicators of



developmental instability, reflecting an organism's ability to buffer against environmental and genetic perturbations during development (Klingenberg, 2015; Palmer & Strobeck, 1986). Increased asymmetry is often associated with stress, rapid growth, and reduced welfare, particularly in intensively selected broiler lines (Dixon, 2020).

Reciprocal crossbreeding between local and commercial genotypes provides an effective approach to investigate genetic, maternal, and heterosis effects on growth, morphology, and developmental stability. Such crosses can reveal differences arising from cytoplasmic inheritance, maternal effects, and sex-linked genes (Shen et al., 2016; Tuiskula-Haavisto & Vilkkilä, 2007). Moreover, crossbreeding strategies may contribute to improved developmental stability and performance by combining desirable traits from different genetic backgrounds.

Collectively, these considerations highlight the need to evaluate genotype, sex, and their interaction across different developmental stages. Therefore, the present study aimed to assess the effects of genotype, sex, and genotype $\times$ sex interaction on tonic immobility, rectal temperature, morphological traits, and developmental stability (FA and RA) in reciprocal crosses between Anadolu-T and commercial broiler lines at 3 and 6 weeks of age.

Material and Methods

Research Location and Animal Material

The study was conducted at the broiler research and development poultry house of the Animal Production Application and Research Center at Kahramanmaraş Sütçü İmam University. As animal material, broiler chicks belonging to four different genotypes, obtained from parents of the same age (46 weeks), were used. The permission numbered 2025/02 from the Kahramanmaraş Sütçü İmam University, Faculty of Agriculture Animal Experiments Local Ethics Committee (KSUZIRHADYK). The crossbreeding combinations of the hybrids used in the study are presented in Table 1.

Table 1. The crossbreeding combinations of the hybrids

Genotype	Sire Line (♂)	Dam Line (♀)
Genotype 1 (AA)	Anadolu-T	Anadolu-T
Genotype 2 (CC)	Commercial Broiler	Commercial Broiler
Genotype 3 (AC)	Anadolu-T	Commercial Broiler
Genotype 4 (CA)	Commercial Broiler	Anadolu-T

Experimental Design and Housing Conditions

Each genotype constituted a treatment group, with four replicates per treatment and 24 chicks per replicate, resulting in a total of $4 \times 4 \times 24 = 384$ chicks used in the study. The experiment was conducted using a completely randomized design, in which replicates were randomly assigned to the experimental treatments.

Environmental Conditions and House Management

The poultry house was a fully controlled, closed-type facility measuring 7 m $\times$ 19 m. The house was divided into pens using wire mesh partitions, and an area of 3 m² (2.0 m $\times$ 1.5 m) was allocated for each replicate, housing 24 birds per pen. The stocking density was 12 birds/m². Ventilation was controlled, and cooling of the poultry house was provided by evaporative cooling pads. As litter material, coarse pine wood shavings were used at a rate of 3 kg/m². A lighting program of 23 h light and 1 h dark was applied from the first day of the experiment. Lighting was provided using 15-W daylight-colored bulbs. Light intensity was measured at feeder level between two bulbs using a Lutron LX-101 lux meter and was maintained at 20 lux. Heating of the poultry house was ensured by air-blowing, thermostatically controlled electric heaters.

Feeding and Management Program

In the study, three commercial diets commonly used in the market and produced by a commercial feed company were used as feed material. The nutrient composition of the diets and the feeding periods are presented in Table 2. Feeding was carried out manually by weighing the feed, using one feeder per replicate. Feed was provided ad libitum throughout the experimental period. Water was supplied ad libitum through nipple drinkers, with five nipple drinkers installed in each replicate pen. A multivitamin supplement was added to the drinking water once a week at a rate of 20 g per 200 L. Live vaccines against Newcastle disease and Gumboro disease were administered via drinking water on days 6 and 13, respectively.



Table 2. Feed types and nutrient composition provided to chicks at different ages

Ingredients, %	0-21 days	22-35 days	36-84 days
Dry matter %	89.63	89.42	89.26
Metabolizable enerji MJ/kg	12.20	12.56	13.08
Crude Protein %	22.00	20.50	19.50

Data Collection and Measurements: The following parameters were recorded during the experimental period:

Morphological Measurements: In the study, a total of 384 broiler chickens from both genotypes were used. Morphological measurements were conducted on 64 chicks (16 males and 16 females from each genotype), and measurements were taken at 21 and 42 days of age, resulting in a total of 256 individual measurements across both time points, using a digital caliper (Van Nuffel et al., 2007). To minimize measurement error, all measurements were performed by the same researcher, and each measurement was taken three times on the same chick, with the average value used for analysis. In the study, each genotype consisted of four replicates, and four male and four female chicks were selected from each replicate. Measurements were taken at the 3rd and 6th weeks. In total, 64 chicks were evaluated (2 genotypes $\times$ 4 replicates $\times$ 16 chicks, comprising 8 males and 8 females per replicate). To evaluate the effects of genotype and sex on selected morphological traits and asymmetry, bilateral measurements were obtained from the head region of roosters on both the right and left sides. The traits measured included Comb length (CL), Comb width (CW), Eye width (EW), Beak length (BL), Facial width (FW), Wattle length (WL), Wattle width (WW) and nose Length (NL).

For the feet, morphological measurements were taken on both the right and left sides, including Joint width (JW), Tarsometatarsus length (TML Tarsometatarsus width at 1 cm above the spur (TMW-1), Tarsometatarsus width at the spur level (TMW-SL), Hind toe length (HTL), Outer toe claw length (OTCL), Fourth phalanx length of the outer toe (OP4L), Third phalanx length of the outer toe (OP3L), Middle toe claw length (MTCL), Fourth phalanx length of the middle toe (MP4L), and Third phalanx length of the middle toe (MP3L). The morphological characteristics evaluated in this study are illustrated in Figures 1 and 2 (Eleroğlu et al., 2020).

Fluctuating asymmetry (FA) was defined as the absolute difference between the right and left measurements, and was calculated as follows;

$$FA = |R - L| \text{ (Campo et al., 2002).}$$

(1)

Relative asymmetry (RA) was expressed as the ratio of the absolute asymmetry to the mean of the right and left trait values and was calculated as follows:

$$RA = (|R - L| / [(R + L)/2]) \times 100 \text{ (Yang, 1998).}$$

(2)

Relative asymmetry (RA) of the left and right bones (%) was calculated as $RA = |R - L| / ((R + L)/2) \times 100$, where R and L are the lengths of the right and left bones (mm), $|R - L|$ is their absolute difference, and $(R + L)/2$ is the average used to standardize the difference relative to bone size.

Physiological Measurements:

Rectal Temperature (RT): Cloacal temperature was measured by inserting the probe of a digital thermometer 2 cm into the cloaca.

Tonic Immobility (TI): Tonic immobility was used to evaluate fear responses in the broiler chicks. Chicks were gently placed on their backs on a padded surface, and light pressure was applied to the chest to induce immobility. The stopwatch was started after the pressure was released, and the duration until the bird attempted to stand up was recorded. Chicks that did not show a righting response within 10 minutes were excluded from the evaluation (Marx et al., 2008; Prieto & Campo, 2010).



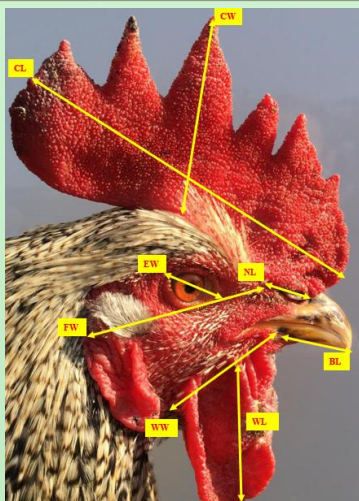


Figure 1. Head measurements

Comb length (CL), Comb width (CW), Eye width (EW), Beak length (BL), Facial width (FW), Wattle length (WL), Wattle width (WW) and nose Length (NL). (Eleroğlu et al., 2020).

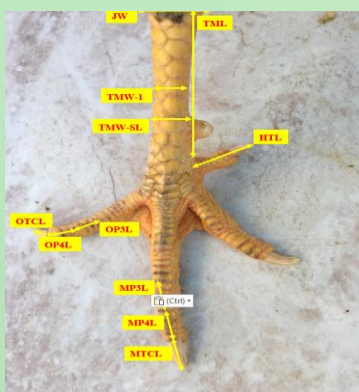


Figure 2. Foot measurements

Joint width (JW), Tarsometatarsus length (TML Tarsometatarsus width at 1 cm above the spur (TMW-1), Tarsometatarsus width at the spur level (TMW-SL), Hind toe length (HTL), Outer toe claw length (OTCL), Fourth phalanx length of the outer toe (OP4L), Third phalanx length of the outer toe (OP3L), Middle toe claw length (MTCL), Fourth phalanx length of the middle toe (MP4L), and Third phalanx length of the middle toe (MP3L). (Eleroğlu et al., 2020).

Statistical Analysis: At the end of each week, all birds were weighed in the afternoon, and average live weights were calculated. Data obtained for traits were evaluated using one-way analysis of variance (ANOVA), and comparisons among means were performed using Duncan's Multiple Range Test (Düzgüneş et al., 1987; Efe et al., 2000; Özdamar, 2002). Statistical analyses were carried out using the SPSS-22 statistical software package (SPSS-22, IBM Corp., USA)

Results are presented as means $\pm$ standard error of the mean (SEM).

Statistical model:

$$Y_{ij} = \mu + G_i + S_j + (G \times S)_{ij} + e_{ij}$$

Where

Y_{ij} = observed value,

μ = overall mean,

G_i = effect of genotype,

S_j = effect of sex,

$(G \times S)_{ij}$ = interaction effect,

e_{ij} = random error.



Result and Discussion

The effects of genotype, sex, and their interaction on tonic immobility (TI) and rectal temperature (RT, °C) of reciprocal crosses between Anadolu-T and Commercial broiler parent stocks are summarized in Table 2. At 3 weeks of age, genotype did not significantly influence TI ($P = 0.677$) or RT ($P = 0.441$), while sex had a borderline significant effect on TI ($P = 0.066$) and a significant effect on RT ($P = 0.024$), with males exhibiting slightly higher rectal temperatures. The genotype $\times$ sex interaction was not significant for either trait (TI: $P = 0.953$; RT: $P = 0.896$). By 6 weeks of age, genotype and genotype $\times$ sex interaction remained non-significant for both TI (genotype $P = 0.760$; interaction $P = 0.913$) and RT (genotype $P = 0.838$; interaction $P = 0.833$). Sex effects on TI and RT were also non-significant at 6 weeks (TI: $P = 0.486$; RT: $P = 0.677$). These findings indicate that early welfare-related traits, as measured by TI and RT, are largely independent of genotype and genotype $\times$ sex interactions in these broiler crosses.

The current study demonstrates that tonic immobility and rectal temperature are largely unaffected by genotype and genotype $\times$ sex interactions in reciprocal crosses of Anadolu-T and Commercial broilers during early (3 weeks) and later (6 weeks) growth stages. This suggests that these welfare-related physiological traits are relatively stable across genotypes, consistent with prior reports on early broiler stress responses (Scanes, 2015; Dixon, 2020). The observed sex effect on rectal temperature at 3 weeks, with males showing slightly higher values, aligns with previous findings that male broilers often have higher basal metabolic rates and body temperatures during early development (Scanes, 2015).

The absence of significant genotype effects indicates that early thermoregulation and fear response, as measured by TI and RT, are largely independent of the genetic background, in contrast to morphological traits such as comb length and width, which show increasing genotype influence in later growth stages (Siegel & Honaker, 2024). Furthermore, the lack of genotype $\times$ sex interactions for TI and RT suggests that sex-specific responses do not differentially modulate these physiological parameters in early development. These results underscore the importance of considering both sex and genotype in morphological and growth studies, while early welfare-related traits may be more influenced by environmental and management factors than genetic selection (Dixon, 2020; Scanes, 2015; Siegel & Honaker, 2024).

Table 2. Effects of Genotype and Sex on Tonic Immobility Reaction and Rectal Temperature (°C) of Reciprocal Crosses between Anadolu-T and Commercial Broiler Parent Stocks

Items		3. week		6. week	
Genotype	Sex	TI $\pm$ SEM	RT $\pm$ SEM	TI $\pm$ SEM	RT $\pm$ SEM
AA	M	157.38 $\pm$ 23.92	41.66 $\pm$ 0.09	132.31 $\pm$ 20.90	41.53 $\pm$ 0.05
	F	127.19 $\pm$ 22.81	41.54 $\pm$ 0.08	138.44 $\pm$ 20.33	41.49 $\pm$ 0.06
	T	142.28 $\pm$ 16.48	41.60 $\pm$ 0.06	135.38 $\pm$ 14.35	41.51 $\pm$ 0.04
CC	M	143.06 $\pm$ 22.81	41.70 $\pm$ 0.06	155.38 $\pm$ 24.96	41.54 $\pm$ 0.06
	F	127.25 $\pm$ 20.09	41.56 $\pm$ 0.07	140.44 $\pm$ 15.21	41.48 $\pm$ 0.06
	T	135.16 $\pm$ 15.02	41.63 $\pm$ 0.05	147.91 $\pm$ 14.44	41.51 $\pm$ 0.04
AC	M	162.94 $\pm$ 24.61	41.69 $\pm$ 0.12	138.63 $\pm$ 20.86	41.48 $\pm$ 0.06
	F	136.13 $\pm$ 23.74	41.61 $\pm$ 0.09	121.94 $\pm$ 8.61	41.51 $\pm$ 0.05
	T	149.53 $\pm$ 16.99	41.65 $\pm$ 0.07	130.28 $\pm$ 11.2	41.5 $\pm$ 0.04
CA	M	144.25 $\pm$ 19.79	41.63 $\pm$ 0.07	137.81 $\pm$ 8.41	41.47 $\pm$ 0.04
	F	103.50 $\pm$ 13.29	41.43 $\pm$ 0.04	128.63 $\pm$ 13.36	41.47 $\pm$ 0.04
	T	123.88 $\pm$ 12.28	41.53 $\pm$ 0.04	133.22 $\pm$ 7.81	41.47 $\pm$ 0.03
Source of variations		Sig.	Sig.	Sig.	Sig.
Genotype		0.677	0.441	0.760	0.838
Sex		0.066	0.024	0.486	0.677
G $\times$ S		0.953	0.896	0.913	0.833

AA: Anadolu – T $\times$ Anadolu – T; CC: Commercial $\times$ Commercial; AC: Anadolu – T male $\times$ Commercial female; CA: Commercial male $\times$ Anadolu – T female; F = Female; M = Male; T: Total; TI = Tonic immobility; RT = Rectal temperatures; Genotype $\times$ Sex; SEM: The Mean of Standard Error

Table 3 presents the effects of genotype, sex, and their interaction on non-bilateral morphological traits—comb length (CL), comb width (CW), and beak length (BL)—at 3 and 6 weeks of age in reciprocal crosses between Anadolu-T and commercial broiler parent stocks.

At 3 weeks of age, genotype did not significantly influence CL, CW, or BL ($P > 0.05$), indicating that the early development of these morphological traits is relatively independent of genetic background. However, sex had a highly significant effect on all traits ($P < 0.001$), with males consistently showing higher values than females across all genotypes. This pattern suggests that sexual dimorphism in morphological characteristics begins to emerge early in broiler development. Similar findings have been reported in modern broiler lines, where males exhibit faster growth and more pronounced morphological development than females (Siegel & Honaker, 2024; Müsse et al., 2022).



The genotype $\times$ sex interaction was only significant for CW ($P < 0.05$), suggesting that comb width development at this stage may be influenced by sex-specific genetic expression. This partial interaction effect implies that while overall genotype differences are not yet pronounced, certain traits may already show differential sensitivity to combined genetic and sex effects ().

At 6 weeks of age, genotype effects became significant for all traits (CL: $P = 0.002$; CW: $P = 0.006$; BL: $P = 0.012$), indicating that genetic background plays a more prominent role as birds approach market age. Among genotypes, the CA group (Commercial male $\times$ Anadolu-T female) exhibited the highest total values for CL (42.47 mm), CW (15.35 mm), and BL (18.56 mm), followed by AA and CC groups, while the AC genotype generally showed lower values. These results suggest a possible maternal or reciprocal cross effect, where the direction of crossing influences phenotypic expression. Reciprocal cross differences have been widely documented in poultry due to maternal inheritance, cytoplasmic effects, and sex-linked genes (Shen et al., 2016; Tuiskula-Haavisto & Vilkki, 2007).

Sex remained a highly significant factor at 6 weeks ($P < 0.001$), with males maintaining superior values for all traits. This is consistent with the continued influence of hormonal and growth-related differences between sexes, particularly in traits such as comb development, which are known to be androgen-dependent (Scanes, 2015). The persistence of sex effects across both ages reinforces the importance of considering sex as a key biological variable in morphological and production studies (Siegel, 2014; Dixon, 2020; FAO, 2022).

The genotype $\times$ sex interaction was significant only for BL ($P < 0.05$) at 6 weeks, indicating that beak development may be differentially regulated depending on both genetic background and sex. Although few studies have specifically examined genotype $\times$ sex interactions on comb width, genotype $\times$ sex interactions have been widely documented for morphological and performance traits in chickens, indicating that combined genetic and sex-specific effects can differentially influence phenotypic expression (Ajayi & Ejiofor, 2009; El-Henfnawy et al., 2022).

The findings demonstrate that while early-stage (3-week) morphological traits are primarily influenced by sex, genotype effects become more pronounced with age (6 weeks). The superior performance of the CA genotype suggests that reciprocal crossing strategies can be utilized to enhance certain morphological traits. These results are consistent with recent research showing that genetic background increasingly influences growth performance at later stages and that sex consistently impacts broiler morphology and performance (England et al., 2022; Xie et al., 2026).

Table 3. Influence of Genotype and Sex on Non-Bilateral Morphological Characteristics of Reciprocal Crosses between Anadolu-T and Commercial Broiler Parent Stocks

Items		3. weeks			6. weeks		
Genotype	Sex	CL	CW	BL	CL	CW	BL
AA	M	36.47 $\pm$ 0.86	14.31 $\pm$ 0.51	16.08 $\pm$ 0.15	50.33 $\pm$ 1.59	20.59 $\pm$ 1.14	18.22 $\pm$ 0.18
	F	25.8 $\pm$ 0.79	7.13 $\pm$ 0.42	15.99 $\pm$ 0.19	29.69 $\pm$ 0.38	7.88 $\pm$ 0.29	17.73 $\pm$ 0.27
	T	31.14 $\pm$ 1.12	10.72 $\pm$ 0.72	16.04 $\pm$ 0.12	40.01$\pm$2.02^b	14.23$\pm$1.28^{ab}	17.97$\pm$0.17^{ac}
CC	M	36.64 $\pm$ 0.83	13.97 $\pm$ 0.44	16.64 $\pm$ 0.14	48.22 $\pm$ 1.38	18.15 $\pm$ 0.73	18.59 $\pm$ 0.29
	F	26.33 $\pm$ 0.63	7.45 $\pm$ 0.4	15.79 $\pm$ 0.16	30.65 $\pm$ 0.51	8.76 $\pm$ 0.43	18.35 $\pm$ 0.23
	T	31.48 $\pm$ 1.06	10.71 $\pm$ 0.66	16.22 $\pm$ 0.13	39.43$\pm$1.74^b	13.45$\pm$0.94^b	18.47$\pm$0.18^{ab}
AC	M	36.56 $\pm$ 0.69	14.03 $\pm$ 0.58	16.27 $\pm$ 0.18	46.62 $\pm$ 1.2	17.82 $\pm$ 1.06	17.79 $\pm$ 0.26
	F	25.93 $\pm$ 0.5	6.87 $\pm$ 0.28	15.64 $\pm$ 0.17	31.14 $\pm$ 0.35	8.13 $\pm$ 0.36	17.89 $\pm$ 0.31
	T	31.24 $\pm$ 1.04	10.45 $\pm$ 0.72	15.95 $\pm$ 0.13	38.88$\pm$1.52^b	12.97$\pm$1.03^b	17.84$\pm$0.2^c
CA	M	36.78 $\pm$ 0.75	12.35 $\pm$ 0.49	16.35 $\pm$ 0.2	51.27 $\pm$ 0.88	20.73 $\pm$ 0.39	19.25 $\pm$ 0.24
	F	24.38 $\pm$ 0.46	7.5 $\pm$ 0.39	15.52 $\pm$ 0.14	33.67 $\pm$ 0.87	9.97 $\pm$ 0.7	17.87 $\pm$ 0.25
	T	30.58 $\pm$ 1.2	9.93 $\pm$ 0.53	15.93 $\pm$ 0.14	42.47$\pm$1.69^a	15.35$\pm$1.04^a	18.56$\pm$0.21^a
Source of variations		Sig.	Sig.	Sig.	Sig.	Sig.	Sig.
Genotype		0.621	0.257	0.309	0.002	0.006	0.012
Sex		0.000	0.000	0.000	0.000	0.000	0.007
G $\times$ S		0.442	0.034	0.086	0.083	0.086	0.033

A: Anadolu – T $\times$ Anadolu – T; CC: Commercial $\times$ Commercial; AC: Anadolu – T male $\times$ Commercial female; CA: Commercial male $\times$ Anadolu – T female; F = Female; M = Male; T: Total; CL = Comb length; CW = Comb width; BL = Beak length; Genotype $\times$ Sex; SEM: The Mean of Standard Error

Fluctuating asymmetry (FA) and relative asymmetry (RA) indices at 3 weeks of age are presented in Table 4. The results showed that genotype had no significant effect on any of the FA traits, including wattle length (WL), wattle width (WW), eye width (EW), nose length (NL), and facial width (FW) ($P > 0.05$). Similarly, genotype $\times$ sex interactions were not significant for these traits, indicating that developmental stability during early growth is largely independent of genetic background. This finding is consistent with previous studies indicating that early morphological development in broilers tends to be relatively uniform across genotypes and is largely shaped by environmental conditions and maternal influences, particularly during the embryonic and early post-hatch periods (Zuidhof et al., 2021; Dixon et al., 2016).



Sex effects on FA traits were generally limited at 3 weeks, with a significant effect observed only for WW ($P < 0.05$). The lack of consistent sex-related differences at this stage suggests that sexual dimorphism has not yet fully manifested in early growth. Similar findings have been reported in broiler chickens, although sex-related differences in growth potential exist, their phenotypic expression is often limited during early developmental stages and becomes increasingly evident as birds approach later growth phases (An & Kong, 2025; England et al., 2023; Siegel, 2014).

For RA traits, genotype and genotype $\times$ sex interaction effects were also non-significant ($P > 0.05$), reinforcing the notion that early developmental instability is not strongly genotype-dependent. However, sex had a highly significant effect on WW ($P < 0.001$), indicating that even at an early age, certain traits may show sensitivity to sex-related physiological differences. This may be linked to early hormonal regulation and differences in tissue growth dynamics (Scanes, 2015).

Overall, the low and non-significant variation observed in both FA and RA traits at 3 weeks suggests that developmental stability is relatively high during early life. This supports the concept that fluctuating asymmetry tends to increase with age as organisms are exposed to cumulative environmental and physiological stressors (Palmer & Strobeck, 1986).

Fluctuating asymmetry (FA) and relative asymmetry (RA) indices at 6 weeks of age are presented in Table 5. Unlike the findings at 3 weeks, genotype had a significant effect on FA for wattle length (WL) ($P < 0.01$) and nose length (NL) ($P < 0.01$). These results indicate that genetic background becomes more influential on developmental stability as age progresses, which is consistent with previous reports highlighting that genetic effects on growth and morphology become more pronounced in later stages of broiler development (Zuidhof et al., 2014).

Sex effects were more pronounced at 6 weeks compared to 3 weeks. Significant sex effects were observed for WW ($P < 0.01$) and NL ($P < 0.05$), suggesting that sexual dimorphism increasingly influences asymmetry patterns with age. This may be explained by endocrine differences between males and females, particularly the role of sex hormones in regulating growth and secondary traits (Scanes, 2015).

Genotype $\times$ sex interactions were significant for several FA traits, indicating that the response of asymmetry traits to sex differs depending on genetic background. Similar interaction effects have been reported in broiler studies, where genotype and sex jointly influence growth patterns, carcass traits, and developmental stability (Siegel, 2014; Dixon, 2020).

For RA traits, genotype significantly affected WL, WW, and NL ($P < 0.05$), while sex effects remained significant for WW and NL. The higher asymmetry observed in certain traits may reflect increased sensitivity of rapidly growing tissues to developmental perturbations, particularly under intensive selection for growth (Dixon, 2020).

When comparing the results between 3 and 6 weeks of age, a clear shift in the determinants of asymmetry is observed. At 3 weeks, both FA and RA traits were largely unaffected by genotype and genotype $\times$ sex interactions, indicating that early developmental stability is relatively uniform across genotypes. In contrast, at 6 weeks, genotype emerged as a significant source of variation, suggesting that genetic differences become more evident with age. This pattern aligns with studies showing that phenotypic divergence among broiler genotypes increases over time due to differential growth rates and metabolic demands (Zuidhof et al., 2014).

Similarly, sex effects, which were limited at 3 weeks, became more evident at 6 weeks. This supports the notion that hormonal influences intensify with age, contributing to differences in growth and morphology between males and females (Scanes, 2015).

The emergence of significant genotype $\times$ sex interactions at 6 weeks further indicates that developmental stability is shaped by a complex interplay of genetic and physiological factors. Previous research has emphasized that such interactions are particularly important in fast-growing broilers, where growth-related stress can differentially affect males and females (Dixon, 2020).

Across both ages, traits such as WL and WW exhibited higher asymmetry compared to more stable traits, suggesting that soft tissue structures are more susceptible to developmental instability. This is consistent with the general theory of fluctuating asymmetry, which states that rapidly growing or sexually dimorphic traits tend to show greater sensitivity to environmental and physiological stressors (Palmer & Strobeck, 1986).

At 3 weeks of age, fluctuating asymmetry (FA) values for tarsometatarsus traits (TML, JW, TMW-1, TMW-SL) did not differ significantly among genotypes ($P > 0.05$). Similarly, sex and genotype $\times$ sex interaction effects were not significant for any FA trait, although sex approached significance for TML ($P = 0.085$) and TMW-1 ($P = 0.103$).

Descriptively, CC and AC genotypes showed relatively higher FA values for TML and TMW-SL, whereas CA males exhibited the lowest TML asymmetry; however, these differences were not statistically significant ($P > 0.05$). Females in the CA genotype showed notably higher JW asymmetry compared to males, but this variation was not statistically significant. For relative asymmetry (RA), genotype had no significant effect on any trait ($P > 0.05$). Sex significantly influenced TML ($P = 0.045$), with females generally showing higher relative asymmetry than males. No significant genotype $\times$ sex interactions were detected.



Table 4. Fluctuating (FA) and Relative (RA) Asymmetry Indices Derived from Bilateral Head Measurements of Reciprocal Crosses between Anadolu-T and Commercial Broiler Parent Stocks at Week 3

Items		3. Week Fluctuating Asymmetry (FA)				
Genotype	Sex	WL±SEM	WW±SEM	EW±SEM	NL±SEM	FW±SEM
AA	M	2.87±0.53	0.85±0.16	0.34±0.05	0.25±0.06	1.03±0.22
	F	2.54±0.55	1.22±0.23	0.29±0.04	0.27±0.05	1.78±0.5
	T	2.7±0.38	1.04±0.14	0.32±0.03	0.26±0.04	1.4±0.28
CC	M	2.71±0.55	1.31±0.22	0.28±0.05	0.27±0.04	1.6±0.31
	F	1.2±0.23	1.13±0.19	0.3±0.04	0.29±0.06	0.91±0.26
	T	1.95±0.32	1.22±0.14	0.29±0.03	0.28±0.04	1.26±0.21
AC	M	2.23±0.42	1.0±0.21	0.28±0.05	0.2±0.05	1.54±0.26
	F	2.0±0.37	1.27±0.18	0.27±0.06	0.23±0.03	1.68±0.29
	T	2.12±0.27	1.13±0.14	0.28±0.04	0.21±0.03	1.61±0.19
CA	M	2.51±0.48	1.53±0.38	0.28±0.05	0.23±0.04	1.96±0.34
	F	1.61±0.28	0.84±0.12	0.27±0.06	0.18±0.04	1.44±0.3
	T	2.06±0.29	1.18±0.2	0.28±0.04	0.21±0.03	1.7±0.23
Source of variation		Sig.	Sig.	Sig.	Sig.	Sig.
Genotype (G)		0.324	0.859	0.845	0.340	0.502
Sex (S)		0.019	0.712	0.714	0.875	0.720
G × S		0.446	0.069	0.904	0.775	0.097
		3. Week Relative Asymmetry (RA)				
Genotype	Sex	WL±SEM	WW±SEM	EW±SEM	NL±SEM	FW±SEM
AA	M	3.75±0.72	1.51±0.27	0.67±0.1	1±0.22	0.64±0.14
	F	4.14±1	3.72±0.66	0.59±0.08	1.17±0.2	1.17±0.35
	T	3.95±0.61	2.61±0.4	0.63±0.06	1.08±0.15	0.9±0.19
CC	M	3.22±0.66	2.58±0.44	0.53±0.1	1.05±0.15	1±0.19
	F	1.68±0.32	3.54±0.5	0.61±0.08	1.24±0.29	0.57±0.16
	T	2.45±0.39	3.06±0.34	0.57±0.06	1.14±0.16	0.78±0.13
AC	M	2.83±0.49	1.92±0.41	0.55±0.1	0.77±0.18	0.96±0.16
	F	2.95±0.54	3.96±0.49	0.54±0.12	0.94±0.13	1.08±0.19
	T	2.89±0.36	2.94±0.36	0.54±0.08	0.85±0.11	1.02±0.12
CA	M	3.26±0.62	2.8±0.62	0.55±0.08	0.92±0.16	1.21±0.21
	F	2.56±0.41	2.74±0.41	0.56±0.12	0.75±0.15	0.91±0.19
	T	2.91±0.37	2.77±0.36	0.55±0.07	0.83±0.11	1.06±0.14
Source of variation		Sig.	Sig.	Sig.	Sig.	Sig.
Genotype (G)		0.112	0.812	0.826	0.248	0.533
Sex (S)		0.329	0.000	0.981	0.498	0.895
G × S		0.412	0.078	0.873	0.732	0.093

A: Anadolu – T × Anadolu – T; CC: Commercial × Commercial; AC: Anadolu – T male × Commercial female; CA: Commercial male × Anadolu – T female; F = female; M = male, T=Total; WL = Wattle length; WW = Wattle width; EW = Eye width; NL = Nose length; FW = Facial width; SEM: The Mean of Standard Error

The lack of significant genotype and interaction effects at week 3 indicates that developmental stability of tarsometatarsus traits is largely maintained across genetic backgrounds during early growth. This finding is consistent with the concept of developmental canalization, which describes the ability of organisms to buffer against genetic and environmental perturbations and maintain stable developmental trajectories (Klingenberg, 2015; Zakharov et al., 2020).

The limited sex effect observed only in RA for TML suggests that sexual dimorphism in developmental instability is still minimal at this stage. Previous studies in broilers have indicated that skeletal development and related morphometric traits show limited sexual dimorphism during early posthatch growth, whereas sex-related differences become more pronounced in later growth stages as divergence in growth rate increases (Rose et al., 1996; Charuta et al., 2013; Müsse et al., 2022).

Although some numerical differences were observed, particularly higher asymmetry in CC and reciprocal cross genotypes, these differences were not statistically significant, indicating that genetic influences on skeletal asymmetry are not yet strongly expressed at week 3. Taken together, these findings suggest a high level of developmental stability during early skeletal growth. This interpretation is consistent with previous broiler studies indicating that fluctuating asymmetry reflects developmental instability arising from genetic and environmental perturbations and can serve as an indicator of the organism's ability to cope with such factors (Van Nuffel et al., 2007; Buijs et al., 2012).

At 6 weeks of age, genotype significantly affected FA values for all traits: TML ($P=0.004$), JW ($P=0.049$), TMW-1 ($P=0.024$), and TMW-SL ($P=0.011$). The AA genotype showed the highest FA for TML ($0.88±0.31$), while CA exhibited the lowest ($0.06±0.02$). For other traits, CC and AC generally displayed higher asymmetry compared to CA.



Table 5. Fluctuating (FA) and Relative (RA) Asymmetry Indices Derived from Bilateral Head Measurements of Reciprocal Crosses between Anadolu-T and Commercial Broiler Parent Stocks at Week 6

Items		6. Week Fluctuating Asymmetry (FA)				
Genotype	Sex	WL±SEM	WW±SEM	EW±SEM	NL±SEM	FW±SEM
AA	M	2.27±0.51	1.96±0.32	0.3±0.06	0.22±0.04	2.16±0.23
	F	1.89±0.39	0.7±0.14	0.14±0.02	0.1±0.02	1.57±0.23
	T	2.08±0.32^b	1.33±0.21	0.22±0.04	0.16±0.02^b	1.87±0.17
CC	M	3.52±0.44	1.34±0.33	0.13±0.03	0.05±0.01	1.15±0.23
	F	2.85±0.26	1.58±0.26	0.41±0.13	0.22±0.06	1.99±0.23
	T	3.18±0.26^a	1.46±0.21	0.27±0.07	0.14±0.03^b	1.57±0.18
AC	M	1.53±0.23	1.72±0.29	0.22±0.03	0.15±0.02	2.26±0.22
	F	1.9±0.24	1.06±0.1	0.16±0.03	0.22±0.03	1.61±0.2
	T	1.71±0.17^b	1.39±0.16	0.19±0.02	0.18±0.02^b	1.93±0.16
CA	M	2.73±0.45	1.77±0.34	0.18±0.04	0.19±0.03	1.52±0.13
	F	1.98±0.27	0.85±0.19	0.26±0.05	0.4±0.11	1.45±0.15
	T	2.35±0.27^b	1.31±0.21	0.22±0.03	0.3±0.06^a	1.49±0.1
Source of variation		Sig.	Sig.	Sig.	Sig.	Sig.
Genotype (G)		0.001	0.937	0.537	0.008	0.085
Sex (S)		0.165	0.001	0.403	0.022	0.419
G × S		0.410	0.031	0.002	0.005	0.001
		6. Week Relative Asymmetry (RA)				
Genotype	Sex	WL±SEM	WW±SEM	EW±SEM	NL±SEM	FW±SEM
AA	M	2.14±0.48	2.27±0.35	0.53±0.11	0.76±0.12	1.16±0.12
	F	2.22±0.45	1.86±0.33	0.26±0.05	0.34±0.07	0.9±0.13
	T	2.18±0.32^b	2.06±0.24^c	0.39±0.06	0.55±0.08^b	1.03±0.09
CC	M	3.72±0.47	1.8±0.44	0.23±0.05	0.18±0.04	0.61±0.12
	F	3.27±0.32	4.38±0.66	0.74±0.22	0.79±0.21	1.11±0.12
	T	3.5±0.28^a	3.09±0.46^a	0.48±0.12	0.48±0.12^b	0.86±0.1
AC	M	1.56±0.25	2.52±0.44	0.38±0.06	0.49±0.08	1.23±0.12
	F	2.4±0.33	3.55±0.39	0.29±0.06	0.84±0.13	0.87±0.11
	T	1.98±0.22^b	3.03±0.3^{ab}	0.33±0.04	0.67±0.08^b	1.05±0.08
CA	M	2.47±0.4	2.05±0.4	0.33±0.07	0.67±0.1	0.82±0.07
	F	2.37±0.34	2.25±0.51	0.48±0.09	1.48±0.4	0.81±0.09
	T	2.42±0.26^b	2.15±0.32^{bc}	0.41±0.06	1.08±0.22^a	0.82±0.05
Source of variation		Sig.	Sig.	Sig.	Sig.	Sig.
Genotype (G)		0.001	0.033	0.568	0.006	0.090
Sex (S)		0.732	0.009	0.315	0.009	0.687
G × S		0.402	0.008	0.002	0.006	0.001

A: Anadolu – T × Anadolu – T; CC: Commercial × Commercial; AC: Anadolu – T male × Commercial female; CA: Commercial male × Anadolu – T female; F = female; M = male, T=Total; WL = Wattle length; WW = Wattle width; EW = Eye width; NL = Nose length; FW = Facial width; SEM: The Mean of Standard Error

The results of fluctuating (FA) and relative (RA) asymmetry analyses derived from bilateral tarsometatarsus measurements at weeks 3 and 6 are presented in Tables 6 and 7, respectively.

Sex had significant effects on TML ($P=0.023$), TMW-1 ($P<0.001$), and TMW-SL ($P=0.049$), indicating increased sexual divergence in asymmetry at this stage. Genotype × sex interaction was significant for JW ($P=0.033$), suggesting that sex-related differences varied depending on genotype.

For RA, genotype significantly influenced TML ($P=0.005$) and TMW-SL ($P=0.023$). The AA genotype showed the highest RA for TML, while CA consistently exhibited the lowest values. Sex significantly affected TML ($P=0.019$) and TMW-1 ($P=0.003$). A significant genotype × sex interaction was observed for JW ($P=0.035$).

The emergence of significant genotype effects across all FA traits at week 6 suggests that genetic background becomes an increasingly important determinant of developmental instability as skeletal growth progresses. In contrast to early developmental stages, later growth phases in broilers are more strongly influenced by genetic differences and the physiological costs associated with rapid growth and selection intensity (Van Nuffel et al., 2007; Buijs et al., 2012). The higher asymmetry observed in certain genotypes (AA for TML, CC and AC for other traits) may reflect genotype-dependent variation in the ability to maintain developmental stability under intensive growth conditions. Commercial broiler lines, which have been intensively selected for rapid growth and feed efficiency, are often associated with increased susceptibility to environmental and physiological stress. Recent experimental evidence in broilers has shown that heat stress and environmental conditions can increase fluctuating asymmetry as an indicator of developmental instability (Havenstein et al., 2003; Carvalho et al., 2026).

Significant sex effects further indicate that males and females differ in their response to developmental stress, likely due to differences in growth rate and hormonal regulation. The presence of genotype × sex interactions supports the idea that these effects are not uniform across genetic backgrounds.



Lower asymmetry in the CA genotype may suggest a potential heterosis effect, as fluctuating asymmetry is widely recognized as an indicator of developmental stability influenced by both genetic background and environmental stressors (Van Nuffel et al., 2007; Møller & Swaddle, 1997). Crossbreeding can enhance biological robustness through increased heterozygosity and favorable gene interactions (Falconer & Mackay, 1996; Wang et al., 2022). However, direct evidence linking heterosis to reduced asymmetry in poultry remains limited and inconsistent across studies (Van Dongen, 2006).

A clear ontogenetic shift in developmental stability is observed between weeks 3 and 6. At week 3, neither genotype nor sex had a significant effect on most FA and RA traits, indicating strong developmental buffering during early skeletal growth. In contrast, by week 6, genotype significantly influenced nearly all asymmetry traits, and sex effects became more pronounced.

This transition suggests that developmental instability increases with age, particularly as growth accelerates and metabolic demands rise. Early-stage canalization appears to protect skeletal development, but this stability diminishes over time, revealing underlying genetic differences.

Notably, the CA genotype consistently exhibited lower asymmetry at week 6, supporting the hypothesis that reciprocal crossbreeding may enhance developmental stability. Conversely, some pure and commercial genotypes showed increased asymmetry, possibly reflecting trade-offs between rapid growth and structural stability.

In summary, while week 3 results reflect uniform and stable skeletal development, week 6 findings highlight the increasing influence of genotype, sex, and their interaction on developmental instability, emphasizing the role of genetic selection and growth dynamics in shaping broiler welfare and morphology.

Table 6. Fluctuating (FA) and Relative (RA) Asymmetry Analyses Derived from Bilateral Tarsometatarsus measurements of Reciprocal Crosses between Anadolu-T and Commercial Broiler Parent Stocks at Week 3

Items		3. Week Fluctuating Asymmetry (FA)			
Genotype	Sex	TML±SEM	JW±SEM	TMW-1±SEM	TMW-SL±SEM
AA	M	0.41±0.11	0.42±0.11	0.3±0.07	0.26±0.04
	F	0.57±0.14	0.55±0.3	0.34±0.06	0.39±0.05
	T	0.49±0.09	0.48±0.16	0.32±0.05	0.32±0.03
CC	M	0.63±0.2	0.4±0.08	0.41±0.06	0.44±0.07
	F	0.6±0.14	0.24±0.07	0.28±0.05	0.42±0.08
	T	0.61±0.12	0.32±0.05	0.35±0.04	0.43±0.05
AC	M	0.41±0.13	0.45±0.12	0.48±0.06	0.45±0.08
	F	0.58±0.15	0.4±0.05	0.33±0.06	0.31±0.06
	T	0.49±0.1	0.42±0.07	0.41±0.04	0.38±0.05
CA	M	0.28±0.09	0.36±0.06	0.34±0.06	0.31±0.06
	F	0.68±0.16	0.77±0.3	0.31±0.05	0.31±0.06
	T	0.48±0.1	0.56±0.15	0.32±0.04	0.31±0.04
Source of variation		Sig.	Sig.	Sig.	Sig.
Genotype (G)		0.755	0.525	0.434	0.227
Sex (S)		0.085	0.483	0.103	0.874
G × S		0.505	0.360	0.347	0.233
Items		3. Week Relative Asymmetry (RA)			
Genotype	Sex	TML±SEM	JW±SEM	TMW-1±SEM	TMW-SL±SEM
AA	M	0.13±0.04	0.48±0.13	0.62±0.14	0.55±0.08
	F	0.19±0.05	0.64±0.33	0.75±0.13	0.84±0.11
	T	0.16±0.03	0.56±0.17	0.68±0.1	0.69±0.07
CC	M	0.19±0.06	0.43±0.09	0.78±0.11	0.86±0.13
	F	0.2±0.05	0.29±0.08	0.59±0.1	0.89±0.17
	T	0.19±0.04	0.36±0.06	0.68±0.08	0.87±0.11
AC	M	0.13±0.04	0.48±0.14	0.96±0.13	0.91±0.15
	F	0.19±0.05	0.47±0.06	0.7±0.13	0.69±0.13
	T	0.16±0.03	0.48±0.07	0.83±0.09	0.8±0.1
CA	M	0.09±0.03	0.4±0.06	0.68±0.13	0.65±0.14
	F	0.22±0.05	0.98±0.41	0.67±0.11	0.69±0.14
	T	0.15±0.03	0.69±0.21	0.68±0.08	0.67±0.1
Source of variation		Sig.	Sig.	Sig.	Sig.
Genotype (G)		0.796	0.444	0.519	0.400
Sex (S)		0.045	0.315	0.334	0.714
G × S		0.549	0.320	0.382	0.304

A: Anadolu – T × Anadolu – T; CC: Commercial × Commercial; AC: Anadolu – T male × Commercial female; CA: Commercial male × Anadolu – T female; F = female; M = male; T = Total; TML = Tarsometatarsus length; ³JW = Joint width; TMW-1 = Tarsometatarsus width at 1 cm above the spur; TMW-SL = Tarsometatarsus width at the spur level; SEM: The Mean of Standard Error



Table 7. Fluctuating (FA) and Relative (RA) Asymmetry Analyses Derived from Bilateral Tarsometatarsus measurements of Reciprocal Crosses between Anadolu-T and Commercial Broiler Parent Stocks at Week 6

Items		6. Week Fluctuating Asymmetry (FA)			
Genotype	Sex	TML±SEM	JW±SEM	TMW-1±SEM	TMW-SL±SEM
AA	M	0.34±0.1	0.24±0.05	0.36±0.05	0.31±0.05
	F	1.41±0.6	0.43±0.06	0.12±0.02	0.18±0.04
	T	0.88±0.31^a	0.34±0.04^b	0.24±0.03^b	0.24±0.03^b
CC	M	0.27±0.08	0.8±0.19	0.5±0.11	0.44±0.06
	F	0.62±0.22	0.39±0.09	0.26±0.04	0.41±0.05
	T	0.44±0.12^{ab}	0.59±0.11^a	0.38±0.06^a	0.43±0.04^a
AC	M	0.2±0.04	0.71±0.2	0.42±0.07	0.5±0.1
	F	0.23±0.07	0.36±0.09	0.25±0.03	0.34±0.03
	T	0.22±0.04^b	0.54±0.11^{ab}	0.34±0.04^{ab}	0.42±0.05^a
CA	M	0.03±0.01	0.35±0.05	0.21±0.06	0.43±0.07
	F	0.09±0.03	0.32±0.07	0.23±0.06	0.39±0.08
	T	0.06±0.02^b	0.33±0.04^b	0.22±0.04^b	0.41±0.05^a
Source of variation		Sig.	Sig.	Sig.	Sig.
Genotype (G)		0,004	0.049	0.024	0.011
Sex (S)		0,023	0.067	0.000	0.049
G × S		0,094	0.033	0.104	0.674
Items		6. Week Relative Asymmetry (RA)			
Genotype	Sex	TML±SEM	JW±SEM	TMW-1±SEM	TMW-SL±SEM
AA	M	0.09±0.03	0.23±0.05	0.7±0.1	0.6±0.09
	F	0.41±0.18	0.48±0.07	0.24±0.04	0.38±0.08
	T	0.25±0.09^a	0.36±0.05	0.47±0.07	0.49±0.06^b
CC	M	0.07±0.02	0.75±0.18	0.89±0.19	0.81±0.12
	F	0.17±0.06	0.41±0.09	0.51±0.09	0.82±0.11
	T	0.12±0.03^{ab}	0.58±0.1	0.7±0.11	0.82±0.08^a
AC	M	0.05±0.01	0.67±0.19	0.77±0.14	0.94±0.2
	F	0.07±0.02	0.39±0.1	0.51±0.07	0.7±0.06
	T	0.06±0.01^b	0.53±0.11	0.64±0.08	0.82±0.1^a
CA	M	0.01±0	0.33±0.04	0.39±0.11	0.79±0.14
	F	0.02±0.01	0.35±0.07	0.47±0.12	0.84±0.16
	T	0.02±0^b	0.34±0.04	0.43±0.08	0.82±0.1^a
Source of variation		Sig.	Sig.	Sig.	Sig.
Genotype (G)		0,005	0.082	0.068	0.023
Sex (S)		0,019	0.253	0.003	0.269
G × S		0,082	0.035	0.105	0.558

A: Anadolu – T × Anadolu – T; CC: Commercial × Commercial; AC: Anadolu – T male × Commercial female; CA: Commercial male × Anadolu – T female; F = female; M = male; T = Total; TML = Tarsometatarsus length; JW = Joint width; TMW-1 = Tarsometatarsus width at 1 cm above the spur; TMW-SL = Tarsometatarsus width at the spur level; SEM: The Mean of Standard Error

The results of fluctuating (FA) and relative (RA) asymmetry analyses derived from bilateral foot measurements at weeks 3 and 6 are presented in Tables 8 and 9, respectively.

At 3 weeks of age, fluctuating asymmetry (FA) of foot traits was significantly affected by genotype only for hind toe length (HTL) ($P=0.012$), whereas no significant genotype effects were detected for the other traits ($P>0.05$). The CC genotype exhibited the highest FA values for HTL (1.61 ± 0.18), while AA, AC, and CA genotypes showed lower and similar values.

Sex and genotype × sex interaction had no significant effects on any FA traits ($P>0.05$), indicating a lack of sexual dimorphism in foot asymmetry at this stage.

For relative asymmetry (RA), genotype significantly influenced HTL ($P=0.013$), with CC again showing the highest asymmetry. No significant effects of sex or genotype × sex interaction were observed for any RA traits.

Overall, asymmetry levels across most traits were moderate, with limited statistically significant variation.

The limited genotype effect observed only for HTL suggests that developmental instability in foot traits is generally low and relatively uniform across genotypes during early growth. This supports the concept that early morphological development is strongly buffered against genetic variation (Klingenberg, 2015).

The absence of sex effects further indicates that sexual dimorphism in foot asymmetry is not yet established at 3 weeks of age. Similar findings in broilers have shown that early skeletal and appendage traits develop under strong developmental control, minimizing variability between sexes (Charuta et al., 2013; Rose et al., 1996).

The higher asymmetry observed in the CC genotype for HTL may reflect early signs of growth-related stress associated with intensive selection; however, the lack of widespread significance suggests that these effects remain limited at this stage. Overall, the results indicate high developmental stability of foot structures in early life.



At 6 weeks of age, genotype significantly affected FA for outer toe claw length (OTCL) ($P=0.019$), while other traits were not significantly influenced by genotype. Sex significantly affected HTL ($P=0.034$) and OP4L ($P=0.003$), indicating increasing sexual divergence in asymmetry.

Significant genotype $\times$ sex interactions were observed for HTL ($P<0.001$), MTCL ($P=0.001$), and MP4L ($P=0.013$), demonstrating that the effects of sex varied depending on genotype.

For RA, genotype significantly influenced OTCL ($P=0.008$), with AA and CC genotypes generally showing higher asymmetry values compared to CA. Sex significantly affected OP4L ($P=0.001$), while genotype $\times$ sex interaction was significant for HTL ($P<0.001$), MTCL ($P=0.001$), and MP4L ($P=0.021$).

Compared to week 3, the emergence of significant genotype, sex, and interaction effects at week 6 may indicate increased developmental instability in foot traits as birds mature. This pattern is consistent with previous studies showing that rapid growth phases and adverse environmental or genetic factors can increase fluctuating asymmetry, reflecting reduced developmental stability (Møller & Manning, 2003; Van Nuffel et al., 2007)

The significant sex effects suggest that males and females differ in growth dynamics and structural development, leading to increased asymmetry in certain traits. This aligns with previous findings that sexual dimorphism in developmental instability becomes more evident at later growth stages (Klingenberg, 2015).

The presence of genotype $\times$ sex interactions highlights the complexity of developmental processes, where genetic background modulates the expression of sex-related differences. Additionally, the relatively lower asymmetry observed in some reciprocal crosses (particularly CA in certain traits) suggests potential heterosis effects improving developmental stability.

Table 8. Fluctuating (FA) and Relative (RA) Asymmetry Analyses Derived from Foot Measurements According to Genotype and Sex of Reciprocal Crosses between Anadolu-T and Commercial Broiler Parent Stocks at Week 3

Items		3. Week Fluctuating Asymmetry (FA)						
G	Sex	HTL $\pm$ SEM	OTCL $\pm$ SEM	OP4L $\pm$ SEM	OP3L $\pm$ SEM	MTCL $\pm$ SEM	MP4L $\pm$ SEM	MP3L $\pm$ SEM
AA	M	0.9 $\pm$ 0.16	0.4 $\pm$ 0.12	0.38 $\pm$ 0.07	0.85 $\pm$ 0.14	0.7 $\pm$ 0.12	0.5 $\pm$ 0.08	0.84 $\pm$ 0.15
	F	0.94 $\pm$ 0.16	0.58 $\pm$ 0.09	0.5 $\pm$ 0.12	0.65 $\pm$ 0.12	0.84 $\pm$ 0.27	0.59 $\pm$ 0.12	0.78 $\pm$ 0.17
	T	0.92$\pm$0.11^b	0.49 $\pm$ 0.07	0.44 $\pm$ 0.07	0.75 $\pm$ 0.09	0.77 $\pm$ 0.15	0.54 $\pm$ 0.07	0.81 $\pm$ 0.11
CC	M	1.52 $\pm$ 0.25	0.68 $\pm$ 0.12	0.47 $\pm$ 0.07	0.86 $\pm$ 0.15	0.49 $\pm$ 0.09	0.5 $\pm$ 0.12	0.71 $\pm$ 0.14
	F	1.7 $\pm$ 0.27	0.52 $\pm$ 0.12	0.48 $\pm$ 0.1	0.87 $\pm$ 0.14	0.52 $\pm$ 0.12	0.43 $\pm$ 0.09	0.79 $\pm$ 0.1
	T	1.61$\pm$0.18^a	0.6 $\pm$ 0.08	0.48 $\pm$ 0.06	0.86 $\pm$ 0.1	0.51 $\pm$ 0.07	0.46 $\pm$ 0.08	0.75 $\pm$ 0.09
AC	M	1.12 $\pm$ 0.21	0.92 $\pm$ 0.14	0.43 $\pm$ 0.09	0.88 $\pm$ 0.11	0.52 $\pm$ 0.13	0.65 $\pm$ 0.15	0.95 $\pm$ 0.18
	F	1.24 $\pm$ 0.18	0.57 $\pm$ 0.08	0.41 $\pm$ 0.05	0.7 $\pm$ 0.15	0.66 $\pm$ 0.11	0.65 $\pm$ 0.11	0.78 $\pm$ 0.16
	T	1.18$\pm$0.14^b	0.74 $\pm$ 0.09	0.42 $\pm$ 0.05	0.79 $\pm$ 0.09	0.59 $\pm$ 0.09	0.65 $\pm$ 0.09	0.86 $\pm$ 0.12
CA	M	1.08 $\pm$ 0.21	0.58 $\pm$ 0.14	1.12 $\pm$ 0.5	0.49 $\pm$ 0.12	0.58 $\pm$ 0.12	0.52 $\pm$ 0.09	0.71 $\pm$ 0.13
	F	1.07 $\pm$ 0.22	0.53 $\pm$ 0.09	0.42 $\pm$ 0.06	0.75 $\pm$ 0.12	0.4 $\pm$ 0.08	0.44 $\pm$ 0.1	0.67 $\pm$ 0.09
	T	1.07$\pm$0.15^b	0.56 $\pm$ 0.08	0.77 $\pm$ 0.26	0.62 $\pm$ 0.09	0.49 $\pm$ 0.07	0.48 $\pm$ 0.07	0.69 $\pm$ 0.08
	Sig.		Sig.	Sig.	Sig.	Sig.	Sig.	Sig.
Genotype		0.012	0.163	0.242	0.321	0.179	0.324	0.662
Sex (S)		0.573	0.236	0.285	0.786	0.734	0.833	0.651
G $\times$ S		0.972	0.138	0.148	0.259	0.632	0.853	0.844
Items		3. Week Relative Asymmetry (RA)						
G	Sex	HTL $\pm$ SEM	OTCL $\pm$ SEM	OP4L $\pm$ SEM	OP3L $\pm$ SEM	MTCL $\pm$ SEM	MP4L $\pm$ SEM	MP3L $\pm$ SEM
AA	M	1.1 $\pm$ 0.19	1.09 $\pm$ 0.31	1.46 $\pm$ 0.26	1.68 $\pm$ 0.29	1.62 $\pm$ 0.28	1.61 $\pm$ 0.24	1.11 $\pm$ 0.21
	F	1.2 $\pm$ 0.21	1.53 $\pm$ 0.23	1.87 $\pm$ 0.45	1.34 $\pm$ 0.26	1.8 $\pm$ 0.51	2.03 $\pm$ 0.42	1.18 $\pm$ 0.25
	T	1.15$\pm$0.14^b	1.31 $\pm$ 0.19	1.67 $\pm$ 0.26	1.51 $\pm$ 0.19	1.71 $\pm$ 0.29	1.82 $\pm$ 0.24	1.15 $\pm$ 0.16
CC	M	1.78 $\pm$ 0.29	1.93 $\pm$ 0.36	1.63 $\pm$ 0.25	1.53 $\pm$ 0.28	1.1 $\pm$ 0.2	1.64 $\pm$ 0.41	0.9 $\pm$ 0.18
	F	2.21 $\pm$ 0.36	1.43 $\pm$ 0.32	1.83 $\pm$ 0.37	1.69 $\pm$ 0.27	1.18 $\pm$ 0.26	1.44 $\pm$ 0.3	1.07 $\pm$ 0.14
	T	2$\pm$0.23^a	1.68 $\pm$ 0.24	1.73 $\pm$ 0.22	1.61 $\pm$ 0.19	1.14 $\pm$ 0.16	1.54 $\pm$ 0.25	0.98 $\pm$ 0.11
AC	M	1.35 $\pm$ 0.26	2.53 $\pm$ 0.38	1.56 $\pm$ 0.33	1.64 $\pm$ 0.22	1.17 $\pm$ 0.29	2.1 $\pm$ 0.51	1.22 $\pm$ 0.23
	F	1.54 $\pm$ 0.23	1.59 $\pm$ 0.23	1.54 $\pm$ 0.19	1.35 $\pm$ 0.28	1.5 $\pm$ 0.25	2.17 $\pm$ 0.35	1.05 $\pm$ 0.22
	T	1.44$\pm$0.17^b	2.06 $\pm$ 0.23	1.55 $\pm$ 0.19	1.5 $\pm$ 0.18	1.33 $\pm$ 0.19	2.13 $\pm$ 0.3	1.14 $\pm$ 0.16
CA	M	1.31 $\pm$ 0.27	1.66 $\pm$ 0.38	3.21 $\pm$ 0.96	0.91 $\pm$ 0.23	1.27 $\pm$ 0.26	1.73 $\pm$ 0.3	0.91 $\pm$ 0.17
	F	1.37 $\pm$ 0.3	1.53 $\pm$ 0.28	1.64 $\pm$ 0.25	1.5 $\pm$ 0.25	0.94 $\pm$ 0.2	1.51 $\pm$ 0.35	0.92 $\pm$ 0.13
	T	1.34$\pm$0.2^b	1.59 $\pm$ 0.23	2.43 $\pm$ 0.51	1.2 $\pm$ 0.18	1.11 $\pm$ 0.16	1.62 $\pm$ 0.23	0.91 $\pm$ 0.1
	Sig.		Sig.	Sig.	Sig.	Sig.	Sig.	Sig.
Genotype		0.013	0.130	0.198	0.444	0.163	0.382	0.549
Sex		0.296	0.212	0.433	0.889	0.750	0.951	0.881
¹⁰ G $\times$ S		0.902	0.163	0.112	0.249	0.714	0.801	0.848

A: Anadolu – T $\times$ Anadolu – T; CC: Commercial $\times$ Commercial; AC: Anadolu – T male $\times$ Commercial female; CA: Commercial male $\times$ Anadolu – T female; F = female; M = male; T = Total; HTL = Hind toe length; OTCL = Outer toe claw length; OP4L = Fourth phalanx length of the outer toe; OP3L = Third phalanx length of the outer toe; MTCL = Middle toe claw length; MP4L = Fourth phalanx length of the middle toe; MP3L = Third phalanx length of the middle toe; SEM: The Mean of Standard Error



A clear developmental progression is evident when comparing Tables 8 and 9. At week 3, asymmetry in foot traits was largely unaffected by genotype and sex, with only HTL showing a significant genotype effect. In contrast, by week 6, multiple traits exhibited significant effects of genotype, sex, and genotype $\times$ sex interaction.

This shift indicates that developmental instability increases with age, particularly in appendage structures such as the foot. Early developmental stages are characterized by strong canalization, ensuring uniform growth, whereas later stages reveal underlying genetic and physiological differences.

The increasing influence of sex at week 6 suggests that differential growth rates and hormonal factors contribute to asymmetry. Moreover, genotype $\times$ sex interactions emphasize that these effects are not uniform across genetic backgrounds.

In general, week 3 results indicate a relatively stable and homogeneous developmental pattern, whereas week 6 findings reveal increased variability and greater sensitivity to genetic and biological factors, suggesting that growth intensity and selection pressures play a more pronounced role in shaping structural symmetry over time.

Table 9. Fluctuating (FA) and Relative (RA) Asymmetry Analyses Derived from Foot Measurements According to Genotype and Sex of Reciprocal Crosses between Anadolu-T and Commercial Broiler Parent Stocks at Week 6

Items		6. Week Fluctuating Asymmetry (FA)						
G	Sex	HTL $\pm$ SEM	OTCL $\pm$ SEM	OP4L $\pm$ SEM	OP3L $\pm$ SEM	MTCL $\pm$ SEM	MP4L $\pm$ SEM	MP3L $\pm$ SEM
AA	M	0.86 $\pm$ 0.1	0.67 $\pm$ 0.09	0.35 $\pm$ 0.06	0.54 $\pm$ 0.13	0.91 $\pm$ 0.15	0.33 $\pm$ 0.05	0.49 $\pm$ 0.11
	F	0.8 $\pm$ 0.13	0.79 $\pm$ 0.11	0.47 $\pm$ 0.09	0.61 $\pm$ 0.09	0.34 $\pm$ 0.09	0.56 $\pm$ 0.06	0.83 $\pm$ 0.12
	T	0.83 $\pm$ 0.08	0.73 $\pm$ 0.07	0.41 $\pm$ 0.05	0.58 $\pm$ 0.08	0.62 $\pm$ 0.1	0.45$\pm$0.04^a	0.66 $\pm$ 0.09
CC	M	1.27 $\pm$ 0.2	0.84 $\pm$ 0.14	0.51 $\pm$ 0.07	0.7 $\pm$ 0.11	0.5 $\pm$ 0.13	0.37 $\pm$ 0.04	0.45 $\pm$ 0.06
	F	0.75 $\pm$ 0.09	0.73 $\pm$ 0.15	0.52 $\pm$ 0.09	0.36 $\pm$ 0.07	0.47 $\pm$ 0.07	0.28 $\pm$ 0.05	0.44 $\pm$ 0.11
	T	1.01 $\pm$ 0.12	0.78 $\pm$ 0.1	0.51 $\pm$ 0.06	0.53 $\pm$ 0.07	0.48 $\pm$ 0.07	0.33$\pm$0.03^b	0.44 $\pm$ 0.06
AC	M	1.99 $\pm$ 0.38	0.83 $\pm$ 0.14	0.31 $\pm$ 0.04	0.84 $\pm$ 0.09	0.41 $\pm$ 0.06	0.32 $\pm$ 0.06	0.52 $\pm$ 0.07
	F	0.68 $\pm$ 0.1	0.46 $\pm$ 0.08	0.68 $\pm$ 0.11	0.6 $\pm$ 0.18	0.54 $\pm$ 0.08	0.31 $\pm$ 0.06	0.48 $\pm$ 0.1
	T	1.33 $\pm$ 0.22	0.65 $\pm$ 0.08	0.5 $\pm$ 0.07	0.72 $\pm$ 0.1	0.47 $\pm$ 0.05	0.31$\pm$0.04^b	0.5 $\pm$ 0.06
CA	M	0.7 $\pm$ 0.15	0.5 $\pm$ 0.08	0.25 $\pm$ 0.05	0.68 $\pm$ 0.18	0.38 $\pm$ 0.07	0.41 $\pm$ 0.07	0.57 $\pm$ 0.07
	F	1.38 $\pm$ 0.25	0.39 $\pm$ 0.09	0.41 $\pm$ 0.1	0.69 $\pm$ 0.09	0.48 $\pm$ 0.08	0.32 $\pm$ 0.05	0.57 $\pm$ 0.1
	T	1.04 $\pm$ 0.16	0.44 $\pm$ 0.06	0.33 $\pm$ 0.06	0.68 $\pm$ 0.1	0.43 $\pm$ 0.05	0.37$\pm$0.04^{ab}	0.57 $\pm$ 0.06
		Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.
Genotype		0.088	0.019	0.076	0.398	0.201	0.090	0.124
Sex (S)		0.034	0.146	0.003	0.151	0.183	0.775	0.287
G $\times$ S		0.000	0.220	0.165	0.331	0.001	0.013	0.163
Items		6. Week Relative Asymmetry (RA)						
G	Sex	HTL $\pm$ SEM	OTCL $\pm$ SEM	OP4L $\pm$ SEM	OP3L $\pm$ SEM	MTCL $\pm$ SEM	MP4L $\pm$ SEM	MP3L $\pm$ SEM
AA	M	0.88 $\pm$ 0.1	1.5 $\pm$ 0.21	1.13 $\pm$ 0.2	0.94 $\pm$ 0.23	1.69 $\pm$ 0.28	0.98 $\pm$ 0.15	0.57 $\pm$ 0.13
	F	0.89 $\pm$ 0.14	1.84 $\pm$ 0.26	1.6 $\pm$ 0.29	1.15 $\pm$ 0.17	0.62 $\pm$ 0.16	1.72 $\pm$ 0.18	1.03 $\pm$ 0.14
	T	0.89 $\pm$ 0.09	1.67$\pm$0.17^a	1.37 $\pm$ 0.18	1.04 $\pm$ 0.14	1.16 $\pm$ 0.19	1.35 $\pm$ 0.13	0.8 $\pm$ 0.1
CC	M	1.26 $\pm$ 0.2	1.96 $\pm$ 0.32	1.56 $\pm$ 0.21	1.11 $\pm$ 0.17	0.94 $\pm$ 0.25	1.09 $\pm$ 0.14	0.51 $\pm$ 0.07
	F	0.85 $\pm$ 0.11	1.69 $\pm$ 0.37	1.78 $\pm$ 0.33	0.65 $\pm$ 0.13	0.88 $\pm$ 0.14	0.9 $\pm$ 0.17	0.53 $\pm$ 0.14
	T	1.06 $\pm$ 0.12	1.82$\pm$0.24^a	1.67 $\pm$ 0.19	0.88 $\pm$ 0.11	0.91 $\pm$ 0.14	1 $\pm$ 0.11	0.52 $\pm$ 0.08
AC	M	2.05 $\pm$ 0.4	1.82 $\pm$ 0.29	1.05 $\pm$ 0.14	1.36 $\pm$ 0.16	0.74 $\pm$ 0.1	0.98 $\pm$ 0.19	0.57 $\pm$ 0.07
	F	0.78 $\pm$ 0.11	1.01 $\pm$ 0.17	2.39 $\pm$ 0.39	1.12 $\pm$ 0.36	0.98 $\pm$ 0.14	0.97 $\pm$ 0.17	0.59 $\pm$ 0.12
	T	1.41 $\pm$ 0.23	1.42$\pm$0.18^{ab}	1.72 $\pm$ 0.24	1.24 $\pm$ 0.19	0.86 $\pm$ 0.09	0.97 $\pm$ 0.13	0.58 $\pm$ 0.07
CA	M	0.68 $\pm$ 0.14	1.1 $\pm$ 0.18	0.79 $\pm$ 0.14	1.12 $\pm$ 0.29	0.68 $\pm$ 0.12	1.19 $\pm$ 0.2	0.64 $\pm$ 0.08
	F	1.47 $\pm$ 0.27	0.85 $\pm$ 0.19	1.4 $\pm$ 0.35	1.25 $\pm$ 0.16	0.92 $\pm$ 0.16	0.99 $\pm$ 0.17	0.7 $\pm$ 0.12
	T	1.07 $\pm$ 0.17	0.97$\pm$0.13^b	1.09 $\pm$ 0.19	1.18 $\pm$ 0.16	0.8 $\pm$ 0.1	1.09 $\pm$ 0.13	0.67 $\pm$ 0.07
		Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.
Genotype		0.089	0.008	0.085	0.377	0.213	0.119	0.070
Sex		0.135	0.182	0.001	0.570	0.214	0.498	0.079
¹⁰ G $\times$ S		0.000	0.178	0.212	0.391	0.001	0.021	0.149

A: Anadolu – T $\times$ Anadolu – T; CC: Commercial $\times$ Commercial; AC: Anadolu – T male $\times$ Commercial female; CA: Commercial male $\times$ Anadolu – T female; F = female; M = male; T = Total; HTL = Hind toe length; OTCL = Outer toe claw length; OP4L = Fourth phalanx length of the outer toe; OP3L = Third phalanx length of the outer toe; MTCL = Middle toe claw length; MP4L = Fourth phalanx length of the middle toe; MP3L = Third phalanx length of the middle toe; SEM: The Mean of Standard Error

Conclusion

This study demonstrated that welfare-related physiological traits (tonic immobility and rectal temperature) were largely unaffected by genotype and genotype $\times$ sex interactions at both 3 and 6 weeks of age in reciprocal crosses between Anadolu-T and commercial broiler parent stocks. These results indicate that early physiological responses related to stress and thermoregulation are relatively stable and primarily independent of genetic background.



In contrast, morphological traits and developmental stability parameters showed a clear age-dependent pattern. While genotype effects were limited at 3 weeks, they became increasingly significant at 6 weeks, particularly for comb, beak, tarsometatarsus, and foot measurements. Similarly, fluctuating asymmetry (FA) and relative asymmetry (RA) analyses revealed low and non-significant variation at early age, whereas marked genotype, sex, and genotype $\times$ sex interaction effects emerged at later growth stages.

Overall, these findings indicate that developmental stability is strongly maintained during early growth but becomes progressively influenced by genetic background, sex, and their interaction as birds mature. The results also suggest that reciprocal crossbreeding may contribute to improved developmental stability in certain traits, highlighting the potential role of heterosis in reducing asymmetry.

Taken together, the study emphasizes that age is a critical factor in the expression of both morphological variation and developmental instability, and that genetic effects become more pronounced as broilers approach later growth stages. These insights are important for optimizing breeding strategies aimed at improving both productivity and welfare in broiler production systems.

Declarations

Ethical Approval Certificate

The experimental procedures of this study were approved by the Local Animal Care and Ethics Committee of Animal Experiments of Kahramanmaraş Sütçü İmam University (Approval date: 28 February 2025; Approval number: 2025/02)

Author Contribution Statement

The authors declare that they have contributed equally to the work. Conflict of Interest The authors declare no conflict of interest. Acknowledgments In this study, we would like to thank TAGEM for providing the animal material we used from project number TAGEM/HAYSÜT/G/22/A4/P4/6230

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The Effect of Nitrogen and Silicon Treatments on Some Nutrient Concentrations in Wheat

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Abstract

Nitrogen (N) is accepted as an essential nutrient for plant growth and development, while silicon (Si) is classified as a beneficial element that can influence stress tolerance and nutrient uptake. The aim of this study was to determine the effects of N and Si treatments on the concentrations of some nutrients (phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn)) in wheat. To this end, a randomized block factorial experimental design was conducted with three replications. In the experiment, four different N doses (0, 50, 100, 150 mg kg⁻¹) and three different Si doses (0, 150, 300 mg kg⁻¹) were applied to the wheat. The results of the study showed that as N treatment doses increased, the concentrations of P, Ca, Mg, and Fe in wheat increased. With increasing silicon treatment doses, Mn and Cu increased to a statistically significant level, while Ca, Mg, Fe, and Zn concentrations were highest in the control group. The results of this study determined that N treatments generally had a positive effect on wheat's mineral nutrition. Conversely, it was found that while Si treatments increased the uptake of some micronutrients, they limited the uptake of others. Based on these results, it was concluded that the role of silicon, particularly in the regulation of micronutrients, requires further detailed investigation.

Keywords: Silicon, Nitrogen, Wheat, Nutrient Uptake

Azot ve Silisyum Uygulamalarının Buğdayda Bazı Besin Elementi Konsantrasyonları Üzerine Etkisi

Özet

Azot (N), bitkilerin büyüme ve gelişme için mutlak gerekli besin elementi olarak kabul edilirken silisyum (Si) stres toleransını ve besin elementi alımını etkileyebilen faydalı elementler sınıfında yer almaktadır. Bu çalışmada, N ve Si uygulamalarının buğdayda bazı besin elementi (fosfor (P), potasyum (P), kalsiyum (Ca), magnezyum (Mg), demir (Fe), çinko (Zn), bakır (Cu) ve mangan (Mn)) konsantrasyonları üzerine etkilerinin belirlenmesi hedeflenmiştir. Bu amaç doğrultusunda tesadüf parselleri faktöriyel deneme planına göre 3 tekerrürlü olarak yürütülmüştür. Denemede, buğdaya 4 farklı N dozu (0, 50, 100, 150 mg kg⁻¹) ve 3 farklı Si dozu (0, 150, 300 mg kg⁻¹) uygulanmıştır. Araştırma sonuçları, N uygulama dozlarının artması ile buğdayda P, Ca, Mg ve Fe konsantrasyonları artmıştır. Silisyum uygulama dozlarının artmasıyla ise Mn ve Cu istatistiksel olarak önemli düzeyde artarken Ca, Mg, Fe ve Zn konsantrasyonu kontrol grubunda en yüksek belirlenmiştir. Bu çalışmanın sonucunda, N uygulamalarının buğdayın mineral beslenmesini genel olarak olumlu yönde etkilediği belirlenmiştir. Buna karşın, Si uygulamalarının bazı mikro elementlerinin alımını artırırken bazı elementlerin alımını sınırlandırdığı saptanmıştır. Elde edilen bulgular doğrultusunda, silisyumun özellikle mikro besin elementlerinin düzenlenmesindeki rolünün daha ayrıntılı araştırılması gerektiği sonucuna varılmıştır.

Anahtar Kelimeler: Silisyum, azot, buğday, besin elementi alımı

Giriş

Poaceae (Gramineae) familyasına ait buğday (*Triticum spp.*), 10.000 yıldan fazla süredir insan uygarlığının temel taşlarından biri olmuştur (Penn, 2021). Buğday, hem ekim alanı hem de ticari değeri açısından küresel ölçekte önemli bir üründür ve insan beslenmesinde temel gıda maddesinden biridir (Walsh ve ark., 2018). Çok yönlülüğü, farklı iklimlere uyum sağlama yeteneği, depolama kolaylığı ve yüksek kalori ve besin değeri, onu küresel gıda taleplerini karşılamada önemli bir oyuncu haline getirmektedir (Sharma and Sharma, 2025). Iqbal ve ark. (2022) ise günlük kalori ve protein alımının %20'sini oluşturan buğday, insan beslenmesinin hayati bir bileşenidir ve gelişmekte olan ülkelerde pirinçten sonra ikinci en önemli gıda ürünü olarak sıralandığını rapor etmişlerdir. Küresel nüfusun artmasına paralel olarak dünya genelinde buğdaya olan ihtiyaç hızla yükselmektedir. Dünya Bankası geliştirmekte olan ülkelerde buğday talebi 2050 yılına kadar %60 oranında artacağını tahminlemektedir (Scott, 2018).



Temel gıda ürünlerinin hammaddesini oluşturan buğdayın üretim miktarı gıda güvenliğini doğrudan ilgilendiren konuların en başında gelmektedir. Artan nüfus, ekonomik krizler, iklim değişikliği, savaşlar ve salgın hastalıklar gıda güvenliğinin önemini ortaya koymaktadır (Çiftçi, 2024). Bitkisel üretimi olumsuz etkileyen tüm bu faktörlerin yanı sıra, verim ve kaliteyi sınırlandıran en önemli etmenlerden biri topraklardaki bitki besin elementi yetersizlikleridir. Düşük toprak verimliliği, gübre uygulamalarını gerektirir ve bu da ürün üretim maliyetini artırır (Agegehu ve ark., 2016). Bitkiler tarafından alınabilir formdaki besin elementlerini içeren gübrelerin maliyetindeki artış, sürdürülebilir buğday üretimi açısından önemli bir sorun oluşturmaktadır.

Buğday, verimini ve kalitesini artıran en önemli faktörlerden birisi azotlu gübrelemedir. Azot; protein, klorofil ve amino asitlerin temel bileşenlerinden olup (Yuan ve ark., 2014) buğday verimini artıran tane verimi, daha yüksek biyokütle ve gelişmiş hasat indeksi ile artırmaktadır (Gholizadeh ve ark., 2017).

Son yıllarda oldukça ivme kazanan silisyum (Si) uygulamaları bitkisel üretimde bitkinin sağlığı, besin elementi alımı, verim ve kalitesi açısından olumlu sonuçlar elde edildiği rapor edilmiştir. Silisyum, yer kabuğunda en bol bulunan ikinci element olmasına rağmen polimerize bir formda bulunduğu için bitkiler tarafından doğrudan alınabilir durumda değildir. Bununla birlikte uzun yıllardır yoğun tarımsal faaliyetlerin yapıldığı topraklarda bitkiler tarafından topraklardaki mevcut alınabilir Si miktarının azaldığı bildirilmiştir (Meena ve ark., 2014). Bitkiler yalnızca depolimerize olmuş çözünür Si formu olan monosilik asidi (H_2SiO_4) alabilir. Bu çözünür form, bitki kökleri tarafından kolayca alınır ve bitki dokularında birikir; konsantrasyonları %0,1 ile %10 arasında değişmektedir (Pati ve ark., 2016). Bu çalışmanın amacı, Kahramanmaraş koşullarında yetiştirilen buğdaya azot uygulaması ile birlikte silisyum (Si) ilavesinin makro ve mikro besin elementi alımına etkisinin belirlenmesidir.

Materyal ve Metot

Araştırma, 2024 yılında Doğu Akdeniz Geçit Kuşağı Tarımsal Araştırma Enstitüsü bahçesinde saksı denemesi olarak gerçekleştirilmiştir. Denemede kullanılan toprak Tarımsal Araştırma Enstitüsü bahçesinden (37°32'11.56"N 36°55'00.44"E) temin edilmiş olup 0-30 cm derinlikten alınmış, gölgede kurutulmuş ve 4 mm'lik bir elekten geçirilmiştir. Kullanılan toprağın bazı fiziksel ve kimyasal özellikleri Çizelge 1'de, bazı makro ve mikro besin elementi içerikleri ise Çizelge 2'de verilmiştir.

Çizelge 1. Araştırmada kullanılan toprağa ait bazı fiziksel ve kimyasal özellikler

Tekstür			pH	EC	Organik Madde	Kireç
%Kum	%Kil	%Silt		$\mu s/cm$	%	%
65	5	30	7.69	541	0.07	10

Çizelge 2. Araştırmada kullanılan toprağa ait bazı makro ve mikro besin elementi içerikleri

P	K	Ca	Mg	Fe	Zn	Cu	Mn
$mg\ kg^{-1}$							
6.8	182	4660	665	12.13	0.79	11.80	2.19

Araştırmada kullanılan toprak %65 kum, %5 kil ve %30 silt içeriği ile kumlu tın bünyeye sahiptir. Toprak pH'sı 7.69 ile hafif alkalın ve hafif tuzlu sınıfında yer almaktadır. Organik madde düzeyi çok düşük, kireci orta, yarayışlı fosforu ise yetersizdir. Değişebilir K, Ca, Mg ve ekstrakte edilebilir Fe, Zn, Cu ile Mn konsantrasyonları yeterli sınıfında yer almaktadır.

Araştırma, tesadüf parselleri deneme planına göre tasarlanmış olup her bir plastik saksıya 1 kg toprak örneği tartılmıştır. Ekimden önce saksılara 0, 150, 300 $mg\ kg^{-1}$ olacak şekilde Si ilave edilmiş ve homojen olacak şekilde karıştırılmıştır. Silisyum kaynağı olarak ticari olarak temin edilmiş olan Na_2SiO_3 kullanılmıştır. Azot uygulamasının (0, 50, 100, 150 $mg\ kg^{-1}$) ise yarısı amonyum sülfat formunda ekimle ve diğer yarısı ise üst gübre olarak üre şeklinde 2'ye bölünerek yapılmıştır. Araştırmada Esperia kışlık buğday çeşidi kullanılmıştır. Her bir saksıya 5 tohum ekilmiş ve çimlenmeden sonra seyreltilme yapıp 3'e düşürülmüştür. Buğdaylar 60 günün sonunda toprak üstü aksamı olarak hasat edilmiştir. Hasat edildikten sonra laboratuvara getirilen bitki numuneleri önce çeşme suyundan daha sonrada birkaç kez saf su ile yıkanmıştır. Etüvde 65°C'de kurutulan numuneler bitki öğütücüsünde kurutularak analize hazır hale getirilmiştir.

Toprak tekstürü Gee ve Bauder (1986) tarafından bildirilen hidrometre yöntemi ile belirlenen % kum, % kil ve % silt içerikleri toprak tekstür üçgenine göre sınıflandırılmıştır. Toprağa ait pH ve EC değerleri ise 1:2.5 oranına göre toprak-su süspansiyonunda pH ve EC metre ile ölçülmüştür (Richards, 1954). Toprak organik madde içeriği Walkley-Black yöntemine göre (Nelson ve Sommers, 1996), kireç ise Scheibler kalsimetresi ile belirlenmiştir (Allison ve Moodie, 1965). Yarayışlı P, 0,5 M $NaHCO_3$ (pH: 8,5) ekstrakte edilerek kolorimetrik olarak (Olsen ve Sommers, 1982, Mg, Ca ve K ise 1 N amonyum asetat (pH: 7.0) ile (Richards, 1954), Fe, Zn, Cu ve Mn Lindsay ve Norvell (1978) tarafından geliştirilen DTPA yöntemine göre atomik absorpsiyon spektrofotometresi (AAS) kullanılarak belirlenmiştir. Bitki örnekleri, Jones (2001) tarafından bildirilen yaş yakma yöntemi ile yakılmış ve P konsantrasyonları, vanadomolibdenofosforik asit (Kuo, 1996) kullanılarak belirlenmiştir. Bitki numunelerindeki Ca, K, Mg, Zn, Fe, Cu ve Mn atomik absorpsiyon spektrofotometresi (AAS) kullanılarak ölçülmüştür.



Bulgular

Buğday Fosfor (P) Konsantrasyonu

Azot ve Si uygulamalarının buğdayın toprak üstü aksamındaki P içeriklerine etkisine ilişkin veriler Çizelge 3’de verilmiş olup N uygulama dozlarının $p < 0.01$ düzeyinde önemli etkisi olduğu belirlenmiştir. Buğdayda N uygulama dozlarının artması ile P konsantrasyonlarının kademeli bir şekilde arttığı belirlenmiş olup en düşük N_0 dozunda $0,29 \text{ mg kg}^{-1}$ olarak saptanmıştır. Azot uygulama dozlarının artması ile artan P konsantrasyonu en yüksek N_{100} ve N_{150} dozlarında sırasıyla $0,35; 0,34 \text{ mg kg}^{-1}$ belirlenmiş olup istatistiksel olarak aynı sınıfta yer almışlardır.

Çizelge 3. Farklı N ve Si uygulama dozlarının buğdaydaki P içeriği üzerindeki etkisi

Uygulamalar		N Dozları (mg kg^{-1})				Ortalama
		0	50	100	150	
Si Dozları (mg kg^{-1})	0	$0,29 \pm 0,012$	$0,30 \pm 0,003$	$0,34 \pm 0,000$	$0,36 \pm 0,019^{\text{öd}}$	0,32
	150	$0,28 \pm 0,004$	$0,32 \pm 0,005$	$0,38 \pm 0,034$	$0,33 \pm 0,017$	0,33
	300	$0,30 \pm 0,009$	$0,33 \pm 0,010$	$0,34 \pm 0,002$	$0,33 \pm 0,018$	0,32
Ortalama		0,29C	0,32BC	0,35A**	0,34AB	

**: $p < 0.01$; *: $p < 0.05$; öd: önemli değil, $\text{LSD}_{0,05}$: $0,033 \text{ N}$ için; Silisyum ve NxSi interaksyonunun buğday P konsantrasyonu üzerine önemli bir etkisi görülmemiştir.

Buğday Potasyum (K) Konsantrasyonu

Farklı dozlarda uygulanan N ve silisyumun buğdayın toprak üstü aksamındaki K içeriklerine etkisine ait veriler Çizelge 4’de verilmiştir. Azot, Si ve NxSi interaksyonunun K konsantrasyonu üzerinde istatistiksel olarak önemli bir etkisi belirlenmemiştir.

Çizelge 4. Farklı N ve Si uygulama dozlarının buğdaydaki K içeriği üzerindeki etkisi

Uygulamalar		N Dozları (mg kg^{-1})				Ortalama
		0	50	100	150	
Si Dozları (mg kg^{-1})	0	$2,85 \pm 0,161$	$3,50 \pm 0,075$	$2,80 \pm 0,000$	$3,03 \pm 0,222^{\text{öd}}$	3,04
	150	$3,23 \pm 0,135$	$3,28 \pm 0,155$	$3,22 \pm 0,003$	$3,07 \pm 0,051$	3,20
	300	$3,38 \pm 0,060$	$3,23 \pm 0,525$	$2,80 \pm 0,017$	$2,77 \pm 0,037$	3,04
Ortalama		3,15	3,33	2,94	2,96	

**: $p < 0.01$; *: $p < 0.05$; öd: önemli değil

Buğday Kalsiyum (Ca) Konsantrasyonu

Azot ve Si uygulamalarının buğdayın toprak üstü aksamındaki Ca içeriklerine etkisine ilişkin veriler Çizelge 5’de verilmiş olup N, Si uygulamaları ve NxSi interaksyonlarının $p < 0.01$ düzeyinde önemli etkisi olduğu belirlenmiştir.

Buğdayda N uygulama dozlarının artması ile toprak üstü aksamının Ca konsantrasyonu kontrole kıyasla artmıştır. En düşük Ca konsantrasyonu N_0 dozunda $0,54 \text{ mg kg}^{-1}$ olarak belirlenirken N_{50} ve N_{100} uygulamaları da istatistiksel olarak aynı grupta yer almıştır. Silisyum uygulama dozları azotun aksine arttıkça buğday Ca konsantrasyonu azalmıştır. En yüksek Ca konsantrasyonu kontrol grubu olan Si_0 uygulamasında $0,70 \text{ mg kg}^{-1}$ olarak belirlenmiştir. En düşük ise Si_{150} ile Si_{300} uygulamalarında belirlenmiş olup istatistiksel olarak aynı grupta yer almıştır.

Çizelge 5. Farklı N ve Si uygulama dozlarının buğdaydaki Ca içeriği üzerindeki etkisi

Uygulamalar		N Dozları (mg kg^{-1})				Ortalama
		0	50	100	150	
Si Dozları (mg kg^{-1})	0	$0,59b-e \pm 0,008$	$0,64bc \pm 0,026$	$0,57b-e \pm 0,007$	$1,01a^{**} \pm 0,059$	$0,70A^{**}$
	150	$0,53b-e \pm 0,006$	$0,56b-e \pm 0,002$	$0,61b-d \pm 0,005$	$0,59b-e \pm 0,007$	0,57B
	300	$0,51de \pm 0,016$	$0,52c-e \pm 0,036$	$0,48e \pm 0,019$	$0,64b \pm 0,010$	0,54B
Ortalama		0,54B	0,57B	0,55B	0,75A**	

**: $p < 0.01$; *: $p < 0.05$; öd: önemli değil, $\text{LSD}_{0,05}$: $0,053, 0,041, 0,120$ sırasıyla N, Si ve $\text{N} \times \text{Si}$ için Azot x Si etkileşiminde ise en yüksek Ca konsantrasyonu $N_{150} \times \text{Si}_0$ uygulamasında $1,01 \text{ mg kg}^{-1}$ olarak belirlenirken en düşük $0,48 \text{ mg kg}^{-1}$ ile $N_{100} \times \text{Si}_{300}$ uygulamasında saptanmıştır.

Buğday Magnezyum (Mg) Konsantrasyonu

Farklı dozlarda uygulanan N ve silisyumun buğdayın toprak üstü aksamındaki Mg içeriklerine etkisine ilişkin veriler Çizelge 6’da verilmiş olup N, Si uygulamaları ve NxSi interaksyonlarının $p < 0.01$ düzeyinde önemli etkisi olduğu belirlenmiştir.



Buğdayda N uygulama dozlarının artması ile toprak üstü aksamının Mg konsantrasyonu kontrole kıyasla artmış olup en düşük Mg konsantrasyonu N_0 ve N_{100} dozlarında $0,29 \text{ mg kg}^{-1}$ olarak belirlenmiş olup istatistiksel olarak aynı grupta yer almışlardır. Buğday toprak üstü aksamında en yüksek Ca konsantrasyonu ise $0,54 \text{ mg kg}^{-1}$ olarak belirlenirken N_{50} ve N_{100} uygulamaları da istatistiksel olarak aynı grupta yer almıştır. Silisyum uygulama dozları azotun aksine arttıkça buğday Ca konsantrasyonu azalmıştır. En yüksek Ca konsantrasyonu kontrol grubu olan Si_0 uygulamasında $0,70 \text{ mg kg}^{-1}$ olarak belirlenmiştir. En düşük ise Si_{150} ile Si_{300} uygulamalarında belirlenmiş olup istatistiksel olarak aynı grupta yer almıştır.

Çizelge 6. Farklı N ve Si uygulama dozlarının buğdaydaki Mg içeriği üzerindeki etkisi

Uygulamalar		N Dozları (mg kg^{-1})				Ortalama
		0	50	100	150	
Si Dozları (mg kg^{-1})	0	0,29a±0,008	0,34a±0	0,31a±0,002	0,35a**±0,017	0,32A**
	150	0,28ab±0,005	0,32a±0,000	0,35a±0,021	0,31a±0,006	0,31A
	300	0,29a±0,014	0,30a±0,007	0,22b±0,010	0,32a±0,029	0,29B
Ortalama		0,29B	0,32AB	0,29B	0,33A**	

**p<0.01; *p<0.05; öd: önemli değil, $LSD_{0,05}$: 0,030, 0,023, 0,069 sırasıyla N, Si ve $N \times Si$ için Silisyum x N etkileşiminde ise en yüksek Mg konsantrasyonu $N_{150} \times Si_0$ uygulamasında $0,35 \text{ mg kg}^{-1}$ olarak belirlenirken en düşük $0,22 \text{ mg kg}^{-1}$ ile $N_{100} \times Si_{300}$ uygulamasında saptanmıştır.

Buğdayda Demir (Fe) Konsantrasyonu

Azot ve Si uygulamalarının buğdayın toprak üstü aksamındaki Fe konsantrasyonuna etkisine ilişkin veriler Çizelge 7’de verilmiş olup N, Si uygulamaları ve $N \times Si$ interaksiyonlarının p<0.01 düzeyinde önemli etkisi olduğu belirlenmiştir.

Buğdayda N uygulama dozlarının artması ile toprak üstü aksamının Fe konsantrasyonu artmış olup en yüksek Fe konsantrasyonu N_{150} dozlarında $87,9 \text{ mg kg}^{-1}$ olarak belirlenmiştir. Buğday toprak üstü aksamında en düşük Fe konsantrasyonu ise N_0 ve N_{50} uygulamalarında belirlenmiş olup istatistiksel olarak aynı grupta yer almıştır. Silisyum uygulama dozlarında ise düzenli artış veya azalış görülmemiştir. En yüksek Fe konsantrasyonu $83,8 \text{ mg kg}^{-1}$ ile Si_0 uygulamasında belirlenirken Si_{300} $79,7 \text{ mg kg}^{-1}$ ile istatistiksel olarak aynı grupta yer almıştır. En düşük ise $71,3 \text{ mg kg}^{-1}$ ile Si_{150} uygulamasında elde edilmiştir.

Çizelge 7. Farklı N ve Si uygulama dozlarının buğdaydaki Fe içeriği üzerindeki etkisi

Uygulamalar		N Dozları (mg kg^{-1})				Ortalama
		0	50	100	150	
Si Dozları (mg kg^{-1})	0	78,8bc±0,440	68,5bc±1,443	87,6ab±4,763	100,0a**±4,618	83,8A**
	150	74,1bc±8,804	64,0c±2,598	67,5bc±2,020	79,6a-c±5,052	71,3B
	300	70,8bc±2,92	77,6bc±1,364	86,8ab±5,840	83,6a-c±2,905	79,7A
Ortalama		74,6BC	70,0C	80,6AB	87,9A**	

**p<0.01; *p<0.05; öd: önemli değil, $LSD_{0,05}$: 9,49, 7,44, 21,49 sırasıyla N, Si ve $N \times Si$, Silisyum x N etkileşiminde ise en yüksek Fe konsantrasyonu $N_{150} \times Si_0$ uygulamasında $100,0 \text{ mg kg}^{-1}$ olarak belirlenirken en düşük $64,0 \text{ mg kg}^{-1}$ ile $N_{50} \times Si_{150}$ uygulamasında saptanmıştır.

Buğdayda Çinko (Zn) Konsantrasyonu

Farklı dozlarda uygulanan N ve silisyumun buğdayın toprak üstü aksamındaki Zn konsantrasyonuna etkisine ilişkin veriler Çizelge 8’de verilmiş olup Si uygulamaları ve $N \times Si$ interaksiyonlarının p<0.01 düzeyinde önemli etkisi olduğu belirlenmiştir.

Buğdayda N uygulama dozlarının Zn konsantrasyonu üzerine istatistiksel olarak önemli farklar belirlenmemiştir. Silisyum uygulama dozlarının artması ile toprak üstü aksamının Zn konsantrasyonu azalmış olup en yüksek Fe konsantrasyonu Si_0 dozunda $29,9 \text{ mg kg}^{-1}$ olarak belirlenirken en düşük Si_{150} ve Si_{300} uygulamalarında belirlenmiş olup istatistiksel olarak aynı grupta yer almıştır.

Çizelge 8. Farklı N ve Si uygulama dozlarının buğdaydaki Zn içeriği üzerindeki etkisi

Uygulamalar		N Dozları (mg kg^{-1})				Ortalama
		0	50	100	150	
Si Dozları (mg kg^{-1})	0	30,0ab±2,020	33,0a±2,309	23,1ab±0,927	33,6a±1,301	29,9A*
	150	26,0ab±2,020	28,5ab±2,886	22,0b±0	23,6ab±2,455	25,0B
	300	24,0ab±1,154	25,5ab±1,732	31,2ab±1,299	28,8ab±3,940	27,3AB
Ortalama		26,6	29,0	25,4	28,7	

**p<0.01; p<0.05; öd: önemli değil, $LSD_{0,05}$: 3,67, 10,61 sırasıyla Si ve $N \times Si$, Silisyum x N etkileşiminde ise en yüksek Zn konsantrasyonu $N_{150} \times Si_0$ uygulamasında $33,6 \text{ mg kg}^{-1}$ olarak belirlenirken en düşük $22,0 \text{ mg kg}^{-1}$ ile $N_{100} \times Si_{150}$ uygulamasında saptanmıştır.

Buğdayda Bakır (Cu) Konsantrasyonu

Azot ve silisyum uygulamalarının buğdayın toprak üstü aksamındaki Cu konsantrasyonuna etkisine ilişkin veriler Çizelge 9’da verilmiş olup N, Si uygulamaları ve $N \times Si$ interaksiyonlarının p<0.01 düzeyinde önemli etkisi olduğu belirlenmiştir.



Buğdayda N uygulama dozlarının toprak üstü aksamının Cu konsantrasyonu en yüksek N₅₀ ve N₁₅₀ dozlarında sırasıyla 9,94 mg kg⁻¹; 9,72 mg kg⁻¹ olarak belirlenmiş olup istatistiksel olarak aynı grupta yer almışlardır. Buğday toprak üstü aksamında en düşük Cu konsantrasyonu ise N₀ ve N₁₀₀ uygulamalarında belirlenmiş olup istatistiksel olarak aynı grupta yer almıştır. Silisyum uygulama dozlarında ise en yüksek Cu konsantrasyonu 10,0 mg kg⁻¹ ile Si₃₀₀ uygulamasında belirlenirken en düşük Si₀ ve Si₁₅₀ uygulamalarında belirlenmiş olup istatistiksel olarak aynı grupta yer almıştır.

Çizelge 9. Farklı N ve Si uygulama dozlarının buğdaydaki Cu içeriği üzerindeki etkisi

Uygulamalar		N Dozları (mg kg ⁻¹)				Ortalama
		0	50	100	150	
Si Dozları (mg kg ⁻¹)	0	9,00b±0,288	9,33b±0,440	8,83b±0,333	10,0ab±0,577	9,29AB
	150	9,00b±0,000	8,83b±0,333	9,00b±0	9,50ab±0	9,08B
	300	9,00b±0,288	11,6a*±1,092	9,66ab±0,166	9,66ab±0,333	10,0A*
Ortalama		9,00B	9,94A*	9,16B	9,72AB	

**p<0.01; p<0.05; öd: önemli değil, LSD_{0,05}: 0,72, 0,76, 2,20 sırasıyla N, Si ve N x Si için Silisyum x N etkileşiminde ise en yüksek Cu konsantrasyonu N₅₀ x Si₃₀₀ uygulamasında 11,6 mg kg⁻¹ olarak belirlenirken en düşük 8,83 mg kg⁻¹ ile N₅₀ x Si₁₅₀ uygulamasında saptanmıştır.

Buğdayda Mangan (Mn) Konsantrasyonu

Azot ve Si uygulamalarının buğdayın toprak üstü aksamındaki Mn konsantrasyonuna etkisine ilişkin veriler Çizelge 10'da verilmiş olup N ve Si uygulamaları p<0.01 düzeyinde önemli etkisi olduğu belirlenmiştir.

Buğdayda N uygulama dozlarının artmasına paralel olarak toprak üstü aksamının Mn konsantrasyonu azalmıştır. En yüksek Mn konsantrasyonu kontrol grubunda 14,2 mg kg⁻¹ olarak belirlenirken en düşük N₁₅₀ uygulamasında 12,2 mg kg⁻¹ olarak belirlenmiştir. Silisyum uygulama dozlarında ise en yüksek Mn konsantrasyonu 14,0 mg kg⁻¹ ile Si₃₀₀ uygulamasında belirlenirken en düşük Si₀ ve Si₁₅₀ uygulamalarında belirlenmiş olup istatistiksel olarak aynı grupta yer aldığı saptanmıştır.

Çizelge 10. Farklı N ve Si uygulama dozlarının buğdaydaki Mn içeriği üzerindeki etkisi

Uygulamalar		N Dozları (mg kg ⁻¹)				Ortalama
		0	50	100	150	
Si Dozları (mg kg ⁻¹)	0	14,1±0,166	14,0±1,443	12,00±0,288	11,5±0,577	12,9AB
	150	13,16±1,301	11,6±1,166	12,66±0,166	11,6±0,166	12,2B
	300	15,3±0,881	14,16±0,440	13,16±0,166	13,66±0,927	14,0A**
Ortalama		14,2A*	13,27AB	12,6AB	12,2B	

**p<0.01; p<0.05; öd: önemli değil, LSD_{0,05}: sırasıyla 1,61, 1,26 N ve Si için Silisyum ve NxSi interaksiyonunun buğday Mn konsantrasyonu üzerine önemli bir etkisi görülmemiştir.

Tartışma

Buğdayda değişik dozlarda uygulanan N ve silisyumun bazı makro (P, K, Ca, Mg) ve mikro (Fe, Zn, Cu, Mn) besin elementleri konsantrasyonuna etkisi incelenmiştir. Azot, bitki metabolizmasında ve dolayısıyla büyümenin belirlenmesinde çok önemli bir rol oynar. Bu nedenle, bitkilerin inorganik beslenmesi, hem ürünün miktarını hem de kalitesini iyileştirdiği için N tarafından domine edilmiştir. Bu nedenle, azotun diğer temel bitki besin maddeleriyle etkileşimini anlamak, bitki büyümesini ve gelişimini iyileştirmek için temel öneme sahiptir (Fageria, 2006). Buğdayın toprak üstü aksamındaki P konsantrasyonu N uygulamasının artması ile kontrole kıyasla artmıştır ancak Si uygulamalarının önemli bir etkisi gözlemlenmemiştir. En yüksek P konsantrasyonu N uygulamasının en yüksek dozları olan N₁₀₀ ve N₁₅₀'de belirlenmiştir. Fageria (2006) bitkinin N tedariğinin artması ile büyümenin arttığını bunun sonucu olarakta diğer besin maddelerine olan talebin arttığını bildirmiştir. Hou ve ark. (2025) sonuçlarımıza benzer şekilde N uygulamasının buğdayda P alımını ve kullanımını artırdığını bildirmişlerdir. Wilkson ve ark. (1999) azotun bitki kök gelişimini artırdığını köklerin fosforu alma ve taşıma yeteneğinin arttığını ve ayrıca NH₄⁺ toprakların pH'sını düşürerek fosforun çözünürlüğünü artırdığını bildirmişlerdir. Buğdayın toprak üstü aksamının K konsantrasyonu N ve Si uygulamalarından etkilenmezken Ca konsantrasyonu p<0.01 önem düzeyinde etkilenmiştir. Azot uygulama dozlarının artmasına paralel olarak Ca konsantrasyonu artmış olup en yüksek N₁₅₀ uygulamasından elde edilmiştir. Güneş ve ark. (2006) tarafından yürütülen çalışmada artan N dozlarının bitki Ca konsantrasyonunu artırdığı bildirilmiştir. Silisyum uygulama dozlarının artmasıyla ise Ca konsantrasyonu buğdayın toprak üstü aksamında azalmıştır. Çalışmamıza benzer şekilde Ma ve Takahashi (1993) Si uygulama dozlarının artması ile Ca bitki tarafından alımının %20 oranında azaldığını bildirmiştir. Bunu ise Si ilave edilmeyen bitkide ki terleme oranının Si uygulanan bitkiye %30 oranında daha fazla olmasıyla ilişkilendirmiştir. Buğday bitkisinin toprak üstü aksamının Mg konsantrasyonu incelendiğinde N ve Si uygulamalarının p<0.01 önem düzeyinde etkili olduğu belirlenmiştir. Artan dozlarda uygulanan azotun Mg konsantrasyonunu artırdığını maksimum en yüksek N dozu olan N₁₅₀ uygulamasından elde edilmiştir. Silisyumun



en yüksek uygulama dozunda ise Mg konsantrasyonu azalmış ancak Si₀ ve Si₁₅₀ aynı grupta yer almıştır. Greger ve ark. (2018) yapılan çalışmada toprağa Si ilavesinin mevcut durumdaki magnezyumun kullanılabilirliğini çok fazla etkilemediğini bildirmiştir. Bununla birlikte Si uygulaması ile bazı besin elementlerinin bitki doku konsantrasyonunun da azalma gözlemlenmiştir ve bunu da büyümedeki artıştan kaynaklanan bir seyreltme etkisinden kaynaklanıyor olabileceği ile ilişkilendirmişlerdir. Buğday kuru maddesinin Fe konsantrasyonu N ve Si uygulamalarından p<0.01 önem düzeyinde etkilenmiştir. Azot uygulama dozlarının artması ile Fe konsantrasyonu artarken Si uygulamasında tam tersi bir sonuç elde edilmiştir. Si₀ ve Si₃₀₀ uygulamalarının Fe konsantrasyonu istatistiksel olarak aynı sınıfta yer almalarına rağmen en yüksek kontrol grubunda belirlenmiştir. Pozza ve ark. (2009) çalışmasına göre, Si ile gübrelenen pirinç bitkilerinde kök yüzeyinde Fe²⁺ ve Mn²⁺'nin oksidasyonu artmakta, bu elementler çökmekte ve bitki tarafından alınamamaktadır. Azot ve Si uygulamasının buğday kuru maddesindeki Zn konsantrasyonu üzerine etkisi incelendiğinde N uygulama dozları arasında farklılık belirlenmezken Si uygulaması Zn konsantrasyonunu p<0.01 önem düzeyinde azaltmıştır. En yüksek Zn konsantrasyonu Si₀ grubunda elde edilirken en düşük Si₁₅₀ ve Si₃₀₀ uygulamalarında belirlenmiştir. Sarto ve ark. (2019) ile Moraes ve ark. (2019) benzer bulgular elde etmiş olup artan Si dozlarıyla buğdayda Zn konsantrasyonunun azaldığını bildirmişlerdir. Buğdayın Cu konsantrasyonu incelendiğinde ise N uygulaması istatistiksel olarak önemli bulunmasına rağmen uygulama dozlarına bağlı olarak düzenli bir artış veya azalış göstermemiştir ancak kontrole kıyasla Cu konsantrasyonu artmıştır. Bakır konsantrasyonu üzerine Si uygulaması p<0.01 düzeyinde önemli bulunmuş olup en yüksek Si₃₀₀ uygulamasında belirlenmiştir. Greger ve ark. (2018) topraklara Si ilavesinin Cu kullanılabilirliğini artırdığı daha yüksek kullanılabilirliğin ise bitki tarafından daha çok alım sağladığını bildirmiştir. Buğdaydaki Mn konsantrasyonu ise Cu benzer şekilde Si konsantrasyonu arttıkça artmıştır. Greger ve ark. (2018) ise benzer sonuçlar elde etmiş olup Si bitkilerde manganın net birikimini ve konsantrasyonunu, köklerden ziyade sürgünlerde daha fazla artırdı bu durumu ise silisyumun manganı bitki kökleri tarafından alınmasından ziyade sürgünlere taşınmasını daha fazla teşvik ettiği ile ilişkilendirmişlerdir.

Sonuç

Araştırma sonuçlarına göre N uygulama dozlarının artması ile buğdayda P, Ca, Mg ve Fe konsantrasyonları artmıştır. Silisyum uygulama dozlarının artmasıyla ise Mn ve Cu istatistiksel olarak önemli düzeyde artarken Ca, Mg, Fe ve Zn konsantrasyonu kontrol grubunda en yüksek belirlenmiştir. Bu çalışmanın sonucunda, N uygulamalarının buğdayın mineral beslenmesini genel olarak olumlu yönde etkilediği belirlenmiştir. Buna karşın, Si uygulamalarının bazı mikro elementlerinin alımını artırırken bazı elementlerin alımını sınırlandırdığı saptanmıştır. Mikro besin elementlerinden Fe ve Zn, bitki gelişimi için gerekli olmakla birlikte, topraklarda aşırı düzeylerde bulunmaları durumunda ağır metal özelliği gösterebilmekte ve bitkiler üzerinde toksik etkilere neden olabilmektedir. Bu nedenle, ağır metal konsantrasyonlarının yüksek olduğu topraklarda Si uygulamalarının, söz konusu elementlerin bitki bünyesine alımını azaltarak toksite riskini hafifletmede potansiyel bir yönetim stratejisi olarak değerlendirilebileceği ifade edilmektedir. Silisyum uygulamalarıyla birlikte Cu ve Mn konsantrasyonlarında meydana gelen artış, silisyumun bu elementlerin alım ve taşınımını tutarlı edebileceğini düşündürmektedir. Literatürde silisyumun mikro besin elementleri üzerindeki etkilerinin tutarlı olmadığı, bazı elementlerin alımını artırırken bazılarının alımını azaltabildiği bildirilmektedir. Bu nedenle elde edilen sonuçlar, silisyumun Cu ve Mn beslenmesi üzerindeki etkisinin buğdayın yetiştirme koşulları ve toprak özellikleriyle yakından ilişkili olabileceğini göstermektedir. Elde edilen bulgular doğrultusunda, silisyumun mikro besin elementlerinin düzenlenmesindeki hala tam olarak anlaşılamayan karmaşık mekanizmasının daha ayrıntılı araştırılması gerektiği sonucuna varılmıştır.

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Comparative Evaluation of In Vitro, In Situ and In Vivo Methods Used in Rumen Fermentation Studies

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Abstract

Accurate and reliable evaluation of rumen fermentation is essential for improving ruminant nutrition, increasing feed utilization efficiency, understanding microbial processes, and controlling enteric methane production. For this purpose, different experimental methods are used in rumen research, which can be broadly classified as *in vitro*, *in situ*, and *in vivo* approaches. Among *in vitro* methods, batch gas production systems and the Rusitec system are the most widely used approaches, whereas *in situ* methods allow direct assessment of ruminal degradability, and *in vivo* methods enable evaluation of the overall biological response at the animal level. In this study, these three major methodological groups commonly used in rumen fermentation studies were comparatively evaluated. Batch gas production systems are rapid, cost-effective, and suitable for the preliminary screening of a large number of samples. The Rusitec system, on the other hand, offers important advantages for monitoring longer-term fermentation processes and microbial changes under more controlled conditions. *In situ* methods are particularly useful for determining ruminal disappearance and degradability characteristics of feeds, although they provide more limited information on fermentation end products. *In vivo* methods provide the highest level of biological relevance by linking rumen fermentation responses with animal performance, physiological reactions, and practical production conditions. However, they are also more demanding in terms of cost, labor, time, and experimental control. Overall, no single method appears to fully reflect the complexity of the rumen ecosystem on its own. Therefore, *in vitro*, *in situ*, and *in vivo* methods should be regarded not as alternatives that replace one another, but as complementary approaches serving different research objectives. In conclusion, selecting the most appropriate method according to the aim of the study, and combining these methods when necessary, may contribute to obtaining more reliable and interpretable results in rumen fermentation research.

Keywords: Rumen fermentation, *In vitro*, Batch gas production systems, Rusitec, *In situ*, *In vivo*.

Rumen Fermentasyon Çalışmalarında Kullanılan *İn Vitro*, *İn Situ* ve *İn Vivo* Metotların Karşılaştırmalı Değerlendirilmesi

Özet

Rumen fermentasyonunun doğru ve güvenilir biçimde değerlendirilmesi, ruminant beslemenin iyileştirilmesi, yemlerden yararlanma düzeyinin artırılması, mikrobiyal süreçlerin anlaşılması ve enterik metan oluşumunun kontrol altına alınması açısından büyük önem taşımaktadır. Bu amaçla rumen araştırmalarında farklı deneysel metotlar kullanılmakta olup, bunlar temel olarak *in vitro*, *in situ* ve *in vivo* yaklaşımlar altında ele alınmaktadır. *In vitro* metotlar içerisinde özellikle kesikli (batch) gaz üretim sistemleri ile Rusitec sistemi öne çıkarken, *in situ* metotlar yemlerin rumende parçalanabilirliğinin doğrudan değerlendirilmesine, *in vivo* metotlar ise tüm biyolojik yanıtın hayvan düzeyinde izlenmesine olanak sağlamaktadır. Bu çalışmada, rumen fermentasyon çalışmalarında yaygın olarak kullanılan bu üç temel metot grubu karşılaştırmalı olarak değerlendirilmiştir. Kesikli gaz üretim sistemlerinin hızlı, ekonomik ve çok sayıda örneğin ön değerlendirilmesine uygun olduğu; Rusitec sisteminin ise daha kontrollü koşullarda, daha uzun süreli fermentasyon süreçleri ile mikrobiyal değişimleri izleme açısından önemli avantajlar sağladığı görülmektedir. *In situ* metotlar, yemlerin rumendeki kaybolma ve parçalanma özelliklerinin belirlenmesinde güçlü bir araç olmakla birlikte, doğrudan fermentasyon son ürünlerini sınırlı düzeyde yansıtmaktadır. *In vivo* metotlar ise rumen fermentasyonuna ilişkin bulguların hayvan performansı, fizyolojik yanıtlar ve pratik üretim koşulları ile birlikte değerlendirilmesine olanak vererek en yüksek biyolojik gerçekliği sunmaktadır. Ancak bu metotların maliyet, iş gücü, zaman ve deneysel kontrol bakımından daha sınırlayıcı olduğu bilinmektedir. Genel olarak değerlendirildiğinde, hiçbir metodun tek başına rumen ekosisteminin tüm karmaşıklığını eksiksiz biçimde yansıtamadığı anlaşılmaktadır. Bu nedenle *in vitro*, *in situ* ve *in vivo* metotlar birbirinin alternatifi değil, farklı araştırma amaçlarına hizmet eden tamamlayıcı yaklaşımlar olarak görülmelidir. Sonuç olarak, rumen fermentasyon çalışmalarında araştırma amacına uygun metodun seçilmesi ve gerektiğinde bu metotların birlikte kullanılması, daha güvenilir ve yorumlanabilir sonuçlara ulaşılmasına katkı sağlayacaktır.

Anahtar Kelimeler: Rumen fermentasyonu, *İn vitro*, Kesikli gaz üretim sistemi, Rusitec, *İn situ*, *İn vivo*.



Giriş

Rumen fermentasyonu, ruminant hayvanların yemi enerjiye ve mikrobiyal ürüne dönüştürmesinde merkezi bir role sahiptir (Mizrahi vd., 2021; Newbold ve Ramos-Morales, 2020). Bu süreçte oluşan uçucu yağ asitleri, mikrobiyal protein, amonyak ve gazlar, hem hayvanın beslenme fizyolojisini hem de üretim performansını doğrudan etkilemektedir (Mahboubi vd., 2026; Qi vd., 2024; Ungerfeld, 2020). Rumen fermentasyonunun doğru değerlendirilmesi, yalnızca yemlerin besleme değerinin belirlenmesi açısından değil, aynı zamanda besin maddelerinden yararlanma etkinliğinin artırılması, rumen mikrobiyotasının daha iyi anlaşılması ve enterik metan oluşumunun azaltılmasına yönelik stratejilerin geliştirilmesi bakımından da önem taşımaktadır (Moss vd., 2000; Purba ve Sangsawad, 2025; Qi vd., 2024; Shinkai vd., 2024; Tseten vd., 2022).

Rumen ekosistemi son derece karmaşık, dinamik ve çok faktörlü bir yapıya sahip olduğu için, bu sistemin tek bir deneysel yaklaşımla bütünüyle açıklanması kolay değildir (Mizrahi vd., 2021; Russell ve Rychlik, 2001). Rasyona, mikrobiyal yapıya, hayvanın fizyolojik durumuna ve çevresel koşullara bağlı olarak değişebilen rumen yanıtları, araştırmacıları farklı metotlar geliştirmeye yöneltmiştir. Bu kapsamda rumen fermentasyon çalışmalarında en yaygın kullanılan yaklaşımlar genel olarak *in vitro*, *in situ* ve *in vivo* metotlar altında toplanmaktadır (Dijkstra vd., 2005; Foster vd., 2023; Tedeschi vd., 2022).

In vitro metotlar, laboratuvar koşullarında yürütülen ve rumen ortamını belirli ölçüde taklit etmeyi amaçlayan sistemleri kapsamaktadır. Özellikle kesikli gaz üretim sistemleri, çok sayıda yem ve yem katkı maddesinin kısa sürede, görece düşük maliyetle ve uygun standardizasyonla görece tekrarlanabilir biçimde değerlendirilmesine olanak sağladığı için uzun yıllardır yaygın biçimde kullanılmaktadır (Foster vd., 2023; Theodorou vd., 1994). Bunun yanında, Rusitec sistemi gibi daha gelişmiş *in vitro* düzenekler, fermentasyonun daha uzun süreli ve daha kontrollü koşullarda izlenmesine imkân vererek klasik batch sistemlerin önemli bazı sınırlılıklarını aşmaya yardımcı olmaktadır (Czerkawski ve Breckenridge, 1977; Martínez vd., 2010). Buna rağmen *in vitro* metotlar, canlı hayvandaki emilim süreçlerini, sistemik metabolik yanıtları ve konakçı-mikroorganizma etkileşimini tam olarak yansıtamamaktadır (Dijkstra vd., 2005).

In situ metotlar ise genellikle fistüllü hayvanlar kullanılarak yürütülen ve yemlerin rumende kaybolma veya parçalanma özelliklerinin doğrudan değerlendirilmesine imkân veren bir yaklaşım sunmaktadır. Özellikle naylon torba tekniği, yemlerin ruminal parçalanabilirliğinin belirlenmesinde uzun yıllardır temel metotlardan biri olarak kabul edilmektedir (Foster vd., 2023; Nocek, 1988; Ørskov ve McDonald, 1979). Bu metot, yemlerin rumen ortamındaki davranışını doğrudan inceleme açısından güçlü olmakla birlikte, fermentasyon son ürünleri, gaz oluşumu veya tüm mikrobiyal süreçler hakkında sınırlı bilgi sağlamaktadır. Bu yönüyle *in situ* metotlar, özellikle yemlerin rumende parçalanma özelliklerini değerlendirmede değerli olmakla birlikte, rumen fermentasyonunu tüm boyutlarıyla açıklamak için tek başına yeterli değildir.

In vivo metotlar ise rumen fermentasyonuna ilişkin süreçleri canlı hayvan düzeyinde değerlendirdiği için en yüksek biyolojik gerçekliği sunmaktadır. Bu metotlarla elde edilen bulgular, hayvan performansı, yem tüketimi, sindirim, metabolik yanıtlar ve pratik yetiştirme koşulları ile birlikte yorumlanabilmektedir. Bu nedenle *in vivo* çalışmalar biyolojik doğrulama için en güçlü yaklaşımlardan biridir (Hristov vd., 2013; Tedeschi vd., 2022). Bununla birlikte, bu metotların maliyetli, zaman alıcı, daha fazla iş gücü gerektiren ve biyolojik varyasyondan daha fazla etkilenen çalışmalar olduğu bilinmektedir. Ayrıca etik kısıtlamalar da *in vivo* çalışmaların planlanmasında göz önünde bulundurulması gereken önemli bir boyuttur.

Bu noktada açıkça görülmektedir ki, *in vitro*, *in situ* ve *in vivo* metotların her biri farklı araştırma sorularına yanıt vermekte ve rumen fermentasyonunun farklı yönlerini öne çıkarmaktadır. Başka bir ifadeyle, bu metotları birbirinin alternatifi olarak değil, birbirini tamamlayan araçlar olarak değerlendirmek daha doğru bir yaklaşım olacaktır. *In vitro* metotlar hızlı ön değerlendirme ve kontrollü tarama çalışmaları için; *in situ* metotlar yemlerin ruminal parçalanabilirliğinin belirlenmesi için; *in vivo* metotlar ise biyolojik doğrulama ve uygulama düzeyindeki sonuçların ortaya konulması için daha uygun görünmektedir.

Bu bildiride, rumen fermentasyon çalışmalarında kullanılan *in vitro*, *in situ* ve *in vivo* metotlar, temel çalışma prensipleri, güçlü ve zayıf yönleri, sağladıkları veri türleri ve araştırma amaçlarına uygunlukları bakımından karşılaştırmalı olarak değerlendirilmiştir.

In vitro metot

In vitro metotlar, rumen ortamını laboratuvar koşullarında belirli ölçüde taklit ederek fermentasyon sürecini kontrollü biçimde incelemeye olanak sağlayan yaklaşımlardır. Bu metotların temel avantajı, araştırmacıya deneysel koşullar üzerinde yüksek düzeyde kontrol sağlama ve çok sayıda yem ya da katkı maddesinin görece düşük maliyetle değerlendirilebilmesine imkân vermesidir (Foster vd., 2023; Getachew vd., 1998;). Bu nedenle *in vitro* metotlar, özellikle ön tarama çalışmalarında, katkı maddesi denemelerinde ve fermentasyon dinamiklerinin ilk düzeyde anlaşılmasında yaygın biçimde kullanılmaktadır (Dijkstra vd., 2005; Menke ve Steingass, 1988; Theodorou vd., 1994;).



İn vitro metotlar genel olarak iki ana grupta değerlendirilebilir: kesikli (batch) gaz üretim sistemleri ve yarı-sürekli yapay rumen sistemleri, bunların en bilinen örneği ise Rusitec'tir. Her iki yaklaşım da canlı hayvan dışında yürütülmesi bakımından aynı ana gruba ait olsa da, çalışma prensibi, gözlem süresi, sağladığı veri türü ve araştırma amacı bakımından birbirinden ayrılmaktadır.

Kesikli (Batch) gaz üretim sistemleri

Kesikli gaz üretim sistemleri, *in vitro* metotlar arasında en yaygın kullanılan yaklaşımlardan biridir. Bu sistemde belirli miktardaki yem örneği, rumen sıvısı ve tampon çözelti ile birlikte anaerobik koşullarda inkübasyona bırakılır ve inkübasyon sırasında oluşan gaz miktarı belirli zaman aralıklarında ölçülür. Ölçülen gaz hacmi, yemin fermentasyon derecesi ve kinetiği hakkında dolaylı ancak değerli bilgiler sağlar (Menke ve Steingass, 1988; Theodorou vd., 1994). Kesikli gaz üretim sisteminin temel çalışma basamakları ve başlıca değerlendirme alanları Şekil 1'de şematik olarak gösterilmiştir. Bu metodun en dikkat çekici yönü, çok sayıda örneğin kısa sürede analiz edilebilmesidir. Bu nedenle kesikli gaz üretim sistemleri, yem hammaddelerinin karşılaştırılması, bitkisel ekstraktların değerlendirilmesi, organik asitlerin veya enzimlerin etkisinin araştırılması ve metan azaltıcı katkı maddelerinin ön taramasında oldukça kullanışlıdır (Getachew vd., 1998; Goel ve Makkar, 2012; Tseten vd., 2022). Ayrıca gaz üretim verileri yalnızca toplam fermentasyonu değil, aynı zamanda fermentasyon hızını ve substratın mikrobiyal kullanım biçimini de yansıtabilmektedir. Bu yönüyle sistem, yemlerin sindirilebilirliği ve potansiyel enerji değeri hakkında da önemli ipuçları sunmaktadır (Dijkstra vd., 2005; Menke ve Steingass, 1988). Bununla birlikte, bu sistemlerin önemli sınırlılıkları da vardır. Öncelikle kesikli olmaları nedeniyle, rumende doğal olarak bulunan sürekli yem girişi, sıvı akışı, fermentasyon ürünlerinin uzaklaştırılması ve mikrobiyal adaptasyon gibi süreçler tam olarak taklit edilemez. Bu durum, özellikle uzun süreli katkı etkilerinin ve mikrobiyal denge değişimlerinin değerlendirilmesinde bir zayıflık yaratmaktadır (Dijkstra vd., 2005; Foster vd., 2023). Başka bir ifadeyle, kesikli gaz üretim sistemleri hızlı ve pratik sonuçlar sunar; ancak gerçek rumen ekosisteminin zaman içindeki karmaşık davranışını sınırlı düzeyde temsil eder. Yine de bu metot, araştırmanın ilk aşamasında hangi yemin ya da katkı maddesinin daha umut verici olduğunu belirlemek açısından son derece değerlidir. Bu nedenle çoğu durumda kesikli gaz üretim sistemi, daha ayrıntılı sistemlere veya *in vivo* doğrulamaya geçmeden önce kullanılan etkili bir başlangıç basamağı olarak görülmektedir (Dijkstra vd., 2005; Getachew vd., 1998; Theodorou vd., 1994).

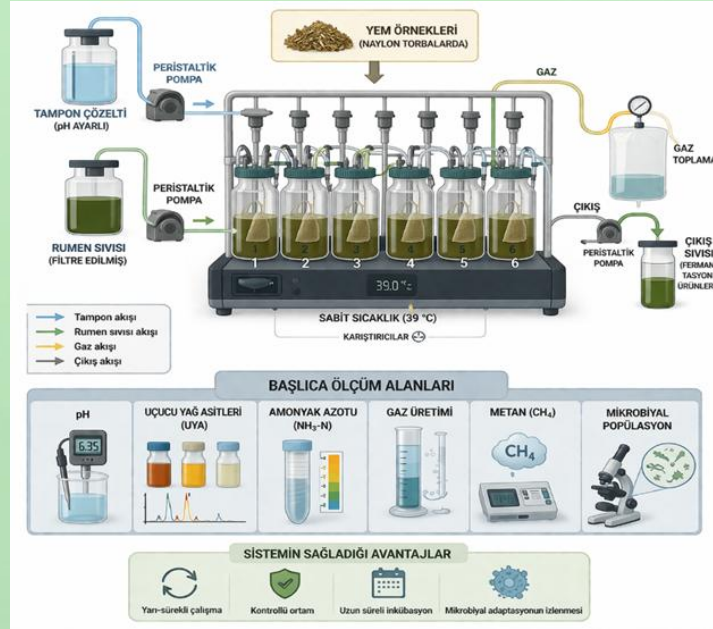


Şekil 1. Kesikli gaz üretim sisteminin şematik gösterimi.



Rusitec sistemi

Rusitec sistemi, klasik kesikli *in vitro* metotların sınırlılıklarını azaltmak amacıyla geliştirilmiş yarı-sürekli bir yapay rumen sistemidir. İlk olarak Czerkawski ve Breckenridge (1977) tarafından tanımlanan bu sistem, rumen sıvısı, tampon akışı ve yem torbalarının birlikte kullanıldığı, daha uzun süreli ve daha kontrollü bir fermentasyon ortamı sunmaktadır. Bu özellikleri nedeniyle Rusitec, batch sistemlere göre rumen ekosistemine daha yakın bir *in vitro* yaklaşım olarak kabul edilmektedir. Rusitec sisteminin temel çalışma prensibi ve başlıca ölçüm alanları Şekil 2’de şematik olarak sunulmuştur. Rusitec’in en önemli üstünlüklerinden biri, fermentasyon sürecinin zamana yayılarak izlenebilmesidir. Sistemde günlük yem değişimi yapılabilmekte, tampon çözelti düzenli şekilde sisteme verilebilmekte ve fermentasyon ürünleri belirli bir akış düzeni içinde uzaklaştırılabilmektedir (Czerkawski ve Breckenridge, 1977). Bu sayede yalnızca pH, amonyak azotu ve uçucu yağ asitleri gibi temel fermentasyon parametreleri değil, aynı zamanda gaz ve metan oluşumu ile mikrobiyal popülasyonlardaki değişimler de daha dengeli koşullarda değerlendirilebilmektedir (Deitmers vd., 2022; Musa vd., 2026). Bu yönüyle Rusitec sistemi, özellikle katkı maddelerinin etki mekanizmalarını anlamaya yönelik çalışmalarda önemli bir araçtır. Kesikli sistemlerde kısa süreli inkübasyon sonucu gözlenen etkiler, Rusitec’te daha uzun süreli fermentasyon boyunca test edilebilmekte ve mikrobiyal adaptasyonun olası etkileri daha net görülebilmektedir (Deitmers vd., 2022). Bu durum, özellikle metan azaltıcı katkıları, enzimler, bitkisel bileşikler ve organik asitlerin değerlendirilmesinde Rusitec’i değerli kılmaktadır (Musa vd., 2026; Öztürk vd., 2015). Ancak Rusitec sistemi de tüm yönleriyle gerçek rumeni temsil etmez. Canlı hayvandaki emilim süreçleri, sistemik metabolik yanıtlar, davranışsal düzenlemeler ve konakçı-fizyoloji etkileşimleri bu sistemde doğrudan yer almaz. Bu nedenle Rusitec, batch sistemlere göre daha gelişmiş ve daha güçlü bir *in vitro* yaklaşım olmakla birlikte, yine de *in vivo* doğrulamaya ihtiyaç duyan bir metot olarak değerlendirilmelidir (Deitmers vd., 2024; Dijkstra vd., 2005; Klevenhusen vd., 2026).



Şekil 2. Rusitec sisteminin şematik gösterimi.

Pratik açıdan bakıldığında Rusitec, kesikli sistemlere göre daha fazla ekipman, daha fazla iş gücü ve daha dikkatli teknik takip gerektirir. Bu nedenle her araştırma sorusu için ilk tercih olmayabilir. Ancak mekanizmaya yönelik çalışmalar, uzun süreli fermentasyon yanıtlarının izlenmesi ve mikrobiyal düzeyde daha ayrıntılı değerlendirme yapılması gereken durumlarda önemli avantaj sağlar (Deitmers vd., 2024).

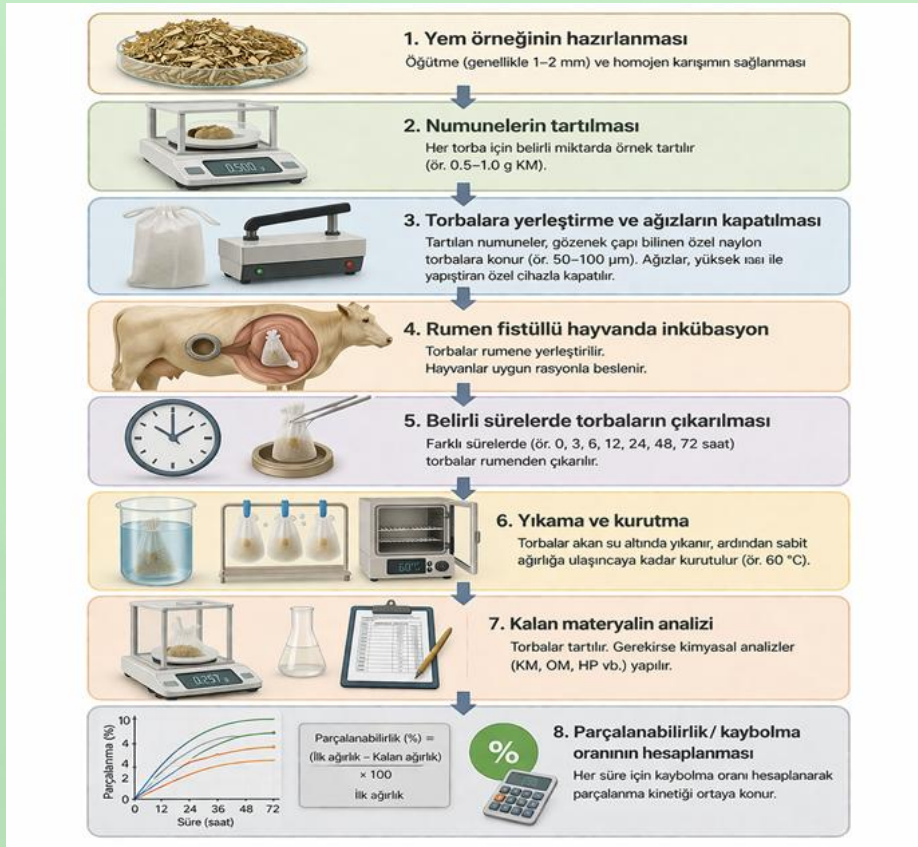
In vitro metotların genel değerlendirmesi

Genel olarak değerlendirildiğinde, *in vitro* metotlar rumen fermentasyon çalışmalarında hız, kontrol edilebilirlik ve ekonomik uygulanabilirlik açısından önemli avantajlar sunmaktadır. Kesikli gaz üretim sistemleri daha çok hızlı ön tarama ve başlangıç değerlendirmesi için uygunken, Rusitec sistemi daha kontrollü ve uzun süreli çalışmalar için öne çıkmaktadır. Bununla birlikte her iki yaklaşım da canlı hayvandaki tüm biyolojik süreçleri yansıtmadığı için, elde edilen bulguların araştırma amacına göre dikkatli yorumlanması gerekir. Bu nedenle *in vitro* metotlar, çoğu zaman tek başına son karar verdiren yöntemler olarak değil, daha ileri değerlendirmelere yön veren güçlü araştırma araçları olarak ele alınmalıdır. Araştırmanın hedefi hızlı karşılaştırma yapmaksa kesikli gaz üretim sistemleri; daha ayrıntılı fermentasyon ve mikrobiyal mekanizmaları incelemekse Rusitec sistemi daha uygun görünmektedir.



In situ metot

In situ metot, yemlerin rumen ortamındaki kaybolma ve parçalanma özelliklerinin doğrudan değerlendirilmesine olanak sağlayan önemli bir yaklaşımdır. Bu metotta yem örnekleri belirli gözenek çapına sahip torbalar içine yerleştirilir ve rumen fistülü bulunan hayvanların rumenine belirli sürelerle inkübe edilir. Daha sonra torbalar rumenden çıkarılır, yıkanır ve geriye kalan materyal analiz edilerek yemin ruminal kaybolma ya da parçalanma düzeyi hesaplanır. Bu yaklaşım özellikle kuru madde, organik madde ve protein parçalanabilirliğinin belirlenmesinde uzun yıllardır yaygın olarak kullanılmaktadır (Foster vd., 2023; Nocek, 1988; Ørskov ve McDonald, 1979). *In situ* metodun temel uygulama basamakları ve değerlendirme mantığı Şekil 3'te şematik olarak gösterilmiştir. *In situ* metodun en önemli avantajı, yem materyalinin doğrudan rumen ortamında değerlendirilmesidir. Bu sayede yem, gerçek rumen sıvısı, doğal mikrobiyota ve rumen motilitesi ile temas eder. Bu özellik, özellikle yemlerin rumendeki parçalanma hızını ve potansiyel parçalanabilirliğini belirlemede önemli bir üstünlük sağlar. Bu nedenle *in situ* metot, ruminant rasyonlarının formülasyonunda ve özellikle protein kaynaklarının rumende yıkılabilirlik özelliklerinin değerlendirilmesinde değerli bir araç olarak kabul edilmektedir (Foster vd., 2023; Ørskov ve McDonald, 1979; van Soest, 1994).



Şekil 3. *In situ* metodun şematik gösterimi.

Bununla birlikte, *in situ* metot yalnızca güçlü yönleri olan bir yaklaşım değildir; bazı önemli sınırlılıkları da vardır. Öncelikle, bu metot rumende meydana gelen fermentasyon son ürünlerini doğrudan ölçmez. Başka bir ifadeyle, uçucu yağ asitleri, amonyak azotu, metan üretimi ya da gaz oluşumu gibi parametreler hakkında doğrudan bilgi sağlamaz. Bu nedenle *in situ* metot, rumen fermentasyonunun bütüncül değerlendirilmesinden çok, yemlerin ruminal parçalanabilirlik özelliklerinin belirlenmesi açısından daha anlamlıdır (Foster vd., 2023; Nocek, 1988; Vanzant vd., 1998). Bir diğer önemli nokta, sonuçların torba materyali, gözenek büyüklüğü, örnek öğütme derecesi, inkübasyon süresi, yıkama işlemi ve hayvana bağlı farklılıklardan etkilenebilmesidir. Bu nedenle *in situ* metodun güvenilir sonuçlar vermesi için standart uygulamaların dikkatle korunması gerekir. Aksi takdirde aynı yeme ait sonuçlar farklı çalışmalar arasında önemli ölçüde değişebilir. Özellikle torba içindeki örnek miktarı ile torba yüzey alanı arasındaki oran ve yıkama prosedürü, sonuçlar üzerinde belirgin etkiye sahip olabilmektedir (Foster vd., 2023; Nocek, 1988; Vanzant vd., 1998).

In situ metot, *in vitro* metotlarla karşılaştırıldığında daha yüksek biyolojik gerçeklik sunar; çünkü değerlendirme doğrudan rumen içinde yapılır. Buna karşılık, *in vivo* çalışmalara göre daha dar bir bilgi alanı sağlar; çünkü hayvan performansı, metabolik yanıtlar veya ürün kalitesi gibi sonuçları doğrudan yansıtmaz. Bu yönüyle *in situ* metot, özellikle yemlerin rumendeki davranışını anlamada güçlü, fakat fermentasyonun tüm çıktıları hakkında sınırlı bilgi veren bir ara yaklaşım olarak değerlendirilebilir. Uygulama alanı bakımından bakıldığında,



in situ metot özellikle ruminant yemlerinde kuru madde, organik madde ve protein parçalanabilirliği çalışmalarında öne çıkmaktadır. Bunun yanında, farklı yem işleme tekniklerinin, katkı maddelerinin veya protein koruma yöntemlerinin ruminal yıkılabilirlik üzerine etkilerinin incelenmesinde de yararlı sonuçlar vermektedir. Ancak metan oluşumu, mikrobiyal popülasyon yapısı ya da uzun süreli fermentasyon dinamikleri gibi konular söz konusu olduğunda, bu metot tek başına yeterli değildir ve çoğu zaman *in vitro* veya *in vivo* yaklaşımlarla birlikte değerlendirilmesi gerekir.

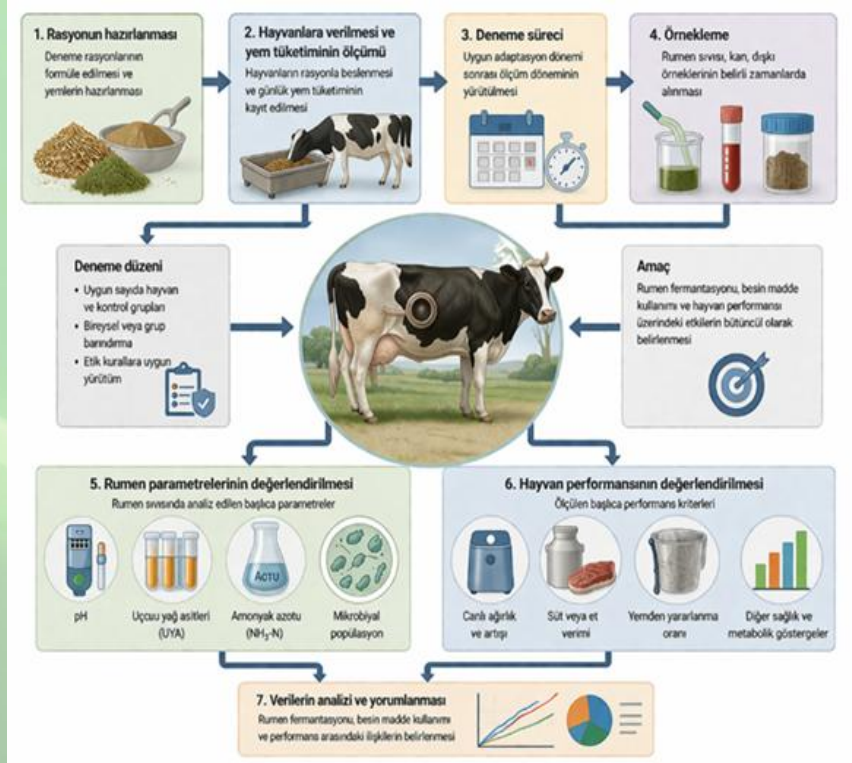
Genel olarak değerlendirildiğinde, *in situ* metot rumen fermentasyon çalışmalarında özellikle yemlerin ruminal parçalanabilirliğini ortaya koymak için güçlü ve yerleşik bir araçtır. Ancak sağladığı bilgi daha çok substrat kaybolması ve parçalanma düzeyi ile sınırlı olduğu için, rumen ekosisteminin tamamını açıklayan bir metot olarak değil, belirli araştırma sorularına yönelik özel bir yaklaşım olarak ele alınmalıdır.

***In vivo* metot**

In vivo metotlar, rumen fermentasyonu ve besin maddelerinin değerlendirilmesini doğrudan canlı hayvan üzerinde inceleyen yaklaşımlardır. Bu metotlar, ruminant besleme araştırmalarında en yüksek biyolojik gerçekliği sunması nedeniyle çoğu uygulamada referans yaklaşım olarak kabul edilmektedir (Hristov vd., 2013; Tedeschi vd., 2022). Çünkü elde edilen veriler yalnızca rumen düzeyindeki fermentatif süreçleri değil, aynı zamanda sindirim, emilim, metabolizma ve hayvan performansı gibi bütüncül yanıtları da kapsamaktadır (Van Soest, 1994; Hristov vd., 2013; Foster vd., 2023). *In vivo* metodda yem tüketiminden performans ve rumen parametrelerinin değerlendirilmesine kadar olan temel süreçler Şekil 4'te şematik olarak gösterilmiştir.

Bu metodun en önemli avantajı, elde edilen sonuçların doğrudan pratik hayvancılık koşullarına uygulanabilir olmasıdır. *In vitro* ve *in situ* metotlarda gözlenen etkiler her zaman hayvan performansına aynı şekilde yansımayaabilirken, *in vivo* çalışmalar bu boşluğu doldurarak sonuçların gerçek üretim sistemleri açısından anlamını ortaya koyar. Bu nedenle özellikle yem katkı maddelerinin etkinliği, metan azaltım stratejileri ve rasyon optimizasyonu gibi konularda çoğu uygulamada *in vivo* doğrulama ile güçlendirilir (Hristov vd., 2013; Tedeschi vd., 2022).

Bununla birlikte, *in vivo* metotların bazı önemli sınırlılıkları da bulunmaktadır. Öncelikle bu çalışmalar yüksek maliyet, uzun deneme süresi ve yoğun iş gücü gerektirir. Ayrıca hayvanlar arası biyolojik varyasyonun yüksek olması, deneysel hassasiyeti azaltabilir ve daha fazla tekrar gerektirebilir. Etik kurallar ve hayvan refahı gereklilikleri de bu çalışmaların planlanmasında önemli bir rol oynamaktadır. Bu nedenle *in vivo* metotlar, genellikle daha önce *in vitro* veya *in situ* metotlarla ön değerlendirmesi yapılmış araştırma konularını doğrulama amacıyla kullanılabilir (Foster vd., 2023; Percie du Sert vd., 2020; Tedeschi vd., 2022).



Şekil 4. *In vivo* metodun şematik gösterimi.

In vivo metotlar, sağladıkları kapsamlı veri yapısı sayesinde yalnızca rumen fermentasyonunu değil, aynı zamanda bu fermentasyonun hayvan performansına ve ürün kalitesine olan etkilerini de ortaya koymaktadır. Örneğin, bir yem katkısının rumende metan üretimini azaltması tek başına yeterli bir sonuç değildir; bu etkinin



hayvanın verim performansını nasıl etkilediği de önemlidir. Bu tür bütüncül değerlendirmeler yalnızca *in vivo* çalışmalarla mümkün olmaktadır (Hristov vd., 2013; Tedeschi vd., 2022). Genel olarak değerlendirildiğinde, *in vivo* metotlar yüksek doğruluk ve uygulama değeri sunmakla birlikte, maliyet ve zaman açısından sınırlayıcıdır. Bu nedenle rumen fermentasyon çalışmalarında genellikle *in vitro* → *in situ* → *in vivo* şeklinde ilerleyen kademeli bir araştırma yaklaşımı benimsenmektedir. Bu yaklaşım, hem kaynakların etkin kullanımını sağlar hem de elde edilen sonuçların bilimsel güvenilirliğini artırır. Tablo 1’de görüldüğü üzere, rumen fermentasyon çalışmalarında kullanılan metotlar birbirinin alternatifi olmaktan çok, farklı araştırma amaçlarına hizmet eden tamamlayıcı yaklaşımlar olarak değerlendirilmelidir. Araştırma sorusuna göre uygun metodun seçilmesi, elde edilen sonuçların güvenilirliği ve yorumlanabilirliği açısından belirleyici öneme sahiptir.

Rumen fermentasyonunun değerlendirilmesinde kullanılan metotlar, sağladıkları veri türü, biyolojik gerçeklik düzeyi ve uygulama alanları bakımından önemli farklılıklar göstermektedir. Özellikle *in vitro* metotların kesikli (batch) ve yarı-sürekli (Rusitec) sistemler olarak ayrılması, metot seçiminin araştırma amacına bağlı olarak değiştiğini açıkça ortaya koymaktadır. Bu kapsamda, söz konusu metotların temel özellikleri ile avantaj ve sınırlılıkları Tablo 1’de karşılaştırmalı olarak sunulmuştur.

Tablo 1. Rumen fermentasyon çalışmalarında kullanılan *in vitro*, *in situ* ve *in vivo* metotların karşılaştırmalı değerlendirilmesi

Karşılaştırma ölçütü	<i>İn vitro</i> metot*		<i>İn situ</i> metot	<i>İn vivo</i> metot
	Batch (<i>in vitro</i> gaz üretim sistemi)	Rusitec (yarı-sürekli <i>in vitro</i> sistem)		
Temel prensip	Yem örneklerinin rumen sıvısı ve tampon ile kesikli anaerobik inkübasyonu sonucu gaz üretiminin ölçülmesine dayanır	Rumen ortamının yarı-sürekli akış sistemi ile simüle edilerek uzun süreli fermentasyonun izlenmesine dayanır	Yem örneklerinin gözenekli torbalarda doğrudan rumende inkübasyonu ile parçalanabilirliğinin belirlenmesine dayanır	Rumen fermentasyonu ve hayvan yanıtlarının doğrudan canlı hayvan üzerinde değerlendirilmesine dayanır
Alt uygulamalar	Basınç sensörlü gaz üretim sistemleri, şırınga veya şişe inkübasyonları	Çok odacıklı fermentör sistemleri (Rusitec)	Naylon torba tekniği	Besleme denemeleri, rumen örnekleme, emisyon ölçümleri
Başlıca avantajı	Hızlı, ekonomik ve çok sayıda örneğin ön taranmasına uygun olması	Daha stabil ve gerçekçi fermentasyon ortamı ile mekanizma çalışmalarına uygun olması	Yemlerin gerçek rumen ortamında parçalanabilirliğini göstermesi	En yüksek biyolojik gerçekliği ve uygulama değerini sağlaması
Başlıca sınırlılığı	Süreklilik ve mikrobiyal adaptasyonun sınırlı olması	Kurulum ve işletim zorluğu, yüksek maliyet	Fermentasyon ürünleri ve mikrobiyal süreçler hakkında sınırlı bilgi	Maliyetli, zaman alıcı ve biyolojik varyasyona açık olması
En uygun kullanım alanı	Ön tarama, katkı maddesi değerlendirmesi, fermentasyon kinetiği	Mekanizma çalışmaları, mikrobiyal etkileşimler, metan araştırmaları	Yemlerin ruminal parçalanabilirliğinin belirlenmesi	Nihai doğrulama, performans ve saha uygulamaları
Biyolojik gerçeklik, maliyet, işgücü ve etik gereksinimi	Düşük	Orta-yüksek	Orta	Yüksek
DeneySEL kontrol düzeyi	Çok yüksek	Yüksek	Orta	Düşük-orta
Tekrarlanabilirlik	Yüksek	Orta-yüksek	Orta	Daha düşük
Deneme süresi	Kısa	Orta-uzun	Orta	Uzun
Çok sayıda örneğin taranması	Çok uygun	Sınırlı	Sınırlı	Uygun değil
Fermentasyon son ürünleri (pH, UYA, NH ₃ -N)	Uygun	Çok uygun	Sınırlı	Uygun
Gaz ve metan ölçümü	Uygun	Çok uygun	Uygun değil / çok sınırlı	En uygun
Mikrobiyal popülasyonların değerlendirilmesi	Sınırlı-uygun	Çok uygun	Sınırlı	Uygun
Yem parçalanabilirliğinin değerlendirilmesi	Dolaylı	Dolaylı-gelişmiş	En uygun	Uygun ancak zahmetli
Uzun süreli fermentasyon dinamikleri	Sınırlı	Çok uygun	Sınırlı	Uygun
Hayvan performansı ile ilişki kurulması	Kurulamaz	Kurulamaz	Sınırlı	Doğrudan kurulabilir

**In vitro* metotlar, kesikli (batch) ve yarı-sürekli (Rusitec) sistemler olarak farklı özellikler göstermekte olup, araştırma amacına bağlı olarak farklı avantajlar sunmaktadır.



Sonuç

Rumen fermentasyonunun değerlendirilmesinde kullanılan *in vitro*, *in situ* ve *in vivo* metotlar, farklı düzeylerde bilgi sağlayan ve birbirini tamamlayan yaklaşımlar olarak öne çıkmaktadır. Bu çalışmada ele alınan metotlar arasında özellikle *in vitro* sistemlerin kendi içinde kesikli (batch) ve yarı-sürekli (Rusitec) olarak ayrılması, metot seçiminin araştırma amacına bağlı olarak ne kadar kritik olduğunu ortaya koymaktadır. Batch sistemler hızlı, ekonomik ve çok sayıda örneğin ön değerlendirilmesine olanak sağlarken, Rusitec sistemi daha stabil ve uzun süreli fermentasyon süreçlerini inceleme imkânı sunarak mikrobiyal etkileşimlerin ve mekanizmaların anlaşılmasında önemli avantajlar sağlamaktadır.

In situ metot, yemlerin rumende gerçek ortamda parçalanabilirliğini ortaya koyması bakımından güçlü bir araç olmakla birlikte, fermentasyon son ürünleri ve mikrobiyal dinamikler hakkında sınırlı bilgi sağlamaktadır. Buna karşılık, *in vivo* metotlar yalnızca rumen fermentasyonunu değil, aynı zamanda hayvan performansı ve ürün kalitesi gibi bütüncül yanıtları değerlendirebilmesi nedeniyle en yüksek biyolojik gerçekliği sunmaktadır. Ancak bu metotların yüksek maliyet, uzun deneme süresi ve etik gereklilikler gibi önemli kısıtları bulunmaktadır.

Bu bağlamda, hiçbir metot tek başına rumen fermentasyon süreçlerini tam olarak açıklayabilecek yeterlilikte değildir. En güvenilir ve anlamlı sonuçlara ulaşabilmek için metotların birbirinin alternatifi olarak değil, tamamlayıcı olarak değerlendirilmesi gerekmektedir. Özellikle *in vitro* metotlarla elde edilen ön bulguların *in situ* ve *in vivo* çalışmalarla desteklenmesi, hem bilimsel doğruluğu artırmakta hem de elde edilen sonuçların pratik hayvancılık uygulamalarına aktarılabilirliğini güçlendirmektedir.

Sonuç olarak, rumen fermentasyon çalışmalarında metot seçimi, araştırma sorusunun niteliğine, beklenen çıktı türüne ve mevcut kaynaklara bağlı olarak dikkatle planlanmalıdır. Gelecekte yapılacak çalışmaların, farklı metotları entegre eden bütüncül yaklaşımlar üzerine odaklanması, rumen ekosisteminin daha doğru anlaşılmasına ve sürdürülebilir ve verimli hayvansal üretim stratejilerinin geliştirilmesine bilimsel bir temel oluşturacaktır.

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Animal products in the development of humanity

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Abstract

Regarding nutrition, the human species has undergone numerous changes throughout its evolutionary and social history, from the hunting and gathering stage, including the discovery of fire, to the application of agriculture and modern times. These changes have had a direct impact on dietary habits and behaviors, while also significantly affecting some aspects of human health and development. Although human nutritional needs are similar to those of other species, they have varied since the earliest periods of history. These needs have varied depending on many factors such as size, temperature, and physical activity, and differences have also been observed between countries and regions. Factors such as religion, recognition, and sociopolitical conditions are also among the factors that influence the formation of dietary habits. In primitive tribes, the diet of hunter-gatherer tribes consisted mostly of plant-based foods in tropical regions, while animal-based foods were prevalent in colder regions. The first revolution in human dietary habits was the "discovery" of fire. Fire allowed humans to utilize food more efficiently. Cooking facilitated the digestion of food and eliminated potential toxins. Today, the decrease in existing food resources in the face of an increasing population has led scientists to research alternative food sources. In the future, many new generation foods such as high-protein insects, genetically modified foods, and lab-grown meat and seafood will take their place on the shelves. Food security and sustainable food systems are also important issues that have been focused on recently regarding animal products, which have played an important role in the development of humanity. This study will discuss the place of animal products in the development of humanity and the importance of animal foods in healthy physical and mental development.

Keywords: Nutrition, animal products, human development, health.

İnsanlığın gelişiminde hayvansal ürünler

Özet

Beslenme ile ilgili olarak, insan türü, evrimsel ve sosyal tarihi boyunca, ateşin keşfi de dahil olmak üzere avlanma ve toplama aşamasından, tarımın uygulanmasına ve modern zamanlara kadar bir çok değişim göstermiştir. Bu değişimler beslenme alışkanlıkları ve davranışları üzerinde doğrudan bir etkiye sahip olurken, insan sağlığının ve gelişiminin bazı yönlerinde de önemli etkilere neden olmuştur. İnsanın beslenme ihtiyacı diğer türlere benzer olmasına rağmen tarihin ilk dönemlerinden itibaren farklılıklar göstermiştir. Bu ihtiyaçlar cüsse, sıcaklık, fiziksel aktivite gibi birçok faktöre bağlı olarak değişiklik gösterdiği gibi, ülkeler ve bölgeler arasında da farklılıklar gözlenmiştir. Din, tanınırlık ve sosyopolitik durumlar gibi faktörler de beslenme alışkanlıklarının oluşmasında etkili olan faktörler arasında yer almaktadır. İlkel kabilelerde avcı-toplayıcı kabilelerin beslenme alışkanlıklarının büyük çoğunluğunu tropik bölgelerde bitkisel besinler oluştururken, soğuk bölgelerde hayvansal kökenli besinler oluşturmuştur. İnsanın beslenme alışkanlıklarındaki ilk devrim, ateşin "keşfi" olmuştur. Ateş, insanların yiyecekleri daha iyi kullanabilmelerine olanak sağlamıştır. Pişirme ile besinlerin sindirimi kolaylaşmış ve gıdada bulunan olası toksinleri ortadan kaldırmıştır. Günümüzde ise artan nüfusa karşın mevcut gıda kaynaklarında meydana gelen azalma, bilim insanlarını alternatif gıda kaynakları araştırmaya sevk etmiştir. Gelecekte yüksek proteinli böcekler, genetiği değiştirilmiş gıdalar, laboratuvarlarda üretilmiş et ve deniz ürünleri gibi birçok yeni nesil gıdalar raflarda yerini alacaktır. İnsanlığın gelişiminde önemli yer tutan hayvansal gıdalar konusunda gıda güvenliği ve sürdürülebilir gıda sistemleri de son dönemlerde üzerinde durulan önemli konulardır. Bu çalışmada insanlığın gelişiminde hayvansal ürünlerin yeri, sağlıklı beden ve zihin gelişiminde hayvansal gıdaların önemi konuları dikkate alınarak tartışılacaktır.

Anahtar Kelimeler: Beslenme, hayvansal ürünler, insanlığın gelişimi, sağlık



Innovative Approaches in Agricultural Water Management

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Abstract

Agricultural water management is increasingly recognized as a critical component of sustainable food production under conditions of water scarcity and climate uncertainty. Agriculture is the largest consumer of freshwater globally, yet the sector is under growing pressure from rising temperatures, changing precipitation regimes, groundwater depletion, land degradation, and increasing competition among water-using sectors. These challenges have exposed the limitations of conventional irrigation practices and highlighted the need for more efficient, integrated, and climate-resilient management approaches. This review evaluates the current status of agricultural water management and examines innovative approaches that can enhance water-use efficiency and strengthen the sustainability of agricultural systems. The analysis covers both global and Turkish perspectives and focuses on irrigation modernization, integrated water resources management, basin-scale planning, smart irrigation systems, sensor-based applications, remote sensing, GIS, and data-driven decision support tools. In addition, the study discusses water-use efficiency, water productivity, and water footprint perspectives as key frameworks for evaluating agricultural water performance. Particular attention is given to the implications of climate change, especially increasing drought risk, variability in water availability, and the growing need for adaptation at field, scheme, and basin levels. The review shows that improving agricultural water management requires more than technological innovation alone; it also depends on effective governance, coordinated planning, strong monitoring infrastructure, and adaptive policy frameworks. It is concluded that future agricultural sustainability will depend on the successful integration of technological, institutional, and ecological approaches within a comprehensive water management framework.

Keywords: Agricultural water management; water scarcity; irrigation modernization; smart irrigation; remote sensing; climate change adaptation

Introduction

Water is one of the most strategic resources in agriculture because it directly influences crop productivity, production stability, rural livelihoods, and food security. Although agriculture is indispensable for feeding a growing global population, it is also the largest user of freshwater resources, placing the sector at the center of sustainability debates (FAO, 2025; Mancosu et al., 2015). In this context, agricultural water management is no longer only a technical issue related to irrigation delivery. It has become a multidimensional challenge involving resource allocation, ecosystem protection, technological innovation, climate adaptation, and institutional coordination (Ringler et al., 2022; Salem et al., 2022).

The global water crisis has intensified under the combined pressures of population growth, urbanization, environmental degradation, groundwater depletion, and climate change. Recent assessments indicate that agriculture accounts for more than 70 percent of global freshwater withdrawals, while land degradation, declining water quality, and climate variability are increasingly constraining agrifood systems (FAO, 2025; Ingrao et al., 2023). Climate change has further aggravated these pressures by altering precipitation regimes, increasing the frequency of droughts and heat extremes, and reducing the reliability of both surface water and groundwater resources (He & Rosa, 2023; Liu et al., 2022). As a result, future food production must increasingly rely on more efficient, resilient, and knowledge-based water management strategies rather than on additional water abstraction alone.

The Turkish context reflects many of these global challenges. National assessments emphasize that agriculture remains the dominant water-using sector in Türkiye and that growing intersectoral demand, basin-scale imbalances, groundwater pressure, and climate-related risks require more efficient and equitable water management approaches (Presidency of Strategy and Budget of the Republic of Türkiye, 2023a, 2023b; Şeren & Yildirim, 2024). At the same time, the transition from conventional irrigation systems to modern pressurized systems, together with the expansion of digital tools, remote sensing applications, and decision support systems, is creating new opportunities for improving irrigation performance and water productivity (Çetin et al., 2024; Semiz et al., 2025).



Against this background, the aim of this review is to evaluate the current status of agricultural water management and to discuss innovative approaches that can improve water-use efficiency, strengthen climate resilience, and support sustainable agricultural production. The paper focuses on five interconnected dimensions: modernization of irrigation systems, integrated water resources management and basin planning, smart irrigation and sensor-based applications, remote sensing and data-driven decision support tools, and water efficiency and water footprint perspectives. It also examines how climate change is reshaping agricultural water management and why adaptation-oriented strategies are becoming increasingly necessary.

Current Status of Agricultural Water Management

Global patterns of water use

Global agricultural development has historically depended on land and water intensification. FAO (2025) reports that most growth in agricultural production during recent decades has been achieved not through large-scale expansion of agricultural land, but through intensification supported by irrigation, improved varieties, fertilizers, and agronomic management. However, this progress has come with major environmental costs, including water scarcity, land degradation, pollution, and biodiversity loss. Agriculture currently accounts for around 72 percent of global freshwater withdrawals, highlighting the sector's dominant role in water demand and its sensitivity to water stress (FAO, 2025).

This situation is particularly critical in arid and semi-arid regions, where the mismatch between water demand and water availability is becoming more severe. Water scarcity in agriculture is shaped not only by physical shortages, but also by economic, institutional, and infrastructural constraints that limit access to and effective management of water resources (Ingrao et al., 2023). In addition, countries facing increasing water scarcity are often also exposed to food security risks because agricultural production capacity is closely linked to water availability and irrigation reliability (Christoforidou et al., 2023; Mancosu et al., 2015).

Agricultural water use in the world and in Türkiye

Globally, irrigation remains one of the most important drivers of agricultural productivity. According to FAO (2025), irrigated land produces a disproportionately high share of crop output relative to its area, confirming the strategic role of irrigation in food systems. However, future irrigation expansion is increasingly constrained by water scarcity, competition among sectors, ecological limits, and climate change (FAO, 2025; Liu et al., 2022).

In Türkiye, agricultural water use follows a similar pattern but with even greater pressure on the sector. National sources indicate that agriculture uses approximately three-quarters of total water withdrawals in the country, while industry and domestic sectors account for the remainder (Presidency of Strategy and Budget of the Republic of Türkiye, 2023a; Şeren & Yildirim, 2024). This structure makes the efficiency of agricultural water use especially important for national water security. The need for fair allocation among sectors, environmentally compatible planning, and efficient field-level use has therefore become a major policy priority (Babaoğlu et al., 2023; Presidency of Strategy and Budget of the Republic of Türkiye, 2023a).

Another major issue in Türkiye is groundwater pressure. Korkut et al. (2025) show that climate change, population growth, and unsustainable use in agriculture and other sectors have significantly affected groundwater quantity and quality, increasing interest in managed aquifer recharge and other recovery measures. This highlights that agricultural water management cannot be reduced to surface irrigation planning alone; it must also include conjunctive use, recharge strategies, and protection of subsurface water systems.

Current challenges and structural problems

The current challenges in agricultural water management are both physical and institutional. At the physical level, water scarcity, drought, salinization, groundwater depletion, and variable rainfall reduce the reliability of agricultural production (Ingrao et al., 2023; Liu et al., 2022). At the system level, inefficient conveyance, open-channel losses, inappropriate irrigation scheduling, and low field application efficiency continue to reduce effective water use in many schemes (Çetin et al., 2024; Santini et al., 2025).

At the institutional level, fragmented governance, insufficient coordination among agencies, inadequate pricing mechanisms, limited monitoring infrastructure, and weak data integration reduce the effectiveness of water planning and management (Presidency of Strategy and Budget of the Republic of Türkiye, 2023a, 2023b; Salem et al., 2022). In Türkiye, policy analyses also suggest that climate-oriented water planning has often remained reactive rather than fully proactive, which limits long-term adaptation capacity (Babaoğlu et al., 2023).

These conditions show that improving agricultural water management requires more than local technical fixes. It calls for a transition toward integrated, basin-aware, digitally supported, and climate-resilient management approaches that connect irrigation practices with governance, data, and adaptation.



Innovative Approaches in Agricultural Water Management

Transition from conventional practices to modern irrigation systems

One of the most visible dimensions of innovation in agricultural water management is the transition from conventional irrigation practices toward modern irrigation systems. Traditional surface and flood irrigation methods often involve high conveyance and application losses, limited control over water delivery, and lower irrigation efficiency, particularly in water-scarce environments (Rastogi et al., 2024; Santini et al., 2025). In response, modernization has increasingly focused on pressurized irrigation systems such as drip and sprinkler irrigation, improved conveyance infrastructure, volumetric delivery, and better on-farm control.

The benefits of modernization can be substantial. Çetin et al. (2024), in a comparative assessment of two irrigation schemes in Türkiye, found that the modern irrigation scheme showed considerably lower total water use and markedly higher irrigation efficiency, water economic productivity, and farmer income than the older surface-irrigated scheme. Likewise, Hashemi et al. (2024) showed that replacing traditional irrigation with drip systems and combining irrigation improvements with crop and water management measures can significantly reduce unsustainable blue water use and improve sustainability indicators.

However, irrigation modernization should not be treated as a universal solution. Santini et al. (2025) emphasize that while field-scale studies often report clear gains in crop yield and irrigation efficiency after the shift from flood to drip irrigation, basin-scale analyses may reveal trade-offs such as increased consumptive use, reduced return flows, and limited real water savings. This is important because it reminds us that higher efficiency at plot scale does not automatically translate into basin-scale sustainability.

A further nuance is provided by Bouimouass et al. (2022), who show that traditional gravity-fed irrigation systems in some semi-arid settings can support groundwater recharge and preserve water quality with relatively low environmental impact. Therefore, modernization should not be understood as a simple replacement of “old” by “new,” but rather as a context-specific redesign of irrigation practices in line with local hydrology, infrastructure, crop patterns, and institutional conditions.

Integrated water resources management and basin-scale planning

Technological change alone is insufficient if it is not embedded in integrated planning and governance. For this reason, integrated water resources management (IWRM) and basin-scale planning have become central approaches in contemporary water policy. Their main premise is that water should be managed not as an isolated irrigation input, but as a shared and limited resource whose allocation affects agriculture, ecosystems, domestic needs, industry, and energy systems (FAO, 2025; Salem et al., 2022).

FAO (2025) stresses that integrated land and water planning is essential where land and water are scarce and where competing societal objectives create trade-offs. Similarly, Ak and Benson (2022), in their comparative analysis of the Konya Closed Basin in Türkiye and the Kern County Subbasin in California, show that water security outcomes are closely linked to actor participation, institutional coherence, and inter-agency collaboration. Their findings suggest that effective basin management depends not only on hydrological conditions but also on how rules structure participation and cooperation.

Baccour et al. (2024) further demonstrate that integrated analysis at basin scale can help identify options that simultaneously improve stream flows, water security, biodiversity, and climate risk reduction. This is especially important under climate change, because sectoral decisions taken in isolation may shift risk from one group of users or ecosystems to another.

In Türkiye, basin-oriented water management has become increasingly prominent in national policy discourse. The *Water Management Specialization Commission Report* and the *Specialization Commission Report on the Management of Soil and Water Resources in Agriculture* emphasize the importance of river basin planning, sectoral water allocation, coordinated management institutions, and climate-sensitive planning frameworks (Presidency of Strategy and Budget of the Republic of Türkiye, 2023a, 2023b). This direction is appropriate, because the success of innovative agricultural water management depends on aligning farm-level practices with basin-scale realities and institutional coordination.

Smart irrigation systems, automation, and sensor-based irrigation management

A major shift in recent years has been the emergence of smart irrigation systems that combine sensors, automation, cloud platforms, and real-time analytics to optimize irrigation decisions. Rather than relying on fixed calendars or farmer intuition alone, these systems use soil moisture, temperature, humidity, weather, and crop condition data to determine when and how much water should be applied (Alharbi et al., 2024; Waqas et al., 2025).

Morchid et al. (2025) present a low-cost IoT-based irrigation system integrated with fuzzy logic and cloud computing, showing that such systems can reduce water losses and maintain soil moisture near a target threshold more effectively than conventional approaches. Similarly, Araújo et al. (2023) propose a cloud-based decision support methodology that integrates data acquisition, predictive analysis, and run-time reasoning. In their case study, the data-driven system reduced water consumption while increasing crop production.



The value of smart irrigation lies in its ability to make irrigation management more precise, timely, and adaptive. Soil moisture sensors improve irrigation scheduling, automation reduces operational delays, and real-time control makes it possible to respond quickly to water stress or changing climatic conditions (Waqas et al., 2025; Xing & Wang, 2024). These systems are particularly relevant under water scarcity, where over-irrigation and under-irrigation both create serious inefficiencies.

Nevertheless, the diffusion of smart irrigation faces barriers such as upfront investment costs, maintenance requirements, digital literacy limitations, interoperability problems, and unequal access to technical support (Ghosh et al., 2025; Waqas et al., 2025). Therefore, the success of smart irrigation depends not only on engineering performance but also on affordability, usability, farmer training, and institutional support.

Remote sensing, GIS, and data-driven decision support systems

Remote sensing, geographic information systems (GIS), machine learning, and decision support systems have expanded the scale and sophistication of agricultural water management. These tools allow water managers and farmers to move beyond field-by-field observation toward spatially explicit, data-driven, and predictive management.

Rabie et al. (2025) show that remote sensing, GIS, and machine learning together provide a powerful framework for monitoring soil moisture, evapotranspiration, vegetation dynamics, and surface water conditions in arid agricultural regions. Hussain et al. (2025) further highlight that remote sensing can support irrigation scheduling, crop water requirement assessment, water stress detection, and monitoring of water-related problems such as salinity and waterlogging. These tools are particularly valuable where large irrigated areas make direct ground monitoring difficult or costly.

An important operational example is provided by Singh and Das (2022), who developed a remotely sensed water-demand index using soil moisture, NDVI, and thermal information to identify water-stressed agricultural areas at high spatial resolution. Their approach shows that decision-making about irrigation advisories and water allocation can be improved using relatively accessible data without relying on overly complex drought indices.

The strategic importance of these technologies has also been recognized in Turkish policy-oriented documents. The *Specialization Commission Report on the Management of Soil and Water Resources in Agriculture* highlights the use of digital agriculture, satellite systems, and UAV-supported assessments for irrigation and drought-related applications, while the *Water Management Specialization Commission Report* notes that advanced monitoring and modeling systems are promising but depend on robust calibration data and institutional capacity (Presidency of Strategy and Budget of the Republic of Türkiye, 2023a, 2023b). In this sense, the real challenge is not only access to technology, but also the development of data infrastructures, interoperable platforms, and decision processes that can translate information into action.

Water-use efficiency, water productivity, and water footprint perspective

An important conceptual shift in agricultural water management has been the move from focusing only on land productivity toward evaluating performance per unit of water. Water-use efficiency, water productivity, and water footprint approaches reflect this change from “more crop per unit land” to “more value per unit water” (Alharbi et al., 2024; Suna et al., 2023).

Water-use efficiency generally refers to how effectively water is used in crop production, while water productivity emphasizes the quantity or value of output generated per unit of water consumed. Water footprint analysis broadens the perspective by distinguishing among blue, green, and sometimes grey water use and by linking production systems to their wider resource implications (Ingrao et al., 2023; Liu et al., 2022).

Alharbi et al. (2024) show that water-use efficiency can be improved through agronomic and technological strategies such as mulching, canopy management, deficit irrigation, and irrigation modernization. Suna et al. (2023) argue that in water-scarce conditions, the objective should shift from maximizing yield per unit land to maximizing productivity and benefit per unit water, which is exactly the logic behind deficit irrigation and related approaches. Hashemi et al. (2024) integrate crop management and water management strategies and demonstrate that combining modernization with management interventions can reduce unsustainable blue water use and improve overall system sustainability.

The climate dimension is also critical. Liu et al. (2022) show that agricultural water scarcity assessments should include both blue and green water, especially under climate change, because rainfall-dependent systems and soil moisture dynamics are central to future food production. Likewise, He and Rosa (2023) emphasize that improved green water management can significantly reduce production losses associated with climate-driven rainfall insufficiency. These studies indicate that efficiency and productivity indicators should be used alongside broader hydrological perspectives rather than as isolated performance metrics.



Climate Change and Water Management

Climate change is reshaping agricultural water management by increasing drought frequency, altering rainfall patterns, raising temperatures, and amplifying uncertainty in water supply. These changes affect not only total water availability, but also crop water requirements, irrigation timing, groundwater recharge, and the reliability of existing infrastructure (He & Rosa, 2023; Liu et al., 2022).

In rainfed systems, climate change intensifies green water scarcity by reducing the ability of rainfall regimes to meet crop requirements. He and Rosa (2023) estimate that the scale of production losses linked to green water scarcity could increase significantly under warming scenarios, but also show that adaptation measures aimed at retaining more moisture in the soil can reduce those losses. In irrigated systems, rising temperatures and more variable hydrological conditions are likely to increase crop water demand while making water resources less predictable (Liu et al., 2022).

At the regional level, Rastegaripour et al. (2024) show that climate change affects crop patterns and water management decisions by making high-water-consuming crops less attractive under scarcity conditions and by increasing the relevance of modern irrigation methods and better farmer training. In Türkiye, the pressure of climate change on water planning has also been widely recognized in national reports and policy assessments, which emphasize adaptation, early warning systems, efficient use, and more proactive planning frameworks (Babaoğlu et al., 2023; Presidency of Strategy and Budget of the Republic of Türkiye, 2023a, 2023b).

Adaptation strategies therefore need to operate at multiple scales. At the field scale, options include efficient irrigation, deficit irrigation, mulching, crop diversification, and the use of drought-tolerant or climate-smart crops (Kabato et al., 2025; Raza et al., 2025). At the system level, adaptation includes improved monitoring, basin-based planning, managed aquifer recharge, better allocation rules, and resilient infrastructure (Baccour et al., 2024; Korkut et al., 2025). The educational and policy-oriented sources considered in this review also reinforce that climate adaptation in agricultural water management cannot be limited to engineering measures; it must include planning, governance, awareness, and institutional readiness (Konukcu & Göçmen, n.d.; Öztürk, 2019).

Conclusions and Recommendations

Agricultural water management is entering a period in which conventional solutions are no longer sufficient. Growing water scarcity, climate change, ecosystem pressures, and increasing food demand require a transition from fragmented and supply-oriented approaches to integrated, efficient, and adaptive management systems. The literature reviewed in this paper shows that innovation in agricultural water management should not be understood narrowly as the adoption of new devices or irrigation hardware. Rather, it should be seen as a broader transformation involving infrastructure modernization, integrated planning, smart monitoring, data-driven decision-making, and climate-resilient governance.

The review indicates that modern irrigation systems such as drip and sprinkler irrigation can substantially improve field-level efficiency and economic performance, especially when combined with better crop and water management. However, modernization must be evaluated at multiple scales, since farm-level gains do not automatically produce basin-level sustainability. Likewise, smart irrigation, sensors, and automation offer strong potential to reduce waste and improve precision, but their success depends on affordability, technical capacity, and institutional support.

Remote sensing, GIS, machine learning, and decision support systems are increasingly central to future water management because they allow monitoring, forecasting, and allocation decisions to be made more accurately and at larger spatial scales. At the same time, water-use efficiency and water productivity should remain key performance concepts, but they should be interpreted together with blue and green water dynamics and broader water footprint considerations.

Finally, climate change makes adaptation unavoidable. This requires a combination of technical, agronomic, institutional, and policy measures, including efficient irrigation, adaptive crop planning, resilient basin governance, groundwater protection, early warning systems, and data-informed water allocation. In the Turkish context, these priorities are especially relevant because agriculture remains the dominant water-using sector and because national planning increasingly recognizes the need for efficient, coordinated, and climate-sensitive management.

In conclusion, sustainable agricultural water management in the future will depend on the ability to combine technology, governance, planning, and adaptation within a coherent framework. The most successful approaches will be those that improve water productivity, support food security, and protect water resources at the same time.

Declarations

Ethical Approval Certificate

Ethical approval was not required for this study because it is a review paper and did not involve animals, human participants, field experiments, or the collection of primary data..



Author Contribution Statement

Eray Harman: Conceptualization, literature review, investigation, data curation, formal analysis, writing—original draft preparation.

Belgin Çakmak: Conceptualization, methodology, supervision, validation, writing—review and editing.

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Conflict of Interest

The authors declare no conflict of interest.

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Long-Term Evaluation of Irrigation Water Use and Agricultural Water Productivity in a Municipality-Operated Open-Canal Scheme: Evidence from Kütahya, Türkiye

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Abstract

This study evaluated long-term irrigation water use and agricultural water productivity in the Kuruçay Pond Irrigation Scheme, a municipality-operated open-canal scheme located in Tavşanlı, Kütahya, Türkiye. Institutional records for the 2012–2025 period were used to analyse irrigated crop pattern, irrigation water delivery, crop-based irrigation water productivity, and water economic productivity. The results showed that active irrigation use remained very limited compared with the 325 ha net command area. The actually irrigated area ranged from 4.5 to 26.8 ha, corresponding to irrigation ratios of approximately 1.4%–8.2%. In contrast, irrigation water delivery per irrigated area was relatively high in several years, indicating intensive water use over the limited area actually irrigated. Crop-based physical water productivity varied considerably among crops. Tomato showed the highest values, followed by sugar beet and potato, whereas alfalfa produced lower physical water productivity despite its important share in irrigation water use. Scheme-level water economic productivity ranged from 0.30 to 1.45 US\$ m⁻³, mainly depending on crop pattern, production value, and the extent of active irrigation use. The findings indicate that water productivity in small municipality-operated open-canal schemes is shaped not only by water delivery, but also by parcel fragmentation, crop selection, canal operation, and institutional management conditions. Short-term improvements should focus on canal maintenance, flow measurement, crop-pattern guidance, and technical support, while long-term modernization should consider land consolidation followed by a closed piped irrigation network.

Keywords: Agricultural water productivity; irrigation water use; water economic productivity; open-canal irrigation; municipality-operated irrigation scheme





LED Light Effects on Soybean Phenology and Agronomics Characters for Speed Breeding

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Abstract

This study was conducted to determine the effects of different LED light spectra on the phenological development and key agronomic traits of soybean (*Glycine max*) cultivars grown under controlled environmental conditions, with a particular focus on their potential application in speed breeding protocols. The experiment was carried out in a controlled growth chamber at the Department of Field Crops, Faculty of Agriculture, Akdeniz University. Five soybean varieties; Lider, AKD 22, AKD 23, Antsoy, and Cinsoy were grown under three distinct LED light conditions. These included combinations of deep blue (DB, 445 nm), high red (HR, 660 nm), far-red (FR, 730 nm), cool white (cW, 6500 K) wavelengths, as well as a 3000K white LED treatment. In all treatments, the photo period was set to 16 hours of light and 8 hours of darkness. Day and night temperatures were maintained at 25°C and 20°C, respectively, while relative humidity was controlled at 60% during the day and 50% at night.

The parameters evaluated were germination time, days to first flowering, plant height, and number of branches. The results showed that LED light spectra significantly influenced phenological development. Notably, under the light spectrum where red light was balanced with blue and white light, soybean plants reached flowering in a shorter time which an advantageous trait for speed breeding systems aimed at rapid generation turnover. Conversely, the 3000K white LED treatment led to a longer flowering period. Varietal differences were also observed for agronomic traits. Overall, the findings indicate that optimizing LED light spectra can effectively shorten the generation time in soybean, making them highly suitable for speed breeding applications. This study provides a scientific result for future breeding programs and controlled-environment research, especially those aiming to accelerate crop improvement through manipulated light regimes.

Keywords: Soybean, Speed breeding, LED lighting, Controlled environment



Quality assessment of gari produced using a *garifrying* machine

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Abstract

Gari is a major cassava-based food product widely consumed in West Africa. In gari processing, the *garification* stage is critical because it largely determines the quality of the final product, and this operation has recently been mechanized. This study evaluated the quality characteristics of gari produced using a *garifrying* machine and compared them with gari produced using the traditional manual *garification* method. Proximate composition, chemical composition, functional properties, and sensory attributes of the gari samples were determined. Results showed significant differences ($p < 0.05$) in ash and moisture contents between the samples. The pH and total titratable acidity values ranged from 3.70–3.82 and 1.36–1.50%, respectively. Hydrogen cyanide contents ranged from 0.12–0.28 mg/kg and differed significantly ($p < 0.05$) between the processing methods, although all values were within safe limits for consumption. No significant differences ($p > 0.05$) were observed in the functional properties, including swelling index, water absorption capacity, and bulk density, which ranged from 4.16–4.23, 5.05–5.62, and 0.69–0.74 g/cm³, respectively. Sensory evaluation of dried gari, soaked gari, and eba showed that machine-produced gari had comparable sensory acceptability to traditionally processed gari, with improved appearance and overall product uniformity. The study demonstrates that *garification* can be successfully mechanized without adverse effects on gari quality, and the *garifrying* machine shows potential for efficient large-scale gari production.

Keywords: Gari, Garification, Garifrying machine, chemical composition, functional properties, sensory attributes

Introduction

Cassava *Manihot esculenta* Crantz is a starchy storage root which is a highly perishable crop and starts to deteriorate within two or three days after harvest if not processed or stored (Babarinsa and Oluwalana 2018). The major cassava food product in Africa is Gari which contribute to about 70% of utilization of cassava for local consumption (Atuna *et al.*, 2021; Ndjouenkeu *et al.*, 2021; Bechoff *et al.*, 2019; Ojiako *et al.*, 2013). Gari is a creamy-white or yellow, granular flour with a faintly fermented flavor and a slightly sour taste made from fermented, gelatinized fresh Cassava tubers. It is consumed as processes or reconstituted with hot water to give a dough-like paste called “Eba”, which is consumed with sauce (Babarinsa and Otesile, 2022). Gari is a versatile commodity because its organoleptic characteristic can be adjusted to conform to consumer specifications.

The processing steps consists of washing, peeling and grating the cassava roots, resultant pulp is put in a porous sack (polypropylene bag) and weighed down with heavy object or hydraulic press while it is fermenting. The dewatered and fermented lump of pulp is pulverized, sifted and the resulting semi dried mash is toasted in a pan (Oladipe *et al.*, 2026). Some of the drawbacks of gari processing is that it is time-consuming, it consumes large amounts of fuel in its preparation and safety and health issue which is caused by operator’s exposure to smoke and sitting posture (Sobowale *et al.*, 2017; Adegbite *et al.*, 2019; Alabi 2024). This ultimately leads to low output and unhygienic products. Therefore, there is a need for more efficient ways of preparing this product especially the *garifrying* process.

Garification (*Garifrying*) is the most important unit operation in gari production. According to Yadang *et al.*, (2021), it is a combination of simultaneous cooking and drying processes. The dehydration process in *garifrying* is not a straight forward drying process, passing of heat only will produce dried cassava granules and not gari. The product is first cooked with the moisture in it and then dehydrated. During this process, the starch within the flour undergoes partial gelatinization, a process during which the starch granule absorb water, swell and undergo structural changes (Sethi *et al.*, 2022).

Traditionally, small open pans are used for frying, but in an attempt to increase production; larger rectangular pans of up to 2.5 x 1.5m was introduced. Oduro and Clarke (1999) used microwave energy in *garification* while Obadina *et al.*, (2002) used rotary drum dryer. Despite these innovations, their adoption has been limited by high capital cost, dependence on electricity, maintenance challenges, and low commercialization potential.



The *garifrying* machine has emerged as a practical alternative to both traditional frying methods and earlier mechanized systems. It has been used satisfactorily in gari processing and can be fabricated from locally available materials. In addition, it reduces operator discomfort associated with excessive heat and smoke exposure, while improving fuel efficiency and lowering energy consumption per unit of dried gari produced.

Over the years, engineers have developed different types of gari fryers; however, most studies have focused primarily on machine performance rather than the quality attributes of the gari produced. Since product acceptability for both local consumption and export markets is often determined by specific physical and chemical properties, it is essential that any improved processing technology produces gari of acceptable quality while remaining technically feasible. Therefore, this study aimed to compare the quality characteristics of gari produced using traditional frying methods and a commonly used *garifrying* machine.

Materials and Methods

Equipment: The *garifrying* machine (Plate 1) is a simple plant that consists of a semi-circular steel plate with rotating paddles. The paddles are eccentrically located in such a manner that their motion compels the frying gari granules to move from one end of the plate to the other. Drying occurs during this period. Heat is also supplied by fire woods. The paddles are driven by an electric motor through several speed reducers and linkage arrangements. The gang of the paddles oscillates through 180°C at 40 reversals per minute (Plate 1).



Figure 1: A *Garifrying* Machine

Sample preparation: 12 months old cassava roots were harvested from the FUNAAB community. Gari was produced by the process described by Onyekwere *et al.* (2004). The cassava root of was peeled manually using a stainless-steel kitchen knife. The peeled roots were washed and grated in a 5Horze Power diesel powered grater. The grated meal was then packed in large basket and allowed to ferment for 72 hours. The fermented pulp was dewatered using hydraulic press. The pressed cake was broken into pieces with hand and sieved with a wire mesh screen. The sieved pulp was *garified* traditionally i.e using a wide shallow cast iron pot and stirred constantly over a low fire until well dried while the remaining sieved pulp was *garified* using a *garifrying* machine. It was then be cooled, packaged, labelled and sealed.

Chemical Analysis: The gari samples were analysed for ash, and moisture content according to the method as described by AOAC (2012). Estimation of hydrogen cyanide was done using silver-nitrate volumetric analysis described by Oboh *et al.*, (2002) while the pH and Total titratable acidity (TTA) as lactic acid were determined according to AOAC, (2012). Swelling index, bulk density water absorption Capacity of the sample were determined using the method described by Ukpabi and Ndimele (1990), AOAC (2012) and Ogungbenle *et al.* (2002) respectively. All analysis were in triplicate

Change in temperature during gelatinization determination: The temperature of the initial grated cassava mash is determined, also during the *garification* period, the temperature of the mash is measured at the interval of Five (5) minutes. A 360°C Thermometer was used. The temperature gradient is determined by plotting a graph of Temperature (°C) against Time (Minutes).

Sensory evaluation: The Gari samples were subjected to organoleptic evaluation using 50-man semi-trained panelist for hedonic (acceptability) test this was carried out in the Sensory laboratory, Department of Food Science and Technology, Federal University of Agriculture, Abeokuta. The tests were carried out on consumable form of gari (dried gari, soaked gari and Eba). For dried gari the color aroma, taste and granularity were evaluated, while for soaked gari, the retention capacity, taste and appearance were evaluated and for Eba the level of mouldability, taste, aroma and appearance were evaluated. In each case, the samples were rated according to a 9-point hedonic



scale of preference with ratings ranging from 1 (like extremely) and 9 (dislike extremely). The results of the evaluation were then subjected to statistical analysis.

Data analysis: Results from the analysis were subjected to analysis of variance ($p < 0.05$) using t-test. Statistical analysis was done using SPSS 17.

Results and Discussion

Ash Content: There were significant differences ($p < 0.05$) among the samples, with the gari produced using the *garifrying* machine having an ash content of $0.98 \pm 0.19\%$, while gari produced using the traditional method recorded $1.44 \pm 0.01\%$ (Table 1). These values fall within the ranges of 0.12–0.48% and 1.40–1.82% reported by Ojo and Akande (2013) and Kure *et al.* (2012), respectively. Ash content is an index of the total mineral composition of food materials and is influenced by factors such as cassava variety, soil mineral composition, agronomic practices, and processing conditions (Babarinsa and Oluwalana, 2018). During gari production, minerals may be lost through leaching into the expressed liquid during dewatering and fermentation processes. The lower ash content observed in gari produced with the machine may therefore be associated with more efficient pressing and moisture removal during processing. The difference in ash content may also suggest variations in the degree of peeling and possible contamination from processing surfaces during traditional *garification*. Traditional *garification* often involves manual handling and contact with metallic or earthen surfaces, which may contribute slightly to residual mineral matter in the final product (Awoyale *et al.*, 2018). Although ash contributes nutritionally by reflecting mineral availability, excessively high ash values may also indicate contamination with extraneous materials such as sand or fibrous residues (Chukwuneke *et al.*, 2020). Therefore, the lower ash value observed in machine-produced gari may indicate improved hygienic handling and better process control.

Table 1: Proximate composition, chemical and functional properties of the different Gari

Quality parameter	Traditional Method	Garifrying Machine Method
Ash content %	1.44 ± 0.01^a	0.98 ± 0.19^b
Moisture content%	10.96 ± 0.42^a	7.85 ± 0.23^b
pH	3.70 ± 0.00^b	3.82 ± 0.02^a
TTA%	1.50 ± 0.08^a	1.36 ± 0.16^a
HCN content mg/kg	0.12 ± 0.00^b	0.28 ± 0.01^b
Bulk density g/cm ³	0.69 ± 0.02^a	0.74 ± 0.03^a
Swelling index	4.16 ± 0.33^a	4.23 ± 0.33^a
Water absorption capacity	5.62 ± 0.11^a	5.05 ± 1.21^a

Values with different superscript letters in the same row are significantly different ($p < 0.05$)

Moisture Content: The moisture content of the gari was significantly affected ($p < 0.05$) by the *garifrying* methods. The moisture content of the traditionally processed sample ($10.96 \pm 0.42\%$) was significantly higher than that obtained for the sample from the *garifrying* machine ($7.85 \pm 0.23\%$). The generally low moisture contents observed are indicative of adequate *garifrying* and drying during *garification* and suggest good keeping quality of the products. However, the rate of drying depends on the efficiency of heat transfer and the ability of the paddles in the *garifrying* machine to ensure uniform movement and mixing of cassava mash during *garifrying*. Longer residence time and improved heat distribution may have enhanced starch gelatinization and moisture evaporation, thereby contributing to the lower moisture content recorded in the machine-processed gari. Moisture content and water activity are important determinants of the microbiological stability and shelf life of food products because high moisture levels favour microbial proliferation and biochemical deterioration (Adejumo and Raji, 2012). The lower moisture content observed in the machine-produced gari therefore suggests a potentially longer shelf stability and reduced susceptibility to mould growth and caking during storage. The moisture content obtained for the machine-produced gari also falls below the 10% maximum limit recommended by the Standard Organisation of Nigeria for safe storage of gari (Sanni *et al.*, 2005). In addition, lower moisture content enhances the crisp texture and overall sensory acceptability of gari during consumption (Abass *et al.*, 2013). The improved moisture reduction observed in the machine method may therefore provide additional technological and commercial advantages in terms of product quality and storage stability.

pH: The *garifrying* methods significantly affected ($p < 0.05$) the pH of the gari samples. Gari produced using the traditional method was more acidic, with a pH value of 3.70 ± 0.00 , compared to the sample produced using the *garifrying* machine, which had a pH of 3.82 ± 0.02 . The obtained values were within the ranges of 3.98–4.01, 3.6–4.0, 4.42–5.98, and 4.65–4.90 reported by Oduro and Clarke (1999), Oduro *et al.* (2000), Sanni *et al.* (2005), and Karim *et al.* (2016), respectively. The pH of gari is strongly influenced by the extent and duration of fermentation prior to *garifrying*. Lower pH values are generally associated with increased production of organic acids such as lactic acid, acetic acid, and other volatile acids by fermentative microorganisms, particularly lactic acid bacteria (Owuamanam *et al.*, 2010). These acids contribute to the characteristic sour taste and aroma of gari, which are



important quality attributes preferred by many consumers. The slightly higher pH observed in the machine-produced gari may indicate reduced acid retention due to more rapid *garifrying* and moisture removal during *garification*. A lower pH has also been associated with improved microbial stability and longer shelf life because acidic conditions inhibit the growth of spoilage and pathogenic microorganisms (Karim *et al.*, 2016). However, excessively low pH may adversely affect consumer acceptability in regions where mildly sour gari is preferred. The pH values obtained in this study therefore suggest that both processing methods produced microbiologically stable products within acceptable acidity ranges.

Total Titratable Acidity (TTA): The total titratable acidity (TTA) of the machine-produced sample ($1.36 \pm 0.00\%$) was not significantly different ($p > 0.05$) from the value obtained for the traditionally processed sample ($1.50 \pm 0.00\%$). The TTA values, expressed as percentage lactic acid, were within the ranges of 1.1–1.2%, 0.6–1.2%, and 1.36–1.70% reported by Oduro and Clarke (1999), Oduro *et al.* (2000), and Karim *et al.* (2016), respectively. Titratable acidity is an important quality parameter in fermented cassava products because it reflects the concentration of total organic acids produced during fermentation. Unlike pH, which measures hydrogen ion concentration, TTA provides a broader indication of the total acid load within the product. The slightly higher TTA observed in the traditionally processed gari may be attributed to slower *garifrying* conditions, which may allow greater accumulation and retention of organic acids. The TTA values obtained indicate that adequate fermentation occurred prior to *garifrying*, thereby contributing to the characteristic flavour profile and preservation qualities of gari. Organic acids generated during fermentation not only enhance sensory quality but also play a role in cyanide detoxification and microbial inhibition (Tadesse, 2026).

Hydrogen Cyanide (HCN) Content: There were significant differences ($p < 0.05$) in the hydrogen cyanide contents of the samples, with gari produced using the *garifrying* machine having a lower HCN value of 0.12 ± 0.00 mg/kg compared to 0.28 ± 0.01 mg/kg for the traditionally processed gari. These values are far below the maximum safe level of HCN recommended by the Nigerian Industrial Standard and Codex Alimentarius Commission for cassava-based foods intended for human consumption (Sanni *et al.*, 2005). The reduction in cyanide content during gari processing is primarily due to fermentation, dewatering, and *garifrying*, which facilitate enzymatic hydrolysis and volatilization of cyanogenic glucosides (Onabolu *et al.*, 2002). The lower HCN content observed in the machine-produced gari may therefore be attributed to improved heat distribution and more efficient *garifrying* conditions, which enhanced cyanide volatilization. Efficient mixing during machine *garification* may also have promoted uniform heat penetration, thereby reducing residual cyanide levels. Hydrogen cyanide is a critical safety parameter in cassava products because prolonged consumption of inadequately detoxified cassava has been associated with serious health conditions such as konzo and tropical ataxic neuropathy (Oluwole, 2015). The very low HCN values recorded in this study indicate that both processing methods were effective in detoxifying cassava mash to safe levels. Nevertheless, the lower cyanide level in the machine-produced gari suggests that mechanized *garification* may provide additional food safety advantages over traditional *garifrying* methods.

Swelling Index: Results presented in Table 1 showed that there was no significant difference ($p > 0.05$) in swelling index between the samples produced by the two *garification* methods. Gari produced using the *garifrying* machine had a slightly higher swelling index (4.23 ± 0.33) than the traditionally processed sample (4.16 ± 0.33). Swelling index describes the ability of gari granules to absorb water and swell during rehydration and is influenced by starch composition, particularly the amylose-to-amylopectin ratio (Olatunde *et al.*, 2021). Swelling index is an important functional property because it reflects the degree of starch gelatinization and the reconstitution characteristics of gari. Higher swelling values indicate weaker associative forces within starch granules, allowing greater water penetration and expansion (Sanni *et al.*, 2001). The values obtained in this study compare favourably with the Codex Alimentarius recommendation of 3.0 and with the ranges of 2.7–3.3, 3.3–4.5, and 3.0–4.5 reported by Oduro and Clarke (1999), Ojo and Akande (2013), and Karim *et al.* (2016), respectively. The slightly higher swelling index observed in machine-produced gari may be related to more uniform heat application during *garifrying*, which could have enhanced starch gelatinization. High swelling capacity is desirable because it improves the texture and mouthfeel of reconstituted gari products such as *eba* and soaked gari.

Bulk Density: The bulk density of the samples did not differ significantly ($p > 0.05$), the gari produced using the traditional method was 0.69 ± 0.02 g/cm³, while gari produced using the machine method had a slightly higher value of 0.74 ± 0.03 g/cm³. These values were higher than the ranges of 0.50–0.58 g/cm³ and 0.53–0.67 g/cm³ reported by Kure *et al.* (2012) and Karim *et al.* (2016), respectively. Bulk density is an important physical property that influences packaging, transportation, storage, and consumer perception of food products. It is affected by particle size, porosity, starch content, and degree of compaction (Barbosa-Cánovas and Juliano, 2005). The slightly higher bulk density observed in machine-produced gari may be attributed to the production of more uniformly sized particles during mechanized *garifrying* and stirring. High bulk density is advantageous because it increases packaging efficiency and reduces storage space requirements. It also affects the dispersibility and reconstitution behaviour of gari in water during preparation of *eba* (Awoyale *et al.*, 2021). The values obtained in this study suggest that gari produced using the *garifrying* machine possesses desirable handling and packaging characteristics suitable for commercial production.



Water Absorption Capacity (WAC): The water absorption capacity of the gari samples was not significantly affected ($p>0.05$) by the *garifrying* methods. The water absorption capacity of the traditionally processed gari (5.62 ± 0.11) was slightly higher than that of the machine-produced gari (5.05 ± 1.21). These values were lower than the ranges of 7.70–8.16 and 5.7–7.5 reported by Kure *et al.* (2012) and Karim *et al.* (2016), respectively. Water absorption capacity reflects the ability of starch and other hydrophilic constituents within gari to bind water through hydrogen bonding (Gaila *et al.*, 2020). Therefore, higher water absorption values indicate a greater number of available hydrophilic sites for water binding. The slightly higher water absorption capacity observed in traditionally processed gari may be associated with differences in starch granule disruption and particle structure resulting from *garifrying* conditions. Excessive heat exposure during machine *garification* may have caused partial collapse of starch granules, thereby reducing their water-binding ability. Nevertheless, the relatively high water absorption capacities observed in both samples indicate good reconstitution properties and suitability for preparation of dough-like products such as *eba*.

Change in temperature during Garification

There is no significant difference $p>0.05$ in the pattern of the change in temperature during granulation. The temperature gradient of the traditional (1.88) (Figure 2) is slightly greater than that of the machine (1.46) (Figure 3). There was a constant increase in temperature for the first five minutes. *Garification* is a combination of simultaneous cooking and drying processes, so drying takes place at the higher temperature (above 80°C) as seen in Figure 2 and 3. It should also be noted that the ratio of fire wood used in the machine as compared to the traditional method was in the ratio 5 to 1 respectively, while the mass of cassava mash of machine to traditional was in a ratio 15:1 respectively. However, in terms of the quality *garified* per batch, the *garifrying* machine would be considered more efficient in energy utilization.

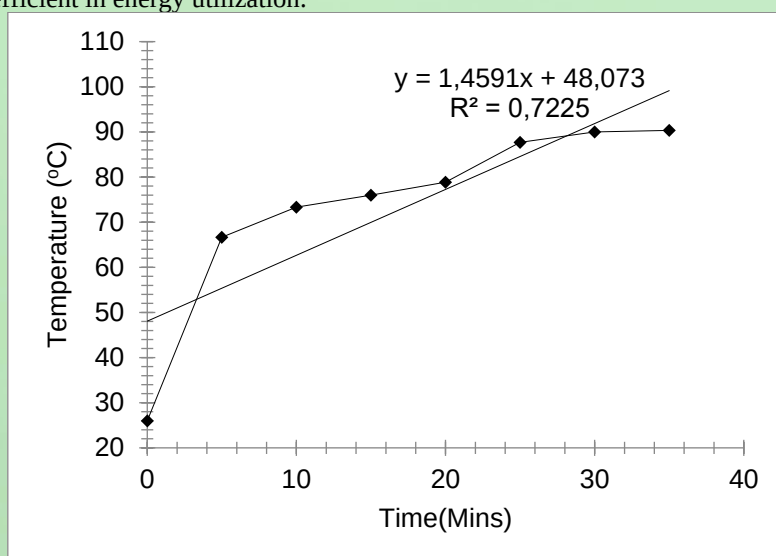


Figure 2: Change in temperature during Garification in garifrying machine

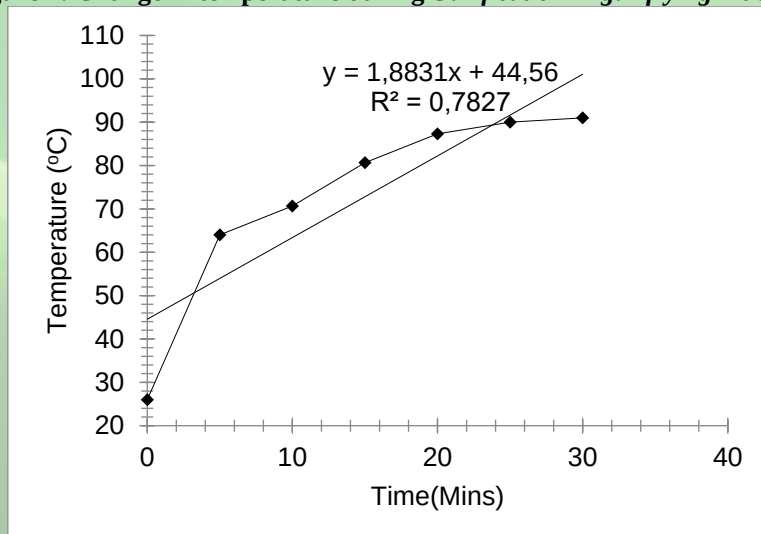


Figure 3: Change in temperature during Garification in Traditional frying method



Sensory Evaluation

Sensory Evaluation of Dried Gari: The sensory evaluation results for dried gari are presented in Table 2. Significant difference ($p < 0.05$) was observed only in appearance (colour). Gari produced using the *garifrying* machine was preferred in terms of appearance (2.11 ± 0.87) and granularity (2.49 ± 1.37) compared to the traditionally processed sample (3.20 ± 1.73 and 2.57 ± 1.65 , respectively). The improved appearance of the machine-produced gari may be attributed to the more uniform heat distribution and continuous agitation provided by the *garifrying* machine. This agrees with the lower moisture content earlier observed in the machine-produced gari, which may have contributed to a drier, crisper, and more visually appealing product. Granularity is an important sensory quality parameter because consumers generally prefer gari with uniform particle size and smooth texture (Ngoualem Kégah and Ndjouenkeu, (2023). The slightly better granularity score recorded for the machine-produced gari suggests that mechanized *garification* enhanced particle uniformity during *garifrying*. The higher bulk density earlier reported for the machine sample may also be associated with improved compactness and particle consistency. However, the aroma and taste of the traditionally processed gari (2.63 ± 1.09 and 2.11 ± 1.18 , respectively) were preferred over those of the machine-produced sample (3.09 ± 1.17 and 2.23 ± 0.91 , respectively). This preference may be due to the stronger flavour and sourness developed during traditional *garification*. Traditional *garifrying* often involves slower heating and direct contact with heated surfaces, which may favour Maillard reactions and the formation of characteristic volatile compounds responsible for the typical gari aroma. In addition, the slightly lower pH and higher titratable acidity previously observed in the traditional sample may have enhanced the characteristic sour taste preferred by consumers.

Table 2: Hedonic Rating for sensory attribute of dried gari

QUALITY PARAMETER	TRADITIONAL	MACHINE
COLOUR	3.2 ± 1.73^a	2.11 ± 0.87^b
TASTE	2.11 ± 1.18^a	2.23 ± 0.91^a
GRANULARITY	2.57 ± 1.65^a	2.49 ± 1.37^a
AROMA	2.63 ± 1.09^a	3.09 ± 1.17^a

Values with different superscript letters in the same row are significantly different ($p < 0.05$)

Sensory Evaluation of Soaked Gari: The sensory evaluation results for soaked gari are presented in Table 3. There were no significant differences ($p > 0.05$) among the sensory attributes evaluated for the soaked gari samples. The appearance of the machine-produced soaked gari (2.29 ± 1.10) was preferred over that of the traditional sample (2.65 ± 1.28). This observation may be linked to the improved colour and granularity of the machine-produced dried gari observed earlier. Uniform granule structure and lower moisture content may have enhanced the visual quality of the soaked gari. The traditionally processed gari recorded slightly better taste (2.29 ± 1.59) and retention capacity (2.38 ± 1.02) than the machine-produced sample (2.66 ± 1.39 and 2.49 ± 1.22 , respectively). Retention capacity refers to the ability of gari granules to maintain their integrity without rapid disintegration during soaking. The slightly better retention ability of the traditional sample may be related to differences in starch structure and gelatinization behaviour developed during *garifrying*. The relatively higher water absorption capacity earlier observed in the traditional sample may also have contributed to improved hydration and mouthfeel during soaking. The preference for the taste of the traditionally processed soaked gari may similarly be associated with its slightly higher acidity and stronger fermentation-derived flavour compounds.

Table 3: Hedonic Rating for sensory attribute of Soaked Gari

QUALITY PARAMETER	TRADITIONAL	MACHINE
RETENTION CAPACITY	2.38 ± 1.02^a	2.49 ± 1.22^a
TASTE	2.29 ± 1.59^a	2.66 ± 1.39^a
APPEARANCE	2.65 ± 1.28^a	2.29 ± 1.10^a

Values with different superscript letters in the same row are significantly different ($p < 0.05$)

Sensory Evaluation of Eba (Gari Stiff Paste): The sensory evaluation results for *eba* prepared from the gari samples are shown in Table 4. Significant difference ($p < 0.05$) was observed only in mouldability. *Eba* produced from traditionally processed gari had better mouldability (2.45 ± 1.02), taste (2.41 ± 1.40), and aroma (2.72 ± 1.69) than *eba* prepared from machine-produced gari (3.29 ± 1.79 , 3.11 ± 1.43 , and 2.74 ± 1.20 , respectively). Mouldability is an important quality attribute of *eba* because it determines the ease with which the paste can be shaped, handled, and consumed. The superior mouldability observed in *eba* from traditionally processed gari may be attributed to differences in starch gelatinization, swelling behaviour, and water absorption characteristics during cooking. The slightly higher water absorption capacity recorded for the traditional sample may have enhanced the cohesiveness and elasticity of the resulting paste. Similarly, the preference for the taste and aroma of *eba* from traditionally processed gari may be associated with stronger fermented and roasted flavour notes retained during traditional *garifrying*. The lower pH and higher titratable acidity earlier observed in the traditional sample may also have contributed to the characteristic sour flavour preferred by panelists. However, the colour of *eba* prepared from



machine-produced gari (2.14 ± 1.31) was preferred over that from traditional gari (2.55 ± 1.48). This further supports the earlier observation that controlled and uniform heating during mechanized *garification* improved the appearance of the final product.

Table 4: Hedonic Rating for sensory attribute of Eba (Gari paste)

QUALITY PARAMETER	TRADITIONAL	MACHINE
MOULDABILITY	2.45 ± 1.02^b	3.29 ± 1.79^a
TASTE	2.41 ± 1.4^a	3.11 ± 1.43^a
AROMA	2.72 ± 1.69^a	2.74 ± 1.20^a
APPEARANCE	2.55 ± 1.48^a	2.14 ± 1.31^a

Values with different superscript letters in the same row are significantly different ($p < 0.05$)

Conclusion

Gari produced using the *garifrying* machine compared favourably with traditionally processed gari and complied with recommended quality standards. The machine-produced gari showed improved moisture reduction, lower hydrogen cyanide content, better appearance, and acceptable sensory properties. These findings indicate that *garification* can be successfully mechanized without adversely affecting product quality. The *garifrying* machine therefore offers a promising alternative for efficient and large-scale gari production.

Declarations

Ethical Approval Certificate

The objectives and significance of the study were thoroughly explained to all participating panelist before obtaining informed consent. Participants were fully informed of the study's purpose, procedures, and implications. Each participant voluntarily agreed to take part in the sensory evaluation after understanding their right to withdraw at any stage without consequences. Informed consent was obtained verbally and in writing to ensure that participants are fully aware of their involvement.

Author Contribution Statement

Olumuyiwa Babarinsa: Conceptualization, project administration, visualization methodology, software and writing of the original draft, reviewing, and editing of the manuscript. **Ibijoke Otesile:** Data curation, formal analysis, investigation, methodology, writing the original draft, reviewing, and editing of the manuscript. **Omolola Omosebi:** reviewing, and editing of the manuscript. **Ajibola Oyinloye:** Investigation, methodology, writing, reviewing, and editing.

Conflict of Interest

The authors declare no conflict of interest

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Determination of the Effects of Saponin Extract Applied at Different Doses on the Germination of *Salvia officinalis* Seeds

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Abstract

This study was conducted to determine the effects of different doses of saponin extract on the germination performance and early seedling development of *Salvia officinalis* L. (medicinal sage) seeds. The study was carried out in the Physiology Laboratory of the Department of Horticulture, Faculty of Agriculture, Kırşehir Ahi Evran University. A total of five different treatments were evaluated in the experiment: control, hydropriming, hydropriming + saponin 1.25%, hydropriming + saponin 2.5%, and hydropriming + saponin 5%. The seeds were incubated at 25 °C for 14 days; parameters such as germination rate, germination speed, germination index, germination energy, germination rate in the first seven days, average germination time, G-50 value, root length, and root thickness were examined. The results showed that increasing saponin concentration significantly suppressed the germination and early seedling development of sage seeds. The highest germination rate (56.67%), germination speed (1.08), germination rate in the first seven days (40%), and root length (40.17 mm) were determined in the control treatment. In particular, it was found that germination was completely inhibited with the 5% saponin application. Although hydropriming applications promoted early germination in some parameters, it was determined that saponin applications had a phytotoxic effect depending on the dose increase. Correlation and principal component analysis (PCA) results showed strong relationships between germination parameters and that high saponin doses had a general suppressive effect on the biological system. In conclusion, it was evaluated that high concentrations of saponin applications inhibited germination and seedling development in *Salvia officinalis* seeds; however, saponins may have the potential to be naturally occurring biological regulators or biological herbicides.

Keywords: *Salvia officinalis*, saponin, germination, hydropriming, seedling development

Farklı Dozlarda Uygulanan Saponin Ekstraktının *Salvia Officinalis* Tohumlarının Çimlenmesinde Etkilerinin Belirlenmesi

Özet

Bu araştırma, farklı dozlarda uygulanan saponin ekstraktının *Salvia officinalis* L. (tıbbi adaçayı) tohumlarının çimlenme performansı ve erken fide gelişimi üzerine etkilerini belirlemek amacıyla yürütülmüştür. Çalışma, Kırşehir Ahi Evran Üniversitesi Ziraat Fakültesi Bahçe Bitkileri Bölümü Fizyoloji Laboratuvarında gerçekleştirilmiştir. Denemede kontrol, hidropriming, hidropriming + %1.25 saponin, hidropriming + %2.5 saponin ve hidropriming + %5 saponin olmak üzere toplam beş farklı uygulama değerlendirilmiştir. Tohumlar 25 °C'de 14 gün süreyle inkübasyona bırakılmış; çimlenme oranı, çimlenme hızı, çimlenme indeksi, çimlenme enerjisi, ilk yedi gün çimlenme oranı, ortalama çimlenme süresi, G-50 değeri, kök uzunluğu ve kök kalınlığı gibi parametreler incelenmiştir. Araştırma sonuçları, artan saponin konsantrasyonunun adaçayı tohumlarının çimlenme ve erken fide gelişimini önemli düzeyde baskıladığını göstermiştir. En yüksek çimlenme oranı (%56.67), çimlenme hızı (1.08), ilk yedi gün çimlenme oranı (%40) ve kök uzunluğu (40.17 mm) kontrol uygulamasında belirlenmiştir. Özellikle %5 saponin uygulamasında çimlenmenin tamamen inhibe olduğu tespit edilmiştir. Hidropriming uygulaması bazı parametrelerde erken çimlenmeyi teşvik etmiş olsa da saponin uygulamalarının doz artışına bağlı olarak fitotoksik etki oluşturduğu belirlenmiştir. Korelasyon ve temel bileşenler analizi (PCA) sonuçları, çimlenme parametreleri arasında güçlü ilişkiler bulunduğunu ve yüksek saponin dozlarının biyolojik sistem üzerinde genel bir baskılayıcı etki meydana getirdiğini göstermiştir. Sonuç olarak, yüksek konsantrasyondaki saponin uygulamalarının *Salvia officinalis* tohumlarında çimlenmeyi ve fide gelişimini inhibe ettiği; buna karşılık saponinlerin doğal kaynaklı biyolojik düzenleyici veya biyolojik herbisit potansiyeli taşıyabileceği değerlendirilmiştir.

Anahtar Kelimeler: *Salvia officinalis*, saponin, çimlenme, hidropriming, fide gelişimi.



Giriş

Çimlenme bir bitkinin toprağa tutunması, beslenmesi gibi hayati fonksiyonlarını yerine getirebilmesi için ilk adımdır (Boyraz ve ark., 2019). Tohumda çimlenme, bitkilerin yaşamı, bitki çeşitliliği ve ekolojik tarım açısından önemlidir (Erkul ve Ülger, 2024). Tohumların çimlenme süreci, yapısal, kimyasal ve metabolik olarak karmaşık bir etkileşimle gerçekleşmektedir. Özellikle metabolizmayı düzenleyen engelleyiciler ve uyarıcılar arasındaki denge, tohumun uygun ekolojik koşullarda filizlenmesini sağlamaktadır. Aksi bir durum tohumda çimlenmeyi doğrudan etkileyebilir (Mayer ve Poljakoff-Mayber, 1982). Uygun çevresel faktörlerin (nem, sıcaklık vb.) bir veya daha fazlası sağlanamaması durumunda çimlenme gerçekleşmeyecek ve tohumlar zorunlu uyku halinde (dormansi) kalacaktır (Bradbeer, 1988). Dormansi, tohumun embriyo yapısına veya kabuk özelliklerine göre fizyolojik, morfolojik ve fiziksel olarak sınıflandırılabilir. Tohum kabuğu, su ve oksijen alımını kısıtlayarak çimlenmeye karşı bir bariyerken absisik asit dormansiyi teşvik ederek tohumun uyku halinde kalmasını sağlamaktadır (Fu ve ark., 2024).

Tohumlara ekim öncesi uygulanan çeşitli işlemlere priming denilmektedir (Elkoca, 2007). Priming uygulaması tohumun çimlenmesi için gerekli fizyolojik değişikliklere neden olur ve bitkilerin strese karşı direncini artırmaktadır (Nile ve ark., 2022). Dormansinin etkisini kırmak, çimlenme ve embriyo çıkışının gerçekleşmesi için ekim öncesi ve hasat sonrası belirli priming uygulamaları yapılmaktadır (Jatana ve ark., 2024). Priming uygulamaları, tohumdaki depo maddelerinin parçalanmasına aracı olan enzimleri aktif hale getirerek çimlenme ve fide gelişimini olumlu etkilemektedir. (Başaran ve ark., 2019). Ekim öncesi tohuma uygulanan çok çeşitli priming uygulamalarının sonuçları, kullanılan bitki materyali, priming kaynağı ve bekletme zamanına bağlı olarak farklı etkinliklerde olmaktadır. (Çopur Doğrusöz ve ark., 2022). Priming uygulamalarından olan hidropriming uygulamalar, tohumların belirli bir süre optimum koşullarda saf suda bekletilip ardından kurutulması işlemi olarak bilinmektedir. Bu uygulamanın en belirgin özelliği ön işlem görmüş tohumların yüksek su alımıyla ilgili fide büyümesindeki artıştır. (Dastanpoor ve ark., 2013; Jisha ve ark., 2013). Literatürde tohumda hidropriming uygulamaları ile ilgili birden fazla çalışma yapılmıştır (Sharaf ve ark., 2026; Sushma ve ark., 2023; Mutetwa ve ark., 2023; Barupal ve ark., 2022, Elmasulu 2025).

Adaçayı (*Salvia spp.*) Lamiaceae familyasına ait çok yıllık bir bitkidir. *Salvia* cinsine ait yaklaşık 900 tür bulunmaktadır. Dünyada coğrafi dağılışı Amerika, Güney-Batı Asya, Kuzey Asya ve Doğu Asya kıtalarına kadar yer almaktadır. Türkiye’de 97 tür ve bu türlerin 51 adeti endemik tür olarak bilinmektedir (Will ve ark., 2017; Aytekin ve ark., 2021). *Salvia* türleri, bünyesinde içerdiği uçucu yağ ve fenolik bileşikler sayesinde, bitkisel çay olarak tüketilirken, antioksidan, antibakteriyel gibi özelliklerinden kaynaklı geleneksel tıpta ve görünüşünden dolayı peyzaj bitkisi olarak kullanılmaktadır (T.C. Tarım ve Orman Bakanlığı, 2024). Ülkemiz istatistiki verilerine bakıldığında, 2643 da üretim alanı ve 14514 ton üretim miktarına sahiptir. Başta Denizli olmak üzere Sakarya, Burdur, Muğla ve Uşak üretim yapan şehirler arasındadır (TÜİK, 2026). Tıbbi adaçayı (*Salvia officinalis* L.), dünya ticari değeri olan bir türüdür. Adaçayı tohumunun çimlenmesi için gerekli alt eşik sıcaklık değerinin 8-10 °C olduğu, aynı zamanda 25-28 °C gibi daha yüksek sıcaklıklarda daha hızlı bir çimlenme oluşumu gözlemlendiği bildirilmiştir (Sharifi-Rad ve ark., 2018). Literatüre göre adaçayı çimlenmesi için birçok çalışma yapıldığı (Mardani Korrani ve ark., 2023; Abdani Nasiri ve ark., 2018) ve çimlenmenin zor olduğu tohumlarının farklı ön işlemler ile test edilmesi gerektiği görülmektedir (Stoian ve ark., 2024).

Saponin ismini çalkalandığında köpük oluşturma özelliği gösterdiği için latince “*Sapo*” yani sabun kelimesinden almıştır. Saponinlerin tripertenik veya steroidal aglikonlu olması çalkalandığında köpük oluşmasını sağlar. Bitki bünyesinde bulunmasının yanı sıra *Echinodermata* ve *Holothuroidea* gibi bazı deniz hayvanlarının bünyesinde de saponin bulunmaktadır. Saponinlerin antifungal, antibiyotik ve antimikrobiyal etkisi olduğu bilinmektedir. Bitkiler, böcekler ile mücadele etmek üzere kendi bünyelerinde saponin sentezleyerek bir savunma oluşturdıkları bilinmektedir (Xiao ve ark., 2025). Saponinlerin biyolojik etkilerinin büyük bir kısmı hücre zarlarının geçirgenliği üzerindeki etkileriyle ilişkilendirilmiştir. Saponinlerin hemolitik etkisini aglikon kısmının hücre zarında bulunan ve çözünmeyen kompleksler oluşturdıkları fosfolipitlere olan afinitesinin sonucu olduğuna inanılmaktadır (Karakurt ve ark., 2010). Literatür araştırmaları sonucunda elde ettiğimiz bilgiler neticesinde bitki büyümesi devam ederken bünyesinde oluşan saponin miktarının doğru orantılı şekilde arttığı bildirilmektedir (Wang ve ark., 2011). Bu çalışmanın amacı *Salvia officinalis* (Adaçayı), tohumlarında farklı dozlarda uygulanan saponin ekstraktının tohumların çimlenmesi üzerindeki etkilerini değerlendirilmesidir.

Materyal ve Yöntem

Bu araştırma, Kırşehir Ahi Evran Üniversitesi Ziraat Fakültesi Bahçe Bitkileri Bölümü Fizyoloji Laboratuvarında 2026 yılında gerçekleştirilmiştir.

Materyaller

Bitkisel materyal, *Salvia officinalis* türüne ait homojen büyüklükteki tohumlar Patika Botanik firmasından temin edilerek kullanılmıştır. Uygulanan saponin maddesi *Saponaria officinalis*, Biomesi Bioagrotechnology R&D firmasından temin edilerek kullanılmıştır.



Yöntemler

Adaçayı (*Salvia officinalis*) tohumları ilk olarak saf sudan geçirilerek ön yıkama işlemi yapılmıştır. Saf sudan geçirilen tohumlar %5 NaClO (çamaşır suyu) + %95 saf su çözeltisinde 10 dk bekletilmiştir. Daha sonra 3'er kez saf su ile yıkanarak sterilizasyon işlemi gerçekleştirilmiştir. Hidropriming uygulanacak tohumlar 25 ml saf su eklenmiş beher kullanılarak 48 saat boyunca bekletilmiştir (Şekil 1.A). Hazırlanan farklı dozlarda saponin ekstraktı, 24 saat boyunca tohumlara uygulanmıştır. Bekletilen tohumlar distile sudan geçirilip daha sonra çift katmanlı kurutma kâğıdı serili petrilere yerleştirilmiştir. Tohum ekimi petri kaplarına yapılmış ve her petri kabına eşit miktarda onar adet tohum kullanılmıştır.



Şekil 1. A. Hidropriming uygulanan tohumlar, B. Çalışmada kullanılan inkübasyon cihazına ait gösterge paneli

Çalışma aşağıdaki şekilde kurgulanmıştır:

1. Kontrol (0)
2. Hidropriming (0)
3. Hidropriming + %1.25 Saponin
4. Hidropriming + %2,5 Saponin
5. Hidropriming + %5 Saponin

A

B

Her uygulama 3 tekrerrür olacak şekilde her tekrerrürde 10'ar tohum olmak üzere toplam 150 adet tohum ile deneme deseni oluşturulmuştur (Şekil 2). Petri kapları 25°C sıcaklık ayarlı inkübatörde 14 gün boyunca düzenli olarak aynı saatte kontroller edilmiştir ve çimlenen tohumlardaki radikula kısmı ölçülmüştür (Şekil 3). 2 mm uzunluğu olan tohumlar çimlenmiş kabul edilmiştir.



Şekil 2. Farklı dozlarda saponin uygulamalarının petri kaplarındaki tohumlara uygulanması 24 saat boyunca uygulanmasına ait görsel



Araştırmada yapılan çimlenme ile ilgili parametreler

1. Kök Uzunluğu: Çimlenmiş kabul edilen tohumlar kumpas yardımı ile her gün ölçülmüş ve mm cinsinden ifade edilmiştir.



Şekil 3. Çimlenen adaçayı tohumlarına ait kök uzunluğu ölçümüne ait örnek görsel.

2. Kök Kalınlığı: Çimlenmiş kabul edilen tohumlar kumpas yardımı ile 14. gün ölçülmüş ve mm cinsinde ifade edilmiştir.



Şekil 4. Çimlenen adaçayı tohumlarının kök kalınlığı ölçümüne ait örnek görsel

3. Çimlenme Oranı: Çimlenme süresi boyunca günlük gözlemler yapılmıştır. Kök uzunluğu 2 mm'yi geçtiğinde tohumların çimlendiği kabul edilmiştir. 14 günlük deneme süresinin sonunda, çimlenen tohumların toplam sayısı kaydedilerek Scott ve ark. (1984) tarafından açıklanan prosedüre göre hesaplanmış ve % olarak ifade edilmiştir.

$$\text{ÇO} = (\text{Çimlenen tohum sayısı} / \text{Toplam tohum sayısı}) \times 100$$

4. Çimlenme Gün Sayısı: Çalışmanın başladığı gün ile ilk çimlenen tohumun gözlemlendiği gün arasındaki süre olarak ifade edilmiştir.

5. Çimlenme İndeksi: Aşağıdaki denklem yardımı ile hesaplanmıştır (Wang ve ark., 2004). Gi: i. günde çimlenme yüzdesi, Tt: çimlenme testi süresinin gün sayısını ifade eder. $GI = \sum(Gi/Tt)$

6. Çimlenme Enerjisi: Karagüzel ve ark. (2004) tarafından uygulanan yöntem kullanılmıştır. Tohum ekim zamanının yarısında çimlenen tohum sayısı, toplam çimlenen tohum sayısına oranlanması ile hesaplanmıştır ve % olarak ifade edilmiştir.

7. Çimlenme Hızı: Aşağıdaki formüle göre yapılmıştır (Abazarian ve ark., 2011). N: Çimlenen tohum sayısı, T: Çimlenmenin gerçekleştiği gün sayısını ifade eder.

$$\text{CH} = N1/T1 + N2/T2 + \dots + Nn/Tn$$

8. İlk 7 Günde Çimlenen Oranı: İlk 7 gün çimlenen tohum sayısının, toplam tohum sayısına oranlanması ile belirlenmiştir ve % cinsinden ifade edilmiştir.

9. G-50: Deneme boyunca toplam çimlenen tohum sayısının %50'sine ulaşması için geçen süreyi ifade etmektedir.

10. Ortalama Çimlenme Süresi: Günlük sayımlar kullanılarak, ortalama çimlenme süresi, Ellis ve Roberts (1980) tarafından geliştirilen yöntem ile aşağıda verilen formülle hesaplanmıştır. n: D zamanında (gününde) yeni çimlenen tohum sayısı, D: Çimlenme testinin başlangıcından itibaren geçen gün sayısı, $\sum n$: Toplam (nihai) çimlenme sayısıdır.

$$\text{OÇS} = \sum (nx D) / \sum n$$



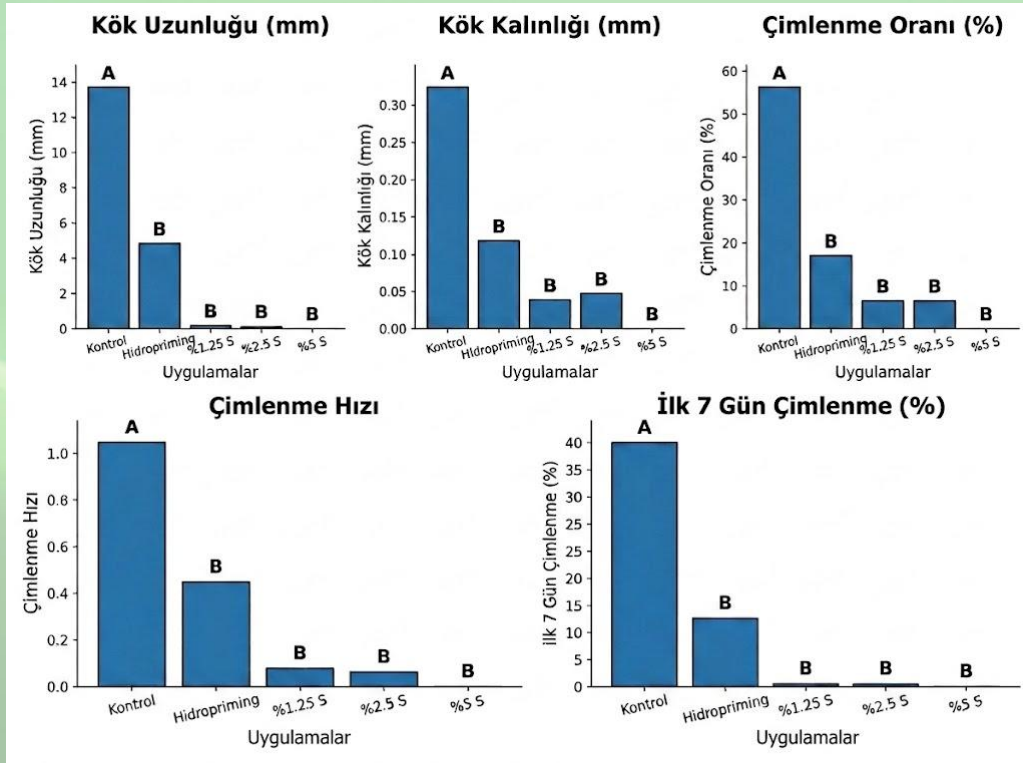
İstatistiki Analiz

Deneme 5 farklı uygulama desenine göre 3 tekerrürlü ve her tekerrürde 10 adet tohum olacak şekilde kurulmuştur. Denemede elde edilen veriler varyans analizi (ANOVA) ile analiz edildikten sonra uygulama ortalamaları arasındaki farkların önemli olup olmadığı Duncan Çoklu Karşılaştırma testi ile belirlenmiştir. Bütün istatistiki analizlerde SPSS (IBM SPSS Statistics 27.0) istatistik programında analiz edilmiştir.

Bulgular

Farklı saponin dozlarının *Salvia officinalis* tohumları üzerine kök uzunluğu, kök kalınlığı, çimlenme oranı, çimlenme hızı, çimlenme enerjisi, çimlenme indeksi, ilk 7 gün çimlenme oranı, çimlenme gün sayısı, G-50 ve ortalama gün sayısı incelenmiş ve veriler aşağıda değerlendirilmiştir.

Bu araştırmada farklı saponin dozlarının *Salvia officinalis* tohumlarının kök uzunluğu, kök kalınlığı ve çimlenme oranı üzerine etkileri incelendiğinde, uygulamalara ait ortalamalar arasında istatistiksel olarak önemli farklılıklar bulunduğu belirlenmiştir (Şekil 5). Kontrol uygulaması deneme süresince en yüksek kök uzunluğu değerlerini oluştururken, saponin konsantrasyonunun artmasına bağlı olarak kök gelişiminin önemli ölçüde baskılandığı belirlenmiştir. Denemenin ilk iki gününde hiçbir uygulamada çimlenme gerçekleşmemiştir. İlk çimlenme, hidropriming uygulamasında 3. günde gözlenmiştir. Bununla birlikte ilerleyen günlerde kontrol uygulamasının kök gelişimi bakımından belirgin şekilde öne çıktığı görülmüştür. Deneme sonunda kontrol uygulamasında kök uzunluğu 40.17 mm olarak belirlenirken, hidropriming uygulamasında bu değer 9.98 mm'ye düşmüştür. %1.25 ve %2,5 saponin uygulamalarında kök gelişimi oldukça sınırlı kalmış, %5 saponin uygulamasında ise kök gelişimi tamamen baskılanmıştır. Ortalama değerlere göre en yüksek kök uzunluğu kontrol uygulamasında (13.74 mm) belirlenmiş olup, diğer uygulamalar aynı istatistiksel grup içerisinde yer almıştır. Özellikle yüksek saponin dozlarının kök uzamasını inhibe ettiği açık şekilde ortaya konmuştur. Kök kalınlığında en yüksek değer, kontrol uygulamasında 0.33 mm olarak ölçülmüş, hidropriming ve saponin uygulamalarında ise belirgin düşüşler meydana gelmiştir. %5 saponin uygulamasında kök gelişiminin tamamen baskılanması nedeniyle kök kalınlığı değeri sıfır olarak ölçülmüştür. Çimlenme oranında en yüksek değer %56,67 ile kontrol uygulamasında elde edilmiştir. Hidropriming uygulamasında çimlenme oranı %16,67'ye düşerken, %1,25 ve %2,5 saponin uygulamalarında yalnızca %6,67 oranında çimlenme gerçekleşmiştir. %5 saponin uygulamasında ise çimlenme tamamen inhibe olmuştur. Elde edilen sonuçlar saponin dozunun artmasıyla birlikte çimlenmenin baskılandığını açık şekilde ortaya koymaktadır. Ayrıca; tohumların 48 saat gibi uzun bir süre su içinde kalmasının embriyoda hipoksiye neden olmuş olabileceği de düşünülmektedir.

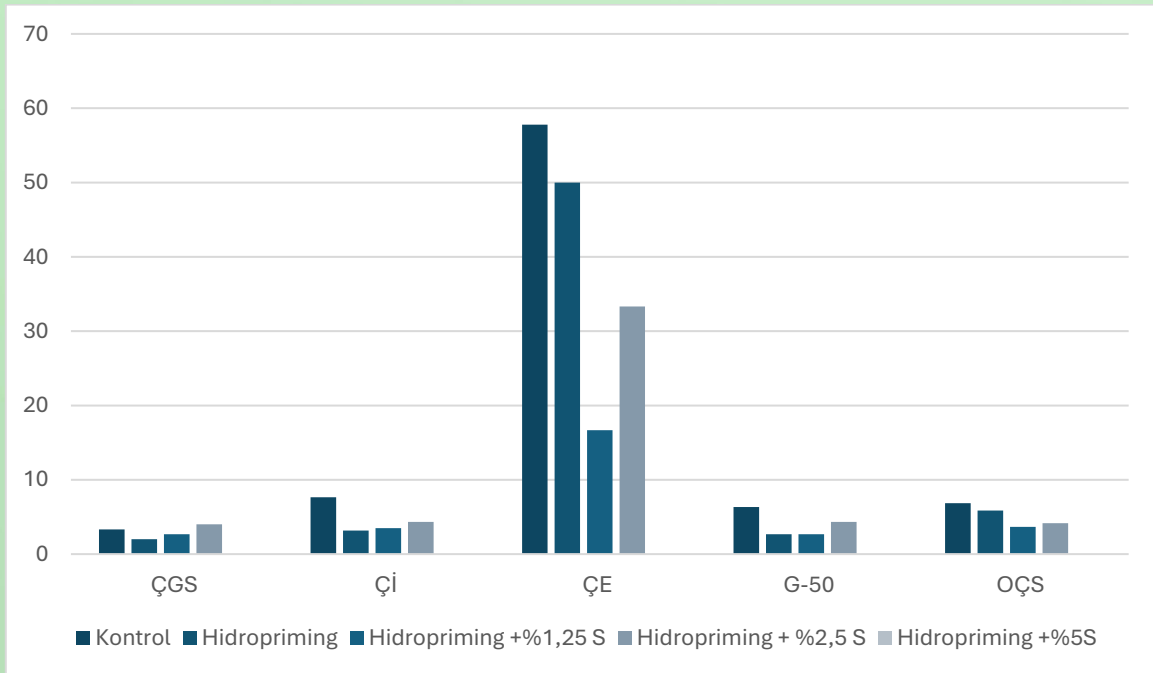


Şekil 5. Saponin uygulamalarının kök uzunluğu***, kök kalınlığı***, çimlenme oranı***, çimlenme hızı* ve ilk 7 gün çimlenme oranı* üzerine etkileri (*:0,05 ve ***:0,001 önemlilik düzeyi)



Çalışmada farklı saponin dozlarının *Salvia officinalis* tohumlarının çimlenme hızı ve ilk 7 gün çimlenme oranı bakımından uygulamalara ait ortalamalar arasında istatistiksel olarak önemli farklılık belirlenmiştir. En yüksek çimlenme hızı kontrol uygulamasında (1.08) elde edilirken, saponin konsantrasyonunun artmasıyla birlikte çimlenme hızında ciddi düşüşler meydana gelmiştir (Şekil 5). İlk 7 gün çimlenme oranı en yüksek değer kontrol uygulamasında (%40) elde edilmiş, hidropriming uygulamasında bu oran %13,33 olarak belirlenmiştir. Saponin uygulamalarında ise ilk yedi gün içerisinde çimlenme gerçekleşmemiştir.

Çimlenme gün sayısı, çimlenme enerjisi, çimlenme indeksi, G-50 ve ortalama çimlenme süresi bakımından uygulamalar arasında istatistiki farklılıklar belirlenmemiştir (Şekil 6). Bununla birlikte uygulamalar arasında sayısal farklılıklar gözlenmiştir. Çimlenme gün sayısı, hidropriming uygulamasında ilk çimlenmenin daha erken başladığı belirlenirken, yüksek saponin dozlarında çimlenmenin geciktiği görülmüştür. Çimlenme indeksi en yüksek değeri kontrol uygulamasında elde edilmiş, hidropriming uygulamasında bu değer 50 olarak belirlenmiştir. Çimlenme enerjisinde ise kontrol uygulamasında en yüksek değer (%57,78) elde edilirken, artan saponin konsantrasyonu ile çimlenme enerjisinde azalma meydana gelmiştir. G-50 bakımından yüksek saponin dozlarında çimlenme performansının düşmesi nedeniyle G-50 değerlerinde düzensiz değişimler meydana gelmiştir. Ortalama çimlenme süresi ise kontrol uygulamasında daha uzun ortalama çimlenme süresi belirlenmiştir. Bu durum kontrol uygulamasında toplam çimlenme sayısının daha yüksek olması ile ilişkilendirilebilir.



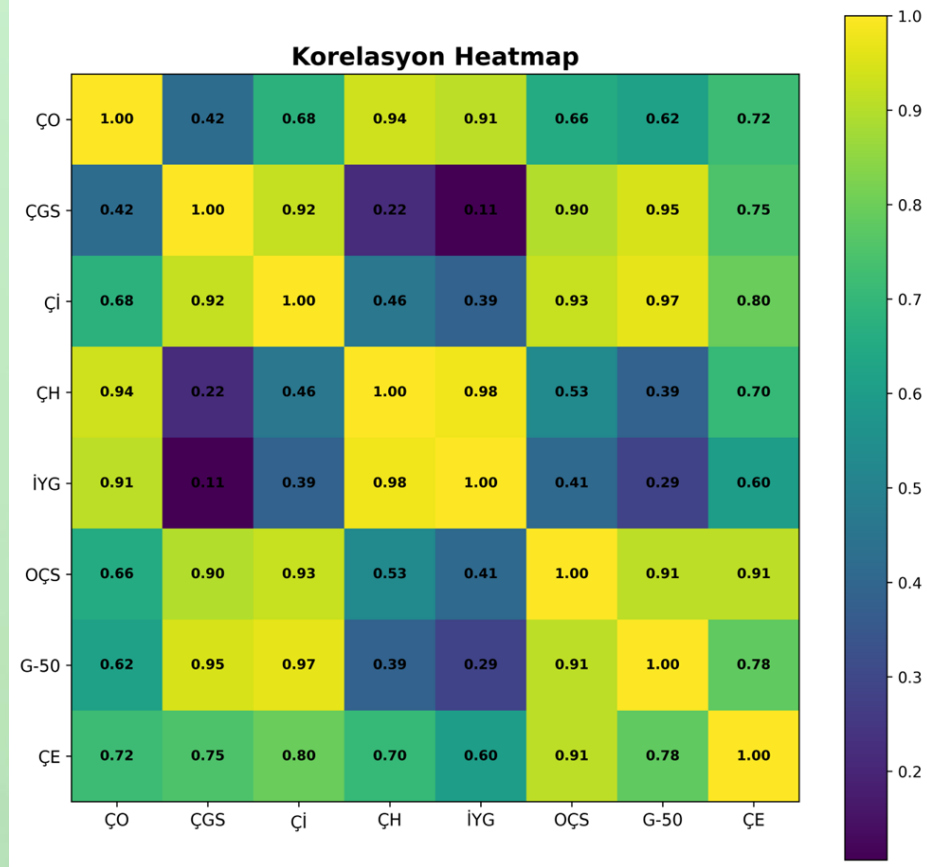
Şekil 6. Uygulamaların çimlenme gün sayısı, çimlenme indeksi, çimlenme enerjisi, G-50 ve ortalama çimlenme süresi üzerine etkileri (ÖD), ÖD: önemli değil, S: Saponin, ÇGS: Çimlenme gün sayısı, Çİ: Çimlenme indeksi, OÇS: Ortalama çimlenme süresi, ÇE: Çimlenme enerjisi

Adaçayı tohumlarında incelenen özellikler arasındaki ilişkiler değerlendirildiğinde, çimlenme oranı ile çimlenme hızı arasında çok güçlü ve pozitif bir ilişki belirlenmiştir ($r=0.936$). Benzer şekilde ilk yedi gün çimlenme oranı ile çimlenme hızı arasında da oldukça güçlü pozitif ilişki saptanmıştır ($r=0.980$). Çimlenme indeksi ile G-50 arasında yüksek düzeyde pozitif ilişki belirlenmiştir ($r=0.968$). Ayrıca ortalama çimlenme süresi ile çimlenme enerjisi arasında güçlü pozitif ilişki bulunmuştur ($r=0.911$). Elde edilen korelasyon sonuçları Şekil 7' de korelasyon haritası olarak verilmiştir. Bu haritadan da görüldüğü üzere çimlenme parametrelerinin birbirleri ile yakın ilişkili olduğunu göstermektedir.

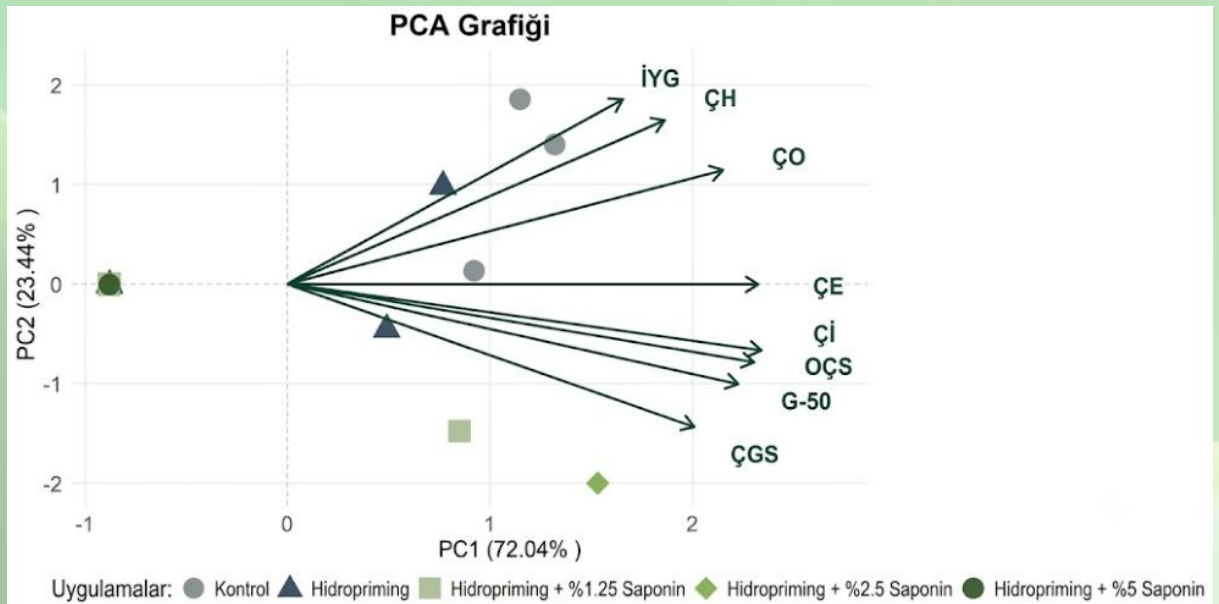
Temel Bileşen Analizi grafiğine göre, ilk iki temel bileşen toplam varyansın %95.48' ini açıklamaktadır (PC1: %72.04, PC2: %23.44). Açıklanan bu yüksek varyans oranı, oluşturulan modelin incelenen fizyolojik değişkenler arasındaki ilişkileri ve muamele farklılıklarını yüksek bir güvenilirlikle temsil ettiğini göstermektedir. Yükleme vektörleri incelendiğinde, değerlendirilen tüm çimlenme parametrelerinin (İYG, ÇH, ÇO, ÇE, Çİ, OÇS, G-50 ve ÇGS) PC1 ekseninin pozitif yönünde konumlandığı görülmektedir. Bu durum, PC1 ekseninin tohumların genel çimlenme performansı ve canlılığı ile doğrudan ilişkili olduğunu ifade etmektedir. Ayrıca, vektörler arasındaki dar açılar, söz konusu parametreler arasında güçlü bir pozitif korelasyon bulunduğunu doğrulamaktadır. Uygulamaların biplot üzerindeki skor dağılımları muamelelerin belirgin kümeler oluşturduğunu göstermektedir. Kontrol ve yalnızca hidropriming uygulanan gruplar, PC1 ve PC2'nin pozitif kadrantında yer alarak özellikle İlk Çimlenme Günü (İYG), Çimlenme Hızı (ÇH) ve Çimlenme Oranı (ÇO) parametreleriyle güçlü bir ilişki



sergilemiştir. Buna karşın, hidropriming ile kombine edilen düşük ve orta doz saponin uygulamaları (%1.25 ve %2.5), sağ alt kadranda konumlanmış ve Çimlenme İndeksi (Çİ), Ortalama Çimlenme Süresi (OÇS), G-50 ve ÇGS gibi değerleri teşvik etmiştir. Öte yandan, en yüksek saponin dozu olan %5 uygulamasının tüm imlenme vektörlerinin aksi yönünde, PC1 ekseninin güçlü negatif bölgesinde izole bir şekilde konumlandığı tespit edilmiştir. Bu bulgu, %5 saponin uygulamasının *S. officinalis* tohumları üzerinde fitotoksik bir etki yaratarak çimlenme sürecini belirgin düzeyde inhibe ettiğini açıkça ortaya koymaktadır (Şekil 8).



Şekil 7. Saponin uygulamalarının *Salvia officinalis* tohumlarındaki çimlenme parametrelerine etkilerine dair korelasyon haritası, ÇO: Çimlenme oranı, ÇGS: Çimlenme gün sayısı, Çİ: Çimlenme indeksi, ÇH: Çimlenme hızı, İYG: İlk yedi gün çimlenme oranı, OÇS: Ortalama çimlenme süresi, ÇE: Çimlenme enerjisi



Şekil 8. Temel Bileşenler Analizi



Tartışma

Saponinler, amfifilik yapıya sahip sekonder metabolitlerdir ve membran sterollerini ile etkileşime girerek hücre zarında geçirgenlik değişimlere neden olduğu bilinmektedir. Bu durum özellikle imbibisyon sürecinde su alımı, iyon dengesi ve metabolik aktivite üzerinde olumsuz etkiler oluşturabilmektedir. Literatürde saponinlerin biyolojik etkilerine ilişkin çok sayıda çalışma bulunmaktadır. Oleszek ve ark. (1998), saponinlerin genç bitki gelişimi üzerinde inhibitör etki oluşturabileceğini belirtmiştir. Kariyawasam ve ark. (2023), eucalyptus saponinlerinin bazı bitki türlerinde çimlenme ve kök gelişimini baskıladığını bildirmiştir. Marques ve ark. (2023) ise Quillaja kaynaklı saponinlerin biyolojik herbisit potansiyeli taşıdığını ifade etmiştir. Saponin ekstraktının %1.25 ve %2.5 gibi en düşük dozlarında dahi çimlenme oranının %6.67 seviyelerine gerilemiş olması, saponinlerin güçlü fitotoksik etkilerinden kaynaklanmaktadır. Triterpenoid veya steroid yapıda olan bu sekonder metabolitler, tohum hidrasyonu esnasında tohum kabuğunun lipid ve sterol bileşenleri ile etkileşime girerek membran bütünlüğünü bozmakta ve hücresel sızıntılara yol açmaktadır. Nitekim, Oleszek et al. (1998) ve Marques et al. (2023) tarafından yapılan çalışmalarda, saponinlerin tohum hidrolik enzim aktivitelerini (özellikle alfa-amilaz) bloke ettiği ve radikula hücre bölünmesini durdurarak güçlü bir herbisit etkisi gösterdiği rapor edilmiştir. Bu durum, çalışmamızda saponin dozlarının artışına paralel olarak gözlenen çimlenme baskılanmasını mekanizmik olarak açıklamaktadır.

Araştırma bulgularımızda, kontrol grubunda %56.67 olan çimlenme oranının, saf su ile gerçekleştirilen hidropripping uygulamasında keskin bir düşüş göstererek %16.67'ye gerilemesi dikkat çekicidir. Bu durum, *Salvia officinalis* tohumlarının 48 saat gibi uzun bir süre su içerisinde statik olarak bekletilmesi esnasında, tohum embriyosunun gereksinim duyduğu çözünmüş oksijene erişememesinden ve buna bağlı gelişen hipoksik (asfiktik) strese kaynaklanabilir. Literatürde, tohum kabuğu geçirgenliği ve müsila yapısı hassas olan bazı tıbbi bitki tohumlarında aşırı su alımının (imbibisyon hasarı) ve oksijensizliğin solunum enzimlerini bloke ettiği bilinmektedir (Karagüzel ve ark., 2002).

Saponinlerin membran sterollerini ile etkileşime girerek hücre membran stabilitesini bozabildiği ve bu nedenle hücre bölünmesi ile uzamasını olumsuz etkileyebildiği bildirilmektedir. Kök gelişiminin baskılanması, saponinlerin hücre zar geçirgenliği üzerindeki etkileri ile daha net ortaya çıkmaktadır. Ayrıca saponinlerin yüksek konsantrasyonlarda oksidatif stres oluşturabileceği ve kök meristem dokularında gelişimi sınırlandırabileceği ifade edilmektedir. Özellikle yüksek saponin konsantrasyonlarının kök gelişimini baskıladığı ve kök dokularında incelmeye neden olduğu belirlenmiştir. Oleszek ve ark. (1998), *Medicago sativa* kaynaklı saponinlerin genç fide gelişimi üzerinde baskılayıcı etkiler oluşturduğunu bildirmiştir. Benzer şekilde Kariyawasam ve ark. (2023), saponin içeren uygulamaların bazı türlerde çimlenme ve kök gelişimini inhibe ettiğini rapor etmiştir. Bu çalışmada elde edilen bulgular söz konusu araştırmalar ile paralellik göstermektedir.

Kök kalınlığındaki azalmanın temel nedenlerinden birinin hücre genişlemesinin baskılanması olduğu düşünülmektedir. Saponinlerin membran geçirgenliği üzerine etkileri nedeniyle su alımı ve hücre turgorunda değişiklikler oluşturabileceği bildirilmektedir. Bu durum özellikle genç kök dokularında gelişim geriliğine yol açabilmektedir. Wang ve ark. (2011), saponinlerin kök dokularında metabolik süreçler üzerinde etkili olduğunu ve özellikle genç kök dokularında gelişimsel değişikliklere neden olabileceğini bildirmiştir. Bu çalışmada elde edilen kök kalınlığı bulguları literatür ile uyum göstermektedir.

Tohum çimlenmesi sırasında imbibisyon, enzim aktivasyonu ve enerji metabolizması büyük önem taşımaktadır. Saponinlerin hücre membranı ile etkileşime girerek membran bütünlüğünü bozabilmesi, su alımı ve metabolik aktiviteyi sınırlandırabilmektedir. Bu durum çimlenme oranında ciddi düşüşlere yol açabilmektedir. Özellikle yüksek doz saponin uygulamalarının embriyo gelişimi ve su alımı üzerinde olumsuz etkiler oluşturabileceği düşünülmektedir. Marques ve ark. (2023), *Quillaja* saponinlerinin yüksek konsantrasyonlarda fitotoksik etki oluşturduğunu ve çimlenmeyi baskıladığını bildirmiştir. Kariyawasam ve ark. (2023) ise *Eucalyptus* den elde edilen saponin uygulamalarının bazı bitki türlerinde çimlenme oranını önemli düzeyde azaldığını ifade etmiştir. Bu çalışmadan elde edilen çimlenme oranı sonuçları ile araştırmalar benzerlik göstermektedir.

Çimlenme zamanındaki değişimler, tohum metabolizması ve su alımı ile doğrudan ilişkilidir. Özellikle düşük doz uygulamalarda priming etkisinin erken çimlenmeyi teşvik ettiği, buna karşın yüksek saponin konsantrasyonlarının embriyo aktivitesini baskılayarak çimlenmeyi geciktirdiği düşünülmektedir. Elkoca (2007), priming uygulamalarının tohumlarda metabolik aktivasyonu hızlandırarak erken çimlenmeyi teşvik ettiğini bildirmiştir. Ancak bu çalışmada saponin konsantrasyonunun artması priming etkisini baskılamış görülmektedir.

Çimlenme indeksiindeki düşüşler, toplam çimlenme oranındaki azalma ve çimlenme hızındaki gerileme ile ilişkilidir. Özellikle yüksek saponin dozlarında düşük çimlenme performansı nedeniyle indeks değerleri düşmüştür. Ellis ve Roberts (1980), çimlenme indeksinin tohum vigorunun önemli göstergelerinden biri olduğunu belirtmiştir. Bu çalışmada saponin uygulamalarının vigor üzerinde baskılayıcı etki oluşturduğu görülmektedir.

Çimlenme enerjisindeki düşüş, tohumların erken dönemde çimlenme yeteneğinin zayıfladığını göstermektedir. Bu durum yüksek saponin konsantrasyonlarının embriyo canlılığı ve metabolik aktivite üzerinde baskılayıcı etki oluşturabileceğini düşündürmektedir. Nitekim erken dönemde çimlenme performansının düşmesi, tohum vigorunun azalması ile doğrudan ilişkilidir. Karagüzel ve ark. (2002), yüksek vigorlu tohumların daha yüksek



çimlenme enerjisine sahip olduğunu bildirmiştir. Boyraz ve ark. (2019), yüksek vigorlu tohumların daha hızlı ve homojen çimlenme gösterdiğini ifade etmiştir. Bu çalışmada özellikle yüksek saponin dozlarının vigor kaybına neden olduğu değerlendirilmektedir.

Çimlenme hızındaki azalma, saponinlerin metabolik süreçleri baskılaması ile ilişkilendirilebilir. Özellikle su alımı, enzim aktivasyonu ve enerji üretim süreçlerinin olumsuz etkilenmesi çimlenmenin yavaşlamasına neden olmuş olabilir. Abazarian ve ark. (2011), stres koşullarının çimlenme hızını önemli ölçüde azaltabileceğini belirtmiştir. Bu çalışmada saponin uygulamalarının özellikle yüksek dozlarda stres faktörü gibi davrandığı değerlendirilmektedir.

G-50 parametresi çimlenme hızının önemli göstergelerinden biri olarak kabul edilmektedir. Düşük G-50 değerleri daha hızlı çimlenmeyi ifade etmektedir. Ancak bu çalışmada düşük çimlenme oranları nedeniyle bazı uygulamalarda parametrenin biyolojik olarak sınırlı değerlendirme sunduğu düşünülmektedir.

Ellis ve Roberts (1980), ortalama çimlenme süresinin çimlenme senkronizasyonunun önemli göstergelerinden biri olduğunu bildirmiştir. Bu çalışmada düşük çimlenme oranı gösteren uygulamalarda ortalama çimlenme süresinin biyolojik olarak sınırlı yorumlanabileceği değerlendirilmektedir.

Bu çalışmada yapılan hidropriming uygulaması, tohumun hızlı su alımı (imbibisyon) ve metabolik aktivasyon aşamalarını tetikleyerek çimlenme için gerekli enzimlerin sentezlenmesine olanak tanır. Elde ettiğimiz sonuçlarda hidropriming uygulamasının çimlenme süresini kısalttığı ve senkronizasyonu artırdığı (G-50 ve Çimlenme Gün Sayısı parametrelerindeki iyileşmeler) görülmektedir. Bu bulgu, *Salvia officinalis* tohumlarına uygulanan hidropriming işleminin nihai çimlenme yüzdesini (FGP) ve çimlenme indeksini (GI) Kontrol grubuna kıyasla önemli ölçüde artırdığını bildiren önceki araştırmalarla doğrudan örtüşmektedir (Dastanpoor vd., 2013; Elmasulu, 2025).

Temel bileşen analizinde, incelenen çimlenme parametrelerinin *S. officinalis* tohumlarında canlılık ve genel performansı belirlemede birbirleriyle yüksek oranda tutarlı belirteçler olduğunu kanıtlamaktadır. Optimum dozlardaki saponin uygulamalarının, hidropriming ile kombine edildiğinde tohum uyanmasını ve çimlenme senkronizasyonunu destekleyici fizyolojik bir etki yaratabildiğine işaret etmektedir. Buna karşın, artan saponin dozunun (%5) tüm çimlenme parametrelerini şiddetli bir biçimde baskılayarak modelde tamamen izole bir noktaya yerleşmesi, bu seviyedeki uygulamanın teşvik edici özelliğini yitirerek tohumlar üzerinde doğrudan fitotoksik ve inhibitör etki yaptığı açıkça ortaya koyulmuştur.

Sonuç

Araştırmada; farklı dozlarda uygulanan saponin ekstraktının *Salvia officinalis* tohumlarının çimlenme ve erken fide gelişimi üzerine etkileri araştırılmıştır. Genel olarak değerlendirildiğinde, saponin konsantrasyonunun artması ile çimlenme performansının önemli ölçüde baskılandığı belirlenmiştir. Özellikle kontrol uygulamasının tüm parametrelerde en yüksek performansı göstermesi dikkat çekici bulunmuştur. Hidropriming uygulamasının dahi kontrol uygulamasının gerisinde kalması, adaçayı tohumlarının su alımına karşı hassas yapıda olabileceğini düşündürmektedir. Bunun yanında saponin uygulamalarının özellikle yüksek dozlarda belirgin fitotoksik etki oluşturduğu görülmüştür. En yüksek saponin konsantrasyonu (%5) belirli bir eşiği (%5) aştığında ise uyarıcı etki yerini toksik ve allelopatik bir baskılamaya bırakmaktadır. Elde edilen bulgular, saponinin düşük dozları da dahil olmak üzere denenilen tüm konsantrasyonların kontrol grubuna kıyasla çimlenme yüzdesini, kök uzunluğunu ve fide gelişimini şiddetli derecede baskıladığını göstermiştir. Bulgularımızda kontrole göre herhangi bir teşvik edici (stimülör) etki saptanmadığından, saponin ekstraktının bu tohumlar üzerinde bimodal bir hormesis etkisinden ziyade, doz bağımlı doğrusal bir fitotoksik ve inhibitör etki mekanizmasına sahip olduğu sonucuna varılmıştır. Saponinlerin özellikle kök morfolojisi ve meristemik aktivite üzerindeki bu güçlü inhibisyon potansiyeli, onların doğal bitki koruma preparatları ve biyo-herbisit geliştirme çalışmalarında değerlendirilebileceğini göstermektedir (Wagner ve ark., 2021).

Bu çalışmanın en önemli bulgusu, saponin uygulamalarının yalnızca çimlenme oranını değil, çimlenme sisteminin tamamını doz-bağımlı şekilde baskıladığını ortaya koymasındır. Artan saponin konsantrasyonları ile birlikte kök uzunluğu, kök kalınlığı, çimlenme hızı, ilk yedi gün çimlenme performansı ve genel vigor parametrelerinde belirgin düşüşler meydana gelmiştir. Çalışmanın bir diğer önemli yönü ise saponinlerin doğal kaynaklı çimlenme düzenleyici veya biyolojik baskılayıcı ajan potansiyeline ilişkin veri sunmasıdır. Günümüzde sentetik herbisit kullanımının çevresel etkileri ve direnç problemleri nedeniyle doğal bileşiklerin allelopatik ve fitotoksik etkileri büyük önem taşımaktadır. Bu çalışmada özellikle yüksek saponin dozlarının çimlenmeyi tamamen inhibe etmesi, saponinlerin doğal biyolojik herbisit veya büyüme düzenleyici adayları olarak değerlendirilebileceğini düşündürmektedir. Bununla birlikte farklı bitki türleri, farklı saponin kaynakları ve daha düşük konsantrasyonlar ile yapılacak ileri çalışmaların konuya önemli katkılar sağlayacağı düşünülmektedir.



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Categorical Evaluation of Consumption Preferences for Dry Pollen Substitute Candidates in Honey Bees

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Abstract

Honey bees are essential pollinators, and pollen is their main nutritional source. When pollen becomes scarce, dry substitutes are required. In this study, 27 materials were tested: bee pollen, beetroot, spinach, pumpkin seeds; red and green lentil, corn, soybean, oat, buckwheat, wheat germ, breadcrumbs, psyllium husk; chia, sesame, roasted chickpea, black cumin, oleaster; whey protein, BCAAs, creatine; cumin, red pepper, black pepper, thyme, turmeric, and ginger. These were evaluated for consumption preferences. Red lentil flour, consumed even more than natural pollen, was the strongest candidate. Green lentil, corn, oat, soybean, and wheat germ flours received moderate interest, while breadcrumbs and buckwheat flour showed low consumption. Most ground vegetables, seeds, mixtures, sports supplements, and spices were minimally preferred or rejected. Whey protein's ultra-fine particles created excessive dust during wing fanning, discouraging bees from interacting with it. Overall, the results show that physical traits such as particle size and dustiness, in addition to nutritional composition, strongly influence product acceptance, and that lentil-based materials hold high potential for developing dry pollen substitutes.

Keywords: Autumn, bees, foraging, dry feeding, dearth period

Bal Arılarında Kuru Polen İkamesi Adaylarının Tüketim Tercihlerinin Kategorik Olarak Değerlendirilmesi

Özet

Bal arıları, ekosistemlerin devamlılığı açısından kritik öneme sahip tozlayıcılardır ve polen, koloni sağlığı için temel besin kaynağıdır; ancak mevsimsel polen kıtlığı dönemlerinde kuru polen ikamesine ihtiyaç duyulmaktadır. Bu çalışmada, arılara sunulan 27 kuru materyalden öğütülmüş ürünler (arı poleni, pancar, ıspanak, kabak çekirdeği), unlar (kırmızı ve yeşil mercimek, mısır, soya, yulaf, karabuğday, buğday rüşeymi, galeta, Psyllium husk), öğütülmüş tohumlar (chia, susam, leblebi, çörek otu, ığde), sporcu ürünleri/protein kaynakları (whey protein, BCAA, kreatin) ve baharatlar (kimyon, kırmızı biber, kara biber, kekik, zerdeçal, zencefil) olarak sınıflandırılarak tüketim tercihleri değerlendirilmiştir. Bulgular, özellikle kırmızı mercimek ununun doğal polenden dahi yüksek oranda tüketilerek en güçlü aday olduğunu, yeşil mercimek, mısır, yulaf, soya ve buğday rüşeymi unlarının orta düzeyde ilgi gördüğünü, galeta ve karabuğday ununun ise düşük düzeyde tüketildiğini göstermiştir. Öğütülmüş sebze, tohum ve karışımların büyük kısmı ile sporcu ürünleri ve baharatlar arılar tarafından ya çok az tercih edilmiş ya da tamamen reddedilmiştir; özellikle whey proteinin ultra ince partikül yapısı, kanat çırpışıyla aşırı toz kalkmasına yol açarak arıları üründen uzaklaştırmıştır. Sonuçlar, besinsel içeriğin yanı sıra partikül boyutu ve tozuma gibi fiziksel özelliklerin arı kabulünde belirleyici olduğunu ve özellikle mercimek türevlerinin kuru polen ikamesi formülasyonları için yüksek potansiyele sahip olduğunu ortaya koymaktadır.

Anahtar Kelimeler: Sonbahar, arılar, tarlacılık, kuru besleme, kuru periyot

Introduction

Protein nutrition is crucial for the growth, development, and productivity of honey bee colonies. Of all the nutritional resources collected by worker bees, pollen is the primary source of proteins, lipids, vitamins, minerals, and other essential nutrients required for brood rearing and physiological maintenance. Adequate pollen intake is directly linked to colony population growth, improved foraging performance, enhanced disease resistance, and increased honey production. However, the availability of natural pollen is often affected by seasonal fluctuations, climatic conditions, and habitat characteristics, resulting in periods when colonies experience nutritional stress (Skubida et al., 2008; Zahra and Talal, 2008).



Insufficient pollen availability can adversely affect colony performance by reducing brood production, shortening worker longevity, and weakening overall colony strength. Such nutritional deficiencies may also increase colony susceptibility to pathogens, parasites, pesticide exposure, and other environmental stressors. As a result, the development of alternative protein sources capable of supporting colony requirements during periods of pollen shortage has attracted considerable attention from researchers and beekeepers alike (Wilson et al., 2005; Macdonald et al., 2002).

Although natural pollen remains the most suitable protein source for honey bees, its collection, storage, and commercial use present several challenges. Large-scale pollen harvesting is labour-intensive and costly, and collected pollen may contain pesticide residues, environmental contaminants, or disease-causing microorganisms. These limitations have encouraged efforts to formulate artificial diets that can partially or completely replace natural pollen when floral resources are inadequate (Pande and Karnatak, 2014; Kumar and Agrawal, 2014). Various ingredients, including soybean flour, brewer's yeast, skimmed milk powder, spirulina, cereal products, and legume-derived flours, have been incorporated into pollen substitute formulations with varying degrees of success (Herbert et al., 1980; Saffari et al., 2010).

The practical value of a pollen substitute depends not only on its nutritional composition but also on its acceptance by bees. A diet containing balanced nutrients may fail to provide benefits if worker bees do not readily consume it. Therefore, feed palatability and consumption preference are among the most important criteria in evaluating the suitability of pollen substitute formulations (Baumont, 1995; Provenza, 1995). Understanding dietary preferences can help identify ingredients that are more attractive to honey bees and improve the effectiveness of supplemental feeding programmes.

In modern beekeeping, supplemental feeding has become an essential management practice, particularly during periods of nectar and pollen scarcity. While migratory beekeeping is often used to alleviate forage shortages, transportation costs, colony stress, and environmental uncertainties frequently limit its effectiveness. Consequently, artificial diets have become a practical and economical approach to maintaining colony development and productivity throughout the year (Saffari et al., 2006; Sharma and Gupta, 2006). Previous studies have mainly focused on evaluating the nutritional performance of individual or a limited number of pollen substitute formulations. However, comprehensive comparisons involving a wide range of candidate ingredients remain relatively rare.

Therefore, the present study aimed to systematically evaluate the consumption preferences of honey bees for 27 different dry pollen substitute candidates and to identify the most acceptable formulations that may serve as promising alternatives for supplemental protein feeding in apicultural practices.

Materials and Methods

Study Area and Experimental Period

The study was conducted in 2025 at the Beekeeping Research and Application Unit of the Department of Animal Science, Muş province/Türkiye. Experimental observations took place during the pollen dearth period (October-November) under natural environmental conditions. Honey bee colonies (*Apis mellifera* L.) maintained in the research apiary were used to evaluate the consumption preferences for candidate dry pollen substitute materials.

Experimental Colonies

A total of 100 colonies with comparable population strength, brood area, queen age, and general health status were selected for the experiment. Before the study, all colonies were inspected to ensure the absence of major disease symptoms and abnormal conditions. Standard colony management practices were applied throughout the experimental period.

Test Materials

Twenty-seven dry pollen substitute candidates representing various plant-derived and protein-rich ingredients were evaluated. The tested materials included bee pollen (control), sugar beet, spinach, pumpkin seed, red lentil flour, green lentil flour, corn flour, soybean flour, oat flour, buckwheat flour, wheat germ, breadcrumbs, plantago ovata powder, chia seed, sesame seed, roasted chickpea flour, black cumin seed, whey protein, branched-chain amino acids (BCAA), creatine monohydrate, cumin, red pepper, and other candidate ingredients. The nutritional characteristics of the tested materials are presented in Table 1.

Feeding and Preference Assessment

All test materials were offered to colonies in dry form under identical field conditions. Equal quantities of each candidate ingredient were simultaneously presented to the colonies in separate feeding containers placed within the apiary. To minimise positional bias, the locations of the feeding containers were periodically rotated during the experiment. Consumption preference was assessed by visually monitoring bee visitation intensity and



measuring the amount of material removed from each feeding container. Observations were conducted at regular intervals throughout the experimental period.

Data Collection and Evaluation

The findings were used to identify dry pollen substitute candidates most readily accepted by honey bees and therefore potentially suitable for use in supplemental feeding programmes.

Table 1. Nutritional composition of bee pollen and candidate dry pollen substitute ingredients used in the study

Product	Crude Protein (%)	Crude Fat (%)	Carbohydrate (%)	Fiber (%)
Bee pollen	22.0	7.5	44.0	13.0
Beetroot powder	20.7	<1.0	70.0	23.0
Spinach	32.0	4.5	40.0	24.0
Pumpkin seed	21.0	51.0	20.0	–
Red lentil flour	24.5	0.91	47.7	15.6
Green lentil flour	23.4	0.96	38.7	24.0
Corn flour	7.8	2.6	76.9	3.7
Soybean flour	52.0	0.96	36.0	3.32
Oat flour	12.6	5.5	60.9	6.7
Buckwheat flour	12.65	3.15	70.98	9.72
Wheat germ	31.0	10.0	49.0	10.0
Breadcrumbs	11.12	1.67	70.90	2.96
Plantago ovata powder	11.8	0.3	62.8	25.5
Chia seed	22.1	33.3	3.5	32.8
Sesame seed	2.55	8.06	3.18	1.4
Roasted chickpea flour	20.0	7.0	56.0	17.0
Turmeric	48.0	7.0	20.0	22.0
Whey protein	72.7	5.5	8.8	–
BCAA (Leucine, Isoleucine, Valine)	4:1:1	–	–	–
Creatine monohydrate	5000 mg per serving (Creatine: 793.65 mg)			
Cumin	20.0	16.9	46.9	1.1
Red pepper	14.8	1.1	51.5	2.6

Results and Discussion

Marked differences in consumption preferences were observed among the 27 dry substitute candidates tested. Overall, honey bees showed clear selectivity depending on material type and physical characteristics.

Of all the materials tested, red lentil flour had the highest level of acceptance and consumption, exceeding even that of natural bee pollen. This result indicates a strong preference for red lentil-based formulations compared to other substitutes. Green lentil, corn, oat, soybean, and wheat germ flours showed moderate consumption and were consistently accepted by the colonies, although at lower rates than red lentil flour.

In contrast, buckwheat flour and breadcrumbs were less accepted, with noticeably reduced consumption compared to the more favourable flours. Most ground vegetable materials (beetroot and spinach), ground seeds (chia, sesame, roasted chickpea, black cumin, oleaster), sports supplements (whey protein, BCAAs, creatine), and spice-based materials (cumin, red pepper, black pepper, thyme, turmeric, ginger) were either minimally consumed or completely rejected by the honey bees.

A notable behavioural response was observed in the whey protein treatment, where its ultra-fine particle structure caused significant dust dispersion during bee wing fanning activity. This appeared to reduce direct contact and feeding activity, further contributing to its low acceptance.

Bee density across the experimental colonies is presented in Table 2, which shows that colony-level bee distribution remained consistent during the feeding period, supporting the conclusion that observed differences in consumption were primarily related to material preference rather than variations in colony strength.

Similar findings have been reported in previous studies (Güneşdoğdu, 2025a). Güneşdoğdu and Buluş (2025b) also highlighted comparable outcomes regarding dry feeding systems and bee acceptance patterns. In addition, Pal and Mall (2026) reported that soybean-based flour and pollen-enriched dry diets were among the most preferred formulations by honey bees, supporting the present findings on the importance of plant-based protein sources in dry diet acceptance.



Table 2. Honey bee density under dry substitute feeding conditions



Conclusion

This study showed that honey bee acceptance of dry pollen substitute materials varies considerably among different sources. Red lentil flour was the most preferred material, followed by moderate acceptance of green lentil, corn, oat, soybean, and wheat germ flours, while most other plant-based powders, seeds, sports supplements, and spices were poorly accepted or rejected. Further studies conducted in different geographic locations and under varying environmental conditions are recommended to validate these findings. In addition, testing different formulations and combinations of the most promising materials, particularly lentil-based products, may contribute to the development of more effective dry pollen substitute diets for honey bee colonies.



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Plant Parasitic Nematodes In Storage Areas

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Abstract

Plant parasitic nematodes are soil-borne pathogens that cause yield loss and decreased tuber quality in potato tubers in storage areas. Nematodes, carried to storage with potato tubers harvested from infected areas, continue to reproduce in an unsuitable storage environment, causing economic losses in tubers. The most important plant parasitic nematodes found in potato storage areas can be listed as: Potato Rot nematode (*Ditylenchus destructor*), Root-knot nematodes (*Meloidogyne* spp.), and Cyst nematodes (*Globodera* spp). *Meloidogyne chitwoodi* causes yield loss and a decrease in chip quality, especially in industrial varieties. The Potato Golden Cyst nematode, *Globodera rostochiensis*, which is under quarantine, causes yield loss and can spread to different regions with soil particles on seed potatoes. *G. rostochiensis*, thanks to its resistant cyst form, can survive in the soil for 10-30 years, continuing to feed on plants of the *Solanaceae* family when they are planted. In Turkey, where potato farming is intensive, the lack of effective chemical control methods for *G. rostochiensis* is a concern for sustainable potato farming. This study focuses on harmful plant parasitic nematodes in storage, their importance, their effects on yield losses, and control strategies.

Keywords: Potato, *G. rostochiensis*, yield loss, storage area, tuber, *M. spp*

Depolama Alanlarındaki Bitki Paraziti Nematodlar

Özet

Bitki paraziti nematodlar, depolama alanlarındaki patates yumrularında verim kaybı ve yumru kalitesinin düşmesine neden olan toprak kökenli patojenlerdir. Bulaşık alandan hasat edilen yumrularla depoya taşınan nematodlar, depolama için uygun olmayan ortamda üremeye devam ederek patates yumrularında ekonomik kayıplara neden olurlar. Patates depolama alanlarında görülen en önemli bitki paraziti nematodlar; Patates Çürüklük Nematodu (*Ditylenchus destructor*), Kök-ur Nematodları (*Meloidogyne* spp.), Kist Nematodları (*Globodera* spp.) olarak sıralanabilir. *Meloidogyne chitwoodi* özellikle sanayilik çeşitlerde verim kaybı yanında cips kalitesinin düşmesine neden olur. Karantina kapsamında bulunan Patates Altın Kist nematodu *Globodera rostochiensis* verim kaybı yanında tohumluk patateslerin üzerindeki toprak parçacıklarıyla farklı bölgelere yayılabilmektedir. *G. rostochiensis* dayanıklı yapı formu olan kistleri sayesinde 10-30 yıl gibi toprakta varlığını devam ettirerek *Solanaceae* familyası bitkilerinin dikimi yapıldığında beslenmeye devam ederek varlığını sürdürür. Türkiye’de yoğun patates tarımının yapıldığı üretim alanlarında *G. rostochiensis*’in etkin ilaçlı mücadelesinin olmaması nedeniyle sürdürülebilir patates tarımı endişe vericidir. Bu çalışmada depolarda zararlı bitki paraziti nematodlar, önemi, verim kayıplarına etkileri ve mücadele stratejileri üzerinde durulmuştur.

Anahtar Kelimeler: Patates, *G. rostochiensis*, verim kaybı, depolama alanı, yumru, *M. spp*



Importance of Primer Selection in Molecular Diagnosis of Canine Parvovirus

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Abstract

Canine parvovirus (CPV), also known as bloody diarrhea in dogs, is associated with high mortality, particularly in unvaccinated animals. The causative agent is Canine Parvovirus-2, which has a single-stranded DNA genome. The most affected group is puppies (1 month and under) that have not yet been vaccinated or that have been exposed to other animals before sufficient immunity has developed after vaccination. Although there is no specific treatment, rapid diagnosis is important in order to differentiate it from other diseases it may be confused with and to guide the necessary precautions. Since clinical symptoms are not sufficient for diagnosis, diagnosis supported by rapid tests is the most commonly used approach. Alternatively, molecular methods such as polymerase chain reaction (PCR) provide a definitive diagnosis. However, the most important parameter for accurate diagnosis in PCR tests is the selection of the gene region targeted for amplification and the appropriate oligonucleotide primers. If the selected gene region is specifically chosen for diagnosis, it should generally be chosen from regions that are resistant to mutation. In this study, blood samples from 12 dogs suspected of having CPV were examined using 3 different primers. Blood samples were centrifuged at 2000 rpm to remove the leukocyte layer, and the collected middle layer was transferred to 1.5 ml sterile polystyrene tubes using a pipette. The phenol/chloroform method was used for viral DNA extraction. Optimizations were first performed with three different primer pairs targeting the capsid-encoding protein: HFor/HRev (target location 3556-3575/4185-4166), Pbs/Pbas (target location 4043-4062/4470-4449), and Pabs/Pabas (target location 3025-3045/3706-3685), and then the samples were tested with different PCR reactions for each primer pair. 7, 5, and 12 positive results were obtained from each primer pair, respectively. This situation reflects the mutations occurring in the CPV genotype variants (2a, 2b, and 2c) present in the field. Consequently, this shows us that even in viral diseases commonly diagnosed in the field, mutations occurring over time can cause difficulties in diagnosis. The results of our study emphasize the importance of always working with multiple primers.

Keywords: Canine Parvovirus, Dog, Molecular Diagnostic, Optimization, PCR

Canine Parvovirus Moleküler Tanısında Primer Seçimi ve Önemi

Özet

Canine parvovirus (CPV) köpeklerin kanlı ishali olarak da bilinmektedir ve özellikle aşısız hayvanlarda yüksek mortalite ile seyretmektedir. Hastalığın etkeni tek zincirli DNA genomuna sahip olan Canine Parvovirus-2'dir. En fazla etkilendiği grup henüz aşılanmamış veya aşılandıktan sonra yeterince bağışıklık oluşmasını beklemeden diğer hayvanlarla temas ettirilen yavru (1 ay ve altı) köpeklerdir. Her ne kadar spesifik bir tedavisi olmasa da hızlı teşhis konulması, karıştığı diğer hastalıklardan ayrılarak alınacak önlemlere rehberlik etmesi bakımından önemlidir. Teşhis olarak klinik semptomlar yeterli olmadığı için çabuk testler ile desteklenerek tanı konulması en sık kullanılan yaklaşımdır. Bunun harici polimeraz zincir reaksiyonu (PCR) gibi moleküler yöntemler ile kesin teşhis koyulmaktadır. Fakat PCR testlerinde doğru teşhis için en önemli olan parametre çoğaltılması hedeflenen gen bölgesi ve buna yönelik oligonükleotid primerlerin seçimidir. Seçilen gen bölgesi özellikle teşhis için seçiliyorsa genel olarak mutasyona kapalı bölgelerden seçilmelidir. Bu çalışmada CPV şüpheli olan 12 köpeğe ait kan örneği 3 farklı primer kullanarak incelenmiştir. Kan örnekleri lökosit tabakası çıkarmak için 2000 devirde santrifüj edilmiş ve orta tabakada toplanan tabaka pipet yardımı ile 1,5 ml steril polistren tüplere aktarılmıştır. Viral DNA ekstraksiyonu için fenol/kloroform yöntemi kullanılmıştır. Kapsit kodlayan proteine yönelik üç farklı primer çifti HFor/HRev (hedef lokasyon 3556-3575/4185-4166), Pbs/Pbas (hedef lokasyon 4043-4062/4470-4449) ve Pabs/Pabas (hedef lokasyon 3025-3045/3706-3685) ile önce optimizasyonlar yapılmış ve sonrasında örnekler her primer çifti için farklı PCR reaksiyonları ile test edilmiştir. Her primer çiftinden PCR reaksiyonu sonucunda sırasıyla 7, 5 ve 12 adet pozitiflik elde edilmiştir. Bu durumun sahada var olan CPV genotip (2a, 2b ve 2c) varyantlarında meydana gelen mutasyonların bir yansıması olarak karşımıza çıkmaktadır. Sonuç olarak bu durum bize sahada yaygın olarak teşhis konulan viral hastalıklarda bile zaman içerisinde meydana gelen mutasyonların tanıda güçlükler neden olabildiğini göstermektedir. Çalışmamızın sonuçları her zaman birden fazla primer ile çalışmanın önemini vurgulamaktadır.

Anahtar Kelimeler: Canine Parvovirus, Köpek, Moleküler Tanı, Optimizasyon, PCR





Effect of different doses of vermicompost applications on oil content and composition of soybean (*Glycine max* (L.) Merrill)

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Abstract

The use of organic fertilizers such as vermicompost is becoming increasingly common in agriculture to reduce the environmental damage caused by chemical fertilizers. This research was conducted in 2025 to determine the effect of applying vermicompost at different doses on the oil content and composition of soybean (*Glycine max* (L.) Merrill). The study was established with three replications according to the “Randomized Block Experimental Design” at the application field of Selcuk University Cumra School of Applied Sciences. In the research, the İlksoy variety was used as material, and vermicompost was applied to the plots at four different doses (0, 50, 100 and 150 kg/da). In the study, seed yield, crude oil content, crude oil yield and fatty acid composition were determined. Vermicompost applications had no statistically significant effect on seed yield, crude oil content and crude oil yield. With different vermicompost applications, the seed yield of the İlksoy variety varied between 205.57–262.00 kg/da, the crude oil content between 13.10% and 15.80%, and the crude oil yield between 27.60–42.70 kg/da. The highest seed yield was obtained with the 50 kg/da vermicompost application, while the highest crude oil content and crude oil yield were obtained with the 100 kg/da vermicompost application. The effects of vermicompost applications on fatty acid composition were not statistically significant, except for oleic acid. According to the results, the ratios of linoleic, oleic, linolenic, palmitic, stearic, caprylic, arachidic and behenic acids ranged between 47.77–49.21%, 20.88–21.41%, 10.05–10.67%, 9.73–10.30%, 5.28–5.87%, 0.63–0.87%, 0.46–0.52%, and 0.35–0.38%, respectively. The highest oleic and palmitic acid ratios were obtained in the control group, while the highest linoleic and arachidic acid ratios were recorded at 100 kg/da, the highest linolenic, stearic, caprylic and behenic acid ratios were obtained with 150 kg/da vermicompost application.

Keywords: Soybean, *Glycine max* (L.) Merrill, Vermicompost, Crude oil, Fatty acid composition





Determination of morphological development, yield and protein characteristics of sprouts from different soybean (*Glycine max* L.) cultivars grown under hydroponic conditions

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Abstract

Sprouting plants under hydroponic conditions optimizes resource use and enables sustainable production with high yield and quality in a short time. This study aimed to determine the morphological development, yield and protein characteristics of sprouts obtained from soybean (*Glycine max* L.) cultivars grown under hydroponic conditions. This research was conducted in 2025 in a 3×2×2 m hydroponic plant production room belonging to Selcuk University Cumra School of Applied Sciences. The experiment was designed in a randomized plot design with three replications, using four soybean cultivars (Traksoy, Mersoy, İlksoy and Kristal22) as plant material. In the hydroponic system, 40×120 cm plastic trays were utilized for the ebb-and-flow irrigation system, while perforated aluminum containers measuring 25×35 cm were used as germination trays. The results revealed statistically significant differences among cultivars in terms of sprout growth, biomass yield, dry matter ratio and yield, as well as protein ratio and yield ($p<0.01$). Plant height, root length, biomass yield, dry matter ratio and yield, protein ratio and yield were determined as 24.73 cm, 8.20 cm, 32.50 kg m⁻², 15.87% and 3.98 kg m⁻², 42.41% and 13.63 kg m⁻², respectively. In terms of plant height, the Mersoy was prominent; whereas İlksoy stood out in terms of root development, biomass, dry matter yield, and protein yield. The Traksoy exhibited the highest protein content, while Kristal22 was distinguished by its dry matter content. Among the essential amino acids, lysine, leucine, phenylalanine, threonine, and isoleucine were significant at $p<0.01$, while valine was significant at $p<0.05$. Statistically significant differences were also determined for all non-essential amino acids, except tyrosine ($p<0.01$). Among the non-essential amino acids, the highest values were found for aspartic acid (17.72 g 100 g⁻¹) and glutamic acid (4.89 g 100 g⁻¹). Lysine (3.76 g 100 g⁻¹) and leucine (2.68 g 100 g⁻¹) were the dominant essential amino acids.

Keywords: Hidroponic system, Soybean sprout, Yield, Protein, Aminoacids, Sustainable production



Geosite Potential of Asar Pond and Its Surroundings in Taşköprü District

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Abstract

This study aims to reveal the geomorphological characteristics of Asar Pond and its immediate surroundings, located within the boundaries of Taşköprü district in Kastamonu Province, and to evaluate its geosite potential. Based on field observations, literature review, and analysis of available data, it has been determined that the pond is situated on a karstic limestone unit and forms a system where natural and anthropogenic processes operate together. The lithological features, morphological diversity, and hydrological structure of the area indicate that it represents a site of significant scientific and educational value. Karstic collapse structures observed around the pond, including dolines, uvalas, and ponors, enhance the morphological diversity and allow direct observation of natural processes in the field. This increases the importance of the area for both education and scientific research. Furthermore, an evaluation of the landscape characteristics shows that slope gradients, sediment accumulations, and the contrast between the water surface and its surroundings strengthen the visual aesthetics of the site. These qualities also support its potential for geotourism and recreational use. According to the assessments conducted, the geosite potential of Asar Pond has been evaluated based on four main criteria: scientific observability, educational value, aesthetic features, and conservation status. The results indicate that the area possesses a high value in terms of all these criteria. However, existing deficiencies in promotion and infrastructure limit the effective and sustainable utilization of this potential. In this context, it is of great importance to develop comprehensive planning strategies for the conservation and management of the area. Protecting natural processes and geomorphological features around the pond, improving visitor information and guidance systems, and planning the area for educational and tourism purposes in a controlled manner are essential. In conclusion, Asar Pond and its surroundings stand out as an important geosite with significant geomorphological, natural, and landscape values in terms of scientific, educational, and touristic aspects. Effective management and conservation practices will contribute to increasing regional environmental awareness and ensuring the sustainable use of natural heritage.

Keywords: Geosite, Asar Pond, Taşköprü, Sustainability

Taşköprü İlçesi Asar Göleti ve Yakın Çevresi Jeosit Potansiyali

Özet

Bu araştırma, Kastamonu ili Taşköprü ilçesi sınırları içerisinde bulunan Asar Göleti ve yakın çevresinin jeomorfolojik özelliklerini ortaya koymayı ve jeosit potansiyelini değerlendirmeyi hedeflemektedir. Gerçekleştirilen arazi gözlemleri, literatür incelemeleri ve mevcut verilerin analizi sonucunda, göletin karstik kalker birim üzerinde konumlandığı ve doğal ile antropojenik süreçlerin birlikte işlediği bir sistem oluşturduğu tespit edilmiştir. Bölgenin litolojik özellikleri, morfolojik çeşitliliği ve hidrolojik yapısı, alanın hem bilimsel hem de eğitimsel açıdan önemli bir saha niteliği taşıdığını göstermektedir. Gölet çevresinde belirlenen karstik çökme yapıları, dolinler, uvalalar ve ponorlar, morfolojik zenginliği artırmakta ve doğal süreçlerin sahada doğrudan gözlemlenebilmesine olanak sağlamaktadır. Bu durum, alanın eğitim ve bilimsel araştırmalar açısından değerini daha da yükseltmektedir. Ayrıca, gölet ve çevresinin peyzaj özellikleri incelendiğinde; yamaç eğimleri, sediman birikimleri ve su yüzeyi ile çevre arasındaki kontrastın görsel estetiği güçlendirdiği belirlenmiştir. Bu nitelikler, alanın jeoturizm ve rekreasyon potansiyelini de desteklemektedir. Yapılan değerlendirmelerde, Asar Göleti'nin jeosit potansiyeli; bilimsel gözlemlenebilirlik, eğitimsel değer, estetik özellikler ve korunabilirlik kriterleri çerçevesinde ele alınmış ve alanın bu ölçütler bakımından yüksek bir değere sahip olduğu ortaya konmuştur. Bununla birlikte, mevcut tanıtım eksiklikleri ve altyapı yetersizlikleri, bu potansiyelin etkin ve sürdürülebilir şekilde kullanılmasını sınırlandırmaktadır. Bu kapsamda, alanın korunması ve yönetimine yönelik planlamaların yapılması büyük önem taşımaktadır. Gölet çevresinde doğal süreçlerin ve morfolojik unsurların korunması, ziyaretçilere yönelik bilgilendirme ve yönlendirme sistemlerinin geliştirilmesi ve alanın eğitim ile turizm amaçlı kullanımının planlı bir şekilde gerçekleştirilmesi gerekmektedir. Sonuç olarak, Asar Göleti ve yakın çevresi; sahip olduğu jeomorfolojik, doğal ve peyzaj değerleri ile bilimsel, eğitimsel ve turistik açıdan öne çıkan önemli bir jeosit alanıdır. Alanın etkin bir koruma ve yönetim anlayışıyla değerlendirilmesi, hem bölgesel çevresel farkındalığın artırılmasına hem de doğal mirasın sürdürülebilir kullanımına katkı sağlayacaktır.

Anahtar Kelimeler: Jeosit, Asar Göleti, Taşköprü, Sürdürülebilirlik



Comparison of bonito (*Sarda sarda* Bloch, 1793) fish and fishing methods in the Black Sea

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Abstract

Different prohibitions and restrictions regarding time, location, and minimum catchable size for bonito (*Sarda sarda* Bloch, 1793) fishing in the Black Sea are prominently featured in Communiqué No. 6/1 and previous communiqués regulating commercial fisheries. However, different opinions and suggestions regarding the fishing of this fish are being brought to the agenda. Bonito fishing methods include bonito hooks, bonito gill nets, seine nets, and bonito purse seines. Additionally, bonito fishing is also carried out using midwater trawls without gates, towed by two boats. This study investigates the effects of five different fishing methods on bonito fishing to ensure the sustainability of bonito stocks and to establish a profitable fishing process with the most appropriate rules and restrictions within a legal framework. The aim is to present this information to the regulatory authorities. In this study, the quantities and compositions of bonito caught using 5 different fishing gear were analyzed in the field, along with their market values, compliance with existing bans and restrictions, and any violations, as the primary data. Fishing with a jig, the simplest method for catching bonito, is permitted starting August 15th, and numerous small fishermen and amateur anglers are intensively catching many small bonito weighing 150-200 grams, which have not yet reached the minimum catch size limit of 25 cm. The edible meat content of these fish is also considerably lower than that of bonito weighing between 500-1000 grams. In recent years, bonito fishing with mid-water trawls has increased in mesh size up to 80 cm on the wings and shoulders of the nets, allowing for faster net pulling and thus enabling smaller bonito to escape the nets. In some fishing seasons, the large quantities of bonito below the minimum catchable size limit caught with jig and purse seines negatively impact the sustainability of these fish stocks. Legal restrictions and regulations should be revised according to the characteristics of all fishing gear and the migration and growth characteristics of bonito.

Keywords: Bonito fish, Purse seine fishing, Stream nets, Seine nets, Bonito jigging, Sustainable aquaculture

Karadeniz’de palamut (*Sarda sarda* Bloch, 1793) balığı ve avcılık yöntemlerinin karşılaştırılması

Özet

Karadeniz’de palamut balığı (*Sarda sarda* Bloch, 1793) avcılığına zaman, yer ve asgari avlanabilir boy olmak üzere farklı yasak ve sınırlamalar, ticari su ürünleri avcılığını düzenleyen 6/1 No lu tebliğde ve daha önceki tebliğlerde önemli bir yer almaktadır. Ancak bu balığın avcılığına ilişkin farklı görüş ve öneriler gündeme getirilmektedir. Palamut balığı avcılığında; palamut çaparası, palamut uzatma ağları, voli-difana ağları, palamut gırgırı kullanılmaktadır. Ayrıca, iki tekne ile çekilen kapısız orta su trolü ağları ile de palamut balığı avcılığı yapılmaktadır. Bu çalışmada 5 farklı yöntem ile avlanan palamut balığının stoklarının sürdürülebilirliğinin sağlanabilmesi ve rantabl bir avcılık sürecinin yasal zeminde en uygun kural ve sınırlamalar ile gerçekleştirilebilmesi için 5 farklı av aracının palamut balığı avcılığı üzerindeki etkileri araştırılmış ve kural-yasa koyucuların bilgisine sunulması gaye edinilmiştir. Araştırmada, 5 farklı av aracı ile yapılan palamut balığı avcılığının sahadaki avcılık uygulamalarına katılarak, avlanan palamut balığı miktarları ve av kompozisyonları ile yakalanan palamut balıklarının piyasa değerleri, yürürlükte olan yasak ve sınırlamalara olan uygunlukları ve ihlalleri esas veri olarak değerlendirilmiştir. Palamut avcılığında en basit yöntem olan çapari ile avcılık 15 Ağustos tarihinde serbest olmakta ve çok sayıdaki küçük balıkçı ve amatör balıkçılar tarafından, asgari avlanma boyu 25 cm olan boy sınırına daha gelmemiş 150-200 gr ağırlığındaki çok sayıda küçük palamutlar yoğun olarak avlanmaktadır. Bu balıkların yenilebilir et oranlarının da 500-1000 gr arasında olan palamutlara göre oldukça düşüktür. Son yıllarda orta su trolleri ile yapılan palamut avcılığında ise, ağların kanat ve omuz kısımlarının göz açıklıklarının 80 cm. ye kadar büyütülmesi sonucunda daha hızlı ağ çekimleri gerçekleştiğinden küçük boydaki palamutların ağdan çıkması mümkün olmaktadır. Bazı av sezonlarında palamut çaparası ve palamut gırgırları ile asgari yakalanabilir boy sınırının altında olan çok miktardaki palamut balıklarının avcılığı, bu balıkların stoklarının sürdürülebilirliğini olumsuz yönde etkilemektedir. Yasal sınırlama ve kurallar, tüm av araçlarının özelliklerine ve palamut balığının göç ve büyüme özelliklerine göre yeniden düzenlenmelidir.

Anahtar Kelimeler: Palamut balığı, Gırgır avcılığı, Akıntı ağları, Voli ağları, Palamut çaparası, Sürdürülebilir su ürünleri avcılığı



Morphological Diversity and Genotypic Discrimination in Tomato (*Solanum lycopersicum* L.): Implications for Breeding, Stress Tolerance, and Germplasm Conservation

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Abstract

Understanding the extent and distribution of phenotypic diversity in tomato (*Solanum lycopersicum* L.) is fundamental for cultivar identification, genetic improvement, and the sustainable utilization of germplasm resources. This study evaluated 15 key qualitative morphological traits across nine genetically diverse tomato genotypes to characterize their phenotypic variability and assess its implications for breeding, particularly for stress resilience. The field experiment was conducted under irrigation during the 2024–2025 off-season at two distinct agro-ecological locations in western Ethiopia: Bako Tibe (1560 m.a.s.l.) and Gambella Tare (2697 m.a.s.l.). Significant inter-genotypic variation was observed for all qualitative descriptors. Fruit traits exhibited pronounced diversity, including predominant shapes (ranging from pyriform to cylindrical), shoulder morphology (flat to strongly depressed), cross-sectional outlines (angular, rounded, irregular), and pistil scar patterns (dot, stellate, linear). Notably, 66.66% of genotypes demonstrated high fruit size homogeneity, while angular cross-sections were predominant (55.55%). The prevalence of abiotic stress-related disorders was genotype-dependent: blotchy ripening was observed in 55.55% of genotypes (slight symptoms), sunscald in 44.44% (exposed), and radial cracking in 55.55% (slightly affected), underscoring the interaction between genetic predisposition and environmental factors. Leaf morphological traits, including type (potato, dwarf, Peruvianum) and attitude (drooping, semi-erect, horizontal), further corroborated the substantial genetic diversity. Correlation analysis from the accompanying quantitative trait evaluation revealed that average fruit weight had a strong, positive, and significant genotypic correlation with total marketable fruit yield ($r_g = 0.35$) and fruit yield ($r_g = 0.716$). Our findings align with global studies on tomato landrace diversity and demonstrate that systematic morphological characterization remains a powerful, cost-effective first step for germplasm conservation and for selecting parental lines with desirable agronomic traits, including stress tolerance. The identified genotypes, particularly; 'Cochoro' for yield and 'Melka-salsa' for fruit quality, offer immediate value for breeding programs targeting climate-resilient and market-preferred cultivars.

Keywords: Abiotic stress, breeding, fruit morphology, genetic diversity, *Solanum lycopersicum*, qualitative traits.

Introduction

Tomato (*Solanum lycopersicum* L.), a member of the Solanaceae family, stands as one of the world's most economically significant and nutritionally valuable vegetable crops, playing a pivotal role in global food and nutritional security [1,2]. Its high polymorphism, manifesting as extensive phenotypic diversity in fruit morphology, plant architecture, and physiological responses, has rendered it an exemplary model for studying crop adaptation, domestication, and the genetic basis of complex traits [3, 4]. While the advent of high-throughput molecular markers and genomic tools has revolutionized plant breeding, morphological characterization remains an indispensable and cost-effective foundational step for several critical applications. These include the distinct identification of cultivars, the systematic conservation of germplasm (especially in underutilized local collections), the description of breeding lines for intellectual property protection (Plant Variety Protection), and the initial selection of traits for improvement [5,6].

Fruit-associated qualitative traits such as shape, shoulder type, cross-sectional profile, and pistil scar morphology are primary determinants of marketability, consumer preference, postharvest handling, and transport durability [7, 8]. For instance, cylindrical fruits are often preferred for processing, while heart-shaped or flattened types may be favored in fresh markets. Similarly, fruit shoulder morphology can significantly influence susceptibility to cracking and postharvest water loss [9]. Previous studies have documented substantial variability in these descriptors among heirloom, landrace, and commercial tomato varieties [10, 11]. However, significant gaps remain in understanding the distribution and adaptive significance of these traits within locally adapted genotypes, particularly in under-researched agro-ecologies like the mid- to high-altitude zones of East Africa [12].

Beyond fruit morphology, abiotic stress-related physiological disorders including blotchy ripening, sunscald, and radial cracking pose major challenges to consistent tomato production, leading to substantial postharvest losses and reduced economic returns [13, 14]. The incidence and severity of these disorders are governed by a complex interplay between genetic susceptibility (e.g., genes controlling cuticle development, pigmentation, and calcium transport) and environmental factors such as light intensity, temperature fluctuations, and nutrient availability [15, 16]. A systematic assessment of the genotypic variation in susceptibility to these disorders is a prerequisite for



breeding programs aiming to develop resilient cultivars for stress-prone environments, particularly under the specter of climate change.

Furthermore, leaf architectural traits, including type (e.g., potato leaf, standard, Peruvianum), attitude (e.g., drooping, semi-erect), and foliage density, have direct implications for photosynthetic efficiency, canopy light interception, air circulation, and susceptibility to foliar diseases [17, 18]. For example, potato leaf types have been linked to altered source-sink relationships and yield potential [19], while drooping leaf attitudes may be an adaptation to high light intensity or water stress. Despite their functional significance, comparative analyses of leaf morphology across diverse tomato genotypes are often overlooked in favor of fruit-centric studies.

This study was designed to address these gaps by providing a comprehensive assessment of phenotypic diversity in nine tomato genotypes using a standardized set of 15 qualitative morphological descriptors. The specific objectives were to: (1) comprehensively characterize the phenotypic variability for fruit and leaf traits; (2) identify key diagnostic descriptors that can effectively differentiate among the genotypes for cultivar identification; (3) assess the genotypic variation in the prevalence of common abiotic stress-related disorders; and (4) discuss the implications of this diversity for targeted breeding and germplasm conservation. By integrating detailed morphological trait analysis with agronomic performance data from a parallel quantitative study, this work aims to provide a holistic framework for selecting elite genotypes suitable for sustainable tomato production in the diverse agro-ecologies of western Ethiopia and beyond.

Materials and Methods

Plant Material, Experimental Sites, and Design

Nine tomato (*Solanum lycopersicum* L.) genotypes, including one local check, were evaluated for phenotypic diversity. The genotypes were selected based on their agronomic performance and adaptability to diverse growing conditions. The study was conducted during the 2024–2025 growing season under irrigation at two locations: Bako Tibe (1560 m.a.s.l., clay loam soil, pH 4.99) and Gambella Tare (2697 m.a.s.l., alluvial loam soil). A randomized complete block design (RCBD) with three replications was used. Each plot measured 3 m × 4 m (12 m²), with seedlings transplanted at 45 days after sowing at a spacing of 0.5 m between rows and 0.4 m between plants.

The study evaluated nine tomato (*Solanum lycopersicum* L.) genotypes, comprising eight improved varieties (Melkashola, Cochoro, ILU-Harar, Sire, Melkasalsa, Chali, Gelilema, Komto) and one local check (Table S1). The genotypes were selected based on their reported agronomic performance and adaptability. The field experiment was conducted during the 2024–2025 dry (off-) season under supplemental irrigation at two distinct agro-ecological locations in western Oromia, Ethiopia: (i) Bako Tibe (Bako Agricultural Research Center; 9°06'N, 37°09'E; 1560 m above sea level [m.a.s.l.]; sub-humid, clay loam soil, pH 4.99) and (ii) Gambella Tare (Nint Agri Plc research site in Boneya Boshe District; 9°4'0"N, 37°01'0"E; 2697 m.a.s.l.; highland, alluvial loam soil). A detailed description of the climatic and soil characteristics of both sites is provided in the supplementary materials (Appendix Tables S2, S3).

A Randomized Complete Block Design (RCBD) with three replications was employed at each location. Each experimental plot measured 3 m × 4 m (12 m²), with 0.5 m between rows and 0.4 m between plants. Seedlings were raised in a nursery for 45 days before being transplanted. Standard agronomic practices for irrigated tomato production were uniformly followed across both sites, including drip irrigation, fertilization (100 kg ha⁻¹ DAP at transplanting and 250 kg ha⁻¹ urea split into three applications), staking, and integrated pest management using recommended fungicides (Mancozeb, Bravo) and insecticides (Karate).

Qualitative Trait Evaluation

Data for 15 qualitative morphological descriptors were recorded on a plot basis from five randomly selected and tagged competitive plants per genotype, at appropriate growth stages (e.g., vegetative, anthesis, and fruit ripening). The descriptors were adopted from the International Plant Genetic Resources Institute (IPGRI) guidelines for tomato [20]. The traits assessed, their codes, and scoring scales are detailed in Table 1. Observations were made between 08:00 and 10:00 AM to standardize assessments, particularly for leaf color and turgor.

Quantitative Trait Data (for Correlation Context)

To contextualize the qualitative findings, data from a parallel study on quantitative traits were used. Sixteen agronomic traits were recorded, including days to 50% flowering (DF), days to maturity (NDM), plant height (PH), number of fruits per plant (NFSP), average fruit weight (AFW), total marketable fruit yield (TMFY, t ha⁻¹), fruit length (FL), fruit diameter (FD), and fruit pericarp thickness (FPTH), following standard protocols [20]. The analysis of these quantitative traits was conducted using SAS 9.0, with ANOVA and mean separation via Fisher's LSD ($p \leq 0.05$). Genotypic correlation coefficients (rg) among key traits were calculated using variance and covariance components [21].



Table 1: List of qualitative morphological descriptors, codes, and scoring scales used for tomato genotype characterization (based on IPGRI [20]).

Trait	Descriptor	Code	Scoring Scale / Class
PFSH	Predominant Fruit Shape	1-8	1. Flattened (oblate); 2. Slightly flattened; 3. Rounded; 4. High rounded; 5. Heart-shaped; 6. Cylindrical; 7. Pyriform; 8. Ellipsoid (plum-shaped)
FshSH	Fruit Shoulder Shape	1,3,5,7	1. Flat; 3. Slightly depressed; 5. Moderately depressed; 7. Strongly depressed
FCSH	Fruit Cross-sectional Shape	1,2,3	1. Round; 2. Angular; 3. Irregular
FsH	Fruit Size Homogeneity	3,5,7	3. Low; 5. Intermediate; 7. High
ShPS	Shape of Pistil Scar	1,2,3,4	1. Dot; 2. Stellate; 3. Linear; 4. Irregular
FBESH	Fruit Blossom End Shape	1,2,3	1. Indented; 2. Flat; 3. Pointed
FrF	Fruit Firmness	3,5,7	3. Soft; 5. Intermediate; 7. Firm
BER	Blossom End Rot Incidence	3,5,7	3. Few; 5. Moderate; 7. Many
BR	Blotchy Ripening	3,5,7	3. Slight; 5. Intermediate; 7. Severe
Ss	Sun Scald	3,5,7	3. Slight; 5. Intermediate; 7. Severe
Rc	Radial Cracking	1,3,5,7	1. Corky lines; 3. Slight; 5. Intermediate; 7. Severe
RUWP	Ripening Uniformity (Whole Plot)	3,5,7	3. Poor; 5. Intermediate; 7. Good
LT	Leaf Type	1-6	1. Dwarf; 2. Potato leaf; 3. Standard; 4. Peruvianum; 5. Pimpinellifolium; 6. Hirsutum
LA	Leaf Attitude	3,5,7	3. Semi-erect; 5. Horizontal; 7. Drooping
Fod	Foliage Density	3,5,7	3. Sparse; 5. Intermediate; 7. Dense

Results

Phenotypic Diversity in Qualitative Traits

The evaluation of 15 qualitative traits across the nine tomato genotypes revealed substantial morphological diversity, with the frequency of phenotypic classes ranging from 11.11% to 77.77% (Table 2). Fruit-related descriptors proved to be the most powerful for differentiating between genotypes.

Fruit Morphological Diversity

A wide range of fruit shapes was observed. The most common shapes were cylindrical (long oblong) and pyriform, each exhibited by 22.22% of the genotypes. Other shapes, including slightly flattened, rounded, high-rounded, heart-shaped, and ellipsoid, were each observed in 11.11% of the genotypes. The flattened (oblate) shape was absent in this germplasm (Table 2; Figure 1). Fruit shoulder morphology also varied considerably, with slightly depressed shoulders being the most prevalent (44.44% of genotypes), followed by flat and moderately depressed types (22.22% each), and strongly depressed shoulders being rare (11.11%).

For cross-sectional shape, angular was the dominant form, observed in over half (55.55%) of the genotypes, while rounded and irregular shapes each accounted for 22.22% (Figure 2). Notably, 66.66% of the genotypes exhibited high fruit size homogeneity, a trait highly desirable for uniform harvest and marketing (Table 2).



Figure 1: Prevalent Fruit Forms Observed in the Evaluated Cultivars (source: own study)





Figure 2: Cross-Sectional Morphology of Fruit in the Investigated Varieties (source: own study)

Pistil scar morphology was predominantly a simple dot (55.55% of genotypes), with stellate and linear scars each present in 22.22%. Irregular scars were not observed. Regarding fruit blossom end shape, the indented form was most common (55.55%), followed by pointed (33.33%) and flat (11.11%) (Table 2). Fruit firmness varied, with soft and firm textures being most frequent (44.44% and 33.33% of genotypes, respectively), while intermediate firmness was less common (22.22%).

Prevalence of Stress-Related Disorders

The incidence of abiotic stress-related disorders was genotype-dependent, indicating a genetic basis for susceptibility (Table 2). Blotchy ripening (BR) was predominantly slight (55.55% of genotypes), though 22.22% each showed intermediate and severe symptoms (**Figure 3b**). Sunscald (Ss) susceptibility showed a different pattern, with 44.44% of genotypes exhibiting intermediate exposure symptoms, 33.33% slight, and 22.22% severe (**Figure 3a**). Radial cracking (Rc) was predominantly slight (55.55% of genotypes), but 22.22% each showed intermediate and severe cracking. Blossom end rot (BER) was minimal (few symptoms) in the majority of genotypes (66.66%), with only a few showing moderate (22.22%) or many (11.11%) symptoms.



Figure 3: Manifestations of Sunscald (a) and Blotchy Ripening (b) in the Evaluated Tomato Cultivar (source: own study).

Leaf Morphological Diversity

Substantial variation was also observed in leaf morphology. The potato leaf type was most common (33.33% of genotypes), followed equally by dwarf and Peruvianum types (22.22% each). The *Pimpinellifolium* and *Hirsutum* leaf types were each observed in a single genotype (11.11% each), and the standard leaf type was absent (Table 2). Leaf attitude was predominantly drooping (44.44% of genotypes), with semi-erect (33.33%) and horizontal (22.22%) also present. Foliage density was most frequently sparse (44.44%), followed by dense (33.33%) and intermediate (22.22%) (Table 2).



Table 2: Percentage frequency distribution of 15 qualitative morphological traits among nine tomato genotypes evaluated in western Ethiopia.

<i>Trait</i>	<i>Class (Code)</i>	<i>Frequency (%)</i>
PFSH (Fruit Shape)	Slightly flattened (2); Rounded (3); High rounded (4); Heart-shaped (5); Ellipsoid (8)	11.11 (each)
	Cylindrical (6); Pyriform (7)	22.22 (each)
FshSH (Shoulder Shape)	Flat (1); Moderately depressed (5)	22.22 (each)
	Slightly depressed (3)	44.44
	Strongly depressed (7)	11.11
FCSH (Cross-section)	Round (1); Irregular (3)	22.22 (each)
	Angular (2)	55.55
FsH (Size Homogeneity)	Intermediate (5)	33.33
	High (7)	66.66
ShPS (Pistil Scar)	Stellate (2); Linear (3)	22.22 (each)
	Dot (1)	55.55
FBESH (Blossom End)	Flat (2)	11.11
	Pointed (3)	33.33
	Indented (1)	55.55
FrF (Firmness)	Intermediate (5)	22.22
	Firm (7)	33.33
	Soft (3)	44.44
BER (Blossom End Rot)	Moderate (5); Many (7)	22.22; 11.11
	Few (3)	66.66
BR (Blotchy Ripening)	Intermediate (5); Severe (7)	22.22 (each)
	Slight (3)	55.55
Ss (Sun Scald)	Slight (3); Severe (7)	33.33; 22.22
	Intermediate (5)	44.44
Rc (Radial Cracking)	Intermediate (5); Severe (7)	22.22 (each)
	Slight (3)	55.55
RUWP (Ripening Uniformity)	Intermediate (5); Good (7)	33.33; 22.22
	Poor (3)	44.44
LT (Leaf Type)	Dwarf (1); Peruvianum (4)	22.22 (each)
	Pimpinellifolium (5); Hirsutum (6)	11.11 (each)
	Potato leaf (2)	33.33
LA (Leaf Attitude)	Horizontal (5)	22.22
	Semi-erect (3)	33.33
	Drooping (7)	44.44
Fod (Foliage Density)	Intermediate (5)	22.22
	Dense (7)	33.33
	Sparse (3)	44.44

Key:- PFSH: Predominant Fruit shape, FshSH: Fruit shoulder shape, FCSH: Fruit cross-sectional shape, FsH: Fruit Size Homogeneity, ShPS: Shape of pistil scar, FBESH: Fruit blossom end shape, FrF: Fruit firmness, BER: Blossom end rot, BR: Blotchy Ripening, Ss: Sun Scald, Rc: Radial cracking, RUWP: Ripening uniformity of the whole plot, LT: Leaf type, LA: Leaf Attitude, Fod: Foliage density.

Correlation of Qualitative with Quantitative Performance

The observed qualitative diversity was reflected in the quantitative agronomic performance of the genotypes (Table 3). For instance, the genotype 'Cochoro', which exhibited a firm fruit texture (FrF=7) and high fruit size homogeneity (FsH=7), also recorded the highest total marketable fruit yield across both locations (91.5 t ha⁻¹ at Bako, 84.3 t ha⁻¹ at Gambella). Conversely, 'Geli-Lema', which had a soft fruit texture (FrF=3) and poor ripening uniformity (RUWP=3), produced the lowest yield at Gambella (42.2 t ha⁻¹). Genotypic correlation analysis from the quantitative study (Table 4) revealed that average fruit weight (AFW) was strongly, positively, and significantly correlated with total marketable fruit yield ($r_g = 0.35$, $p < 0.05$) and fruit yield ($r_g = 0.716$, $p < 0.01$), highlighting the direct contribution of fruit size to overall productivity.



Table 3: Mean performance for key quantitative traits of nine tomato genotypes grown at two locations (Bako Tibe and Gambella Tare).

Genotype	TMFY (t ha ⁻¹)	AFW (g)	NFSP	PH (cm)	Key Qualitative Traits
Cochoro	91.5 (Bako) / 84.3 (Gambella)	146.1	36.0	76.1	Firm fruit, high size homogeneity
Melka-shola	77.2 / 73.3	62.3	42.2	93.5	Indented blossom end, soft fruit
Chali	69.6 / 51.4	102.4	45.8	73.6	Rounded shape, pointed blossom end
Melka-salsa	60.9 / 55.3	51.4	75.4	78.5	Cylindrical fruit, high ascorbic acid
Geli-Lema	61.3 / 42.2	87.2	42.8	93.2	Soft fruit, poor ripening uniformity
LSD (5%)	17.2 / 16.4	19.0 / 33.9	13.5 / 12.1	6.9 / 9.5	

Key: TMFY: Total Marketable Fruit Yield; AFW: Average Fruit Weight; NFSP: Number of Fruits per Plant; PH: Plant Height.

Table 4: Estimates of genotypic correlation coefficients (rg) among key quantitative traits for nine tomato genotypes (combined across two locations).

Trait	AFW	FY	FD	FPTH
NFSP	-0.606*	-0.359	-0.312	-0.775*
AFW	-	0.716**	0.778*	0.806**
TMFY	0.735*	0.99***	0.457	0.495
PH	-0.603*	-0.369	-0.716*	-0.148

Key: AFW: Avg. Fruit Weight; FY: Fruit Yield; FD: Fruit Diameter; FPTH: Fruit Pericarp Thickness; NFSP: Number of Fruit Sets per Plant; TMFY: Total Marketable Fruit Yield; PH: Plant Height. *, **, *** indicate significance at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

Discussion

This study successfully delineated the substantial phenotypic diversity present within a panel of nine tomato genotypes using a robust set of qualitative morphological descriptors. The frequency of phenotypic classes varied widely (11.11% to 77.77%), demonstrating the utility of this approach for discriminating between cultivars, as has been shown in diverse germplasm collections globally [6, 22]. The significant variation observed in key traits, particularly those related to fruit morphology and stress disorder susceptibility, has direct and important implications for targeted breeding, germplasm conservation, and the development of climate-resilient varieties.

Fruit Morphology as a Tool for Cultivar Differentiation and Market Suitability

Our results confirm that fruit morphological descriptors are among the most powerful for distinguishing tomato genotypes [5, 23]. The observed variation in fruit shape from pyriform to cylindrical to heart-shaped is not merely cosmetic but has functional significance for different market segments and uses. For instance, cylindrical (long-oblong) fruits, like those of 'Melka-salsa', are often preferred by the processing industry for producing sauces and pastes due to higher solids content and ease of peeling [7]. In contrast, heart-shaped or slightly flattened fruits may be more appealing for fresh market consumption [24]. The absence of the flattened (oblate) shape in our germplasm suggests a specific genetic background in these locally adapted lines, diverging from some commercial varieties.

The predominance of angular cross-sectional shapes (55.55%) and high fruit size homogeneity (66.66%) are particularly noteworthy. Angular shapes have been associated with specific genetic markers linked to cell wall development and fruit firmness [25]. High size homogeneity is a critical trait for commercial producers, as it reduces sorting costs and ensures a more uniform, high-value product [26]. The significant positive genotypic correlation we observed between average fruit weight and both marketable yield ($rg = 0.35$) and total yield ($rg = 0.716$) underscores the economic importance of selecting for larger, more homogenous fruits. This finding is consistent with studies showing that fruit weight is a major component of yield in tomato [27, 28].

Genotypic Variation in Abiotic Stress-Related Disorders

The genotype-dependent variation in the incidence of physiological disorders like blotchy ripening (BR), sunscald (Ss), and radial cracking (Rc) provides crucial insights for breeding programs. Our finding that 55.55% of genotypes showed only slight BR symptoms suggests that some of these lines harbor tolerance mechanisms. BR is often linked to imbalances in potassium and calcium, exacerbated by environmental stresses [15]. The variation in Ss susceptibility (from 33.33% slight to 22.22% severe) indicates a clear genetic component in the ability to withstand high light intensity and UV radiation. This aligns with research demonstrating cultivar-specific thresholds for photo-oxidative damage [29, 30]. Tolerance mechanisms could include differences in canopy



architecture (leaf attitude and foliage density) and fruit pigmentation. The high-altitude site, Gambella Tare (2697 m.a.s.l.), with its higher UV radiation and lower temperatures, likely exacerbated the expression of sunscald and other stress-related disorders in susceptible genotypes, highlighting the importance of screening germplasm under target environments [37].

The observed variation in radial cracking (55.55% slight, 22.22% severe) is another key finding, as cracked fruits are unmarketable. Cracking susceptibility is influenced by fruit cuticle properties, cell wall elasticity, and water uptake dynamics [16, 31]. The strong negative genotypic correlation we observed between number of fruit sets per plant (NFSP) and fruit pericarp thickness (FPTH, $rg = -0.775$) suggests a potential trade-off. Genotypes that set many fruits may allocate fewer resources to pericarp development, leading to thinner skins and potentially higher crack susceptibility. This highlights the need for balanced selection, where yield components are improved without compromising fruit integrity. For example, 'Melka-salsa', while producing the highest number of fruits per plant (50.6), exhibited thinner pericarp (3.4 mm) and may be more susceptible to cracking, whereas 'Cochoro', with moderate fruit set (30.9), had the thickest pericarp (6 mm) and firmer fruits, demonstrating this trade-off [37].

Functional Significance of Leaf Morphological Diversity

The observed variation in leaf morphology (type, attitude, density) extends beyond taxonomic interest, having functional implications for crop performance. The prevalence of drooping leaf attitude (44.44%) and sparse foliage density (44.44%) in our study could represent adaptive strategies. For instance, drooping leaves might be a response to reduce exposure to excessive solar radiation, mitigating heat and light stress [32]. Similarly, a sparse canopy can improve air circulation, reducing the risk of foliar diseases like early blight or powdery mildew in humid environments, while a dense canopy might be advantageous in arid regions for conserving soil moisture and suppressing weeds [33]. The absence of the "standard" leaf type and the presence of rarer types like *Peruvianum* and *Hirsutum* underscore the unique genetic resources present in this collection, which could harbor alleles for pest or disease resistance [19]. The diversity in leaf morphology observed in this study (potato, dwarf, Peruvianum, Pimpinellifolium, Hirsutum) represents a valuable genetic resource for breeding programs targeting improved canopy architecture, light interception, and stress adaptation [37].

Implications for Breeding and Germplasm Conservation

Our comprehensive characterization provides a clear roadmap for leveraging this diversity. For immediate agronomic use, 'Cochoro' emerges as the top candidate for high marketable yield, while 'Melka-salsa' is recommended for superior fruit quality (e.g., high ascorbic acid, cylindrical shape for processing). Previous research supports these recommendations, demonstrating that 'Cochoro' consistently produced the highest marketable yields across both low-altitude (Bako Tibe: 91.5 t ha⁻¹) and high-altitude (Gambella Tare: 84.3 t ha⁻¹) sites, while 'Melka-salsa' exhibited the highest ascorbic acid content (26.30 mg/100g) [37]. For long-term genetic improvement, the identified diversity serves as a foundation for:

1. **Targeted Crossing:** Genotypes with complementary traits can be selected as parents. For example, crossing a high-yielding but stress-susceptible genotype with a stress-tolerant one (e.g., a genotype showing low Ss and BR) could produce segregating populations for selecting resilient, high-yielding lines.
2. **QTL Mapping:** The clear phenotypic variation for traits like fruit shape, cracking, and sunscald makes this germplasm suitable for genome-wide association studies (GWAS) to identify the underlying quantitative trait loci (QTLs) and develop molecular markers for marker-assisted selection (MAS) [34,35].
3. **Germplasm Conservation:** The presence of rare phenotypes (e.g., *Hirsutum* leaf type, ellipsoid fruit shape) highlights the urgency of systematically conserving these genotypes in gene banks, as they represent a unique and irreplaceable pool of alleles for future breeding needs [36].

Conclusion

This study provides a robust, field-based assessment of morphological diversity in a panel of tomato genotypes, revealing significant and exploitable variation in fruit and leaf traits, as well as in susceptibility to abiotic stress-related disorders. Fruit morphology (shape, shoulder, cross-section) proved to be highly effective for cultivar differentiation. The genotype-dependent prevalence of blotchy ripening, sunscald, and radial cracking provides a valuable foundation for breeding programs aimed at enhancing stress resilience. The identification of 'Cochoro' as a high-yielding genotype and 'Melka-salsa' as a quality-focused genotype offers immediate options for producers and breeders. The substantial diversity observed, including rare leaf types and fruit shapes, underscores the importance of conserving this germplasm. This work reinforces the enduring value of systematic morphological characterization as a cornerstone of modern, climate-smart tomato breeding programs.



Declarations

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CRediT Authorship Contribution Statement

Usman Mohammed Ali: Conceptualization, Methodology, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, Visualization, Project Administration.

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Micromorphological and Essential Oil Responses of Japanese Mint (*Mentha arvensis* L.) under Drought and Salinity Stress

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Abstract

Climate change-induced drought and salinity stress pose major challenges to the growth, physiology, and secondary metabolite production of medicinal and aromatic plants, including Japanese mint (*Mentha arvensis* L.). This study evaluated the effects of drought and salinity stress on growth, physiological traits, micromorphological characteristics, and essential oil content of Japanese mint under controlled conditions. The experiment was conducted in a factorial Completely Randomized Design with three drought levels (100%, 75%, and 50% field capacity) and three salinity levels (0, 50, and 75 millimoles sodium chloride). Growth traits showed limited variation under stress conditions; however, physiological responses differed significantly among treatments. Moderate drought combined with salinity improved chlorophyll content, whereas relative water content declined under severe combined stress. Micromorphological analysis revealed amphistomatic leaves with diacytic stomata and higher stomatal density on the abaxial surface than the adaxial surface. Both glandular and non-glandular trichomes were observed, with capitate glandular trichomes being the predominant type. Glandular trichome density increased markedly under severe drought conditions, suggesting stress-associated changes in metabolite production. Essential oil accumulation was strongly influenced by stress treatments, with the highest oil yield (5.16% on dry weight basis) recorded under moderate drought without salinity, while severe drought and higher salinity reduced oil accumulation and biomass production. Essential oil composition remained menthol-dominant across treatments, although menthone and pulegone contents varied under stress conditions. The findings indicate that moderate stress conditions can enhance essential oil yield and maintain desirable oil quality in Japanese mint, also, moderate stress affects in the pathway level rather than chemotypes of oil. These results provide useful insights for sustainable cultivation and quality improvement of Japanese mint under changing environmental conditions.

Keywords: Amphistomatic, Capitate trichomes, Diacytic, Glandular trichomes, Menthol



The ongoing transformation of bottom trawling fishing in the world and in Türkiye over the past 25 years.

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Abstract

Bottom trawls, an effective and widely used method for fishing in parts of the seabed and a few meters above, are constantly evolving and skillfully improved worldwide. The structure and equipment feature of trawl nets are increasing their fishing capacity in accordance with modern technology. Many electronic devices also enhance fishing activities and increase catch efficiency in the identification of target species. On the other hand, this situation also negatively affects the natural state of the marine ecosystem, especially the fish bottoms. Therefore, it is one of the most debated and subject to various bans and restrictions on fisheries worldwide. Various methods exist in different countries in Europe, Australia, and the Far East, according to their own conditions and characteristics, to sustain this fishing profitably without negatively impacting the marine ecosystem and fish stocks. This research aims to evaluate the academic studies of the dynamic development process of bottom trawling over the last 25 years, its current bans and restrictions, and to compare it with diverse practices in other geographical areas. This research's data source consists of bottom trawling operations in our country's seas and participation in bottom trawling operations in countries on different continents, examining the catch composition, catch yield, and the effectiveness and results of various bans and restrictions imposed on this type of fishing. According to the research findings and results, although each country imposes numerous bans and restrictions on bottom trawling, the catch of non-target species, also known as discards, and economically valuable species that have not reached reproductive maturity at a young age and size, constitutes at least one-third of the total catch on average in all countries. This ratio varies depending on the country and the species being caught. For sustainable fisheries, it is crucial that the bans and restrictions imposed on this fishing gear, considering the dynamic characteristics of our seas affected by climate change, are updated promptly when necessary, taking into account location, time, and technical specifications, and that the decisions made are meticulously monitored in practice in the field.

Keywords: Bottom trawling, bottom-dwelling fish, sustainable fisheries, fish finder devices, discard species

Dünyada ve Türkiye'deki dip trolü balıkçılığının 25 yıllık süreçte değişiminin izlenmesi

Özet

Denizlerin taban kısmı ve birkaç metre yukarısında yaşayan su ürünlerinin avcılığında etkin ve yaygın olarak kullanılan dip trolleri dünyada ve ülkemizde sürekli gelişim içerisinde. Trol ağlarının yapısal ve donanım özellikleri modern teknolojiye uygun olarak, avcılık kapasitelerini artırmaktadır. Hedef türlerin tespitinde birçok elektronik cihaz da avcılık faaliyetlerini kolaylaştırmakta ve av verimi artırmaktadır. Bu durum diğer yandan başta dip balıkları olmak üzere deniz ekosisteminin doğal dengesini olumsuz yönde etkilemektedir. Bu nedenle dünyada ve ülkemizde en çok tartışılan ve farklı yasak ve sınırlamalara maruz kalan bir su ürünleri avlanma aracıdır. Deniz ekosistemine ve su ürünleri stoklarına olumsuzluk yaratmadan, rantabl olarak bu avcılığın sürdürülmesinde Avrupa, Avusturalya ve Uzakdoğu da ki farklı ülkeler kendi şartları ve coğrafi özelliklerine göre çeşitli önlemler almaktadırlar. Ülkemizde de en çok gündemde olan ve tartışılan dip trolü avcılığının son 25 yıllık süre içerisindeki yapısal gelişim süreci ile, mevcut yasak ve sınırlamalarının akademik araştırmalar ışığında değerlendirilmesi, diğer farklı coğrafyalardaki ülkelerdeki uygulamaları ile karşılaştırılması bu araştırmada amaç edinilmiştir. Ülkemiz denizlerinde kullanılan dip trolleri ve dünyanın farklı kıtalarındaki ülkelerdeki dip trolü avcılık operasyonlarına katılarak, elde edilen av kompozisyonu, av verimi ile bu avcılığa getirilmiş olan çeşitli yasak ve sınırlamaların uygulamadaki etkinliği ve sonuçları araştırmanın veri kaynağını oluşturmaktadır. Araştırma bulguları ve sonuçlarına göre dip trolü avcılığı faaliyetine her farklı ülke birçok yasak ve sınırlama getirmesine karşın, tüm ülkelerde iskarta olarak da bilinen hedef dışı türler ile üreme olgunluğuna ulaşmamış küçük yaş ve boylarda olan ekonomik türlerin de avcılığı da ortalama olarak toplam av miktarının en az 1/3 oranında gerçekleşmektedir. Bu oran ülkelere ve avlanacak türlere göre farklılıklar göstermektedir. Sürdürülebilir su ürünleri avcılığı için, yer, zaman ve teknik özellikler bakımından bu av aracına getirilmiş olan yasak ve sınırlamaların iklim değişikliği etkisinde olan denizlerimizin dinamik özelliklerini de değerlendirerek gerektiğinde gecikmeden güncellenmesi ve alınan kararların uygulamada, sahada titizlikle kontrol edilmesi büyük önem taşımaktadır.

Anahtar kelimeler: Dip trolü, dip balıkları, sürdürülebilir su ürünleri avcılığı, balık bulucu cihazlar, iskarta türler,



Effects of Fermentation with Different Starter Culture Combinations at Low Temperature and Different Packaging Materials on Selected Quality Parameters of Akçakatık Cheese

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Abstract

Background: Akçakatık cheese is a traditional cheese produced using traditional methods and containing black cumin and cloves. This study aimed to determine the effects of fermentation at low temperature using different starter culture combinations and ripening in rumen and polyethylene packaging materials on selected physicochemical and microbiological properties of Akçakatık cheese.

Methods: In cheese production, pasteurized milk was inoculated with 3% yogurt culture (YC) and a combination of yogurt and cheese cultures (YCC). As an alternative to the traditional production method, the milk was allowed to ferment at 20°C for approximately 24 h. The resulting cheese samples were packaged in rumen and polyethylene packaging materials and stored at +4°C for 90 days. Physicochemical, color, and microbiological properties of the samples were analyzed throughout the storage period.

Results: Titratable acidity values increased throughout storage. Acidity development was more pronounced in the YCC group, in which the combination of yogurt and cheese cultures was used. Cheese samples ripened in rumen packaging had higher dry matter, fat, ash, salt, and color b* values, while their water activity values were significantly lower. The similarity of tyrosine values among all samples throughout storage indicated that no significant bitterness developed during storage. In terms of color, L* and a* values decreased, whereas tyrosine values remained unchanged. Moisture loss resulting from the permeable structure of the rumen packaging increased dry matter and other parameters associated with dry matter. The color values were also affected by the matte and dry appearance of the product. According to the microbiological analyses, cheese samples ripened in polyethylene packaging had higher counts of *Lactobacillus* spp. and *Lactococcus* spp., whereas the counts of these microorganisms decreased in the rumen-packaged samples due to the reduction in water activity during storage. In addition, prolonged fermentation at 20°C supported the growth of mesophilic starter culture microorganisms. Yeast and mold counts increased throughout storage and reached higher levels in the rumen-packaged samples. Lipolytic bacterial counts decreased regularly throughout storage in all samples, whereas proteolytic bacterial counts showed a limited increase during the initial period followed by a decrease during the later stages of storage.

Conclusion: Different starter culture combinations had significant effects on both the physicochemical and microbiological properties of Akçakatık cheese during the ripening process.

Keywords: Akçakatık cheese, starter culture, rumen packaging, ripening

Düşük Sıcaklıkta Farklı Starter Kültür Kombinasyonu ile Mayalamanın ve Farklı Ambalaj Kullanımının Akçakatık Peynirinin Bazı Kalite Parametreleri Üzerine Etkisi

Özet

Arka Plan: Akçakatık peyniri, geleneksel yöntemlerle üretilen çörekotu ve karanfilli geleneksel bir peynirdir. Bu çalışmada, düşük sıcaklıkta farklı starter kültür kombinasyonları ile gerçekleştirilen fermentasyonun ve karın ile polietilen ambalaj materyallerinde olgunlaştırmanın Akçakatık peynirinin bazı fizikokimyasal ve mikrobiyolojik özellikleri üzerindeki etkilerinin belirlenmesi amaçlanmıştır.

Yöntemler: Peynir üretiminde düşük sıcaklıkta pastörize edilen süte %3 oranında yoğurt kültürü (YK) ile yoğurt ve peynir kültürü kombinasyonu (YPK) ilave edilmiştir. Geleneksel üretime alternatif olarak sütler 20°C’de yaklaşık 24 saat fermentasyona bırakılmıştır. Üretilen peynir örnekleri karın ve polietilen ambalaj materyallerinde paketlenmiş ve +4°C’de 90 gün depolanmıştır. Depolama süresince örneklerin fizikokimyasal, renk ve mikrobiyolojik özellikleri analiz edilmiştir.

Sonuçlar: Depolama süresince titrasyon asitliği değerleri artış göstermiştir. Yoğurt ve peynir kültürü kombinasyonunun kullanılan YPK grubu örneklerde asitlik gelişiminin daha belirgin olduğu belirlenmiştir. Karın ambalajında olgunlaştırılan peynirlerde kurumadde, yağ, kül, tuz, renk b* değerlerinin daha yüksek olduğu, su aktivitesi değerlerinin ise önemli düzeyde azaldığı tespit edilmiştir. Tirozin değerinin depolama süresince tüm örneklerde benzer olması, depolama sırasında acılaştırmanın meydana gelmediğini göstermektedir. Renk açısından L* ve a* değerlerinin azaldığı, tirozin değerinin değişmediği belirlenmiştir. Karın ambalajının geçirgen yapısına bağlı olarak oluşan nem kaybından dolayı kurumadde ile ilişkili olan diğer değerlerin de arttığı, ürünün mat ve kuru görünümü nedeniyle renk değerlerinin etkilendiği tespit edilmiştir. Mikrobiyolojik analiz bulgularına göre, Polietilen ambalajda olgunlaştırılan peynirlerin





Lactobacillus spp. ve *Lactococcus* spp. sayılarının daha yüksek olduğu, karın ambalajda su aktivitesinin depolama süresince azalması nedeniyle bu mikroorganizma sayılarının azaldığı saptanmıştır. Ayrıca 20°C’de gerçekleştirilen uzun süreli fermentasyonun mezofilik starter kültür mikroorganizmalarının gelişimini desteklediği saptanmıştır. Maya-küf sayılarının depolama süresince arttığı ve karın ambalajlı örneklerde daha yüksek değerlere ulaştığı tespit edilmiştir. Tüm örneklerin lipolitik bakteri sayıları depolama boyunca düzenli olarak azalırken, proteolitik bakteri sayılarında başlangıçta sınırlı artış, ilerleyen dönemlerde ise azalma meydana gelmiştir.

Sonuç: Farklı starter kültür kombinasyonun Akçakatık peynirlerinin olgunlaşma sürecinde hem fizikokimyasal hem de mikrobiyolojik özellikler üzerinde önemli etkiler yarattığı belirlenmiştir.

Anahtar kelimeler: Akçakatık peyniri, starter kültür, karın ambalajı, olgunlaşma



Methods for Controlling *Varroa destructor* in Organic Beekeeping

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Abstract

Organic beekeeping is a controlled and certified form of beekeeping in which bees collect nectar, pollen, water, and propolis from nature and transform them into various bee products, with every stage of production, from production to consumption, being subject to control and certification (Cengiz, Genç, & Dodoloğlu, 2010). There are various diseases and pests affecting the honey bee (*Apis mellifera*), which is a social insect species. It has been observed that, if these diseases and pests are not controlled, colony productivity decreases and colonies may eventually collapse (Burğut, Kumova, Eldeniz, & Burğut, 2011). *Varroa destructor*, known as one of the most important parasites of honey bees worldwide and in Türkiye, feeds on the hemolymph of honey bees, causing colonies to weaken and eventually collapse within a few years. Today, various methods are available for the detection of *Varroa destructor*. Among the principal diagnostic methods are shaking adult honey bees in liquids such as ether, alcohol, hot water, detergent, or gasoline; treating honey bees with powdered sugar; and examining drone brood cells for the presence of the parasite (Tutkun, 2016). Chemical, genetic, and locally adapted control methods are used to combat honey bee diseases and parasites. In particular, chemical methods are widely used for the control of *Varroa destructor* and are frequently preferred and applied by beekeepers. However, the intensive use of chemicals has resulted in the development of resistance in pests and pathogens, gradually reducing the effectiveness of the treatments used for control (Burğut et al., 2011). Various organic treatments are used for the control of *Varroa destructor*. Research has increasingly focused on organic acids and essential oils derived from aromatic plants because they are considered safer in terms of residues. In many countries, particular attention has been given to the effects of essential oils, and extracts or dried leaves of plants such as thyme (*Thymus* spp.), juniper tar, pine (*Pinus* spp.), tobacco (*Nicotiana* spp.), and pyrethrum (*Pyrethrum* spp.) have been used at different doses and in various combinations to control the varroa mite (Tutkun, 2016). Thus, the use of such natural products can help reduce the risk of pesticide residues in honey while providing beekeepers engaged in organic production with alternative, naturally derived methods for controlling *Varroa destructor* (Şahinler & Alapala, 2017).

Keywords: Honey bee, organic beekeeping, *Varroa destructor*, control methods

Organik Arıcılıkta *Varroa Destructor* ile Mücadele Yöntemleri

Özet

Organik arıcılık; doğada bulunan nektar, polen, su ve propolisin arılar tarafından toplanarak çeşitli arı ürünlerine dönüştürülmeleri işleminde, üretimden tüketime kadar her aşaması kontrollü ve sertifikalı bir yetiştiricilik biçimidir. (Cengiz&Genç& Dodoloğlu, 2010). Sosyal canlılar gurubunda yer alan bal arısı türünü (*Apis mellifera*) etkileyen farklı arı hastalıkları ve zararlıları vardır. Bu hastalıklarla ve zararlılarla mücadele edilmediği takdirde kolonilerin verim düzeylerinin düştüğü ve hatta öldükleri gözlemlenmiştir (Burğut& Kumova& Eldeniz& Burğut, 2011). Dünya’ da ve ülkemizde bal arılarının en önemli paraziti olarak bilinen *Varroa destructor* (arı akarı) bal arılarının hemolenfini emerek kolonilerin zayıflamasına ve birkaç yıl içerisinde sönmesine neden olmaktadır. Günümüzde *Varroa destructor* teşhisi amacı ile kullanılan pek çok yöntem bulunmaktadır. Ergin bal arıların eter, alkol, sıcak su, deterjan, gazolin gibi sıvılarla çalkalanması veya bal arılarının pudra şekeri ile muamele edilmesi, erkek petek gözlerinde parazit varlığının araştırılması gibi teknikler hastalığın tanısında kullanılan başlıca yöntemlerdendir (Tutkun, 2016). Bal arısı hastalık ve parazitleriyle mücadelede; kimyasal, genetik ve yöresel kontrol yöntemleri uygulanmaktadır. Özellikle *Varroa destructor* mücadelesinde kimyasal yöntemler çok yoğun bir şekilde uygulanmakta olup arıcılar tarafından çok tercih edilmekte ve uygulanmaktadır. Ancak kimyasalların yoğun olarak kullanılması neticesinde hastalık ve zararlılar direnç kazanmaya başladı ve mücadelede kullanılan ilaçlar etkisiz hale gelmeye başlamıştır (Burğut ve ark., 2011). *Varroa destructorun* tedavisinde bir çok organik ilaçlar kullanılmaktadır. Organik asitler ve aromatik bitkilerden çıkarılan uçucu yağ asitlerinin kalıntı (rezidü) yönünden daha güvenli olmaları nedeniyle araştırmalar bu konuda yoğunlaştırılmıştır. Birçok ülkede öncelikle uçucu yağ asitlerinin etkileri üzerinde durulmuş, kekik (*Thymus* spp), ardıç katranı, çam yaprağı (*Pinus* spp), tütün (*Nicotiana* spp) ve pireotu (*Pyrethrum* spp) gibi bitkilerin özü veya kurutulmuş yaprakları farklı doz ve karışımlar halinde arı akarı mücadelesinde kullanılmıştır (Tutkun, 2016). Böylece hem pestisit kalıntılarının balda kalması önlenmiş hem de organik arıcılık yapan arıcılara *Varroa destructor* ile mücadele için doğal ürünler sunulabilmiştir (Şahinler & Alapala, 2017).

Anahtar kelimeler: Bal arısı, Organik arıcılık, *Varroa destructor*, Mücadele yöntemleri



Giriş

Dünya nüfusunun hızla artmasına paralel olarak ortaya çıkan daha fazla üretme zorunluluğu gıda üretimde güvenlik ve kalite gibi bazı özelliklerin göz ardı edilmesi ihtimalini doğurmuştur. Ancak zamanla beslenme bilincinin değişmesi ve gelir seviyesinin yüksek olmasına bağlı olarak bazı toplumlarda yeni talepler ortaya çıkmıştır (Demir& Sandalcıoğlu&Erkan, 2023). Organik arıcılık, arı ürünlerinin üretiminde, üretimden tüketime kadar tüm aşamalarında hiçbir suni besleme ve kimyasal ilaçlama yapmadan, doğal yapısı bozulmamış alan veya organik tarım alanlarında yapılan arıcılık faaliyetleri şeklinde tanımlanmaktadır (Gökçe&Konak, 2003). Arıcılık ürünlerinin organik üretim olarak nitelendirilmesi için; kovanların özellikleri, çevre kalitesi, arıcılık ürünlerinin elde edilmesi, işlenmesi ve depolanması koşullarının ne derece organik tarım standartlarına göre uygulandığına bağlıdır. Bu sebeple bir arıcılık işletmesi ile aynı bölgede tarımsal faaliyetlerin olması, mevcut tüm faaliyetlerin organik üretim koşullarına uygun olmasını gerektirir (Gül& Şahinler& Akyol& Şahin, 2005). Bu koşullar Tarım ve Orman Bakanlığının 118 no'lu eğitim broşüründe belirttiği “Organik Arıcılık Esasları” temel alınmalıdır. Organik arıcılık için bakanlık tarafından tavsiye edilen kriterler şu şekilde belirlenmiştir: Organik arı yetiştiriciliği yapılacak alan, asgari uçuş çapı 3 km olmak koşuluyla 1 yıl önceden kontrol altına alınır ve harita üzerinde yeri belirtilir. Ayrıca uçuş çapı dışında kirlenmeye yol açması muhtemel olan; kent merkezleri, sanayi bölgeleri, atık merkezleri, maden işletmeleri, hidrolik ve termik enerji santralleri ile atık yakma merkezlerinden 3 km, Karayolları Genel Müdürlüğü ağındaki ana yollara 1 km uzaklıkta olmalıdır. Kovanların yerleştirildiği yerde, yeterli nektar, polen ve temiz su kaynağı bulunmalıdır. Karantina tedbirleri uygulanan ve kimyasal mücadele yapılan alanlarda organik arıcılık yapılamaz. Bir mütessesbisin, aynı bölgede birçok arıcılık birimini işletmesi durumunda bütün birimlerin bu yönetmelik gereklerine uygun olması gerekmektedir (Kekeçoğlu&Çaprazlı&Bir, 2021). Organik arıcılık, her aşaması kontrol ve sertifikasyon kuruluşları tarafından denetlenilen bir faaliyettir. Organik arıcılık faaliyetinde balın yanında propolis, polen, bal mumu ve arı sütü gibi arı ürünlerine de yer verilmektedir. Arı ürünlerinden bal, polen ve propolis doğadan toplanmakta, arı sütü, arı zehri ve bal mumu ise bal ve polen kullanılarak arıların metabolizmalarından elde edilmektedir. Elde edilen arı ürünlerinin organik niteliğe sahip olması; arı ürünlerin üretimden tüketime kadar olan her aşamasının organik tarım standartlarına uygunluk göstermesine bağlıdır (Merdan, 2020).

Varroa Destructor ve Mücadele Yöntemleri

Bal arıları istenildiği zaman istenildiği kadar bulunması, bölgeye ve bitkiye bağımlı olması, istenildiğinde taşınabilmesi, yüksek uçuş ve çalışma etkinliği nedeniyle gerek bitkisel üretimde gerekse ekolojik dengenin korunmasının sağlanmasında çok önemli bir konuma gelmiştir. Bu nedenle bal arılarının görevlerini etkin bir şekilde yapabilmeleri için iyi bir bakım besleme programına tabi olmaları gerekir. Arıların kendilerinden beklenen görevleri yerine getirebilmeleri ve etkin bir şekilde çalışabilmelerini sınırlayan faktörlerden birisi de kolonilerin sağlık problemleridir. Tüm canlılarda olduğu gibi arılarda da bir çok hastalık ve parazit arıların yaşamlarını tehdit etmektedir. Gezgin arıcılık programları arı hastalık ve parazitlerinin arılar ve arıliklar arasında hızla yayılmasına neden olmaktadır. *Varroa destructor*, Türkiye'ye 1976 yılında Bulgaristan üzerinden Trakya bölgesine, oradan da ayçiçeği balı üretmek için bölgeye giden Anadolu'daki arıcıların arıliklarına bulaşmış ve Anadolu'ya taşınmıştır. 1977-78 yıllarında Ege bölgesinde görülen parazit daha sonra çam balı üretmek amacıyla ülkenin tüm bölgelerinden Ege Bölgesine özellikle Muğla iline gelen arıcıların arıliklarına bulaşmış ve onların da kendi bölgelerine dönmeleri ile 4-5 yıl gibi çok kısa bir süre içerisinde tüm ülkeye yayılmıştır. Parazit ülkemizde ilk yıllarda çok büyük tahribat yaparak yaklaşık 600 bin koloninin sönmesine ve 7000-7500 ton ürün kaybına neden olmuştur (Akyol&Korkmaz, 2005). Koloni sağlığı açısından hayati önemi olan patojenler arasında ön sıralarda yer alan *Varroa destructor* dünyanın farklı yerlerine yayılmış durumdadır. *Varroa destructor* erginleri sadece bal arısı üzerinde bulunan, kolonilerde verim ve yaşam kayıplarına neden olan bir dış parazittir. *Varroa destructor* ve bal arıları kolonideki yavru gözlerini ortak kullanırlar. Bal arısı pupalarının vücut sıvılarını emerken bazı virüsleri de nakleden *Varroa destructor* kış salkımının oluşamaması ya da erken sonlanmasına neden olabilir. *Varroa destructor* karşı çeşitli mücadele yöntemleri vardır. Bunlar; Biyolojik Kontrol Yöntemleri, İnorganik sentetik kimyasallar ve Organik ürünlerin kullanılmasıdır. Yavru gözlerin taşınması ve tuzak yöntemi, işçi arı gözlerinin kovandan uzaklaştırılması, erkek arı gözlerinde tuzaklama yöntemi, yapay oğul alarak tuzaklama yöntemi, tel kafesli ve çekmeceli taban uygulama yöntemi, genç ana arı kullanma yöntemi, polen tuzağı kullanmak biyolojik kontrol yöntemleri arasında kullanılır (Akyol&Korkmaz, 2006).

Günümüzde bal arısı kolonilerinde *Varroa* akarı popülasyonunun kontrolü için kimyasal mücadele büyük önem taşımaktadır. Bu kontrol akarisitlerin kullanılmasıyla sağlanabilmektedir. *Varroa* akarlarının kontrolünde kullanılan akarisit kimyasalların tamamına “Varroasitler” adı verilmektedir. Piretroidler (tau-fluvalinat, flumetrim), formamidinler (Amitraz) ve organofosfatlar (Coumaphos) gibi sentetik akarisitler *Varroa* kontrolünde yıllardır kullanılan en etkili ilaçlar olmuştur (Gürçay&Gül&Kaya, 2024). Ancak mücadelede kullanılan ilaçların bal ve diğer arı ürünlerinde kalıntı bırakması ciddi sağlık riski oluşturur ve arı ürünlerinin değerini düşürür (Muz&Arslan&Girişgin, 2014).



Varroa kontrolünde, organik asitler ve aromatik bitkilerden çıkarılan uçucu yağ asitlerinin kalıntı (rezidü) yönünden daha güvenli olmaları nedeniyle araştırmalar bu konuda yoğunlaştırılmıştır. Birçok ülkede öncelikle uçucu yağ asitlerinin etkileri üzerinde durulmuş, kekik (*Thymus spp*), ardıç katranı, çam yaprağı (*Pinus spp*), tütün (*Nicotiana spp*) ve pireotu (*Pyrethrum spp*) gibi bitkilerin özütü veya kurutulmuş yaprakları farklı doz ve karışımlar halinde *V. destructor* mücadelesinde kullanılmıştır. Timol, isopropyl metakreozol yapısında eterik (uçucu) bir yağ asididir. Kapalı formülü C₁₀H₁₄O dur. Timol akarisit etkiye sahiptir ve aynı zamanda bu madde bir protein denatürantıdır. Yani *V. destructorun* sitoplazmik membranın geçirgenliğini değiştirmekte ve plazmanın hücre dışına çıkışını artırmaktadır. Böylece hayati organlardaki tüm hücresel prosesleri bozarak etkisini göstermektedir. Diğer kimyasal bileşiklerden farklı olan bu etki mekanizması sayesinde *V. destructor* kısa sürede timolün öldürücü etkisine maruz kalmakta ve dolayısıyla uzun yıllar direnç kazanması mümkün olmamaktadır (Tutkun, 2016).

Varroa destructor akarına karşı pudra şekeri uygulaması periyodik şekilde ve destekleyici tedavi olarak başarıyla uygulanabilir. Yöntemin arılar üzerinde olumsuz bir etkisinin olmaması, arı ürünlerinde herhangi bir kalıntı bırakmaması, mekanik olarak etkisini gösterdiği için akarların direnç geliştirememesi gibi çeşitli avantajları nedeniyle, diğer kimyasal ilaçların aksine nektar akımı zamanında da kullanılabilecektir (Muz ve ark., 2014).

Nentchev'in (2003) yaptığı bir çalışmada *Hyssopus officinalis L.* Eterik yağı *Varroa destructor* ile mücadelede uzun vadeli kullanıldığında umut verici ekolojik bir araçtır. Kış döneminde kullanıldığında arı kolonilerindeki *Varroa*'ların popülasyon artışını % 80,08 oranda azalmaktadır. *Hyssopus officinalis L.* eterik yağı kullanıldığında arı kolonisi üzerinde veya uygulayan arıcılar üzerinde anormal bir etkisi görülmemiştir.

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Carcass yield of West African dwarf goats fed graded level of millet husk – based diets

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Abstract

The study evaluated the effect of replacing wheat bran with millet husk on the carcass traits of West African dwarf (WAD) goats under. Twenty weaner goats were randomly allocated to five dietary treatments (T1 – T5 in a Completely Randomized Design, with 4 animals per treatment. T1 serves as the control with 0% millet husk, while T2, T3, T4, and T5 contained 6.25%, 12.5%, 18.75 and 25% millet husk inclusion levels as a replacement for wheat bran respectively. The feeding trial lasted 90 days and carcass characteristics were assessed. The results revealed that goats on T1 exhibited superior growth and carcass characteristics compared to those on T2 –T5 ($p<0.05$). However, goats fed diets containing up to 50% millet husk replacement maintained appreciable live weight and carcass traits, indicating that millet husk and serve as a viable partial substitute for wheat bran. The inclusion of millet husk also promotes the utilization of an agricultural waste, reduce environmental pollution, and adds economics value to millet husk. Additionally, it provides a practical alternatives to mitigate feed scarcity during the lean period of the year. It is therefore concluded that millet husk can replace wheat bran at up to 50% in the diets of WAD goats without compromising growth and carcass performance.

Keywords: WAD goat, millet husk, wheat bran, carcass traits and feed scarcity

Introduction

In Nigeria, goat farming is majorly on the indigenous breed of West African dwarf (WAD) goat in the forest zone, Sahel and red Sokoto goats in the drier parts of the northern country. These breeds have adapted to the environment and their reproductive traits are not compromised. WAD goats are known for their high prolificacy and have an average of 1.7kg at birth. They often give birth to multiple litters of twins, triplet and even quadruplet and, under traditional system they kids three times in two years (Mamabolo and Web, 2005). In this vein, the flock size grow fast and give returns to the keeper. They support income generation through sale of live animals, and their products of meat, milk, and manure which is used to promote crop production (Alilo *et al.*, 2018).

Most importantly, WAD goats could be maintained on low cost feed resources like grasses, browse leaves, farm wastes, kitchen wastes and industrial by-products (Ogunbosoye, 2012). Goetsch *et al.* (2011) and Wang *et al.* (2014) reported that feeding concentrate –based diets improves the growth rate, dressing percentage and carcass characteristics of goats compared to grass-fed goats. Similarly, Bambou *et al.* (2021) concluded in their research that the feeding mode and the age at slaughter greatly influenced the carcass traits of goat.

Millet husk (or hull) is a byproduct from the millet crop and constitute an important roughage source for ruminants in many areas. The husk is the scaly protective casings of the millet that is dehulled to obtain the grain parts. The husk is indigestible by humans, but livestock can eat it and used as fodder feed materials (Jones, 2006). Million tons of millet husk are wasted in Nigeria after threshing of millet in the farms. The proximate composition of millet husk was reported to be 5.2% CP (Maidala and Bakoji, 2016). These waste materials can be harnessed and used as a source of fibre or energy for ruminant animals, most especially when it is carefully combined with other ingredients that are of high quality to produce a least cost feed for ruminants, for maximum profits.

In the feed industry, maize, soybean, and wheat are the main feed sources from grain that are in competition with humans. Competition with humans on millet is limited owing to wide usage of millet as raw material in food industry. During the processing of these feed materials, tons of by-products, such as straw, hull, and husk are produced. The use of these by-product in animal nutrition especially ruminant nutrition could greatly lower the cost of production while also serving as back-up feed materials in case of scarcity of forages especially during the dry season. Their utilization by the animal would also help to reduce environmental pollution that characterized their disposal and increase feed availability to mitigate feed shortage and to enhance ruminant productivity. Hence, the objective of this study is to investigate the carcass traits of WAD goat fed millet-based diet in replacement of wheat bran at graded level.



Materials and methods

Collection and Processing of Millet Husk

Millet husk was obtained from milling industries in Niger State. The husk was transported to the Teaching and Research Farm of Kwara State University, Malete. All unwanted materials were removed from the husk, the husk was dried properly and then made ready for use.

Experimental Animals

The experimental animals comprised of twenty (20) growing WAD goats of average 8 months with average weight of 7.5kg sourced from Ajase Ipo Cattle market, Kwara State. They were quarantined upon arrival at the Small Ruminant Unit of the Teaching and Research Farm and administered with Rinderpest Tissue Culture (RTCV) vaccine, subcutaneously at 1 ml/10 kg body weight against Peste de Petite Ruminant, Ivermectin (dewormer at 3 ml/10 kg body weight), dusted with ectoraid against ectoparasites and treated with oxytetracycline HCl (a broad spectrum antibiotics) prior to the commencement of the experiment. The animals were housed in their individual pen, supplied with a plastic container to offer experimental diets and have *ad libitum* access to clean water in their specific compartment throughout the entire feeding trial period.

Experimental Design and Diet Formulation

The animals were randomly allotted to five dietary treatments in a completely randomized design (CRD) with four (4) goats in each of the treatments. The five experimental treatments administered are:

Treatment 1: Basal diet at 0% millet husk (Control).

Treatment 2: Basal diet at 25% millet husk

Treatment 3: Basal diet at 50% millet husk

Treatment 4: Basal diet at 75% millet husk

Treatment 5: Basal diet at 100% millet husk

Table 1: Composition (%) of the Experimental Diets at Graded Level of Millet Husk

Ingredients	Treatments				
	T1 (0%) MH	T2 (25%) MH	T3 (50%) MH	T4 (75%) HM	T5 (100%) RMH
Wheat bran	25	18.75	12.5	6.25	0
RMH	0	6.25	12.5	18.75	25
SBMW	10	10	10	10	10
Cassava Peel	45	45	45	45	45
Palm Kernel Cake	10	10	10	10	10
Maize	2.5	2.5	2.5	2.5	2.5
Urea	4	4	4	4	4
Bone meal	2	2	2	2	2
Oyster Shell	0.5	0.5	0.5	0.5	0.5
Salt	1	1	1	1	1

MH = raw millet husk, SBM = soybean waste

Chemical Composition

Crude protein, crude fibre, ether extract and ash concentrations of the experimental diets were estimated. The moisture content of the diets was determined by drying in a forced-air oven at 60°C until constant weight was achieved. After drying, samples was ground to pass a 2mm sieve and then subjected to proximate analysis according to AOAC, (2005). Neutral detergent fibre (NDF), Acid detergent fibre (ADF), Acid detergent lignin (ADL) and Hemicelluloses and cellulose were analyzed according to Van Soest *et al.* (1994) procedure.

Carcass Evaluation

At the termination of the feeding trial, the animals were fasted for 24 hours (Kalio and Amadi 2018), weighed and three animals per treatment were slaughtered. They were bled by severing both the carotid arteries and jugular veins on both sides, using a sharp knife without stunning. After slaughter, they were skinned and then washed thoroughly. The warm carcass weight (WCW) was then determined. The carcasses were eviscerated to separate the various internal organs (stomach, intestine, liver, kidney, etc). The warm carcasses (WCs) were carefully split into two halves along the vertebral axis and subsequently separated into the various cuts using a sharp machete.

The separation into the cuts comprised the head, hind and fore leg, lion, flank, breast, rack, shoulder, neck and tail. The method of separation of the carcass to their primal parts was according to the procedures described by Kalio and Amadi (2018). The shoulder was separated between the 5th and 6th vertebrae perpendicular to the back line, 1.25cm above the elbow joint. The breast, shank and flank were separated from the face of the leg parallel to the back line and perpendicular to the first cut. Leg removal was at the tip of the ilium perpendicular to the back



line, while the loin and rack were cut along the back of the 13th rib perpendicular to the backline. The carcass weight and relative prime cuts weights were determined pre-chilled. The relative weights were calculated by expressing the weights of the cut parts as percentage of the dressed carcass weight. Each primal cut was weighed and its proportion relative to the carcass determined.

Organ Weight Determination

After dissection, the internal organs such as the liver, kidney, lung, heart, and spleen, abdominal fat, intestine, both left and right testes and oesophagus were weighed (using a sensitive digital weighing balance).

Data Analysis

Data collected for all determined parameters were subjected to Analysis of Variance (ANOVA) and differences between treatment means were separated by least significance difference using General Linear Model procedure of Statistical Analysis System (DSAASTAT, 2011).

Results and Discussion

Carcass Yield of WAD Goats Fed Graded Levels of Millet Husk as a Replacement of Wheat Bran

The results of the carcass yield of the goat fed graded levels of millet husk in replacement of wheat bran is presented in Table 2. There were significant variations ($p < 0.05$) between the experimental treatments in the parameters investigated (live weight, slaughtered weight and carcass weight). Goats fed the control diet had superior live weight (11.20 kg), slaughter weight (10.80 kg) and carcass weight (8.20 kg) compared to those on millet-based diets. This suggests wheat bran was more effective in supporting weight gain and carcass yield. It can be observed that the live weight and slaughter weight of goats on T2 and T3 were statistically the same but were better than those goats on T4 and T5. The carcass weight of goats on T2, T3 and T5 were statistically the same and were better than those goats on T4. Nonetheless, these parameters were not too low for the animals fed millet-based diets. The carcass yield of WAD goat in this study is comparable to that obtained by Kalio and Amadi (2018) in WAD goat fed unconventional feed materials.

Table 2: Carcass Yield of WAD goats Fed Graded Levels of Millet Husk as a Replacement of Wheat Bran

Parameters	Treatments					
	T1	T2	T3	T4	T5	SEM
Live Weight (kg)	11.20 ^a	9.40 ^b	9.80 ^b	7.80 ^c	7.80 ^c	0.47
Slaughter weight (kg)	10.80 ^a	9.00 ^b	9.00 ^b	7.60 ^c	7.40 ^c	0.46
Carcass weight (kg)	8.20 ^a	6.80 ^b	6.80 ^b	5.60 ^c	6.80 ^b	0.33

^{a,b,c} means with different superscript letters across the rows indicate the significant difference ($P < 0.05$); SEM = Standard Error of Mean. T1 = 0% millet husk (Control), T2 = 25% millet husk, T3 = 50% millet husk, T4 = 75% millet husk, T5 = 100% millet husk

Table 3 shows the carcass characteristics (primal cuts) of WAD goats fed graded level of millet husk in replacement of wheat bran. The carcass components observed varied ($p < 0.05$) among treatments with goats on T1 having the highest primal cut values and hence better carcass characteristics than the other treatment groups. This is followed by the goats on T2, and then those on T5 and T3 while those on T4 had the least values. It is observed that the goats on T2 had better primal cut after the control group. This indicates that the lower inclusion level of millet husk resulted in an improved muscle and bone structures which resulted in an appreciable development of various body parts of the goats. The prime cuts of WAD goat in this study is comparable to that obtained by Babale *et al.* (2019) in WAD goat fed groundnut haulms and cowpea husk.

Table 3: Prime Cuts of WAD goats Fed Graded Levels of Millet Husk as a Replacement of Wheat Bran

Parameters	Treatments					
	T 1	T 2	T 3	T4	T5	SEM
Neck (g)	0.37 ^a	0.37 ^a	0.29 ^b	0.32 ^{ab}	0.33 ^{ab}	0.02
Ribs (g)	1.07 ^a	0.71 ^b	0.61 ^b	0.64 ^b	0.76 ^b	0.08
Back (g)	0.54 ^b	0.42 ^d	0.50 ^c	0.42 ^d	0.59 ^a	0.01
Fore Shank (g)	0.83 ^a	0.59 ^c	0.64 ^{bc}	0.41 ^d	0.74 ^{ab}	0.04
Hind Shank (g)	1.01 ^a	1.01 ^a	0.84 ^b	0.57 ^c	0.70 ^{bc}	0.05

^{a,b,c,d} means with different superscript letters across the rows indicate the significant difference ($P < 0.05$); SEM = Standard Error of Mean. T1 = 0% millet husk (Control), T2 = 25% millet husk, T3 = 50% millet husk, T4 = 75% millet husk, T5 = 100% millet husk



Organ Weight (g) of WAD goats Fed Graded Levels of Millet Husk as a Replacement of Wheat Bran

The relative organ weights (%) of the liver, kidney, stomach, heart, abdominal fat and large intestine were significantly ($P<0.05$) influenced by the experimental treatments (Table 4). The relative weight of liver, kidney, heart and abdominal fat were highest in goats on control diets (T1) compare to other treatments groups. However, goats on T2 also recorded highest values in heart and stomach while goats on T3 had the highest values in large intestine. Thus goats on T2 and T3 recorded an appreciable organ weight in this study, suggesting that millet husk at lower inclusion level improved the performance of the goats than inclusion at higher level. This may be attributed to the higher fibre content and abrasive nature of millet husk and the possible presence of anti-nutritional factors. It is a common practice in experimental trials to use weights of some internal organs like the liver or kidneys as indicators of toxicity because they should differ significantly if there was any serious health effect or effect of anti-nutritional factors on them being major detoxification organs (Lopez-Moreno *et al.*, 2020). The organ weight of WAD goat in this study is lower than what was obtained by Wuanor and Carew (2018) in WAD goat. The difference may be due to age, management system and nutritional differences.

Table 4: Organ Weight (g) of WAD goats Fed Graded Level of Millet Husk as a Replacement of Wheat Bran

Parameters	Treatments					SEM
	T1	T2	T3	T4	T5	
Liver	0.18 ^a	0.12 ^b	0.10 ^b	0.12 ^b	0.13 ^b	0.005
Kidney	0.04 ^a	0.02 ^b	0.03 ^{ab}	0.02 ^b	0.01 ^b	0.005
Heart	0.05 ^a	0.05 ^a	0.02 ^b	0.03 ^b	0.03 ^b	0.003
Stomach	0.14 ^b	0.19 ^a	0.11 ^c	0.11 ^c	0.08 ^d	0.005
Abdominal Fat	0.09 ^a	0.02 ^c	0.04 ^b	0.01 ^c	0.01 ^c	0.003
Small intestine	0.13	0.11	0.12	0.13	0.11	0.007
Large intestine	0.05 ^d	0.11 ^b	0.22 ^a	0.07 ^c	0.11 ^b	0.005

^{a,b,c,d}= means with different superscript letters across the rows indicate the significant difference ($P<0.05$); SEM =Standard Error of Mean. T1 = 0% millet husk (Control), T2 = 25% millet husk, T3 = 50% millet husk, T4 = 75% millet husk, T5 = 100% millet husk

Conclusion

In conclusion, this study revealed that while T1 outperformed T2-T5, the inclusion of millet husk at up to 50% replacement of wheat bran yielded acceptable growth and carcass performance in WAD goats. Beyond this, this practice converts millet husk waste into valuable feed resources, minimizes environmental pollution, and offers a practical solution to seasonal feed shortages.

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Evaluating the Effectiveness of the Malaysia Diabetes Prevention Programme (MyDiPP) Mobile Application in Supporting Weight Loss Among Adults at Risk of Type 2 Diabetes: A Randomised Controlled Trial

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Abstract

Background: Type 2 diabetes mellitus (T2DM) is a growing public health concern in Malaysia, and early intervention is critical for prevention. Mobile health (mHealth) applications, such as the Malaysia Diabetes Prevention Programme (MyDiPP), offer promising platforms to support behavioural modification and reduce diabetes risk. This study aimed to evaluate the effect of the MyDiPP mobile application on body weight change among adults at high risk of developing T2DM. Methods: A single-blind, randomised controlled trial was conducted among 112 high-risk adults in Kuala Terengganu, Malaysia. Participants were randomly assigned to either the intervention group (n=56), which received access to the MyDiPP mobile application comprising educational modules, self-monitoring tools, health coaching, and peer support for 12 months, or the control group (n=56), which received standard health education. Body weight was measured at baseline, 6 months, and 12 months. Changes in body weight were analysed using repeated measures ANCOVA under an intention-to-treat (ITT) approach. Results: The intervention group achieved significantly greater reductions in body weight compared to the control group at both 6 months (mean difference: -2.28 kg; 95% CI: -4.09 to -0.46; p = 0.014) and 12 months (mean difference: -2.09 kg; 95% CI: -4.11 to -0.08; p = 0.042). While within-group weight changes did not reach statistical significance, the between-group differences support the added value of the digital intervention. Conclusions: The MyDiPP mobile application demonstrates potential as an effective, scalable mHealth tool to promote modest weight loss among high-risk individuals, thereby supporting diabetes prevention efforts in Malaysia. Future research should investigate long-term adherence, user engagement strategies, and the integration of such digital tools into national public health initiatives.

Keywords: Diabetes Prevention, Lifestyle Intervention, mHealth, Mobile Apps, Obesity, Type 2 Diabetes Mellitus





Multi-Grid Spatial Modeling of Wheat Yields within the Impact of Climate Change in Southeastern Türkiye

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Abstract

Southeastern Türkiye, particularly the provinces of Gaziantep and Şanlıurfa, faces increasing threats from climate-induced thermal and moisture stress, making it a critical wheat production corridor. Accurate regional yield estimation is essential for developing localized adaptation strategies; however, the impact of spatial resolution on model precision remains a key challenge. This study utilizes a high-resolution modeling approach to estimate wheat productivity by integrating the DSSAT crop model within two distinct spatial frameworks: the Pythia platform and the CCAFS Regional Agricultural Forecasting Toolbox (CRAFT).

The study methodology employs a comparative grid-based analysis, utilizing Pythia at a coarse resolution of 55 km and CRAFT at a finer resolution of 10 km to capture localized environmental heterogeneities. Climate forcing data were derived from the GFDL, MPI, and UKESM1 Earth System Models under multiple Shared Socioeconomic Pathways (SSP1-2.6, SSP3-7.0, and SSP5-8.5) to project yield trajectories through the mid-century and end-century. Furthermore, the study evaluates the efficacy of different adaptation measures, such as sowing date, to mitigate the projected shortening of the grain-filling period.

Preliminary results indicate that the 10 km CRAFT-based simulations provide significantly more granular insights into yield anomalies and climate "hotspots" compared to the 55 km Pythia output, particularly in the topographically diverse areas of Gaziantep. This multi-scalar assessment demonstrates that while coarse-resolution models are effective for broad regional trends, 10 km grid-based modeling is necessary for province-level agricultural planning and for optimizing sowing dates. The findings provide a robust evidence base for policymakers to enhance food security and implement precision adaptation strategies in Türkiye's Mediterranean climate hotspot.

Keywords: Wheat Yield, Climate Change, SSP, sowing dates



Bee Bread: Chemical Composition and Potential Health Benefits

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Abstract

Perga, also known as bee bread, is a natural bee product formed through the fermentation of pollen collected by honey bees after being mixed with nectar, honey, and bee-derived enzymes and stored within honeycomb cells. During the fermentation process, the activity of lactic acid bacteria enhances the bioavailability of pollen and induces significant biochemical modifications in its nutritional composition. Bee bread is characterized by a rich chemical composition including proteins, free amino acids, carbohydrates, fatty acids, vitamins, minerals, and phenolic compounds. In particular, bioactive constituents such as flavonoids, phenolic acids, and carotenoids contribute substantially to its antioxidant capacity.

Recent studies have demonstrated that bee bread may exert several beneficial effects on human health. Owing to its phenolic compound content, bee bread has been reported to reduce the effects of free radicals and contribute to the prevention of oxidative stress. Furthermore, it has been associated with antimicrobial, anti-inflammatory, immunomodulatory, and hepatoprotective activities. Bee bread has also been suggested to positively influence the gut microbiota and exhibit prebiotic properties. In addition, regular consumption may support the immune system, regulate energy metabolism, and contribute to the maintenance of overall health.

In this review, the chemical composition of bee bread, the biochemical changes occurring during the fermentation process, and its potential health effects were evaluated in the light of current literature. Bee bread appears to possess considerable potential as a functional food and natural health-promoting product; however, further advanced clinical studies are needed to better elucidate its mechanisms of action.

Keywords: Bee bread, phenolic compounds, antioxidant activity, apitherapy, functional food

Arı Ekmeğinin Biyokimyasal Bileşeni ve Sağlık Üzerine Etkisi

Özet

Arı ekmeği, bal arılarının topladığı polenin nektar, bal ve enzimlerle karıştırılarak petek gözlerinde fermente edilmesi sonucu oluşan doğal bir arı ürünüdür. Fermentasyon süreci sırasında laktik asit bakterilerinin etkisiyle polenin biyoyararlanımı artmakta ve besin içeriğinde önemli biyokimyasal değişiklikler meydana gelmektedir. Arı ekmeği; proteinler, serbest aminoasitler, karbohidratlar, yağ asitleri, vitaminler, mineraller ve fenolik bileşikler bakımından oldukça zengin bir bileşime sahiptir. Özellikle flavonoidler, fenolik asitler ve karotenoidler gibi biyoaktif bileşenler ürünün antioksidan kapasitesine önemli katkı sağlamaktadır.

Son yıllarda yapılan çalışmalar, arı ekmeğinin sağlık üzerine olumlu etkiler gösterebileceğini ortaya koymaktadır. İçerdiği fenolik bileşikler sayesinde serbest radikallerin etkisini azaltarak oksidatif stresin önlenmesine katkı sağladığı bildirilmektedir. Ayrıca antimikrobiyal, antiinflamatuvar, immünomodülatör ve hepatoprotektif etkilerinin bulunduğu ifade edilmektedir. Arı ekmeğinin bağırsak mikrobiyotası üzerine olumlu etkileri olduğu ve prebiyotik özellik gösterebildiği de belirtilmektedir. Bunun yanında düzenli tüketiminin bağışıklık sisteminin desteklenmesi, enerji metabolizmasının düzenlenmesi ve genel sağlığın korunması açısından potansiyel faydalar sağlayabileceği düşünülmektedir.

Bu derlemede arı ekmeğinin kimyasal bileşimi, fermentasyon sürecinde meydana gelen değişiklikler ve sağlık üzerine etkileri güncel literatür ışığında değerlendirilmiştir. Arı ekmeğinin fonksiyonel gıda ve doğal sağlık destekleyici ürün olarak kullanım potansiyelinin yüksek olduğu, ancak etki mekanizmalarının daha iyi anlaşılabilmesi için ileri düzey klinik çalışmalara ihtiyaç duyulduğu sonucuna varılmıştır.

Anahtar Kelimeler: Arı ekmeği, fenolik bileşikler, antioksidan aktivite, apiterapi, fonksiyonel gıda

Giriş

Arı ekmeği (perga), bal arılarının doğadan topladıkları polenleri nektar, bal ve çeşitli enzimatik salgılar ile karıştırarak petek gözlerinde depolaması sonucu oluşan fermente bir arıcılık ürünüdür (Anderson vd., 2011). Arılar yaşamlarını sürdürebilmek için gerekli besin öğelerini doğrudan doğal kaynaklardan sağlamaktadır. Bu kapsamda nektar, koloni için temel karbohidrat ve enerji kaynağını oluştururken; polen ise protein, yağ, vitamin ve mineral bakımından önemli bir besin kaynağı olarak görev yapmaktadır. Özellikle işçi arılar, yüksek besin değerine sahip ve uzun süre depolanabilen bir protein kaynağına ihtiyaç duymaktadır. Bu nedenle toplanan polenler, arıların



salgıladıđı enzimler ve petek ierisindeki mikrofloranın etkisiyle fermentasyona uđrayarak arı ekmeđine dnsmektedir. Gerekleen bu biyokimyasal dnm sonucunda rnn besin deđeri, sindirilebilirliđi ve biyoyararlanımı artmaktadır. Zengin ieriđi sayesinde arı ekmeđi, hem koloni beslenmesinde nemli bir yere sahip olmakta hem de fonksiyonel bir arı rn olarak dikkat ekmektedir (Anderson vd., 2011; Karaman vd., 2017; Nakilciođlu-Ta ve Nurko, 2022).

Arı ekmeđi, fermente edilmi arı poleni olarak tanımlanan ve arılar tarafından petek gzlerine depolanan polenin belirli bir sre mikrobiyal ve enzimatik srelere maruz kalması sonucunda oluan bir arı rndr. Depolama srecinde meydana gelen fermentasyon, rnn kimyasal yapısında eitli biyokimyasal deđiimlere neden olmaktadır. Ancak yapılan alımalar, bu dnm srecinin fenolik bileiklerin miktarında belirgin bir kayba yol amadıđını gstermektedir (Kieliszek vd., 2018; Parlakpınar ve Polat, 2021). Arı ekmeđi; besin đelerinin biyoyararlanımının artması, sindiriminin daha kolay olması ve ierdiđi biyolojik aktif bileenlerin zenginlemesi nedeniyle arı polenine kıyasla daha yksek besleyici deđere sahip bir rn olarak deđerlendirilmektedir (Kieliszek vd., 2018). Perga veya arı maması olarak da bilinen arı ekmeđi kovan bireylerinden olan kralie ve ii arıların besin kaynaklarındandır. Arıların yaam evrelerinden olan pupa dnemi olarak bilenen bu dnemden sonra yavru arılar ilk 5 gn boyunca arı ekmeđi ile beslenmelerine devam ederler. Yapısal olarak besleyici zelliđi ile bilinen bu rn genellikle amber renkli olarak bilinmektedir. Ancak her arı rnnde olduđu gibi arı ekmeđinin renk skalası da toplandıđı bitki orijinine bađlı olarak deđiiklik gstermektedir (imek vd., 2023).

Arı ekmeđinin kimyasal yapısına bakıldıđında ieriđini %70 polen, %25 oranında bal ve %5 oranında da nektar barındırdıđı ve bunlara ek olarak da arı salgıları, probiyotik bakterilerden ve mayalardan olumaktadır (elik 2019). Arı ekmeđi (perga), fermentasyon srecine uđramı polenden oluan ve yksek besin deđerine sahip bir arı rndr. Bileiminde karbondhidratlar (%24–35) en byk payı olutururken, protein ieriđi yaklaık %20, lipid ieriđi ise %1,6 dzeyindedir. Bunun yanı sıra demir, kalsiyum, fosfor, potasyum, inko, bakır, selenyum ve magnezyum gibi temel mineraller bakımından zengindir. Pergada en az 18 farklı amino asit tespit edilmi olup eitli yađ asitleri, karbondhidrat bileikleri, enzimler ve koenzimler de bulunmaktadır. Ayrıca askorbik asit, tokoferol ve B grubu vitaminleri de dahil olmak zere ok sayıda vitamin iermesi, bu rn beslenme aısından deđerli bir dođal kaynak haline getirmektedir (Artık ve Konar, 2018)

Protein ieriđi

Arı ekmeđinin en dikkat ekici besinsel zelliklerinden biri yksek protein ieriđidir. Literatrde kuru madde bazında yapılan analizlerde protein miktarının 14,1–37,3 g/100 g arasında deđitiđi, ortalama deđerin ise $23,1 \pm 2,9$ g/100 g olduđu bildirilmitir. Bu deđerlerin, arı poleninde rapor edilen protein dzeylerine olduka yakın olması, arı ekmeđinin oluumu sırasında gerekleen biyokimyasal dnmlerin polen tanesinin ieriđini nemli lde deđitirmediđini gstermektedir. Arılar tarafından gerekletirilen fermentasyon srecinin temel etkisi, polen duvarının paralanarak besin maddelerinin biyoyararlanımının artırılmasıdır (Fuenmayor ve ark., 2014; Zuluaga ve ark., 2015; Kaplan ve ark., 2016). Arı ekmeđinin kimyasal bileiminde amilaz, fosfataz ve glukoz oksidaz gibi eitli enzimler de yer almaktadır. Ayrıca glutamik asit, aspartik asit ve prolin bata olmak zere arginin, valin, histidin, lsin, izolsin, lizin, metiyonin ve triptofan gibi birok esansiyel ve esansiyel olmayan amino asit iermesi, bu rnn besleyici deđerini artıran nemli zellikler arasında gsterilmektedir (Salazar-Gonzlez vd., 2016).

Lipid ve yađ asidi ieriđi

Yapılan aratırmalar incelendiđinde arı ekmeđinin yapısında bulunan lipid ieriđinin bitki rtsne bađlı olarak deđiiklik gsterdiđi belirtilmitir (Urcan ve ark., 2017). Arı ekmeđi, doymamı yađ asitleri bakımından zengin bir bileime sahip olup, farklı mevsimlerde gerekletirilen analizlerde be adet ω -3, drt adet ω -6 ve  adet ω -9 oklu doymamı yađ asidinin varlıđı ortaya konulmutur. Toplam yađ asitleri ierisinde en yksek oranlara sahip doymamı yađ asitlerinin oktadesenoik asit ve ikosatetraenoik asit olduđu, bu bileiklerin toplam yađ asitlerinin yaklaık %15'ini oluturduđu bildirilmitir (Human ve Nicolson, 2006). Yapılan baka bir alımada ise kolza ve sđt ađalarından retilen arı ekmeđinde 22 yađ asidi tanımlanmı ve bunların arasından (%27–43,8) ω -3 grubunda yer alan oktadekatrienoik aside ait olduđunu rapor etmitir (eksteryt ve Jansen; 2012). Bir baka alımada 5 farklı bitkiden toplanılan (Pamuk , kestane, yonca, narenciye ve ayieđi) arı ekmeđi rneklerinde, 5.93-11.55 g/100 g arasında lipid ieriđine sahip olduđu bildirilmitir. Aynı aratırmanın sonucunda ayieđi ve pamuk ierikli arı ekmeđinde lipid ieriđinin diđer rneklerden daha yksek olduđu bildirilmitir (Kaplan ve ark., 2016). Kolombiya da gerekletirilen bir alımanın sonucunda ise arı ekmeđinin lipid ieriđinin 1.65-5.50 g/100 g arasında olduđu bildirilmitir (Zuluaga ve ark., 2015). Yađ asitleri, bal arılarında reme performansı, geliim ve genel sađlık durumunun korunmasında nemli biyolojik ilemlere sahiptir.

Gncel aratırmalar, arı ekmeđinin insan beslenmesi aısından byk nem taıyan oklu doymamı yađ asitleri (PUFA) iin deđerli bir kaynak olduđunu gstermektedir. İnsan organizması bu yađ asitlerini



sentezleyemediğinden, söz konusu bileşiklerin diyet yoluyla alınması gerekmektedir. Arı ekmeğinde bulunan doymamış/doymuş yağ asidi oranının, yumurta sarısında belirlenen oranlarla benzerlik gösterdiği bildirilmiştir. Ayrıca yağ asidi profillerinin karşılaştırılması sonucunda arı ekmeği, arı poleni ve yumurta sarısının benzer çoklu doymamış yağ asitlerini içerdiği ve bu açıdan birbirlerine yakın bir besinsel kompozisyona sahip oldukları ortaya konmuştur (Çeksteryt ve ark., 2016).

Vitamin ve Mineral içeriği

Vitaminler, organizmada çok sayıda metabolik reaksiyonda görev alan, enzimlerin etkinliğini destekleyen ve antioksidan özellikleriyle hücrel fonksiyonların sürdürülmesine katkı sağlayan biyolojik açıdan önemli organik bileşiklerdir (Ares ve ark., 2018; Bakour ve ark., 2022). Arı ekmeğinin vitamin yönünden oldukça zengin bir ürün olduğu ve vitamin kompozisyonunun büyük ölçüde elde edildiği bitkisel kaynak tarafından şekillendirildiği bildirilmektedir (Aylanc ve ark., 2021; Bakour ve ark., 2022). Arı ekmeğinde B grubu vitaminleri ile birlikte askorbik asit ve tokoferol gibi önemli vitaminlerin bulunduğu bildirilmiştir. Tiamin, riboflavin, biyotin, niasin, nikotinik asit, folik asit, pantotenik asit, inositol ve piridoksin arı ekmeğinde tespit edilen başlıca vitaminler arasında yer almaktadır (Khalifa ve ark., 2020). Bakour ve arkadaşları (2019) yaptıkları araştırmada, α -tokoferol ve δ -tokoferol düzeylerini sırasıyla 10,50 mg/100 g ve 0,40 mg/100 g olarak rapor etmiştir. Bunun yanında, farklı arı ekmeği örneklerinde askorbik asit miktarının 10,51–11,42 mg/100 g arasında değiştiği bildirilmiştir (Mohammad ve ark., 2020). Bu zengin vitamin profili, arı ekmeğinin besleyici ve fonksiyonel özelliklerine önemli katkı sağlamaktadır.

Arı ekmeği kimyasal kompozisyonunda ki mineral madde içeriğinin incelendiği çalışmalarda kalsiyum, magnezyum, fosfor, demir, sodyum, potasyum, alüminyum, mangan, kükürt ve bakırın arı ekmeğinde bulunan başlıca mineraller arasında yer aldığı bildirilmiştir (Anđelković vd., 2012). Mineral kompozisyonu incelendiğinde, potasyumun yaklaşık %0,74 ile en yüksek konsantrasyonda bulunduğu, bunu kalsiyum ve fosforun izlediği belirlenmiştir. Ayrıca arı ekmeğinin demir ve çinko bakımından da önemli düzeylerde mineral içerdiği rapor edilmiştir (Stanciu vd., 2009). Arı ekmeğinde ki mineral madde içeriği polenle kıyaslandığında daha fazla kalsiyum, potasyum, fosfor, magnezyum ve demir miktarlarının polene kıyasla daha yüksek olduğu bildirilmiştir (Anđelković vd., 2012).

Karbonhidrat içeriği

Yapılan kimyasal analiz sonuçlarına göre arı ekmeğinin yapısının yaklaşık olarak k %24,40 ile %34,80 arasında değiştiği bildirilmiştir (Berene vd., 2015). Monosakkaritler arasında fruktozun en yüksek orana sahip olduğu ve toplam taze ağırlığın %57,51'ini oluşturduğu, bunu glukozun %42,59 oranı ile izlediği belirtilmiştir. Maltoz %3,37 oranında iken Sükroz oranı %0,12 olduğu bildirilmiştir (Stanciu vd., 2008). Bu oranların düşük olmasının sebebi ise polenin arı ekmeğine dönüşümü sırasında laktik fermentasyon aşamasında bileşiğin monosakkaritlere parçalanması olarak bildirilmiştir. Ayrıca trehaloz, turanoz ve izomaltoz gibi diğer disakkaritlerin toplamda yaklaşık %1,82 oranında bulunduğu rapor edilmiştir. Kovan içerisinde gerçekleşen doğal fermentasyon sürecinde *Lactobacillus* türlerinin karbonhidratları substrat olarak kullanarak laktik asit ürettiği ve bu üretimin yaklaşık %3,2 konsantrasyona ulaşabildiği bildirilmektedir.

Arı Ekmeğinin Sağlık Üzerine Etkisi

Perga (arı ekmeği), arıların topladığı çiçek poleninin fermente edilmesiyle elde edilen ve bu süreçte polenin hücre duvarının enzimatik olarak parçalanması sonucu biyolojik olarak daha aktif hale gelen doğal bir arı ürünüdür (Zakaria ve Haron, 2018). Bu fermentasyon süreci, perganın besinsel ve terapötik potansiyelini ham polene kıyasla önemli ölçüde artırmaktadır. Prganın amino asitler, B grubu vitaminleri, C ve E vitaminleri ile kalsiyum, demir, magnezyum, potasyum ve çinko gibi mineraller açısından zengin bir bileşime sahip olduğu yapılan araştırmalarda bildirilmiştir. Özellikle dallı zincirli amino asitler (valin, izolösin ve lösin) protein sentezi ve kas onarımında kritik rol oynarken, demir ise kırmızı kan hücrelerinin üretimine katkıda bulunarak anemi riskini azalttığı belirtilmiştir (Pascoal ve ark., 2014). Bunlara ek olarak, pergada bulunan fenolik asitler ve flavonoidler güçlü antioksidan etkiler göstererek oksidatif stresi azaltmakta ve kronik hastalık risklerini düşürmektedir (Markiewicz-Żukowska ve ark., 2013). Prganın en dikkat çekici özelliklerinden biri de probiyotik etkisidir. Fermentasyon sürecinde üreyen laktik asit bakterileri sayesinde pergada özellikle *Lactobacillus* ve *Bacillus* türleri gibi faydalı bakteriler bulunmaktadır (Mohammad ve ark., 2021). Bu probiyotik bakteri içeriği, sindirim sistemi mikroflorasını düzenlemekte, zararlı mikroorganizmaları baskılamakta, bağışıklık sistemini güçlendirmekte ve karaciğer fonksiyonlarını iyileştirdiği literatürlerde bildirilmiştir. Yapılan çalışmalar, iki tatlı kaşığı arı ekmeğinin yaklaşık 10 milyar probiyotik bakteri içerdiğini bildirmiştir (Mohammad ve ark., 2021). Hayvan modelleri üzerinde yürütülen deneysel çalışmalar da bu bulguları desteklenmiştir. Örneğin, Zakaria ve Haron (2018) tarafından ratlar üzerinde yapılan bir araştırmada, bir ay boyunca günlük 0.5 g arı ekmeği verilen deney grubunda, kontrol grubuna kıyasla sperm sayısı ve



morfolojisinde önemli derecede olumlu artışlar gözlemlenmiş ve arı ekmeğinin erkek üreme sistemine katkı sağladığını vurgulamıştır. Benzer şekilde, Othman (2021) obez ratlar üzerinde yaptığı çalışmada, 6 hafta süresince arı ekmeği verilen grupta lipid profili ve kan değerlerinde iyileşmeler tespit etmiş ve arı ekmeğinin obezite ile ilişkili kardiyovasküler hastalıkların gelişimini azalttığını belirlemiştir.

Sonuç

Perganın karbonhidrat içeriği, hızlı bir enerji kaynağı olarak metabolizma tarafından kullanılabilirken, içerdiği lipitler hücre membranı yapısı ve hormonal denge için hayati önem taşımaktadır. Tüm bu bilimsel kanıtlar ışığında, sağlık açısından olumlu etkilerinden dolayı, çocukların günlük 1 tatlı kaşığı, yetişkinlerin ise günlük 2 tatlı kaşığı arı ekmeği tüketmesi tavsiye edilmektedir (Mohammad ve ark., 2021). Sonuç olarak perga; güçlü antioksidan, antimikrobiyal, antiinflamatuar ve probiyotik özellikleriyle insan sağlığına çok yönlü katkılar sunan, hem beslenme hem de terapötik açıdan değerli bir fonksiyonel gıdadır.

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A governance-by-design framework for secure ai-enabled digital agriculture platforms

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Abstract

Digital agriculture platforms now bring together a wide range of data sources, including sensor measurements, satellite imagery, meteorological records, farm-level observations, mobile applications, and AI-based models. This integration creates clear opportunities for precision agriculture, climate-smart production, evidence-informed advisory services, and more sustainable use of agricultural resources. Yet the same platforms also raise difficult questions about data ownership, cybersecurity, model reliability, privacy, and accountability in decision-making. In practice, many digital agriculture projects still give greater attention to predictive performance than to the governance and security structures required for responsible use. This imbalance becomes especially problematic when such systems are expected to inform real decisions that affect farmers, public institutions, production planning, and environmental sustainability.

This study develops a governance-by-design framework for secure AI-enabled digital agriculture platforms. The framework is organized around three mutually reinforcing layers: data governance, cybersecurity and AI risk management, and decision accountability. The data governance layer covers issues such as data ownership, access rights, consent, data quality, provenance, and responsible data sharing. The cybersecurity and AI risk management layer deals with identity management, role-based access control, API security, IoT and sensor vulnerabilities, data poisoning, model manipulation, system logging, and incident monitoring. The decision accountability layer focuses on how AI-generated recommendations should be explained, validated, documented, and linked to human oversight.

The central contribution of this study is its shift in perspective. Rather than treating digital agriculture platforms mainly as model-driven prediction tools, the study frames them as trustworthy decision-support infrastructures. By bringing together information systems governance, cybersecurity controls, and AI accountability principles, the proposed framework offers a conceptual basis for designing agricultural digital platforms that are secure, auditable, and responsibility-aware. In this respect, the framework can support researchers, software developers, agricultural institutions, and policymakers in building more reliable and accountable digital transformation strategies for agriculture.

Keywords: Digital agriculture, Data governance, Cybersecurity, Artificial intelligence, Decision support systems, Agricultural information systems, Decision accountability

Introduction

Digital agriculture is changing how agricultural production is monitored, how advisory services are delivered, and how institutions make decisions. This transformation is driven by the increasing use of sensor networks, satellite observations, farm management systems, mobile applications, cloud platforms, and AI-based analytics. Earlier studies on smart farming had already shown that big data, IoT, cloud computing, and AI extend decision-making capacity beyond the boundaries of individual farms and affect the wider agri-food supply chain (Wolfert et al., 2017). More recent social science research further underlines that digital agriculture should not be understood as a purely technical shift. It is also a socio-technical transition shaped by questions of ownership, privacy, ethics, farmer identity, institutional arrangements, and agricultural knowledge systems (Klerkx et al., 2019).

AI-enabled digital agriculture platforms can support many practical decisions, including irrigation scheduling, disease risk monitoring, fertilizer recommendations, climate-smart production, input optimization, and early-warning services. Yet these platforms are increasingly used in contexts where their outputs may have direct consequences for production costs, crop losses, environmental performance, and trust in institutions. For this reason, their design cannot be evaluated only through model accuracy. The responsible AI literature in agriculture has already warned that AI systems may introduce risks related to data reliability, interoperability, safety, security, unintended socio-ecological effects, and the under-representation of vulnerable producers (Tzachor et al., 2022).

Despite the growing interest in AI-supported agriculture, governance, cybersecurity, and accountability are still often handled as secondary concerns. This is a major weakness. Agricultural decision-support systems rely on heterogeneous data flows coming from farmers, sensors, public agencies, private service providers, and environmental monitoring infrastructures. When these flows are not governed carefully, digital agriculture platforms may reproduce or even intensify problems such as dependency, opacity, surveillance, misuse of data, and institutional risk. Recent reviews similarly point to continuing concerns about data privacy, ownership, stakeholder trust, infrastructure constraints, and the ethical deployment of AI in agricultural systems (Omotayo et al., 2025; Rouzky et al., 2025).



This study proposes a governance-by-design framework for secure AI-enabled digital agriculture platforms. The framework brings together three complementary layers: data governance, cybersecurity and AI risk management, and decision accountability. The central claim is that digital agriculture platforms should not be designed merely as prediction engines. They should be treated as trustworthy decision-support infrastructures in which data rights, security controls, model-related risks, human oversight, and decision records are defined from the outset.

The contribution of the study is threefold. First, it reframes digital agriculture platforms as socio-technical information systems rather than isolated AI models. Second, it develops a layered framework that connects data governance, cybersecurity, and decision accountability within a single design logic. Third, it presents an illustrative use case showing how an AI-generated agricultural recommendation can be traced from data input to institutional accountability.

Problem Background

A first challenge is data governance. Digital agriculture platforms rely on large and diverse datasets, including farm-level records, environmental observations, agronomic measurements, geospatial layers, and operational data. These data may be generated through sensors, farm machinery, mobile applications, satellite imagery, weather stations, or public administrative systems. Yet the governance of agricultural data is still far from settled. Rouzky et al. (2025) note that smart farming lacks standardized data governance frameworks, that security mechanisms remain insufficiently explored, and that farmers often have limited awareness of data privacy and security issues.

A closely related issue is the ambiguity surrounding data ownership and control. As Atik (2022) argues, the debate cannot be resolved simply by assigning ownership rights to farmers, because the more difficult questions involve data lock-in, fragmentation, access barriers, and trust. This point is particularly important for AI-enabled digital agriculture platforms. Farmers may generate valuable data through their land, machinery, production practices, and local observations, while platform providers may control the infrastructure, analytics layer, and user-facing decision interface. Under such conditions, governance needs to clarify not only who “owns” the data, but also who is allowed to access, process, share, monetize, or reuse it.

Cybersecurity forms another critical concern. Smart agriculture systems are increasingly connected to IoT devices, cloud services, APIs, mobile applications, and external data providers. This connectivity expands the attack surface of agricultural information systems. A systematic literature review on cybersecurity in smart agriculture emphasizes that cyberattacks on agricultural ICT infrastructures can have serious consequences and that organizations need both technical safeguards and training processes to identify and respond to cyber threats (Campoverde-Molina & Luján-Mora, 2025). In this context, cybersecurity cannot be reduced to database protection. It must also cover identity management, device security, API protection, continuous monitoring, incident response, and supply-chain dependencies.

A further challenge relates to AI risk management. AI models may generate recommendations that are inaccurate, biased, opaque, or unsuitable for the local context in which they are applied. NIST’s AI Risk Management Framework organizes AI risk management around four functions: Govern, Map, Measure, and Manage, with the Govern function operating across all stages of organizational AI risk management (NIST, 2023). This perspective is highly relevant for digital agriculture, where AI-based recommendations may shape farming practices, resource allocation, and institutional advisory services.

Decision accountability is also unresolved. AI-enabled platforms often produce recommendations, but the responsibility chain behind these recommendations is not always clear. If a recommendation leads to a poor outcome, responsibility may be distributed across several actors: the software developer, the data provider, the agricultural institution, the human expert, the model vendor, or the farmer who acted on the advice. Alexander et al. (2024) show that responsible AI in agriculture involves several gray areas, including data access, regulation, adoption barriers, and trust-building. For this reason, digital agriculture systems need explicit mechanisms for explanation, human validation, decision logging, and responsibility assignment.

Taken together, these issues show why AI-enabled digital agriculture platforms require a governance-by-design approach. Governance, cybersecurity, and accountability should not be attached to the platform later as external compliance requirements. They need to be embedded directly into the platform architecture from the beginning.

Material and Methods

The proposed framework is structured around three interdependent layers: the Data Governance Layer, the Cybersecurity and AI Risk Management Layer, and the Decision Accountability Layer. These layers do not operate in isolation; rather, they are linked through a decision-support flow that connects data inputs, risk controls, AI-based analysis, human oversight, and accountable decision records (Figure 1).



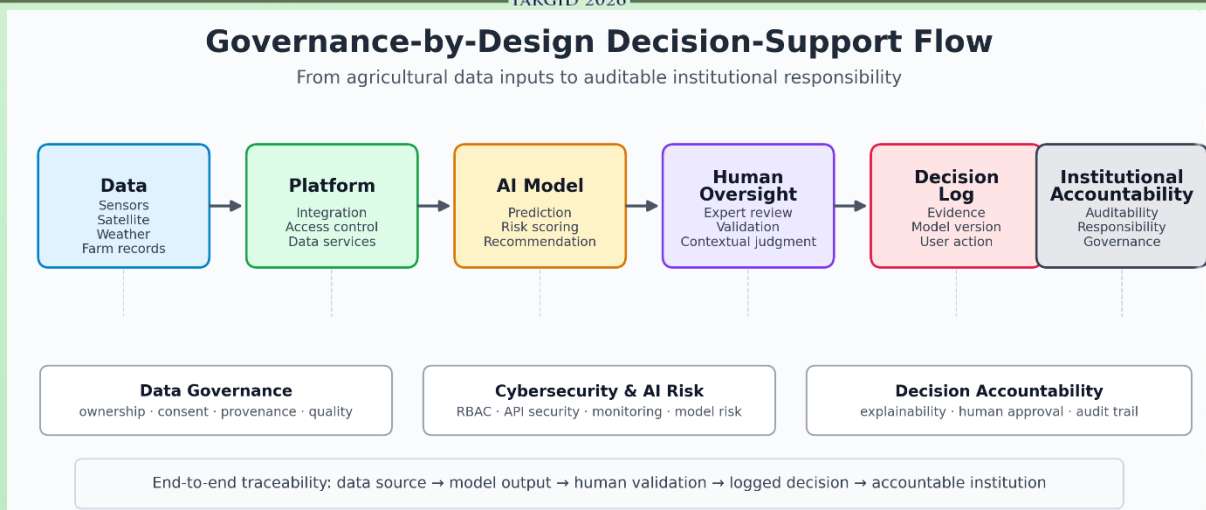


Figure 1. Conceptual flow for secure and accountable AI-enabled digital agriculture platforms.

This flow is based on the view that trustworthy agricultural decision support depends on traceability across the entire process, from input data to the final decision record. In other words, the platform should make it possible to answer five core questions: Which data were used? Who was authorized to use them? How was the system protected? How was the AI-generated recommendation produced and validated? And finally, who carries responsibility for the decision that is recorded or acted upon?

Data Governance Layer

The Data Governance Layer defines how agricultural data are collected, accessed, processed, shared, and retained throughout the platform. In AI-enabled agriculture, this layer should not be seen as a narrow technical data management function. It is also a mechanism for building trust among farmers, institutions, technology providers, and decision-makers. Wolfert et al. (2017) identify governance issues, including data ownership, privacy, and security, as key research concerns in smart farming. Similarly, Klerkx et al. (2019) show that power relations, ownership, privacy, and ethics are central themes in the wider digital agriculture debate.

This layer includes six core components:

1. **Data ownership and usage rights:** defining the legal and operational rights associated with farm-level, environmental, and platform-generated data.
2. **Access control policies:** specifying which users, institutions, service providers, and AI models are allowed to access specific types of data.
3. **Consent and purpose limitation:** ensuring that farmers and institutions are informed about how their data will be used and for what purposes.
4. **Data quality and validation:** documenting missing values, sensor errors, outdated records, inconsistent measurements, and other reliability issues.
5. **Data provenance:** recording the source, timestamp, transformation history, and reliability status of each data item used in the platform.
6. **Responsible data sharing:** defining the conditions under which data may be shared with researchers, public institutions, private vendors, or third-party analytics providers.

The purpose of this layer is to create a reliable and trustworthy data foundation for agricultural decision support. Without such a foundation, AI-generated recommendations may appear technically sophisticated, but they remain institutionally fragile and difficult to justify in real-world decision contexts.

Cybersecurity and AI Risk Management Layer

The Cybersecurity and AI Risk Management Layer protects the platform, data flows, models, devices, and users against both technical and organizational risks. Smart agriculture platforms are not simple software systems; they operate through connected sensors, mobile applications, cloud dashboards, APIs, external data services, and AI-based decision engines. For this reason, they require a broad cybersecurity and risk management perspective. The NIST Cybersecurity Framework 2.0 places governance at the center of cybersecurity risk management by emphasizing the need to define and monitor strategy, expectations, policies, roles, responsibilities, oversight mechanisms, and supply-chain risk management practices (NIST, 2024).

This layer addresses two groups of risks. The first group includes conventional cybersecurity risks such as unauthorized access, weak authentication, API vulnerabilities, device compromise, data exfiltration, ransomware,



and service disruption. The second group consists of AI-specific risks, including data poisoning, model manipulation, adversarial inputs, model drift, poor calibration, and excessive dependence on automated recommendations.

The main controls in this layer include:

- identity and access management,
- role-based access control,
- secure API design,
- encryption of sensitive data,
- IoT and sensor hardening,
- system logging and anomaly detection,
- backup and recovery mechanisms,
- incident response procedures,
- supplier and third-party risk management,
- AI model monitoring and periodic validation.

This layer treats cybersecurity as a direct component of agricultural decision quality. For example, if a disease-risk alert is generated from manipulated sensor data, the problem is not merely a technical breach. It also becomes a decision-support failure, because the platform may guide farmers, experts, or institutions toward an incorrect action.

Decision Accountability Layer

The Decision Accountability Layer defines how AI-generated recommendations are explained, validated, recorded, and linked to human responsibility. In agricultural decision support, a platform should not merely produce outputs such as “irrigate,” “apply fertilizer,” or “disease risk is high.” It should also clarify why such a recommendation was produced, which data sources were used, how confident the system is, which model version generated the output, and whether expert validation is needed before action is taken.

This layer is consistent with the responsible AI literature, which places strong emphasis on trust, transparency, and accountability. Alexander et al. (2024) show that responsible AI in agriculture and food-system technologies requires attention to data access, regulation, adoption barriers, and trust-building. Similarly, Tzachor et al. (2022) argue that AI applications in agriculture should be assessed not only through isolated performance metrics, but also in terms of systemic risks, externalities, and broader socio-ecological consequences.

The Decision Accountability Layer includes the following elements:

- explanation of the AI-generated recommendation,
- uncertainty or confidence information,
- model version and timestamp,
- summary of data provenance,
- expert validation status,
- farmer or institutional decision record,
- assignment of responsibility,
- post-decision feedback and outcome tracking.

Through these elements, the layer transforms an AI output into an auditable decision-support artifact. Its main role is to ensure that recommendations are not only generated, but also made traceable, reviewable, and institutionally accountable (Table 1).

The proposed framework is organized around three interdependent governance layers: data governance, cybersecurity and AI risk management, and decision accountability. Together, these layers move AI-enabled digital agriculture platforms beyond a narrow focus on prediction performance. Instead, they position such platforms as trustworthy decision-support infrastructures where data use, security controls, model-related risks, explanations, human oversight, and institutional responsibility are addressed as part of the system design. Figure 2 illustrates this layered governance architecture and shows how it supports secure, auditable, explainable, and accountable agricultural decision support.

Illustrative Use Case

Consider a digital agriculture platform that produces disease-risk recommendations for tomato producers. The platform draws on several data sources, including weather station records, humidity measurements, satellite-derived vegetation indicators, farmer-submitted field observations, historical disease occurrence, and an AI-based risk model. Based on these inputs, the system generates the following recommendation: “High disease risk is detected for the next 72 hours; preventive action is recommended.”



Table 1. Governance-by-Design Framework for Secure AI-Enabled Digital Agriculture Platforms

Layer	Core Question	Main Risk	Control Mechanism	Decision-Support Effect
Data Governance	Who controls and uses the data?	Unauthorized use, unclear ownership, poor data quality, data misuse	Data ownership rules, access policies, consent, provenance, quality checks, responsible sharing	Creates a reliable and legitimate data foundation
Cybersecurity and AI Risk Management	How is the platform protected?	Cyberattack, data poisoning, API vulnerability, model manipulation, service disruption	Authentication, RBAC, API security, encryption, IoT hardening, logging, model monitoring, incident response	Supports secure and resilient platform operation
Decision Accountability	Who is responsible for the recommendation and final decision?	Wrong, opaque, or unvalidated recommendation	Human oversight, explainability, uncertainty reporting, decision logs, responsibility assignment	Enables auditable and accountable decision support

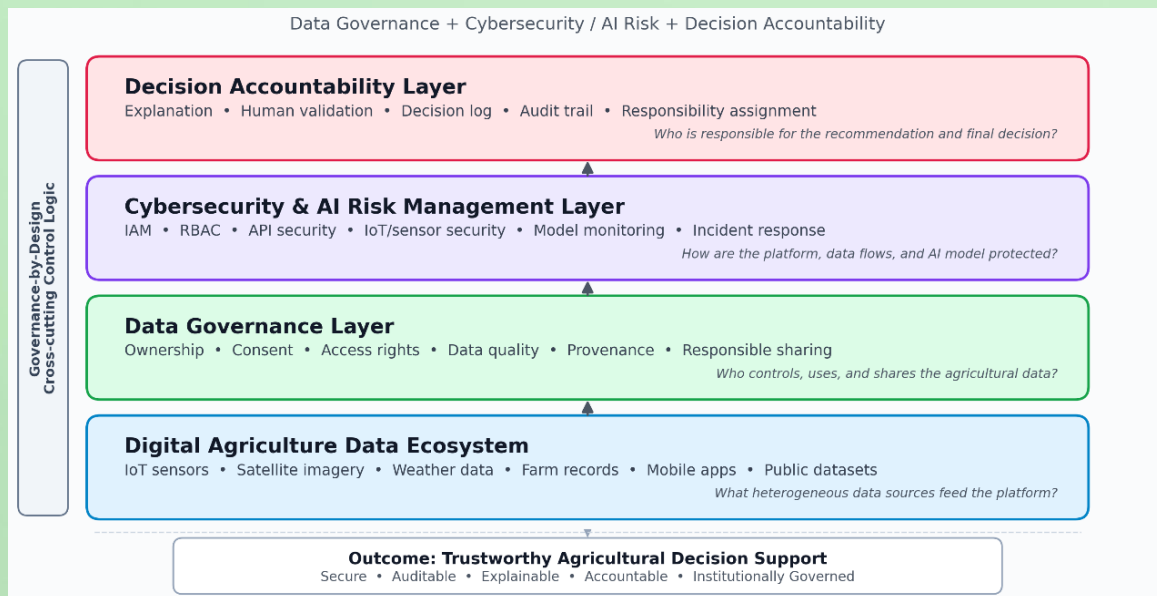


Figure 2. Three-layer governance architecture for secure AI-enabled digital agriculture platforms

In a conventional model-centric system, this recommendation might be presented directly to a farmer or agricultural advisor. In the proposed governance-by-design framework, however, the recommendation is not treated as a standalone model output. Before it becomes an actionable decision-support item, it is examined through three governance layers.

The Data Governance Layer first checks whether the data used in the recommendation are authorized, up to date, and traceable. The platform records the data sources, collection time, consent status, missing data indicators, and transformation history. For instance, the system should indicate whether the humidity data were obtained from a local sensor, a public meteorological service, or a third-party API. It should also show whether the farmer-submitted field observation was manually entered, automatically collected, or inferred from another source.

The Cybersecurity and AI Risk Management Layer then evaluates whether the data flow and system environment can be trusted. If a sensor produces abnormal values, an API call fails, an unusual login attempt is detected, or the model operates outside its validated range, the recommendation should be flagged for additional review. This step is critical because agricultural advice generated from compromised, incomplete, or low-quality data may result in unnecessary pesticide use, economic loss, or environmental harm.

Finally, the Decision Accountability Layer converts the AI output into an auditable recommendation. At this stage, the platform records the model version, confidence level, key evidence, uncertainty warning, expert validation status, and final user action. If an agricultural expert reviews the recommendation before it is communicated to farmers, this approval is attached to the decision log. If no human review is available, the system should clearly state that the recommendation is automated and advisory rather than fully validated (Table 2).



Table 2. A simplified decision record may include:

Field	Example Record
Recommendation ID	DR-2026-0611-0001
Recommendation Type	Tomato disease-risk alert
Data Sources	Weather station, satellite index, farmer observation
Model Version	DiseaseRisk-AI-v1.3
Confidence Level	0.82
Key Evidence	High humidity, recent rainfall, vegetation stress
Human Review	Approved by agricultural advisor
User Action	Farmer notified through mobile application
Accountability Status	Advisory recommendation; expert-reviewed
Audit Trail	Data, model, reviewer, and notification logs stored

This example demonstrates how the proposed framework prevents the AI system from becoming a black-box advisory tool. Instead, the platform becomes a traceable decision-support infrastructure where data, security, model behavior, human oversight, and institutional responsibility are connected.

Discussion

The proposed framework contributes to the field of Management Information Systems by positioning digital agriculture platforms as organizational decision-support systems rather than as narrow technical applications. This distinction is important because agricultural platforms bring together multiple stakeholders, including farmers, advisors, cooperatives, ministries, technology providers, researchers, and private-sector service providers. These actors do not approach the platform with the same priorities. Their expectations may differ in terms of data access, trust, privacy, responsibility, system reliability, and institutional control.

From an information systems perspective, the framework links platform governance directly to decision quality. A model may perform well in technical terms, but it can still fail as a decision-support system if data rights are unclear, security mechanisms are weak, recommendations cannot be explained, or accountability is left undefined. This argument is consistent with the broader digital agriculture literature, which shows that digitalization is not only a matter of technical innovation. It also involves institutional arrangements, power relations, ethics, and responsible innovation (Klerkx et al., 2019; Wolfert et al., 2017).

From a cybersecurity perspective, the framework extends the discussion from data protection to decision protection. In agricultural platforms, cyber incidents may affect not only the confidentiality or availability of information, but also the quality of agricultural advice. Manipulated irrigation data may lead to inefficient water use. Compromised disease-risk alerts may result in unnecessary chemical applications. Unavailable advisory services may delay time-sensitive farm decisions. For this reason, cybersecurity should be embedded throughout the decision-support lifecycle, not treated as a separate technical layer.

From an AI governance perspective, the framework addresses the growing need for responsible and trustworthy AI in agriculture. Existing studies show that AI adoption in agricultural systems is shaped by trust, ethical concerns, infrastructure limitations, data access, and governance challenges (Alexander et al., 2024; Omotayo et al., 2025; Tzachor et al., 2022). The proposed framework translates these broad concerns into concrete platform-level mechanisms, including provenance tracking, access policies, security monitoring, model validation, human oversight, and decision logging.

The framework also has practical value for agricultural institutions, software developers, and policymakers. For institutions, it can serve as a checklist for assessing whether a digital agriculture platform is suitable for real-world advisory use. For software developers, it clarifies which governance, security, and accountability mechanisms should be incorporated from the early design stage. For policymakers, it offers a conceptual basis for regulating AI-enabled agricultural decision-support systems without reducing evaluation to model accuracy alone.

This study nevertheless has limitations. It presents a conceptual framework and does not empirically validate the proposed structure through an operational platform. Future research should test the framework in concrete agricultural decision-support settings, such as irrigation advisory systems, disease early-warning platforms, fertilizer recommendation tools, climate-risk dashboards, or public agricultural e-government services. Further studies may also develop maturity models, audit checklists, or scoring instruments to assess the governance readiness of AI-enabled digital agriculture platforms.

Conclusion

This study proposed a governance-by-design framework for secure AI-enabled digital agriculture platforms. The framework was organized around three layers: data governance, cybersecurity and AI risk management, and decision accountability. Its main argument is that digital agriculture platforms should not be assessed only through



predictive performance. They should also be evaluated according to how responsibly data are governed, how securely systems operate, how AI models are monitored, how recommendations are explained, and how decisions are recorded and audited.

The proposed framework shifts the design perspective from model-centric prediction to trustworthy decision-support infrastructure. Within this perspective, AI is not treated as an autonomous decision-maker. Rather, it functions as one component of a governed agricultural information system. Data provenance, access control, cybersecurity safeguards, human oversight, and decision logging therefore become core design requirements, not optional additions.

For agricultural institutions, the framework offers a way to support safer and more accountable digital transformation. For researchers, it connects digital agriculture with information systems governance, cybersecurity, and responsible AI. For software developers, it provides guidance on how governance and accountability mechanisms can be embedded into platform architecture from the beginning. Future research should operationalize the framework through case studies, prototype implementations, maturity assessments, and empirical validation in real agricultural advisory contexts.

Declarations

Ethical Approval Certificate

Not applicable. This study is a conceptual framework study and did not involve human participants, animals, clinical procedures, experimental interventions, or survey-based data collection requiring ethical approval.

Author Contribution Statement

Cevher Özden: Conceptualization, methodology, literature review, framework design, visualization, writing the original draft, review and editing.

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Conflict of Interest

The author declares no conflict of interest.

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A knowledge graph-based agricultural information architecture for sustainable decision support

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Abstract

Sustainable agricultural decision support increasingly depends on the ability to connect different kinds of knowledge rather than simply accumulate more data. Crop characteristics, soil properties, climate conditions, water requirements, pest and disease information, farm practices, regional constraints, and sustainability indicators all enter into agricultural decisions. In many existing digital agriculture systems, however, these resources are stored in separate structures and described with different terms and assumptions. This fragmentation reduces interoperability and reuse, and it also makes recommendations harder to explain. Prediction and monitoring tools are useful, but they often leave the relationships among crops, soils, environmental conditions, management practices, risks, and decision outcomes only weakly represented.

This study develops a knowledge graph-based agricultural information architecture for sustainable decision support. The architecture represents agricultural decision knowledge through connected entities such as crop, soil, climate condition, water resource, disease, pest, farm practice, region, sustainability indicator, and recommendation. These entities are linked through relations such as requires, is suitable for, increases risk of, reduces, is affected by, and is recommended for. Representing agricultural knowledge as a graph makes it possible to support structured queries, semantic integration, evidence tracing, and interpretable recommendations.

The contribution of the study is mainly architectural. It moves the discussion from isolated repositories and model-centered prediction tools toward relational knowledge infrastructures. Such an infrastructure can support crop-soil suitability analysis, irrigation advisory, disease-risk interpretation, sustainable practice recommendation, and region-specific agricultural planning. From a Management Information Systems perspective, the study treats knowledge graphs as a reusable semantic backbone for agricultural information systems. From a Computer Engineering perspective, it provides a graph-based structure for integrating heterogeneous agricultural data and supporting explainable, query-driven, and sustainability-oriented decision intelligence.

Keywords: Knowledge graph, Agricultural information architecture, Sustainable agriculture, Decision support systems, Semantic integration, Relational decision intelligence, Smart farming

Introduction

Digital agriculture now draws on a wide ecosystem of data sources: sensors, satellite observations, weather services, farm records, soil databases, crop calendars, disease reports, mobile advisory tools, and institutional datasets. The problem is not that these resources are unavailable. In many cases, the relevant information already exists. The difficulty is that it is scattered across platforms and described through different formats, labels, and assumptions. As a result, agricultural decision-support systems often have access to data without having a sufficiently connected knowledge structure for reasoning, explanation, and reuse.

This issue becomes especially visible in sustainability-oriented agriculture. A decision about irrigation, crop choice, disease prevention, or input use is rarely driven by a single variable. It usually depends on a combination of crop requirements, soil characteristics, local climate, water availability, pest and disease pressure, management practices, regional constraints, and environmental indicators. Earlier smart farming research has already shown that big data applications influence not only field-level production but also the wider agri-food chain. Yet the value of these data depends on how they are organized, shared, and converted into decision support (Wolfert et al., 2017).

Knowledge graphs offer a useful response to this design problem. They represent entities and relationships in a structured, machine-readable, and semantically meaningful form. Hogan et al. describe knowledge graphs as graph-based structures that support the use of diverse, dynamic, and large-scale collections of data. Ji et al. similarly emphasize their role in knowledge representation, acquisition, completion, and knowledge-aware applications (Hogan et al., 2021; Ji et al., 2022).

This paper does not introduce another agricultural prediction model. Its starting point is more basic: before prediction outputs can become reliable decision support, agricultural knowledge must be organized in a form that makes relationships explicit. For this purpose, the study proposes a knowledge graph-based agricultural information architecture. The architecture connects core entities such as crop, soil, climate condition, water resource, disease, pest, farm practice, region, sustainability indicator, and recommendation. Once these entities



and their relations are represented explicitly, the system can support structured querying, semantic integration, evidence tracing, and interpretable decision support.

The study contributes in three ways. First, it treats agricultural decision support as a problem of relational knowledge organization, not merely as a data analytics task. Second, it proposes a domain-oriented architecture that links heterogeneous agricultural knowledge sources through a knowledge graph. Third, it illustrates how this architecture can support practical decision-support scenarios, including crop-soil suitability analysis, irrigation advisory, disease-risk interpretation, and sustainable practice recommendation.

Problem Background

Agricultural decision-support systems work with heterogeneous data. These data may include numerical sensor measurements, categorical soil descriptions, remote sensing products, meteorological observations, expert rules, farm management records, pest and disease descriptions, and policy-related sustainability indicators. Heterogeneity itself is manageable. The more difficult issue is semantic disconnection. The same concept may be named differently across systems, while concepts that are logically related may remain hidden in separate databases.

This semantic fragmentation weakens interoperability. A crop database may define water requirements; a soil database may describe drainage capacity, pH, and texture; a weather service may report rainfall anomalies; and an advisory tool may issue an irrigation recommendation. If these resources are not connected through shared concepts and explicit relations, the system cannot easily explain why a recommendation fits a particular crop, soil type, region, and climate condition. This concern is consistent with the digital agriculture literature, which argues that technical innovation needs to be examined together with data infrastructures, institutions, knowledge systems, and socio-technical arrangements (Klerkx et al., 2019).

A second problem is low reusability. Many agricultural information systems are designed for a narrow task such as yield prediction, disease identification, irrigation scheduling, or farm monitoring. They may work for their immediate purpose, but their knowledge structures are rarely reusable across other decision-support tasks. Knowledge used for crop-soil suitability, for example, may also be relevant for irrigation planning, disease-risk assessment, and sustainable input management. Without a relational structure, this knowledge remains trapped inside task-specific applications.

A third limitation is explainability. Data-driven platforms can generate recommendations, but they often say little about the evidence behind them. In agricultural decision-making, this is not a minor problem. Farmers, advisors, cooperatives, and public institutions may need to know which crop requirement was considered, which soil property mattered, which climate condition increased the risk, or which sustainability objective was affected. Ontology-based agricultural decision-support systems, such as AgrODSS, show the value of semantic models for representing plant disease and pest knowledge in a machine-understandable form and for providing evidence-based explanations (Alharbi et al., 2024).

A fourth issue concerns the absence of a reusable semantic backbone in many agricultural platforms. Agricultural knowledge organization systems already exist. AGROVOC, for instance, is a multilingual controlled vocabulary and linked data resource for food and agriculture, developed to improve access and interoperability across domains and languages (Subirats-Coll et al., 2022). Still, many decision-support platforms do not use such semantic resources as part of their internal information architecture.

These problems point to the same conclusion: sustainable agricultural decision support requires more than data collection and model development. It needs an information architecture that can connect heterogeneous knowledge sources, represent relations explicitly, and make recommendations interpretable.

Material and Methods

The architecture proposed in this study is built around an Agricultural Knowledge Graph. The graph acts as a semantic layer between raw data sources and decision-support applications. Instead of keeping agricultural information in isolated tables, files, or documents, the architecture represents domain knowledge as connected entities and relations.

At the core of the architecture are several entity types that commonly appear in agricultural decision-making:

Crop: wheat, tomato, maize, chickpea, potato, citrus.

Soil: clay loam, sandy soil, salinity condition, pH level, organic matter.

Climate Condition: rainfall anomaly, high humidity, heat stress, frost risk.

Water Resource: irrigation source, water availability, water requirement.

Pest and Disease: fungal disease, insect pest, disease-risk condition.

Farm Practice: drip irrigation, crop rotation, fertilization, pesticide application.

Region: province, district, agroecological zone, farm location.

Sustainability Indicator: water-use efficiency, soil health, input intensity, environmental risk.



Recommendation: irrigation advice, crop suitability advice, disease-risk warning, sustainable practice suggestion.

These entities gain decision-support value through their relations. Examples include:

Crop requires Water Requirement.

Crop is suitable for Soil Type.

Climate Condition increases risk of Disease.

Farm Practice reduces Water Use.

Region has Soil Property.

Recommendation is based on Evidence.

Sustainability Indicator is affected by Farm Practice.

This relational structure is the main difference between a conventional database and a knowledge graph. A database can store crop, soil, and weather records. A knowledge graph can additionally represent why these records are connected and how their relationships support a recommendation. Sustainable agricultural decision support needs this second capability, because it requires contextual interpretation as well as data retrieval.

The architecture can be organized into four layers.

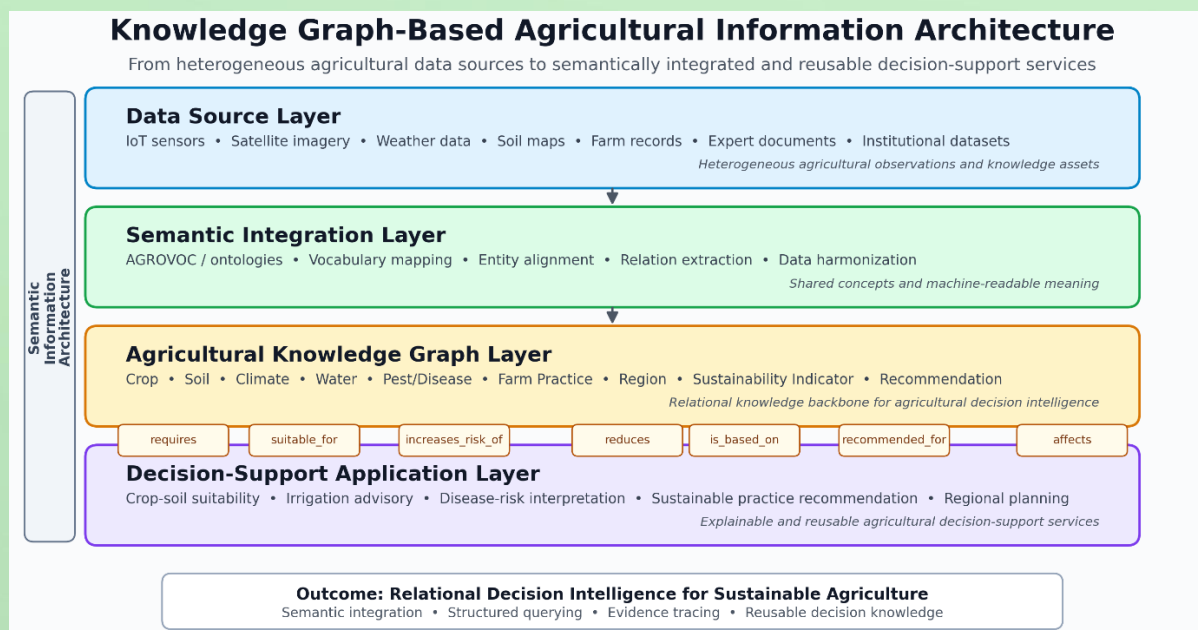


Figure 1. Knowledge Graph-Based Agricultural Information Architecture for Sustainable Decision Support

Data Source Layer: This layer contains raw and semi-structured agricultural data, including sensor measurements, satellite-derived indicators, weather records, soil maps, crop databases, expert documents, farm records, and institutional datasets.

Semantic Integration Layer: This layer maps heterogeneous data sources onto shared agricultural concepts. Controlled vocabularies and linked data resources, such as AGROVOC, can support semantic consistency and interoperability across systems (Subirats-Coll et al., 2022).

Agricultural Knowledge Graph Layer: This is the central layer of the architecture. It represents agricultural entities and their relations as a graph, connecting crops, soils, climate conditions, water resources, diseases, farm practices, regions, sustainability indicators, and recommendations.

Decision-Support Application Layer: This layer uses the graph to support advisory tasks such as crop-soil suitability analysis, irrigation planning, disease-risk interpretation, sustainable practice recommendation, and regional agricultural planning.

Table 1. Simplified entity-relation structure

Entity	Example	Relation	Decision-Support Value
Crop	Tomato	requires -> Water need	Supports irrigation planning
Soil	Clay loam	suitable_for -> Crop	Supports suitability analysis
Climate Condition	High humidity	increases_risk -> Disease	Explains disease risk
Farm Practice	Drip irrigation	reduces -> Water use	Supports sustainability advice
Region	Adana	has_climate -> Profile	Supports local advisory
Recommendation	Irrigation warning	based_on -> Evidence	Enables explainable support



The knowledge graph is therefore not only a storage layer. It is a reasoning-ready information structure. It allows a decision-support system to ask questions such as: Which crops match this soil and climate profile? Which disease risks increase under recent humidity and temperature conditions? Which practices reduce water use without raising disease risk? Which recommendations are supported by which evidence?

Results

The architecture can support several agricultural decision-support scenarios. Figure 2 presents an illustrative agricultural knowledge graph that connects crop, soil, climate, water, disease, practice, region, sustainability indicator, and recommendation entities through semantically meaningful relations.

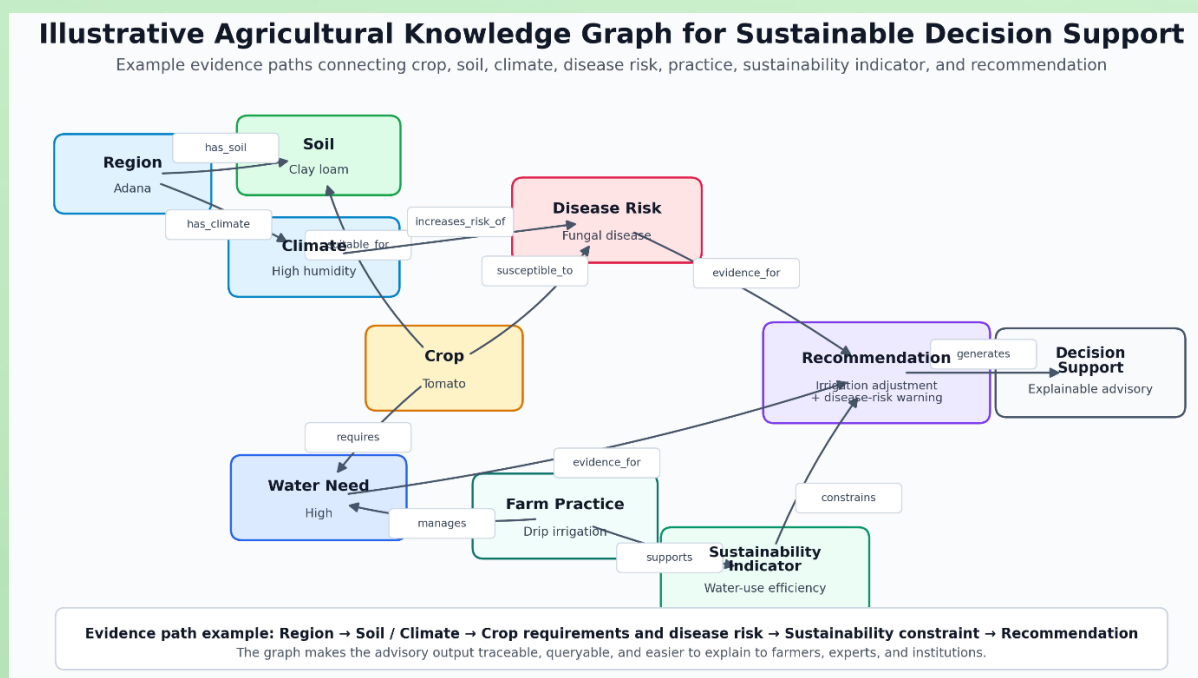


Figure 2. Illustrative Agricultural Knowledge Graph for Sustainable Decision Support

The following scenarios show how graph-based knowledge representation can improve interpretation and reuse.

Crop-Soil Suitability

A farmer or advisor may ask whether tomato is suitable for a specific field. A conventional system might consult a crop table and a soil table separately. A knowledge graph-based system can connect crop requirements, soil texture, pH level, salinity condition, drainage status, regional climate, and previous production constraints in one relational structure.

A graph-based query may follow a logic such as: find crops that are suitable for clay loam soil, tolerate the local pH range, match the regional temperature profile, and do not exceed available irrigation capacity.

The important point is that the answer is not just a label such as suitable or unsuitable. The system can show the supporting relations: crop-soil compatibility, water requirement, climate match, and regional constraints. This improves transparency for agricultural advisors and makes the recommendation easier to justify.

Irrigation Advisory

Irrigation decisions are shaped by several interacting factors, including crop growth stage, crop-specific water requirement, soil moisture, rainfall, evapotranspiration, irrigation method, and available water resources. In many agricultural information systems, these variables are stored or evaluated separately. A knowledge graph can bring them together within a reusable relational structure.

For example, tomato has a high water requirement during fruit development. If the region has received limited rainfall in recent days, the soil has only moderate water retention capacity, and the farm uses drip irrigation, the system may recommend irrigation. However, the recommendation should not stop at saying that irrigation is needed. It should also indicate that the amount of water should be adjusted carefully to avoid unnecessary use.



This scenario shows why sustainability indicators matter. The recommendation is not limited to a binary output such as irrigate or do not irrigate. It can also be linked to water-use efficiency, resource conservation, and environmental risk. In this sense, the graph supports both production-oriented and sustainability-oriented decision-making.

Disease-Risk Interpretation

Disease-risk warnings are often difficult to explain because they depend on interactions among humidity, temperature, rainfall, crop susceptibility, pest and disease knowledge, and farm management practices. Ontology-based systems in agriculture have shown that semantic models can support plant disease and pest identification by representing domain knowledge in machine-understandable form (Alharbi et al., 2024).

In the proposed architecture, a disease-risk warning can be generated and explained through graph relations. High humidity may increase the risk of fungal disease. Tomato may be susceptible to that disease under humid conditions. Recent rainfall may further support disease development, and the field may also have a previous disease record. When these pieces of evidence are connected, the system can explain why the disease risk is considered high.

This is more useful than a black-box alert. Instead of only presenting a warning, the system can show the evidence path behind it. Such evidence paths are particularly valuable for agricultural extension services, where recommendations need to be understandable, traceable, and defensible.

Sustainable Practice Recommendation

Sustainability-oriented agricultural decisions often involve trade-offs. A practice may reduce water use but increase labor requirements. Another may lower disease pressure but require additional management effort or chemical input. A knowledge graph can represent these trade-offs explicitly by connecting practices, expected benefits, possible risks, and sustainability indicators.

For example, drip irrigation may reduce water consumption, crop rotation may reduce disease pressure, and excessive nitrogen application may increase environmental risk. A decision-support system should therefore recommend a practice package that balances water efficiency, disease prevention, input intensity, and environmental protection.

The strength of the graph-based approach is that it can connect each practice to multiple sustainability indicators. This makes the architecture suitable for systems that need to move beyond productivity alone and include environmental, resource-efficiency, and long-term sustainability concerns.

Discussion

The MIS contribution of this study lies in a simple but often overlooked point: agricultural decision support is also an information architecture problem. In many digital agriculture projects, most attention goes to data collection, dashboards, and predictive models. These components are useful, but they do not by themselves create a reusable decision-support infrastructure. A sustainable system also needs a semantic structure through which data, expert knowledge, and decision logic can be connected and interpreted together.

From a Computer Engineering perspective, the knowledge graph provides a graph-based structure for integrating heterogeneous agricultural data. This matters because agricultural knowledge is not only numerical. It includes categories, textual descriptions, expert rules, regional classifications, spatial entities, temporal observations, and domain-specific concepts. Knowledge graphs are well suited to this complexity because they can represent entities, relations, schemas, context, and queryable knowledge structures within the same framework (Hogan et al., 2021; Ji et al., 2022).

From the perspective of relational decision intelligence, the architecture shifts attention from isolated prediction to connected reasoning. A machine-learning model may estimate disease risk or water demand, but a knowledge graph can place that output within a broader decision context. It can link the prediction to crop susceptibility, local climate, soil condition, management practice, sustainability target, and advisory recommendation. This makes the decision-support process more interpretable, reusable, and easier to justify.

The architecture also has practical value for agricultural institutions. It can support advisory platforms where knowledge from different departments, data providers, and expert groups needs to be integrated. It can also reduce the repeated development of disconnected systems for separate agricultural problems. Instead of creating isolated knowledge structures for irrigation, disease management, crop selection, and sustainability planning, institutions can build a shared agricultural knowledge graph and reuse it across services.

The study also has limitations. It presents a conceptual architecture and does not implement a complete agricultural knowledge graph. Future studies should operationalize the architecture using real datasets, domain ontologies, graph databases, and query examples. Further work may also evaluate the architecture with agricultural



experts, compare it with conventional relational database designs, and test its usefulness in domains such as irrigation advisory, plant disease management, crop suitability analysis, and regional sustainability planning.

Conclusion

This study proposed a knowledge graph-based agricultural information architecture for sustainable decision support. Its main argument is that agricultural decision-support systems should not be designed only as data repositories, dashboards, or prediction tools. They should also function as relational knowledge infrastructures that connect crops, soils, climate conditions, water resources, pests, diseases, farm practices, regions, sustainability indicators, and recommendations within a shared semantic structure.

The architecture places the Agricultural Knowledge Graph at the center of the decision-support process. By representing agricultural entities and their relationships explicitly, it supports semantic integration, structured querying, evidence tracing, and interpretable recommendations. In practical terms, it can be used for crop-soil suitability analysis, irrigation advisory, disease-risk interpretation, sustainable practice recommendation, and region-specific planning.

For Management Information Systems, the study positions knowledge graphs as a semantic backbone for agricultural information systems. For Computer Engineering, it offers a graph-based structure for integrating heterogeneous agricultural data and supporting query-driven decision intelligence. For sustainable agriculture, it provides a way to connect production decisions with environmental and resource-efficiency indicators.

The main message is straightforward: digital agriculture should move beyond the ambition to collect more data. The next step is to organize agricultural knowledge relationally, so that decision-support systems can reason across crops, environments, practices, and sustainability goals.

Declarations

Ethical Approval Certificate

Not applicable. This study is a conceptual framework study and did not involve human participants, animals, clinical procedures, experimental interventions, or survey-based data collection requiring ethical approval.

Author Contribution Statement

Cevher Özden: Conceptualization, methodology, literature review, framework design, visualization, writing the original draft, review and editing.

Fund Statement

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Conflict of Interest

The author declares no conflict of interest.

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In Vitro and In Silico Analysis of the Potential Effects of Kaempferol on Cell Viability and Calcium-Mediated Apoptotic Pathways in C6 Glioma Cells

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Abstract

This study aimed to investigate the effects of kaempferol on cell viability, intracellular calcium signaling, and apoptosis-related possible molecular mechanisms in C6 glioma cells. C6 rat glioma cells were cultured under appropriate cell culture conditions and treated with 25, 50, and 100 µM concentrations of kaempferol for 24 hours. Cell viability was evaluated using the XTT assay. Changes in intracellular calcium levels were analyzed by fluorescent calcium imaging using Fluo-4 AM fluorescent dye. To evaluate the potential effects of kaempferol on calcium-mediated apoptotic mechanisms, a protein-protein interaction (PPI) network including BAX, VDAC1, CYCS, CASP9, and CASP3 proteins was constructed using the STRING database. In addition, KEGG pathway enrichment analysis was performed for the selected gene/protein set. Statistical analyses were conducted using one-way ANOVA followed by Tukey's post hoc test, and $p < 0.05$ was considered statistically significant. The findings demonstrated that kaempferol treatment significantly reduced the viability of C6 glioma cells and increased intracellular calcium signaling. In conclusion, kaempferol may exert antiproliferative effects in C6 glioma cells through calcium-mediated apoptotic mechanisms. However, further molecular and functional studies are needed to confirm the underlying mechanism more comprehensively.

Keywords: Kaempferol, C6 glioma, apoptosis, calcium signaling, XTT

Kaempferol'ün C6 Glioma Hücrelerinde Hücre Canlılığı ve Kalsiyum Aracılı Apoptotik Yolaklar Üzerindeki Olası Etkilerinin İn Vitro ve İn Silico Analizi

Özet

Bu çalışmada, kaempferolün C6 glioma hücrelerinde hücre canlılığı, hücre içi kalsiyum sinyali ve apoptoz ile ilişkili olası moleküler mekanizmalar üzerindeki etkilerinin araştırılması amaçlandı. C6 rat glioma hücreleri uygun hücre kültürü koşullarında çoğaltıldı ve 25, 50 ve 100 µM konsantrasyonlarında kaempferol ile 24 saat süreyle muamele edildi. Hücre canlılığı XTT yöntemi ile değerlendirildi. Hücre içi kalsiyum düzeylerindeki değişimler Fluo-4 AM floresan boyası kullanılarak floresan kalsiyum görüntüleme yöntemi ile analiz edildi. Kaempferolün kalsiyum aracılı apoptotik mekanizmalar üzerindeki olası etkilerini değerlendirmek amacıyla BAX, VDAC1, CYCS, CASP9 ve CASP3 proteinlerini içeren protein-protein etkileşim ağı (PPI) STRING veri tabanı kullanılarak oluşturuldu. Ayrıca seçilen gen/protein kümesine yönelik KEGG yolak zenginleştirme analizi gerçekleştirildi. İstatistiksel analizlerde one-way ANOVA ve Tukey post hoc testi kullanıldı ve $p < 0.05$ değeri anlamlı kabul edildi. Elde edilen bulgular, kaempferol uygulamasının C6 glioma hücre canlılığını anlamlı şekilde azalttığını ve hücre içi kalsiyum sinyalizasyonunda artışa neden olduğunu gösterdi. Sonuç olarak, kaempferolün C6 glioma hücrelerinde kalsiyum aracılı apoptotik mekanizmalar üzerinden antiproliferatif etki gösterebileceği düşünülmektedir. Bununla birlikte, mekanizmanın daha güçlü biçimde doğrulanabilmesi için ileri moleküler ve fonksiyonel çalışmalara ihtiyaç vardır.

Anahtar kelimeler: Kaempferol, C6 glioma, apoptoz, kalsiyum sinyalizasyonu, XTT.





Adoption Dynamics and Economic Valuation of Urban Rooftop Gardening: Micro econometric Evidence from Bangladesh

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Abstract

Urban rooftop gardening is increasingly viewed as a practical response to food insecurity, rising urban temperatures, and environmental stress in South Asian megacities. Yet the household economics shaping adoption decisions and the potential demand for commercial rooftop gardening services remain insufficiently examined. This paper presents what appears to be the first integrated microeconomic analysis of rooftop gardening in Dhaka that jointly estimates household adoption behaviour, willingness to pay for professional services, and the factors associated with that willingness within a unified household production framework. The study uses original survey data collected from 445 households located in Dhaka North and South City Corporations. Household adoption is estimated through a Probit model grounded in Random Utility Maximisation, with HC3 heteroskedasticity consistent standard errors and a Firth penalised likelihood specification used for robustness assessment. Mean willingness to pay is estimated through a double bounded contingent valuation framework with bootstrap confidence intervals, while the determinants of willingness to pay are examined using a log normal interval censored regression model. The estimated mean willingness to pay for a professional rooftop gardening package is BDT 1765 per month with a 95 percent confidence interval ranging from BDT 1651 to BDT 1894. The findings reveal several notable asymmetries. Higher income households are less likely to engage in rooftop gardening directly, yet they display substantially higher willingness to pay for outsourced services. Neighbourhood gardening exposure increases the probability of adoption but reduces willingness to pay, suggesting the presence of localised free rider incentives. Social media exposure raises willingness to pay without generating a corresponding increase in adoption. Across both behavioural margins, rooftop water access emerges as the strongest predictor. The results point to a segmented urban market composed of self-producing households and service oriented consumers, with implications for municipal infrastructure planning and urban environmental policy.

Keywords: *Contingent valuation; Dhaka; Household production; Rooftop gardening; Urban agriculture; Willingness to pay*





Thermal Inactivation of *Salmonella* spp. in Tandoori Chicken

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Abstract

Salmonella spp. is a major foodborne pathogen commonly associated with meat products and the processing environment. Although thermal processing effectively eliminates this pathogen, the efficacy of microbial inactivation depends strongly on the applied time–temperature combination. This study aimed to evaluate the microbial reduction of *Salmonella* spp. in tandoori chicken under defined cooking conditions at temperatures of 55°C and 60°C using defined heating time intervals. The objectives were to determine the thermal inactivation parameters (D-value and z-value) and to calculate the F-value required to achieve a 7-log reduction of *Salmonella* spp. in tandoori chicken. Tandoori chicken samples (25 g) were inoculated with a three-strain *Salmonella* cocktail to achieve an initial population of approximately $7 \log_{10}$ CFU/g and subjected to thermal treatment at 55°C and 60°C under controlled conditions. Survivor curves were generated to determine decimal reduction times (D-values) and the z-value using linear regression analysis, and F_7 values were calculated to estimate the process time required to achieve a 7-log reduction. Recovery of thermally injured cells was assessed using TSA and TSA/XLD overlay agar. *Salmonella* inactivation was markedly temperature-dependent, with more than 5 log reductions achieved within 15 min at 60 °C, compared to a gradual reduction at 55 °C. The D-values of *Salmonella* spp. in tandoori chicken were 3.79 min at 55°C and 1.02 min at 60°C, with a z-value of 8.77°C. The corresponding F_7 values were 26.53 min and 7.14 min at 55°C and 60°C, respectively, demonstrating substantially greater lethality at the higher treatment temperature. Enhanced recovery on TSA/XLD overlay agar suggested the presence of sublethal injured cells following thermal exposure. These findings provide matrix-specific thermal inactivation parameters for *Salmonella* spp. in marinated poultry and contribute data for the validation of scientifically robust cooking processes and HACCP-based control strategies to improve poultry product safety.

Keywords: D-value; Marination; *Salmonella*; Tandoori Chicken; Thermal Inactivation; z-value



Infusion variables for maximum bioactive compounds yield in dry scent leaf, *Ocimum gratissimum* Linn, tea

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Abstract

Despite its traditional and culinary use, the industrial application of scent leaf, *Ocimum gratissimum* Linn, as a tea is low, especially in Nigeria. To support its industrial and wider use as a tea, this study examines the infusion variables capable of yielding the maximum bioactive compounds in dry scent leaf as well as its nutritional value. Study finding revealed that a maximum bioactive compounds yield was realised at 0.3 mm (particle size), water temperature of 70 °C and soaking duration of 7 minutes. The infusion was rich in carbohydrates (9.95 %), protein (4.18 %), potassium (120.5 ppm), phytate (2.32 mg/100g) and vitamin C (12.94 mg/100g), but low in crude fibre (0.07 %), magnesium (8.67 ppm), saponin (0.42 mg/100g), and vitamin A (205.92 µg/100g). This indicates that scent leaf tea could provide a modest contribution to dietary energy and amino acids, capable of serving as a natural electrolyte and mineral source. In the analysis, this study used 2 grammes (g) of dry, milled scent leaf of average moisture content below 10 per cent (%) (wet basis) and 25 millilitres (mL) of water.

Keywords: Scent leaf tea; Bioactive compounds yield; Infusion variable; Nutritional value

Introduction

Scent leaf, *Ocimum gratissimum* Linn, a medicinal and aromatic herb widely used in traditional medicine and culinary applications, has gained increasing attention due to its rich bioactive compounds (Orafidiya, *et al.*, 2001; Prakash and Gupta, 2005). These compounds, including essential oils, flavonoids, saponins, tannins, and other phytochemicals, have contributed to its various health benefits, such as antioxidant, anti-inflammatory, antimicrobial, and anti-diabetic properties (Osei *et al.*, 2021; Okigbo *et al.*, 2009). Owing to this, there has been a growing interest in enhancing the extraction yield of these compounds for use in food, beverages, and medicinal preparations (Nwankwo *et al.*, 2020). However, the release of these compounds in water depends heavily on the interplay between soaking duration, water temperature, and surface area, each playing a vital role in the release of phytochemicals and dissolved solids into the solvent medium (Chemat *et al.*, 2017; Adeyemo and Olagoke, 2020).

There is no acceptable single technique for extracting bioactive compounds from plant matters (Ghenabzia *et al.*, 2023). However, one of the most common methods of extracting bioactive compounds from plant materials is infusion, where plant matters are soaked in hot or warm water to release their soluble compounds (Bello *et al.*, 2019; Adeyemo and Olagoke, 2020) (see the study of Ghenabzia *et al.* (2023) for a review of the different methods of extraction of bioactive compounds and their effects on biological activity). The extraction performance is influenced by several factors, including temperature, soaking duration and particle size of the plant material. These significantly impact the quantity and quality of the dissolved favours and phytochemicals in the final infusion (Okoro *et al.*, 2021; Oladipo and Fagbohun, 2022). Temperature plays a vital role in the extraction process by enhancing the solubility of water-soluble compounds and increasing the diffusion rate of phytochemicals from the plant tissue into the water (Chemat *et al.*, 2017). The studies of Okoro *et al.* (2021) and Bello *et al.*, (2019) have shown that higher infusion temperatures significantly increase the dissolved solids in herbal infusions due to enhanced solubility of compounds such as flavonoids, saponins, and tannins. However, excessive heating may lead to the degradation of thermolabile compounds, including certain vitamins and polyphenols, and antinutrients (Adesina *et al.*, 2021; Sudirman *et al.*, 2024), thereby necessitating careful studies to balance solubility and thermal stability. Soaking duration is another key factor influencing extraction performance. Longer soaking duration generally allows more time for the plant material to release its soluble compounds into the water, thus promoting a higher concentration of extractable bioactive compounds (Adeyemo and Olagoke, 2020). While the literature is thin on the optimal soaking duration, Nwankwo *et al.* (2020) observed that extending soaking duration from 3 to 10 minutes led to significant increases in antioxidant and polyphenol contents yield in herbal teas. Notwithstanding this, Wang and Weller (2006) had cautioned that prolonged exposure may also result in the loss of certain volatile compounds due to evaporation or degradation. Therefore, determining an appropriate soaking duration is central to maximizing nutrients release without jeopardising the stability of beneficial phytochemicals (Adeyemo and Olagoke, 2020). Particle size is equally important, as it directly affects the surface area of the plant material exposed to the solvent. Smaller particle sizes result in a greater surface area, enhancing the extraction performance by allowing more water to come into contact with the exposed plant matter, thus leading to more effective leaching of soluble compounds (Bello *et al.*, 2019). However, larger particle sizes may hinder the extraction process,



limiting the amount of bioactive compounds that can be released into the water. Studies, including those of Adeyemo and Olagoke (2020) and Okoro *et al.* (2021), have demonstrated that pulverizing plant materials into fine particles significantly improves extraction yield compared to coarser sizes. Where tea bags are not used, extremely fine particles may also lead to filtration difficulties and increased turbidity in infusions, suggesting that while finer particles enhance extraction, they must be balanced with product clarity. Overall, the literature is thin on the optimal particle size, water temperature, and soaking duration beyond which further reduction/increase may not significantly improve extraction or can even negatively impact the process.

The study of Edo *et al.* (2023) has offered an excellent review of the phytochemistry and pharmacological compounds present in scent leaf. Although not exhaustive, Onyebuchi and Kavaz (2020) explored the effect of extraction temperature and solvent type on the phytochemical and bioactive properties of *O. gratissimum* extracts. Assié, *et al.* (2021) examined the combined effect of particle size, temperatures and soaking times on some Nigerian herbs including *Moringa oleifera*, *Vernonia amygdalina*, and *Hibiscus sabdariffa*, while that of Builders, *et al.*, (2020) looked at the effect of these influencing factors on some herbal tea blends such as lemon grass (*Cymbopogon citratus*), hibiscus (*Hibiscus sabdariffa*, commonly known as Zobo), and ginger (*Zingiber officinale*) infusions. The review of these literature strongly supports the influence of temperature, soaking duration, and particle size on the extraction of bioactive compounds from herbal plants. However, studies investigating the combined effect of, and suggesting the, soaking duration, water temperature and particle size that offers a higher extraction yield of bioactive compounds from dry scent leaf are rather scarce. This is the motivation and justification for this study. It fills this knowledge gap by evaluating the interactive effect of particle size, water temperature and soaking duration on dry scent leaf tea, suggesting the treatment that offers the highest bioactive compounds yield and its nutritional value. The outcome of this study contributes to scent leaf tea and therapeutic product development and use.

Materials and Methods

Sample sourcing, collection and pre-treatment

Fresh scent leaves, *Ocimum gratissimum* Linn, were sourced from a garden recognized for its adherence to sustainable agricultural practices in Ado Ekiti in November 2024. Harvesting was carried out in the early hours of the morning (around 6:00 am) to minimize postharvest wilting and quality degradation, transported to the laboratory in ventilated, sealed containers to maintain its freshness and prevent microbial contamination, and manually sorted to remove any damaged, insect infested, and discoloured leaves. The selected leaves were subjected to ambient air drying at room temperature under the shade. Leaves moisture content was monitored using the gravimetric method (modified after ISO 662) until it fell below 10 per cent (%) (wet basis), considered suitable for storage and further processing.

Tea preparation and total dissolved solids (TDS) measurement

600 grammes (g) of air-dried scent leaves were milled and sieved into three pre-selected particle size ranges using the literature and similar tea in the market as a guide: 0.30 mm, 0.60 mm, and 1.18 mm. 2 g each was weighed and placed in labelled tea bags. For tea preparation, 25 millilitres (mL) of distilled water were measured and poured into a glass beaker. The initial electrical conductivity (EC) and total dissolved solids (TDS) of the distilled water were measured prior to infusion. The beaker was then heated to the pre-selected temperatures of 30, 50, and 70 °C. Cost of water heating (or energy cost) and possible phytochemical degradation or loss favoured limiting the maximum water temperature to 70 °C. The bagged scent leaf samples (based on particle size) were immersed in the heated water and allowed to infuse for the pre-selected soaking durations of 3, 5, and 7 minutes (see Figure 1 for the tea preparation process). The pre-selected soaking duration drew on real life situation and documentary evidence. At the end of each soaking duration, the bags were removed. Post-infusion measurements of TDS and EC were carried out using the same calibrated digital EC/TDS meter) to determine the amount of solids extracted from the measured 2 g dry scent leaf samples. The TDS of each tea sample were obtained by subtracting the pre- from the post- infusion measurements.

The extraction rate, a measure of how much bioactive compounds (in this case, using the TDS as an indicator) extracted per unit time, was calculated using Equation 1, while Equation 2 was used to evaluate the extraction efficiency. As shown in Equation 2, the theoretical infusion yield represents the maximum amount of bioactive compounds that can potentially be extracted from a given amount of herbs.

$$\text{Extraction rate (mg/min)} = \frac{\text{TDS} \left(\frac{\text{mg}}{\text{L}} \right) \times \text{Volume of infusion water (L)}}{\text{Soaking time (min)}} \quad \text{Eq. 1}$$

$$\text{Extraction efficiency (\%)} = \left(\frac{\text{Extracted TDS}}{\text{Theoretical infusion yield of scent leaf}} \right) \times 100 \quad \text{Eq. 2}$$



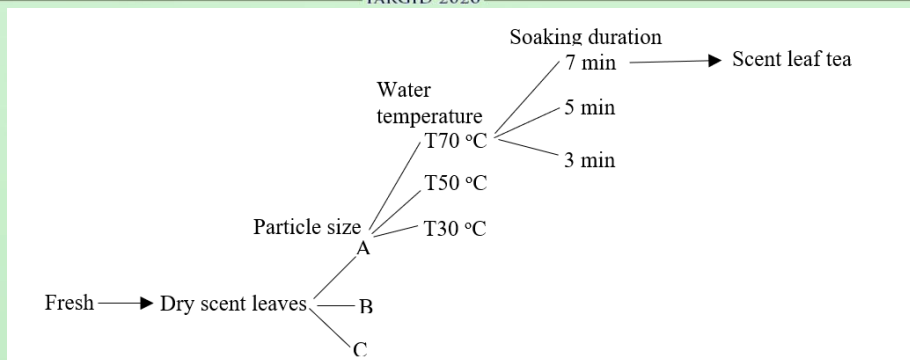


Fig. 1: The schematic diagram illustrating the tea preparation process

Note: A indicates 0.3 mm, B 0.6 mm and C 1.18 mm particle size

Nutrients evaluation

The proximate contents - protein, fat, ash, and carbohydrate - of the scent leaf tea were assessed following standard procedures outlined in the AOAC (2009). The anti-nutritional elements - tannins, phytates and oxalates - were quantified using spectrophotometric techniques described in Adebisi et al. (2019). Minerals – Na, Ca, K, and Mg – and vitamins – A and C (selected based on their health impacts) – were determined based on the methods described in AOAC (2005), Onwuka, 2005). Samples for analyses were obtained from the 25 mL. Overall, costs of laboratory analyses served to limit the numbers of treatments and nutritional elements considered.

Statistical analyses

The obtained TDS data were subjected to both descriptive (mean, median, standard deviation, etc.) and inferential (one-way between-groups analysis of variance (ANOVA) and independent-samples t-test) statistical analyses. For the ANOVA, data were checked for significant outliers (using the boxplot), normality (using the Shapiro-Wilk test), and homogeneity of error variances (using the Levene's test). A p-value ≤ 0.001 suggests a violation of normality and homogeneity tests, while data points located outside the boxplot whiskers suggest the presence of significant outliers. The one-way ANOVA was used to explore any significant difference in grouped (by temperature) treatment TDS, while the independent-samples t-test was used to compare the means between the treatments with the highest and the lowest nutritional values, using IBM SPSS Statistics version 25, alpha (α) value of 0.001 for the test of significance. In the case of the one-way between-groups ANOVA, where differences exist, post-hoc comparisons were carried out using the Tukey Honestly Significant Difference (HSD) test.

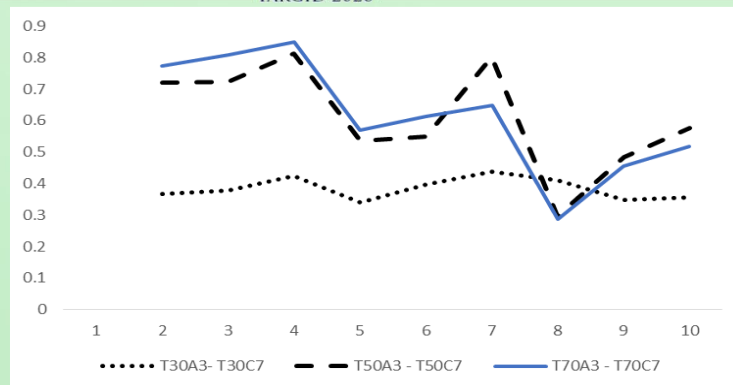
Results and discussion

TDS value

The average moisture content of the fresh scent leaves at harvest was 82.5 % (wet basis), while that of the dry scent leaves was 2.96 % (wet basis). Dry scent leaves were considered suitable for further analyses once their moisture contents fell below 10 % (wet basis). The 10 % moisture content (wet basis) was adopted to prevent microbial attack in storage, decolouration and loss of nutrients. Twenty seven experimental treatments (or Runs) were carried out to measure the TDS values (Figure 1). The X-axis represents coded combinations of temperature, particle size and soaking duration, while the Y-axis represents the mean TDS values. The summary of measurements for the top 5 and bottom 5 TDS treatments, including their extraction rate and efficiency values is illustrated in Table 1.

The distribution of mean TDS values under various experimental treatments revealed a general increase in mean TDS values, with increase in water temperature. Except for T30A3 – T30C7 that had a fairly stable mean TDS yield, others T50A3 – T50C7 and T70A3 – T70C7 showed a decreasing mean TDS value, impacted by particle size. At lower temperatures, the combine effect of particle size and soaking duration is slight. It becomes more pronounced at higher temperatures. Soaking duration had an increasing yield and bioavailability of active compounds impact under varying particle size holding temperature constant (see the spikes at 4, 7 and 10, Figure 1). This is supported by Table 1. It lists the five treatments with the highest mean TDS values, all of which involved finely ground particles (0.30 mm) and elevated temperatures (50–70°C), with longer soaking durations (5–7 minutes) compared with the bottom lowest five. The peak mean TDS value of 0.87 mg was observed in treatment T70A7 (70 °C, 0.30 mm, 7 min), underscoring the importance of combined thermal and particle size effects on bioactive compounds yield. This finding aligns with existing literature which suggests that smaller particles increase surface area for solute transfer, while higher temperatures accelerate cell wall softening and solute diffusion (Yusoff *et al.*, 2022; Rudrapal *et al.*, 2023).





0.7730	0.8085	0.8510	0.5690	0.6120	0.6490	0.2860	0.4565	0.5170
	3	4	5	6	7	8	9	10
T30A3	T30A5	T30A7	T30B3	T30B5	T30B7	T30C3	T30C5	T30C7
0.3680	0.3775	0.4240	0.3390	0.3980	0.4375	0.4115	0.3495	0.3575
T50A3	T50A5	T50A7	T50B3	T50B5	T50B7	T50C3	T50C5	T50C7
0.7215	0.7235	0.8120	0.5360	0.5495	0.8030	0.2970	0.4835	0.5755
T70A3	T70A5	T70A7	T70B3	T70B5	T70B7	T70C3	T70C5	T70C7

Fig 1: The TDS means plots (n = 2) for the scent leaf tea under the various treatments

Note: T30A3 means: water temperature 30 °C, A (particle size) = 0.30 mm (finely ground), and 3 = soaking duration (min); B = 0.60 mm (moderately ground), and C = 1.18 mm (coarsely ground). For example, T70C7 indicates: water temperature 70 °C, particle size 1.18 mm, and 7 mins soaking duration. Table 1: The top 5 and bottom 5 mean TDS values, including their extraction rate and extraction efficiency

Table 1: The top 5 and bottom 5 mean TDS values, including their extraction rate and extraction efficiency

Rank	Treatment	Temperature (°C)	Particle size (mm)	Soaking duration (min)	Mean TDS value* (mg/L)	Extraction rate ($\times 10^{-3}$ mg/min)
Top 5						
Run 21	T70A7	70	0.30	7	0.87	3.11
Run 12	T50A7	50	0.30	7	0.82	2.93
Run 15	T50B7	50	0.60	7	0.81	2.89
Run 20	T70A5	70	0.30	5	0.81	4.05
Run 19	T70A3	70	0.30	3	0.78	6.50
Bottom 5						
Run 9	T30C7	30	1.18	7	0.36	1.29
Run 8	T30C5	30	1.18	5	0.35	1.75
Run 4	T30B3	30	0.60	3	0.34	2.83
Run 16	T50C3	50	1.18	3	0.30	2.50
Run 25	T70C3	70	1.18	3	0.29	2.42

*n = 2

Table 2: Results of the descriptive statistical tests

Statistic	Mean (std. error)	Median	Variance	Std. deviation	Minimum	Maximum	Range	Interquartile range	Skewness (std. error)	Kurtosis (std. error)
T30A3 - T30C7	0.39 (0.02)	0.37	0.004	0.065	0.283	0.525	0.242	0.124	0.37 (0.54)	-0.396 (1.04)
T50A3 - T50C7	0.61 (0.04)	0.60	0.029	0.170	0.269	0.890	0.621	0.261	-0.30 (0.54)	-0.412 (1.04)
T70A3 - T70C7	0.614 (0.05)	0.60	0.038	0.195	0.280	0.949	0.669	0.218	0.18 (0.54)	-0.311 (1.04)
Overall	0.54 (0.04)	0.51	0.035	0.186	0.269	0.949	0.680	0.297	0.55 (0.33)	-0.557 (0.64)

Statistic	99 % confidence interval for mean: Lower bound	Upper bound	5 % trimmed mean
T30A3 - T30C7	0.34	0.43	0.38
T50A3 - T50C7	0.50	0.73	0.62
T70A3 - T70C7	0.48	0.75	0.61
Overall	0.47	0.60	0.53



As shown in Table 1, Run 21 exhibited the peak extraction performance, with a TDS of 0.875 mg. Run 21, which was characterized by fine particle size (0.30 mm), highest temperature (70°C), and longest soaking time (7 minutes), likely enhanced nutrients transfer due to increased surface area and thermal energy. Similar extraction performance was observed in Runs 12, 15 and 20, highlighting the significance of the combined effect of temperature, particle size and soaking duration. However, the lowest extraction performances were observed in Runs 25 and 16, both associated with coarser particles and potentially lower soaking durations. On the other hand, holding temperature and particle size constant, the extraction rate increased with decrease in soaking duration (see, for example, Runs 21, 20, and 19; and Runs 9 and 8 in Table 1). Although the water-to-leaf ratio in this study was held constant for all the treatments (12.5 to .0; (v/m)), the diffusion rate was expected to tail off after some few minutes of soaking due to saturation effects, water temperature cooling off, plant tissue resistance, and extractability limitation associated with use of water-infusion method. As revealed in Figure 1, increasing the soaking duration did contribute to a higher extraction yield. The only exception was T30C3 – T30C7 that resulted in a decrease. Particle size (1.18 mm) and the possibility of nutrients migrating back into the plant tissues may explain the observed phenomenon. With scent leaf having an average theoretical infusion yield, the Runs with the highest and lowest extraction efficiency were 21 and 25, respectively (Table 1). Overall, the extraction kinetics were more strongly influenced by the interplay of higher temperature, fine particle size, and increased soaking duration. This observation is consistent with the findings of Adeoye *et al.* (2023) and Chen *et al.* (2022) who emphasized that diffusion and solute migration are enhanced by higher temperatures and reduced particle sizes due to lower diffusion barriers and improved solubility.

Table 2 illustrates the results of the descriptive statistical tests. Looking at Table 2 and Figure 1 together, the T70 grouping had the lowest minimum mean TDS, 0.86 mg, facilitated by higher particle size (1.18 mm) and lower soaking duration (3 minutes). Overall, the T70 grouping had the highest median TDS (0.61 mg), followed by the T50 grouping (0.58 mg), further supporting the influencing role of water temperature in nutrients extraction. The T30 grouping had the lowest range (0.098 mg), while the T70 grouping had the highest range (0.565 mg). The difference in range between T70 and T50 was slight (Table 2). This suggests the need to check if there is any statistical significant difference between the mean TDS values of the three groupings.

Data checked for significant outliers, normality ($W = 0.958$ (T30), 0.964 (T50), 0.954 (T70)); $p > 0.001$) and test of homogeneity of variances ($p > 0.001$) revealed no statistically significant violation. As shown in Table 3, the results of the one-way between-groups ANOVA revealed a statistically significant difference at the $p < 0.001$ level in mean TDS for the different temperature levels: $F(2, 51) = 13.11$, $p = 0.000$; the effect size was large (partial eta squared = 0.34). Post-hoc comparisons using the Tukey HSD test indicated that the mean TDS values for T30 grouping ($m = 0.39$, $SD = 0.07$), T50 ($m = 0.611$, $SD = 0.17$) and T70 grouping ($m = 0.614$, $SD = 0.20$) were significantly different from each other. The T50 grouping ($m = 0.611$, $SD = 0.17$) and T70 grouping ($m = 0.614$, $SD = 0.20$) did not differ significantly from one another. This suggests that looking at water temperatures, T50 and T70 groupings did not differ in terms of their mean nutrients yield. However, by mean and median values (Table 2), The T70 grouping was slightly higher. Therefore, the effect of water temperature is crucial to nutrients yield holding other infusion variables constant.

Table 3: Results of the one-way ANOVA

	Sum of squares	df	Mean square	F	Sig.
Between groups	0.622	2	0.311	13.11	0.000
Within groups	1.210	51	0.24		
Total	1.832	53			

Nutrients value

As shown in Table 4, the treatments with the highest mean TDS value (Run 21) and with the lowest mean TDS value (Run 25) were analysed for their nutrients values. For Run 21, the analysis revealed that the tea was rich in carbohydrates (9.95 %), protein (4.18 %), potassium (120.5 ppm), phytate (2.32 mg/100g) and vitamin C (12.94 mg/100g), but low in crude fibre (0.07 %), magnesium (8.67 ppm), saponin (0.42 mg/100g), and vitamin A (205.92 µg/100g). This indicates that the tea could provide a modest contribution to dietary energy and amino acids, with scent leaf tea capable of serving as a natural electrolyte and mineral source. The anti-nutrients profile was low and within tolerable limits, posing minimal interference with mineral absorption, while the infusion retained a beneficial level of vitamin C (12.94 mg/100g), which is vital for antioxidant function and immune health. This supports the studies of Afolayan and Jimoh (2009) and Gbashi *et al.* (2021) who emphasized that a careful balance of extraction variables not only increased extraction yield but also preserved the integrity of bioactive and nutritional compounds. However, Table 4 further revealed that extraction performance had some implications for tea nutritional value. The t-test results between Runs 21 and 25 were statistically significant at $p < 0.01$ levels (Table 4).



Table 4: Run 21 (top highest) and Run 25 (bottom lowest) nutritional values

Parameter	Value (mean*)		% difference	t-tests
	Run 21	Run 25		
Proximate (%):				p = 0.000, significant
Ash	0.21	0.17	+ 19.05	
Fat	0.19	0.24	- 26.30	
Crude fibre	0.07	0.06	+ 14.29	
Protein	4.18	3.18	+ 23.92	
Carbohydrate	9.95	8.72	+ 12.36	
Mineral (ppm):				p = 0.000, significant
Na	15.5	10.13	+ 34.65	
Ca	72.83	50.63	+ 30.48	
K	120.5	110.53	+ 8.27	
Mg	8.67	7.16	+ 17.42	
Anti-nutrient (mg/100g):				p = 0.000, significant
Tannin	2.20	2.65	- 20.46	
Phytate	2.32	3.18	- 37.07	
Saponin	0.42	0.53	- 26.19	
Oxalate	2.21	1.72	+ 22.17	
Vitamin:				p = 0.000, significant
A (µg/100g)	205.92	250.62	- 21.91	
C (mg/100g)	12.94	12.74	+ 1.55	

*n = 3; t-test (p < 0.001, Sig. (2-tailed)) suggests a significant difference between Runs 21 and 25, otherwise not. + indicates an increase, while - indicates a decrease. Data checked for significant outliers, normality and Levene's test for homogeneity of variances revealed no significant violation.

Conclusion

This study explored the combined effect of particle size, soaking duration, and water temperature on the extraction performance and nutritional composition of scent leaf, *Ocimum gratissimum* Linn. tea. The highest mean extraction yield – mean TDS of 0.88 mg/L - occurred at 0.3 mm (particle size), 70 °C (water temperature) and 7 minutes (soaking duration). This highlights the importance of combining fine particle size, longer soaking duration, with higher temperatures to maximize solute extraction in herbal teas. The tea obtained at mean TDS of 0.88 mg/L contained favourable nutritional characteristics, including appreciable amounts of protein (4.18 %), carbohydrates (9.95 %), potassium (120.5 ppm), and vitamin C (12.94 mg/100g), with low anti-nutrient levels. This outcome indicates that scent leaf tea holds promise as a nutritious and health-supporting herbal drink, capable of delivering essential nutrients and antioxidant benefits. To support its household use and industrial applications, the initial conclusion of this study is that dry scent leaf should be ground to 0.30 mm particle size, steeped in water at 70 °C, for 7 minutes. This is capable of ensuring maximum bioactive compounds extraction and nutritional value.

Notwithstanding the above, this study has some limitations worth mentioning. Firstly, the study assumes increase in mean TDS value to be associated with increase in nutritional value. This claim requires further investigations as some volatile nutrients may be evaporated or degraded at higher temperatures. Secondly, the boundary conditions, for example, for particle size, were purposively selected with some literature as a guide. However, future studies should look at 0.1 and 0.2 dry scent leaf particle sizes and compare the effects on bioactive compounds yield holding soaking durations (3, 5, 7 minutes) and water temperatures (30, 50 and 70 °C) constant, and thirdly, both the effect of changes in the volume of the dissolving solvent, water, and the interactions between water volume and solute mass, or water-to-leaf ratio, were not investigated. The present study had kept the solute mass constant at 2.0 g and solvent volume at 25 mL. To explain the possibility of any significant interactions between solvent volume and solute mass may benefit from future studies.

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Utilisation of Carrot Pomace as an Ingredient in Tomato Paste Production

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Abstract

Carrot pomace, a by-product accounting for 50% of food waste from carrot juice extraction, is significantly valued for its high content of antioxidants, minerals, vitamins, and dietary fibre. Tomatoes, one of the most widely consumed vegetables, are often processed into tomato paste for year-round availability. However, significant nutrient loss occurs during processing, making fortification necessary. This study investigated the effect of incorporating carrot pomace on the nutritional profile and quality attributes of tomato paste. The tomato paste formulations were prepared with varying proportions of carrot pomace, specifically 20%, 27.5%, 35%, 42.5%, and 50%, with the remaining composition consisting of tomato and a control made up of 100% tomatoes. The formulated tomato-carrot pomace pastes were evaluated for their proximate composition, pH, titratable acidity, total soluble solids, beta-carotene content, lycopene content, vitamin C content, colour parameters, and microbial load. Results showed significant variations in moisture, ash, protein, oil/fat, fibre, and carbohydrate content. Beta-carotene content and total soluble solids increased with the addition of carrot pomace, while pH, titratable acidity, lycopene content, and vitamin C content decreased. Colour analysis revealed an increase in yellowness (b^*), while redness (a^*) and lightness (L^*) exhibited a decrease. Samples with a higher proportion of tomato recorded relatively high yeast and mould counts. The optimized formulation, consisting of 61.8% tomato and 38.2% carrot pomace, was well rated for appearance, texture, taste, and aftertaste. The incorporation of carrot pomace into tomato paste not only enhances its nutritional profile but also contributes to reducing food waste, offering a sustainable and functional approach to improving food products.

Keywords: Carrot pomace, by-product, tomato paste, food enrichment, food waste reduction



Preserving the Quality Characteristics of Eggs Using Nanotechnology

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Abstract

Eggs are known as one of nature's most complete and functional food sources. In addition to their high nutritional value, their rich mineral and vitamin content makes them an important commercial product, particularly due to their unique applications in the food industry. However, due to their source of production and physical properties, they have a short shelf life, and quality loss is inevitable. Due to its structure, the egg is a food susceptible to microbial contamination (*Salmonella* sp.). To derive greater benefit from such a valuable food, methods such as liquid egg pasteurization and powdered egg production are employed. However, in recent years, modern preservation techniques such as nanotechnological coating have been widely researched and applied. In this study, lavender (*Angustifolia-Sevtopolis*) extract was nanoencapsulated within a polyvinyl alcohol polymer using the electrospinning method, collected on wax paper and aluminum foil, and used to coat chicken eggs contaminated with *Salmonella typhimurium* (ST). Over a 35-day storage period at 4 °C, the internal and external quality parameters, total aerobic bacterial count, and *Salmonella* count of the egg samples were determined. The thermal behavior, molecular characterization, and morphological properties of the produced nanofibers were determined using TGA, FTIR, and SEM analyses. As a result, compared to the control group samples (without nanofiber application), total aerobic bacterial growth in the egg samples was inhibited by up to 31.9% (1.38 log CFU/g) over the 35-day storage period. It was demonstrated that the treatment inhibited ST growth by up to 3.2 log CFU/g on aluminum foil and 2.6 log CFU/g on wax paper. The applied nanoencapsulation method reduced weight loss without affecting shell thickness; it also maintained critical quality parameters such as the white index, yellow index, and Haugh unit at high levels compared to the control. The application of nanofibers containing lavender extract has been demonstrated as an effective nanotechnological strategy applicable to the food industry, which preserves egg quality parameters and enhances microbiological safety.

Keywords: Nanotechnology, Electrospinning, *Salmonella typhimurium*, Egg quality parameters

Nanoteknoloji ile Yumurtanın Kalite Özelliklerinin Korunması

Özet

Yumurta, doğanın en eksiksiz ve fonksiyonel besin kaynaklarından biri olarak bilinmektedir. Yüksek besin, mineral ve vitamin içeriğiyle gıda sanayisinde benzersiz özelliklere sahip, ticari değeri yüksek bir üründür. Ancak üretim kaynağı ve fiziksel özellikleri gereği raf ömrü kısadır ve kalite kayıpları kaçınılmazdır. Yumurta, yapısı gereği mikrobiyal kontaminasyona (*Salmonella* sp.) açık bir gıdadır. Bu kadar değerli bir gıdadan daha fazla yararlanmak için; sıvı yumurta pastörizasyonu ve toz yumurta üretimi gibi yöntemler kullanılmaktadır. Ancak son yıllarda nanoteknolojik kaplama gibi modern muhafaza teknikleri yaygın olarak araştırılmakta ve uygulanmaktadır. Çalışmada; *Lavandula angustifolia* ekstresi, polivinil alkol polimeri içersine elektrospinning yöntemiyle Nanoenkapsüle edilerek, yağlı kağıt ve alüminyum folya üzerinde toplanarak *Salmonella typhimurium* (ST) ile kontamine edilmiş tavuk yumurtası kaplanmıştır. 4 °C'de 35 günlük depolama süresi boyunca yumurta numunelerinin; iç-dış kalite parametreleri, toplam aerobik bakteri ve *Salmonella* sayımı gerçekleştirilmiştir. Üretilen nanofiberlerin termal davranışı, moleküler karakterizasyonu ve morfolojik özellikleri TGA, FTIR ve SEM analizleri ile ortaya konulmuştur. Sonuç olarak; kontrol grubu numunelerine (nano uygulama yapılmamış) kıyasla, 35 günlük depolama süresi boyunca yumurta numunelerindeki toplam aerobik bakteri üremesi %31,9'a (1,38 log CFU/g) kadar engellenmiştir. ST büyümesini; alüminyum folyoda 3,2 log CFU/g ve yağlı kâğıtta 2,6 log CFU/g'ye kadar engellediği gösterilmiştir. Uygulanan nanoenkapsülasyon yöntemi kabuk kalınlığını etkilemeksizin ağırlık kaybını azaltırken; kontrole oranla ak indeksi, sarı indeksi ve Haugh birimi gibi kritik kalite parametrelerini yüksek düzeyde korumuştur. Lavanta ekstraktı içeren nanofiber uygulaması, yumurtaların kalite parametrelerini koruyan ve mikrobiyolojik güvenliğini artıran, gıda sanayine uygulanabilir etkin bir nanoteknolojik strateji olarak ortaya konmuştur.

Anahtar Kelimeler: Nanoteknoloji, Elektrospinning, *Salmonella typhimurium*, Yumurta kalitesi

Giriş

Küresel nüfus artışı ve tüketici bilincinin yükselmesi, gıda endüstrisinde hem besleyici değeri yüksek hem de mikrobiyolojik açıdan güvenli gıdalara olan talebi artırmıştır. Hayvansal kaynaklı protein, esansiyel amino asitler, vitamin ve mineraller bakımından en zengin ve ekonomik besin kaynaklarından biri olan yumurta, insan beslenmesinde



kritik bir role sahip olduğu bilinmektedir (Kovacs-Nolan ve ark., 2005; Pal ve Molnar 2021). Ancak yumurta, yumurtlamadan tüketime kadar geçen süreçte biyolojik yapısı gereği fizikokimyasal ve mikrobiyolojik bozulmalara karşı oldukça hassastır. Depolama süresince kabuktaki gözenekler vasıtasıyla meydana gelen su ve karbondioksit kaybı; iç kalite parametreleri olan; hava boşluğunun büyümesine, ak ve sarı indeksinin düşmesine ve Haugh birimi değerinin azalmasına neden olmaktadır. Bunun yanı sıra, kabuk yüzeyindeki mikroorganizmaların gözeneklerden içeri sızması, başta *Salmonella* sp. türleri olmak üzere patojenik kontaminasyon riskini artırarak hem gıda güvenliğini hem de halk sağlığını ciddi şekilde tehdit etmektedir.

Literatürde, kümes barınak sistemlerinin *Enterococcus* ve *Escherichia coli* gibi spesifik indikatör patojenlerin horizontal geçiş riski ve toplam mikrobiyal popülasyon seviyeleri üzerinde belirleyici bir rol oynadığı rapor edilmektedir. Yapılan çalışmalarda, en düşük kontaminasyon oranlarına geleneksel (4.05 log CFU/yumurta) ve zenginleştirilmiş (3.98 log CFU/yumurta) kafes sistemlerinde rastlanırken; büyük kafeslerden elde edilen yumurtaların 5.49 log CFU/yumurta mikrobiyal yüke sahip olduğu, en yüksek kirliliğin ise altlıklı kümes sistemlerinde (6.24 log CFU/yumurta) meydana geldiği bildirilmiştir (Englmaierova ve ark., 2014).

Niğde ve Kayseri illerinde; market ve köy yumurtalarının mikrobiyolojik kalitelerinin araştırılması amaçlanmıştır. Bu kapsamda, Niğde ve Kayseri'deki çeşitli market ve açık pazarlardan alınan toplam 200 yumurta (100 market ve 100 köy) örneği mikrobiyolojik analize tabi tutuldu. Her bir yumurta kabuğu ve içeriği koliform, *Escherichia coli*, *Campylobacter* sp., *Staphylococcus aureus*, *Salmonella* sp. ve maya- küf bakımından incelendi. İncelenen yumurta örneklerinin hiçbirinde *Campylobacter* sp. ve *S. aureus*'a rastlanmazken, bir örnekte (yumurta kabuğu) *Salmonella* sp. belirlendi. Ayrıca 27 (%13.5) yumurta kabuğunun ve 6 (%3) içeriğinin koliform bakteriler ile sırasıyla 12 (%6) ve 31 (%15.5) yumurta kabuğunun ise sırasıyla *E. coli* ve maya- küf ile kontamine olduğu tespit edilmiştir (Karadal ve ark., 2018).

Geleneksel olarak yumurta kalitesini korumak amacıyla soğuk zincir uygulamaları, mineral yağlarla kaplama veya modifiye atmosfer paketleme gibi yöntemler kullanılmaktadır. Ancak bu yöntemlerin yüksek maliyet, sınırlı raf ömrü uzatma kapasitesi ve çevresel sürdürülebilirlik gibi açılardan çeşitli dezavantajları bulunmaktadır. Son yıllarda gıda bilimi ve teknolojisinde yaşanan devrimsel gelişmeler, yenilikçi bir yaklaşım olarak nanoteknolojinin gıda muhafaza sistemlerine entegrasyonunu ön plana çıkarmıştır. Nanoteknoloji, materyallerin nano boyutta (1-100nm) manipüle edilerek üstün mekanik, bariyer ve antimikrobiyal özelliklere sahip yeni biyomalzemelerin geliştirilmesine olanak tanımaktadır.

Yumurtanın muhafazasında nanoteknolojik yaklaşımlar; özellikle elektro-eğirme (electrospinning) gibi yöntemlerle üretilen nanofiberlerin, nanokompozit ambalajların ve nano-enkapsüle edilmiş aktif bileşenlerin (esansiyel yağlar, organik asitler vb.) kullanımına odaklanmaktadır. Nano ölçekteki bu yapılar, çok yüksek bir yüzey alanı/hacim oranına sahip olmaları sayesinde kabuk yüzeyini homojen ve mikroskobik düzeyde kaplayarak gaz ve nem transferini minimuma indirmekte, böylece iç kalite kayıplarını etkili bir şekilde yavaşlatmaktadır. Aynı zamanda, yapıya entegre edilen antimikrobiyal nano-ajanların kontrollü salınımı sayesinde kabuk yüzeyindeki mikrobiyal yükün penetrasyonu engellenmekte ve ürünün mikrobiyolojik güvenliği en üst düzeye çıkarılmaktadır.

Bu çalışmanın amacı, yumurtanın depolama sürecindeki fizikokimyasal ve mikrobiyolojik kalitesini korumak adına nanoteknoloji tabanlı yenilikçi biyomalzemelerin (PVA) kullanım potansiyelini incelemektir. Bu doğrultuda, geliştirilen nanoteknolojik sistemlerin yumurta kabuğu üzerindeki bariyer etkileri, fonksiyonel özellikleri ve patojen mikroorganizmalara karşı gösterdiği antimikrobiyal etkinlik detaylı bir şekilde ele alınmıştır (Demirci 2026).

Materyal ve Yöntem

Uçucu Yağ Ekstraksiyonu

Araştırmada kullanılan *Lavandula angustifolia* bitkisinden uçucu yağ eldesi, Clevenger sistemi kullanılarak gerçekleştirilmiştir. Ekstraksiyon işlemi, çözücü olarak saf su varlığında 5 saat süreyle kesintisiz olarak sürdürülmüş; elde edilen uçucu yağ fazı ayrıştırılarak sonraki aşamalarda kullanılmak üzere 4°C'de muhafaza edilmiştir.

Elektrospın Çözeltilisinin Hazırlanması

Eğirme çözeltisinin hazırlanmasında, matris materyali olarak poli(vinil alkol) (PVA; Mv: 50.000-85.000 Da g/mol, Acros Organics) tercih edilmiştir. Kütlece %10'luk stok PVA çözeltisi, saf su içerisinde, manyetik karıştırıcıda 45°C sıcaklıkta, 350 rpm karıştırma hızında 4 saat süreyle tam çözünme sağlanana kadar stabilize edilmiştir. Ardından, elde edilen *L. angustifolia* uçucu yağı, hazırlanan homojen PVA matrisine toplam hacme oranla (%1.5, w/V) oranında ilave homojen olması sağlanmıştır (Demirci ve ark., 2025).

Elektroeğirme (Electrospinning) Prosesi

Hazırlanan biyoaktif emülsiyon çözeltisinin elektroeğirme işlemi, özelleştirilmiş bir elektrospinning düzeneğinde (Faraday Elektrik ve Elektronik Ltd., Erzurum, Türkiye) gerçekleştirilmiştir. Çözelti, bir dijital çift sıringa pompası (Harvard Apparatus 11 Plus, Holliston, Massachusetts, ABD) vasıtasıyla sisteme uyarlanmıştır. Proses parametreleri; akış hızı 0,450 mL/h, iğne ucu ile toplayıcı plaka arasındaki mesafe 12 cm ve uygulanan elektriksel potansiyel fark 10,8



kV olarak optimize edilmiştir. İşlem sonucunda elde edilen nanolifli (nanofiber) membran yapılar, karakterizasyon ve performans analizleri için kurutulmuş ve kullanılmıştır.

Nano Materyalin Karakterizasyon Analizleri

Lavanta ile üretilen nanofiberlerin morfolojileri, sırasıyla 10, 25 ve 50 kx büyütme oranlarında taramalı elektron mikroskobu (SEM) kullanılarak incelenmiştir.

Nanofiberlerin termal davranışları, bir termogravimetrik analizör (TGA; New Castle, DE, ABD) kullanılarak belirlenmiştir. Azot akış hızları 20 mL/dk olarak, sıcaklık aralığı ise 25°C ile 800°C arasında 10°C/dk hızında ayarlanmıştır. Belirtilen ısıtma aralığında (30°C ile 520°C) ayrışma ve buna bağlı ağırlık kaybı gözlemlenmiştir. Fourier dönüşümlü kızılötesi spektroskopisi

Üretilen nanofiberlerin kızılötesi spektrumlarına dayalı FTIR sonuçları, Bruker Optics (Almanya) tarafından üretilen ve ATR elmas modülüne sahip bir FTIR spektrometresi kullanılarak 400 ile 4000 cm⁻¹ (4 cm⁻¹ çözünürlük) dalga sayıları aralığında ölçülmüştür (Demirci ve ark., 2024; 2025).

Yumurtanın Kaplanması

Erzurum Atatürk Üniversitesi yumurta üretim çiftliğinde aynı gün üretilen, boyuta göre sınıflandırılmış (53-62 g, M) ve *salmonella* içermeyen yumurta örnekleri, test örnekleri olarak kullanılmıştır. Tüm yumurta örnekleri, 4,5 log (CFU/ml) *Salmonella typhimurium* içeren bir çözeltiye 2 saniye boyunca daldırılmış, ardından yumurta yüzeyindeki nemin kurumasına izin verilmiştir. Bu işlemlerin ardından, her numune için 10 dakika boyunca elektrospraying yöntemiyle hazırlanan ve nanomalzemelerle kaplanmış alüminyum folyo ve pişirme kağıdı (15x15 cm) yumurta yüzeyine uygulandı. Tüm yumurta numuneleri (kaplamasız numuneler: kontrol grubu, lavanta nanofiberlerinden üretilmiş alüminyum folyo ve pişirme kağıdı ile işlenmiş numuneler) 35 gün boyunca 4°C'de saklanmıştır.

Yumurta İç-Dış Kalite Parametre Analizleri

Yumurta, ağırlığı, kabuk kalınlığı ve şekil indeksi olarak dış kalite; hava boşluğu, ak- sarı indeksi ve haugh biri olarak iç kalite özelliklerini oluşturmaktadır.

Yumurta Ağırlığı (g): Hassas terazi (0.001 g, hassasiyetli) kullanılarak her bir yumurtanın kütlesi ölçülmüştür.

Kabuk Kalınlığı (µm): Yumurta kırıldıktan sonra iç zarı soyularak; Yumurtanın küt ucu, sivri ucu ve ekvator (orta) bölgesinden mikrometre dijital kumpas ile ölçümler alınarak ortalama değer kaydedilmiştir.

Yumurta hava boşluğu (mm): Yumurta ışık altında tutularak ölçüm cetveli yardımıyla ölçülmüştür.

Yumurta Ak İndeksi (%): Yumurta kırıldıktan sonra ak uzunluğu ve ak genişliği dijital kumpas ile ölçülerek kaydedilmiştir. Ak yüksekliği de mikrometre ile ölçülerek aşağıdaki formüle göre hesaplama yapılmıştır.

Ak İndeksi = (Ak Yüksekliği (mm) / ((2 * Uzun Çap (mm) + Kısa Çap (mm)) / 3)) * 100

Yumurta Sarı İndeksi (%): Yumurta kırıldıktan sonra sarı çapı dijital kumpas ile ölçülerek kaydedilmiştir. Sarı yüksekliği de mikrometre ile ölçülerek aşağıdaki formüle göre hesaplama yapılmıştır.

Sarı İndeksi = ((Sarı Yüksekliği (mm) / Sarı Çapı (mm)) * 100

Haugh Birimi (Haugh, HU): Yumurta tazeliğinin ve ak (albumin) kalitesinin literatürdeki en temel göstergesidir. Yumurta kırıldıktan sonra, sarının hemen etrafındaki yoğun ak tabakasının yüksekliği üç ayaklı mikrometre ile ölçülmüştür. Ardından yumurta ağırlığı da denkleme katılarak şu formülle HU hesaplanmıştır:

HU=100×log(H+7.57-1.7×W^{0.37}), H = Ak yüksekliği (mm), W =Yumurta ağırlığı (g)

Yumurtanın Mikrobiyolojik Analizleri

Nanofiber kaplamalı numunelerin ve kontrol yumurta örneklerinin toplam aerobik bakteri sayısı, Townsend ve Naqui (1998) tarafından tanımlanan yöntemle göre belirlenmiştir. Her numune için, bozulmamış yumurta numunesi, 100 ml seyreltme solüsyonu (%1 pepton ve %0,85 NaCl) içeren steril bir Stomacher torbasına konulmuştur; 5 dakikalık aralıklarla iki kez elle çalkalandıktan sonra, üç grup için seri seyreltiler (10¹ ila 10⁷) hazırlandı. Tüm seyreltilmiş numuneler, TAB üremesini tahmin etmek amacıyla 35 °C'de 2 gün (48 saat) süreyle inkübe edildi. TAB ile ilgili mikrobiyolojik ölçümler, her analiz gününde üç kez tekrarlandı ve sonuçlar ortalama±standart sapma olarak verilmiştir.

Toplam aerobik bakteri sayımı için, seyreltiler (10¹–10⁶ CFU/ml) *Salmonella typhimurium*'a özgü olan XLD agarında (Ksiloz Lisin Deoksikolat Agar, Merck 1.05287) inkübe edildi. 37°C'de 24 saatlik inkübasyonun ardından, besiyeriyle aynı renkte, yarı saydam ve bazen ortası siyah olan koloniler *Salmonella typhimurium* olarak sayılmıştır (Wenke, 2009; ISO 6887-1: 2017).

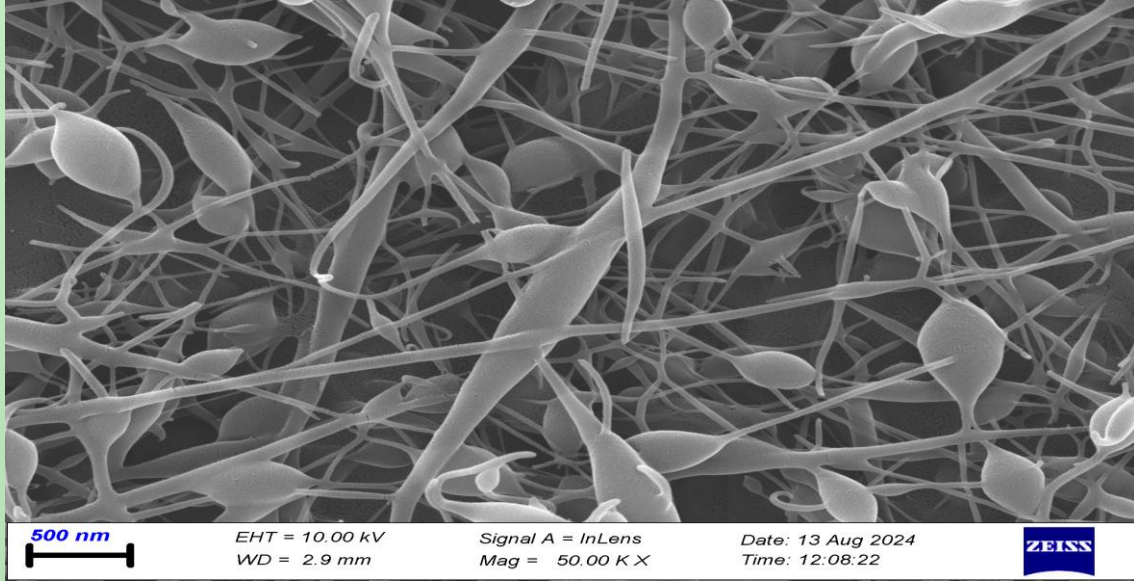
Bulgular ve Tartışma

Polivinilalkol nano polimeri içerisine gömülü olan lavanta yağı ekstresi ile kaplanan yumurta örnekleri 35 gün boyunca 4°C'de saklanmıştır. Bu süreçte yumurtanın iç-dış kalite özellikleri araştırılırken nano materyalin karakterizasyon morfolojisi de ortaya konmuştur.



Nano Materyalin Karakterizasyon Sonuçları

Yumurta örneklerinin kaplanması için üretilen nanofiberler **Şekil 1**'de gösterilmiştir. SEM'e dayalı bu görüntüler, nanofiberlerin başarıyla elde edildiğini ortaya koymuştur. Bu bağlamda, nanofiberlerin çapları 135,23 ile 589,514 nm aralığında ölçülmüş olup, ortalama değer ise $230,92 \pm 128,539$ nm olarak belirlenmiştir. Nanofiberlerin çaplarından da anlaşıldığı üzere, PVA'ya lavanta yağı eklenmesi çapı artırmıştır. Üretilen nanomalzemelerin çaplarının farklı boyutlarda olması kullanılan malzeme türüne (polisakkarit veya protein vb.) değişmekle birlikte elektrospin parametrelerinin (yüksek voltaj, mesafe ve toplayıcı türü) değişkenliğine bağlı olarak farklılık göstermektedir (Demirci ve ark., 2024; 2025; Ceylan ve Meral 2023). Papaya ve sirsak yaprağı özütlerinin akne tedavisindeki terapötik etkilerinden yararlanmak amacıyla geliştirilen PVA bazlı nanolifli sistemler, yenilikçi bir topikal taşıyıcı matris alternatifi sunmaktadır. Bu iki biyoaktif ekstraktın elektrospin ile polimerik PVA matrisine eş zamanlı entegrasyonunun, akne patolojisine yönelik lokal uygulamalarda hedef kütle transferini ve biyoaktiviteyi destekleyecek kararlı fizikokimyasal özelliklere sahip nanoliflerin üretilmesine zemin hazırladığı bildirilmektedir. Üretilen nanofiberlerin çapları solüsyondaki bitki ekstresi miktarına bağlı olarak 962-1232nm aralığında değişmiştir (Sastia ve ark., 2025). Bu çalışmada, *Salmonella*'nın inhibisyonunun hayati önem taşıması nedeniyle, 230,92nm dalga boyundaki nanofiberin uygulanması, yumurta numunelerinin kabuğunda barınabilecek bakterilerin yüzeyinde daha geniş bir temas alanı sağlayarak hızlı üremelerini engellediği görülmektedir.

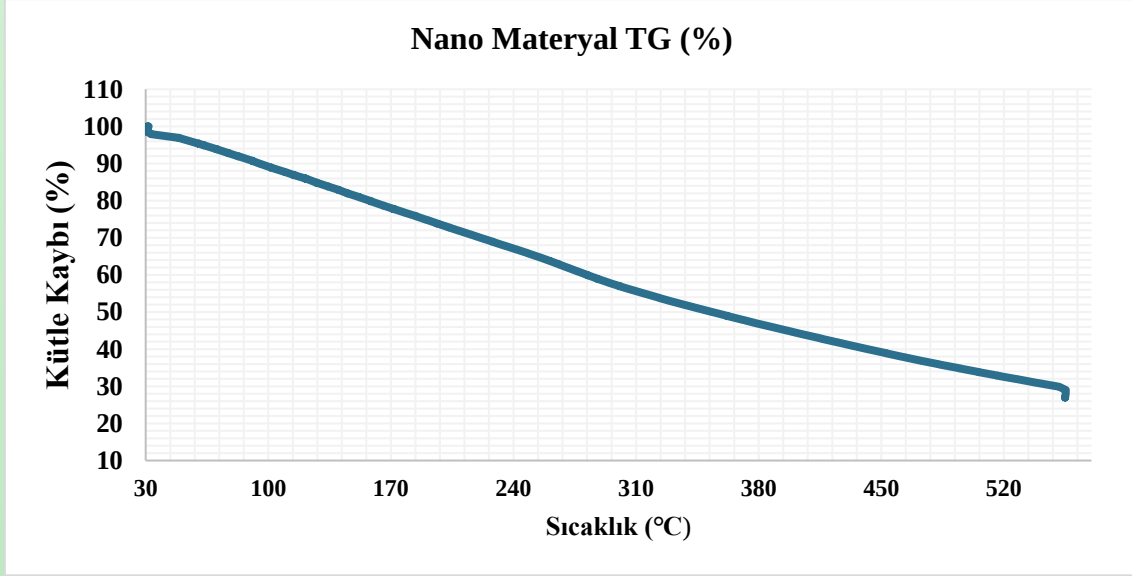


Şekil 1: Nano materyalin 500nm'deki SEM grafiği

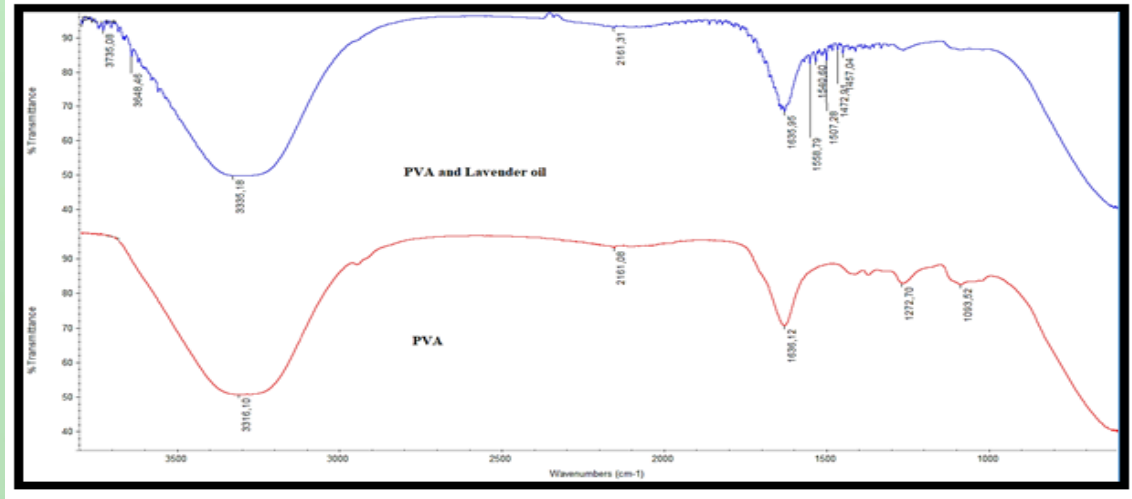
Nanofiberlerin termogravimetrik analizinde ağırlık kaybının, 100 °C'ye kadar %2'nin altında olduğu tespit edilmiştir. Bu kayba sebep olarak nem içeriğinin neden olabileceği ifade edilmektedir. Özellikle, nanofiberde 100 °C ile 550 °C aralığında belirgin bir termal ayrışma gözlemlenmemiştir (Şekil 2). Bu durum, üretilen nanolifin sıcaklığa karşı son derece önemli bir stabilite sağladığını göstermektedir. Gıda bilimi ve teknolojisinde, bütün yumurta veya yumurta ürünlerinde *Salmonella* sp. varlığının eliminasyonu; pastörizasyon, sterilizasyon ve ısı işlem (kızartma/pişirme) gibi termal proseslerin sıcaklık-zaman optimizasyonuna doğrudan bağlıdır. Bu bağlamda, depolama sürecinde (özellikle 35°C gibi hızlandırılmış veya uygunsuz sıcaklık koşullarında) meydana gelebilecek kütle kaybı, yumurta kabuğunun mikro gözenekli yapısı üzerindeki bariyer etkinliğini zayıflatmaktadır. Dolayısıyla, bu sıcaklık derecesindeki kütle ve nem kaybının baskılanması, kabuk yüzeyinde lokalize olan patojenlerin albumin (yumurta akı) veya vitellusa (yumurta sarısı) doğrudan penetrasyon riskini minimize etmek ve mikrobiyolojik güvenliği sürdürmek açısından nano kaplama kritik bir parametre olarak değerlendirilmektedir.

Bu çalışmada, PVA içinde nanofiber olarak bulunan lavanta yağı, dayanıklılığını ve kullanışlı işlevselliğini sağlamak için başarılı bir şekilde nanolif olarak kapsüle edilebildiği gözlemlenmiştir. Yumurta numuneleri için kullanılan üretilmiş nanofiberlerin kızılötesi spektrumundaki pikler Şekil 3'te sunulmuştur. Lavanta nanofiberlerine ait bazı spesifik bantlar; 3735,08, 3648,46 ve 3335,18 cm⁻¹ tespit edilmiştir. Bu bağların; O-H, C=C, CH₂ ve CH₃ gruplarındaki elementler arasındaki gerilme, titreşim ve bükülme simetrisinden kaynaklandığı ifade edilmektedir. Ayrıca, Tarhan ve ark. (2023) tarafından lavanta esansiyel yağı üzerine yürütülen çalışmada, esansiyel yağı nano materyallerinin 2200 ile 400 cm⁻¹ aralığında normal spektrumlara sahip olduğu bildirilmiştir.





Şekil 2: Nano materyalin Termogravimetrik analiz grafiği



Şekil 3: Nano materyalin FTIR analiz grafiği

Sanei-Dehkordi ve ark. (2023), lavantadan elde edilen nanoemülsiyonun O-H titreşimleriyle ilişkili olarak yaklaşık 3467 cm⁻¹'de bir tepe noktası gösterdiğini ve 2966, 2925, 2876, 1449, 1368 ve 1238 cm⁻¹'deki C-H, 1737 cm⁻¹'de C=O ile ilişkili pikler olduğu ve ayrıca 1044 ve 1092 cm⁻¹'de bulunan bantların alkol, eterler, karboksilik asit ve esterlerin C-O titreşimleriyle ilişkili olabileceği belirtilmiştir. Bu çalışmanın FTIR sonuçları, yukarıda bahsedilen çalışma ile karşılaştırılmıştır. Bu bağlamda, FTIR sonuçları, Salmonella'nın ortadan kaldırılmasında kullanılabilecek lavanta yağı-PVA nanofiber üretiminin başarılı olduğunu doğrulamıştır.

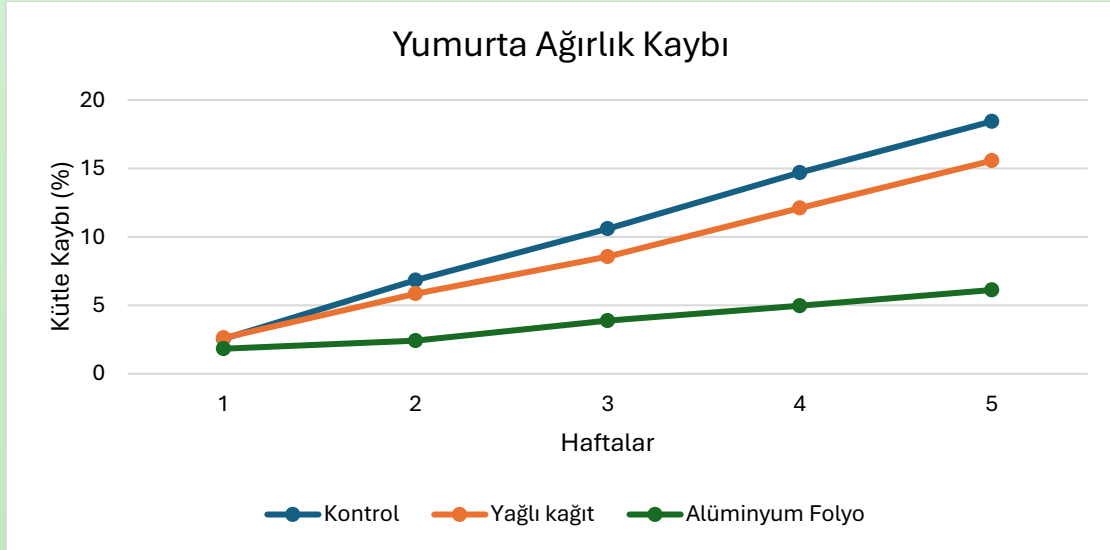
Yumurta İç-Dış Kalite Parametre Analiz Sonuçları

Çalışmada, yumurtanın iç ve dış kalite özelliklerinden bazıları 4°C'de 35 gün depolama süresince ölçülmüştür. Yumurta örneklerinin depolama süresinde ağırlık kaybı ölçüm sonuçları Şekil 4'te verilmiştir. Çalışmada; 5 hafta boyunca ağırlıkları ölçülen yumurtaların; 3. haftadan itibaren kontrol örneklerindeki kayıpların %10 u aşarak yumurtanın M boydan S boya indiği görülmektedir. 5. Haftada ise ağırlık kaybının en az (%6) alüminyum folyo ile kaplanan yumurta örneğinde olduğu görülmektedir.

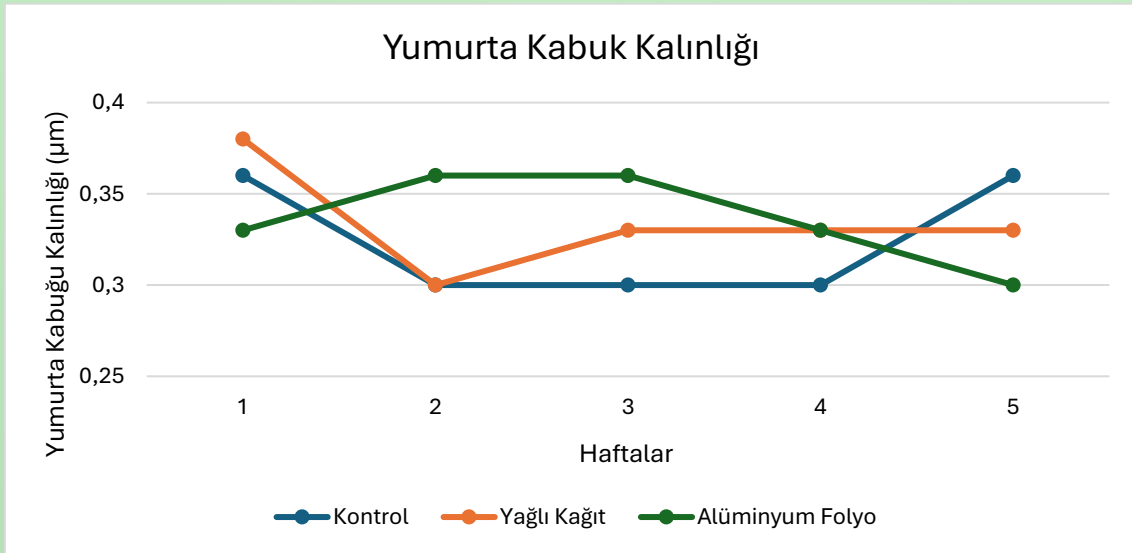
Çalışmada yumurta kabuk kalınlığındaki değişim analiz sonuçları Şekil 5'te verilmiş olup, nano kaplamadan bağımsız olarak önemli olmayan düzensiz bir dağılım görülmektedir. Bunun sebebinin her ne kadar aynı koşullardaki yumurtalar kullanılsa bile, yumurtalar arasındaki farklılıkların olduğu düşünülmektedir.

Yumurta örneklerinin depolama süresince iç hava boşluğundaki değişimi Şekil 6'da verilmiştir. Çalışmada; yumurta iç hava boşluğunun en yüksek kontrol örneğinde olduğu gözlemlenirken alüminyum folyo ile kaplanan yumurta örneklerinde en az boşluk ölçülmüştür. Bu sonuçlar yumurta toplam ağırlık kaybı ile paralellik göstermektedir.

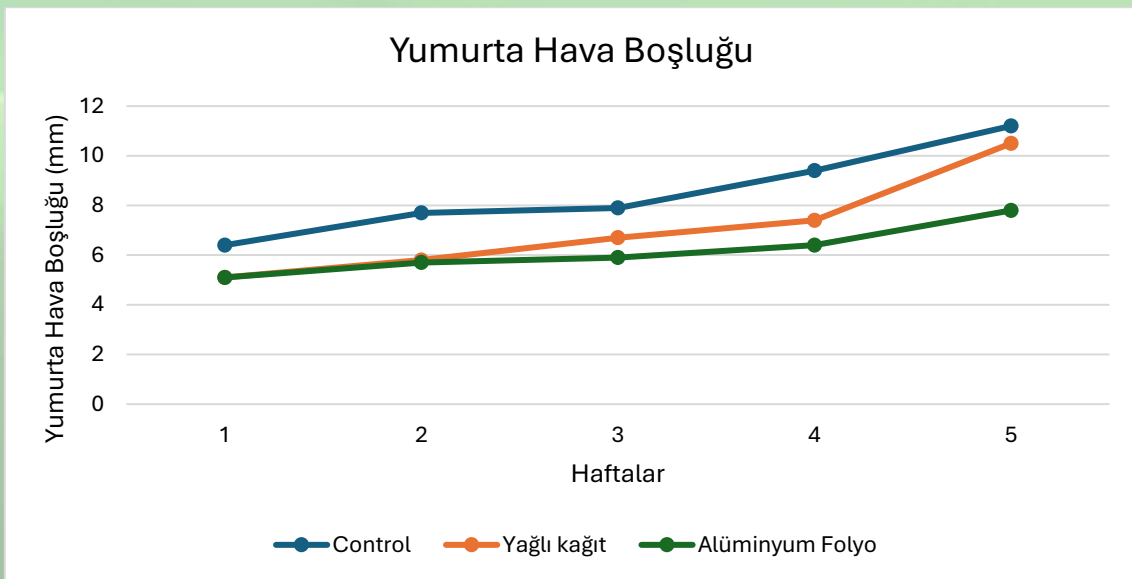




Şekil 4: Yumurta örneklerinin depolama süresinde ağırlık kaybı

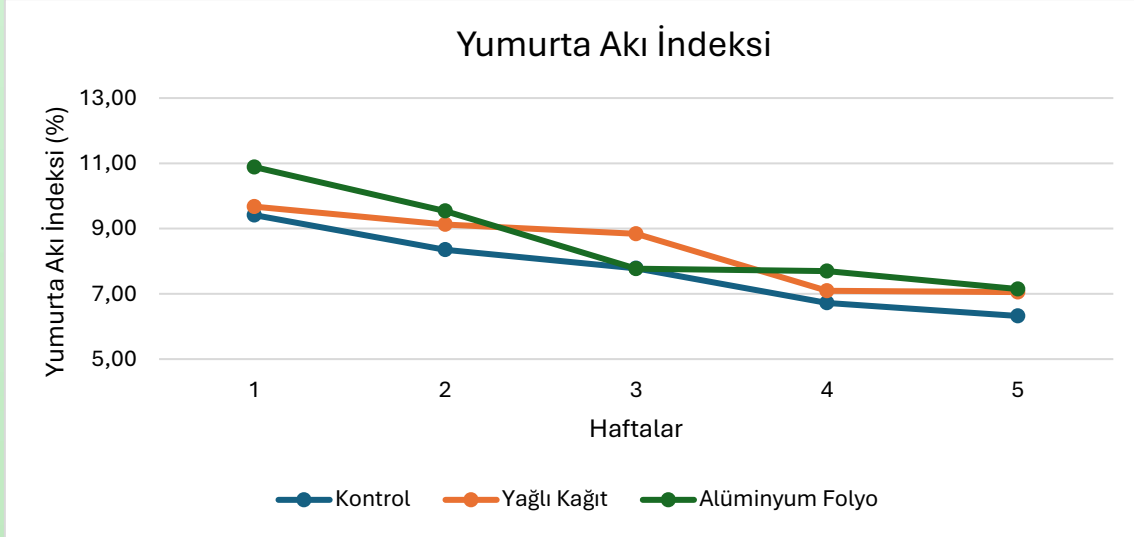


Şekil 5: Yumurta örneklerinin depolama süresince kabuk kalınlığı

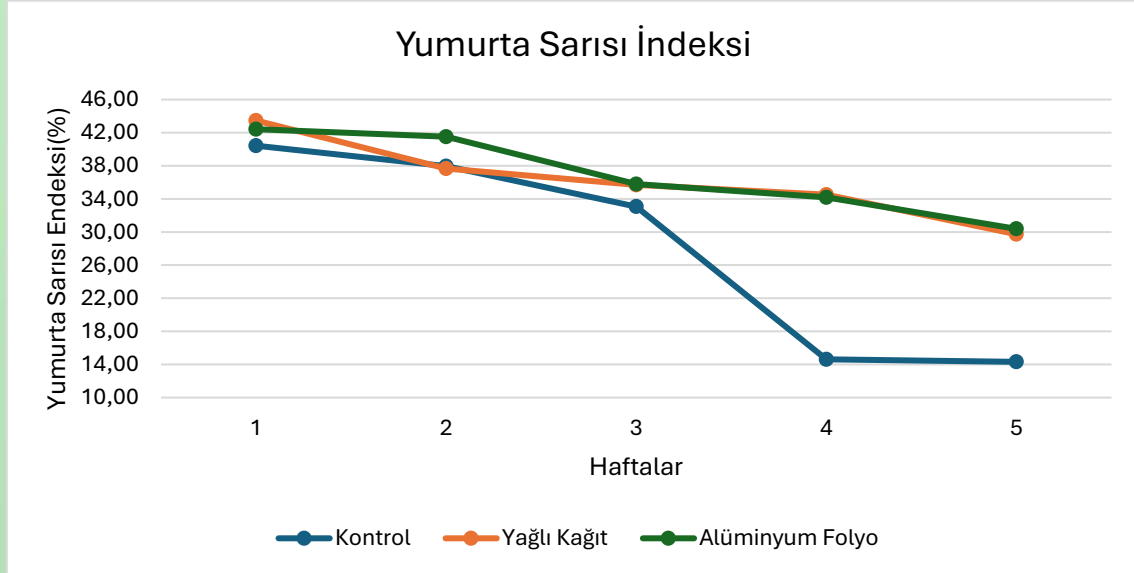


Şekil 6: Yumurta örneklerinin depolama süresince iç hava boşluğundaki değişimi





Şekil 7: Yumurta örneklerinin depolama süresince Ak indeksindeki değişimi



Şekil 8: Yumurta örneklerinin depolama süresince Sarı indeksindeki değişimi

Yumurtaların sınıflandırılmasında Haugh birimi (HU) esas alınmaktadır. $HU \geq 72$ AA, 71-60 A, 59-31 B ve <30 C olarak gruplandırılmaktadır. Çalışma sonuçlarımıza bakıldığında; başlangıçta A sınıfında olan yumurtalar kontrol grubu 2. haftadan itibaren bir alt grup olan B sınıfına düşerek 3. haftayı geçerken C sınıfının da altına düşmüştür. 5 haftalık bu süreçte nanokaplanan yumurtalar sadece 1 sınıf değer kaybetmişlerdir. Bu durumda nano kaplamanın yumurta HU birimini önemli ölçüde koruyabilmiştir.

Çalışmada; yumurta ak indeksi (Şekil 7) kontrol örneğinde 4. haftaya doğru düşük kalite sınıfına girerken nanokaplananlar orta kalitede kalabilmiştir.

Sarı indeksinde (Şekil 8) ise 3. haftadan itibaren kontrol grubu düşük kalite sergilerken yine nanokaplanan yumurta örnekleri orta kalite sınıfını koruyabilmiştir.

Yumurtanın Mikrobiyolojik Analiz Sonuçları

Yumurta, hem üretici hem de tüketici için mikrobiyolojik açıdan güvenilir olmalıdır. Üretim hattı olarak değerlendirdiğinde yumurta kontaminasyona maruz kalan ve sonrasında da içeriğindeki zenginliği sayesinde bulaşa çok müsait bir gıda konumundadır. Yumurtlama olduktan sonra yumurtanın bulunduğu ortam şartları ve tüketiciye ulaşana kadar geçen süreçteki taşıma muhafaza koşulları bulaşa ve var olan kontamine mikroorganizmaların üremesine olanak sağlayabilmektedir. Yumurtanın kendini belirli bir savunma sistemi (kütikula tabakası, avidin ve lizozim enzimi vb.) olduğu bilinmektedir (Yüceer ve Caner 2013; Chousalkar ve ark., 2021). Ancak ticari kazanç hırsı yumurtaların yeterince kabuk ve zar kısımlarının oluşmadan kısa sürelerde yumurtlama olmasını istemektedirler. Bu durumda ince kabuk ve hasar görmesi daha muhtemel yumurtalar oluşmaktadır. Sonuç olarak; hem mikrobiyal anlamda güvenilir hem de kalite özellikleri korunmuş yumurta istenmektedir.

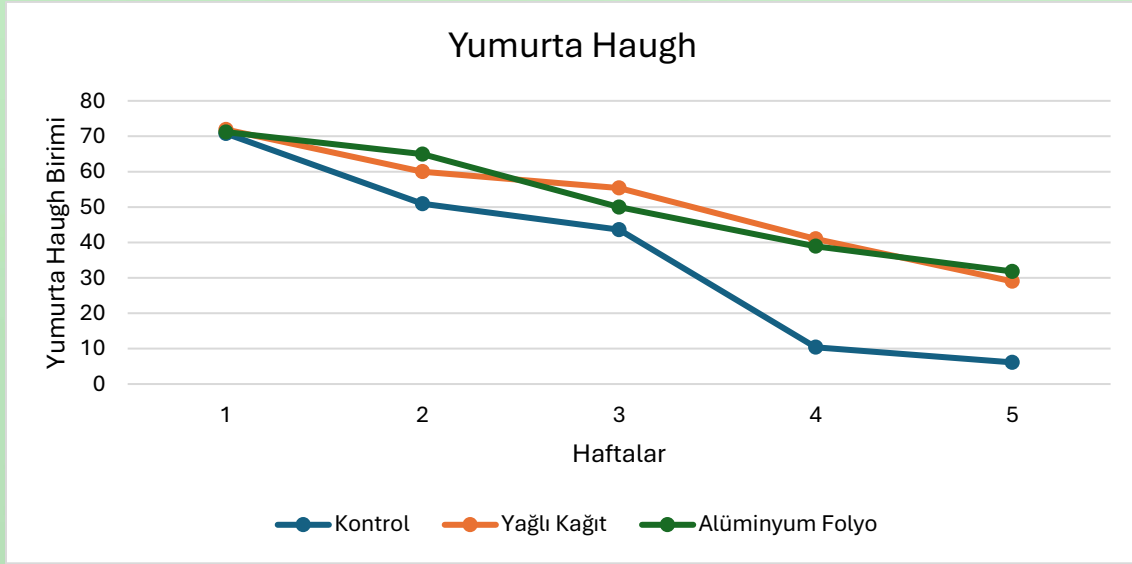


Kanatlı hayvanlar, *Salmonella* spp. patojeni için doğal bir rezervuar teşkil etmekte olup; söz konusu kontaminasyon, çevresel yollarla veya yumurta oluşumu esnasında içsel olarak şekillenebilmektedir. Bu çalışmada, hem çevresel faktörler hem de içsel fizyolojik süreçlerden kaynaklanan kontaminasyon mekanizmaları neticesinde, yumurta kabuk yüzeyinde yaklaşık 5 log CFU/mL düzeyinde yüksek bir bakteriyel popülasyonu tespit edilmiştir. Elde edilen bu kritik mikrobiyal yük, yumurtanın muhafaza sürecinde patojenlerin kabuk bariyerini aşarak iç yapılara penetrasyon riski taşıdığını ve halk sağlığı açısından ciddi bir gıda güvenliği tehdidi oluşturduğunu doğrulamaktadır (Aguiar ve ark., 2026).

Yumurta örnekleri, depolama boyunca materyal metot kısmında anlatıldığı gibi *Salmonella Typhimurium* ve Toplam Aerobik Bakteri Sayısı yönüyle analiz edilmiştir. Analiz veri sonuçları Tablo 1’de sergilenmiştir.

Çalışmada; lavanta ekstresi nanokapsüle edilen materyal *Salmonella* sp. üzerine 9mm’lik zon çapında antimikrobiyal etki göstermiştir.

Yumurtanın mikrobiyolojik analiz sonuçlarında; Tablo 1 ve Şekil 10 birlikte değerlendirildiğinde antimikrobiyal aktivitesi olduğu bilinen lavanta ekstresinin elektrospin yöntemiyle ile nanolif oluşturularak antimikrobiyal etkinliği artırıldığı görülmektedir. Tablo 1, detaylıca incelendiğinde kontrol örneklerinde hem *Salmonella* hem de toplam bakteri sayısının depolama boyunca yüksek oranda görüldüğü ancak çalışmanın 2. haftasından itibaren nano uygulanan örnek yumurtalarda mikrobiyal güvenliğin sağlandığı gözlemlenmiştir. Sonuç olarak uygulanan nanoteknolojik işlemin yumurta mikrobiyal güvenliğini sağlayarak paralelinde diğer kalite paralelinde de iyileşme sağladığı ortaya konulmuştur.

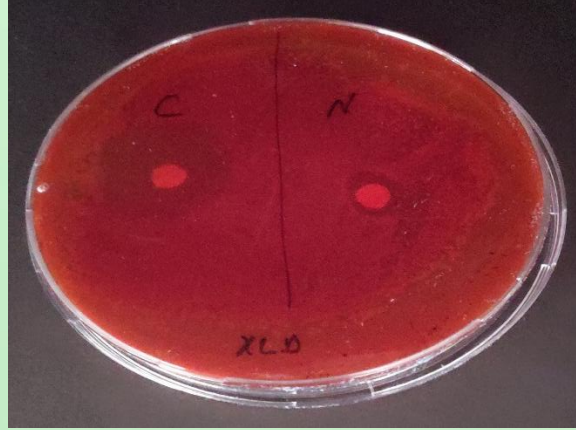


Şekil 9: Yumurta örneklerinin depolama süresince Haugh birimi değişimi

Tablo 1: Yumurta örneklerinin mikrobiyolojik analiz sonuçları

Uygulama Grupları	Depolama Süresi (Hafta)	<i>Salmonella Typhimurium</i> (CFU/ml)	Toplam Aerobik Bakteri Sayısı (TAB, CFU/ml)
Kontrol	1	4.3±0.01	4.15±0.02
	2	4.3±0.03	4.47±0.02
	3	4.2±0.05	4.76±0.01
	4	4.2±0.01	4.62±0.04
	5	4.1±0.06	4.88±0.05
Fırın kağıdı	1	4.3±0.04	4.32±0.08
	2	3.2±0.02	3.34±0.04
	3	1.1±0.05	3.23±0.01
	4	1.0±0.01	3.12±0.01
	5	-	2.94±0.06
Alüminyum folyo	1	4.3±0.04	3.89±0.05
	2	2.6±0.05	3.41±0.04
	3	1.2±0.04	3.21±0.05
	4	1.0±0.05	3.15±0.01
	5	-	2.76±0.07





Şekil 10: *Salmonella Typhimurium* üzerine antimikrobiyal test uygulaması (C: pozitif kontrol gentamisin sülfat, 20g/ml; N: lavanta ekstresinin Nanoenkapsüle edilmiş hali, 5 mm'lik disk)

Sonuç

Yumurta nanoenkapsülasyonunda kullanılan maddenin karakterizasyon sonuçları; elektroegirme yöntemiyle ortalama 230,09 nm çapında üniform nanoliflerin başarıyla üretildiğini göstermiştir. Nanoliflerin termal kararlılığı, yumurta muhafaza uygulamalarında test edilen sıcaklık sınırları içerisinde yapısal bir bozunma sergilememiştir. Ayrıca FTIR analizlerinde, lavanta uçucu yağına özgü karakteristik spektral bantların net bir şekilde tespit edilmesi, biyoaktif bileşenlerin polimerik matris içerisinde kimyasal bütünlüklerini kaybetmeden başarıyla enkapsüle edildiğini kanıtlamaktadır. Kontrol grubu numunelerine (nano uygulama yapılmamış) kıyasla, 35 günlük depolama süresi boyunca yumurta numunelerindeki toplam aerobik bakteri üremesi %31,9'a (1,38 log CFU/g) kadar engellenmiştir. ST büyümesini; alüminyum folyoda 3,2 log CFU/g ve yağlı kağıtta 2,6 log CFU/g'ye kadar engellediği gösterilmiştir. Uygulanan nanoenkapsülasyon yöntemi kabuk kalınlığını etkilemeksizin ağırlık kaybını azaltırken; kontrole oranla ak indeksi, sarı indeksi ve Haugh birimi gibi kritik kalite parametrelerini yüksek düzeyde korumuştur. Lavanta ekstraktı içeren nanofiber uygulaması, yumurtaların kalite parametrelerini koruyan ve mikrobiyolojik güvenliğini artıran, gıda sanayine uygulanabilir etkin bir nanoteknolojik strateji olarak ortaya konmuştur.

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Abdullah Demirci, corresponding yazar; veri toplama, araştırma, biçimsel analiz, yazım ve idüzenlemeden sorumludur.

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Contribution of sensors on emerging contaminants in agricultural wastewater

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Abstract

Sensors are constructed from materials based on ordered mesoporous carbon that have unique structural and electrochemical properties that work as a useful sensing platform for locating environmental pollutants in wastewater. In agricultural fields, a variety of pollutants, including fertilizers, pesticides, and sediments, affect water resources. These newly discovered pollutants are typically present in surface runoff in agricultural watersheds at readily detectable amounts. These also pose significant risks to the living world, which makes pollutant detection crucial for preserving the safety and quality of water. In-depth monitoring and control of agricultural water quality are made possible by small, reasonably priced sensors that may be used in the field to detect pollutants at their source. The aim and objectives of this study are to evaluate the nature of pollutants, their effects, and the role that sensors play in agricultural wastewater monitoring. In order to investigate their type, impacts, and presence in agricultural water bodies, a targeted literature search was carried out on scientific databases like Google Scholar and journal repository platforms, primarily ScienceDirect and Elsevier. In this review, the occurrence, detection, and monitoring of heavy metals, pesticides, and other pollutants are summarized using contemporary sensors. This research offers a roadmap for other researchers to use sensing methods to monitor and identify pollutants in water bodies by outlining the benefits and drawbacks of various detection techniques.

Keywords: Sensors, Contaminants, Wastewater, Agricultural wastewater, Monitoring





Antioxidant properties of probiotic *Bacillus* strains isolated from tarhana

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Abstract

The presence of antioxidant capacity in a probiotic microorganism may provide an additional health benefit by reducing oxidative stress caused by free radicals. Furthermore, the use of probiotics with antioxidant properties in food systems can contribute to the preservation of product quality and the extension of shelf life by limiting oxidative deterioration. In this study, antioxidant capacities of twelve probiotic *Bacillus* isolates were investigated. The antioxidant activities (DPPH and ABTS radical scavenging activities) of cell-free supernatant, intact cells and intracellular extracts were determined. The isolates were grown in nutrient broth at 37 °C for 24 h. Subsequently, they were centrifuged to separate the supernatant and the cells. The supernatants were filtered through a 0.22 µm membrane filter, and the cells were washed three times with phosphate-buffered saline (pH 7.2). Some cells were separated for the analysis of the intact cells, and the rest were subjected to ultrasonication to disrupt the cells. After ultrasonication, they were centrifuged and the activity of the upper phases were determined. Antioxidant activities were determined using 96-well plates using a microplate reader. The results showed that DPPH radical-scavenging activities of the supernatants (47.4-65.6 %) were significantly higher than those of the intracellular (10.0-13.5 %) or intact cells (7.5-28.7 %). On the other hand, ABTS radical scavenging activities of the intact cells (16.3-49.1 %), and intracellular extracts (7.9-39.2 %) were higher than DPPH activities. In addition, the supernatants showed ABTS activity ranging from 50.4 to 57.1 %. In conclusion, probiotic *Bacillus* isolates exhibited antioxidant potential, particularly in their cell-free supernatants, suggesting that antioxidant compounds released by the isolates may contribute to their functional properties and support their use as probiotic cultures in food applications.

Keywords: *Bacillus*, probiotic, antioxidant, DPPH, ABTS

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Investigation of Effects of Different Nitrogen Doses on Yield And Yield Components of Bread and Durum Wheat Varieties

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Abstract

This study aimed to investigate the effects of different nitrogen doses on yield and yield components in durum and bread wheat varieties. In study, Kızıltan 91 durum wheat and Obala bread wheat varieties were used, and nitrogen application doses of 0, 4, 8, 12, 16, and 20 kg da⁻¹ were applied. The study was conducted in Göksun district of Kahramanmaraş between November and July. The experiment was conducted using a split-plot design with 20 cm row among, 6 rows, and 500 seeds per m² sown manually. The tillering number, plant height, flag leaf length, flag leaf width, hectoliter weight, number of fertile spikelets, and grain yield characteristics of Kızıltan 91 durum wheat and Obala bread wheat varieties were examined. Statistically significant differences were recorded among varieties in terms of plant height, flag leaf length, flag leaf width, and grain yield. Fertilizer doses were found to have a positive effect on all examined characteristics and to create statistically significant differences. The highest grain yield per decare was obtained from the Kızıltan 91 durum wheat and Obala bread wheat varieties with a nitrogen dose of 20 kg da⁻¹, yielding 493 and 508 kg respectively. It was recorded that 502 kg of grain yield per decare was obtained from the application of a 16 kg da⁻¹ nitrogen dose to the Obala bread wheat variety, and no statistically significant difference was observed between the 16 kg da⁻¹ and 20 kg da⁻¹ nitrogen dose applications. Grain yield was obtained as 418 kg da⁻¹ for the Kızıltan 91 durum wheat variety and 464 kg da⁻¹ for the Obala bread wheat variety.

Keywords: Bread wheat, durum wheat, nitrogen doses, yield, yield components

Farklı Azot Dozlarının Ekmeklik ve Makarnalık Buğday Çeşitlerinin Verim, Verim Unsurlarına Etkisinin Araştırılması

Özet

Bu çalışmada, makarnalık ve ekmeklik buğday çeşitlerine, farklı azot dozu uygulanarak, azot dozlarının verim ve verim unsurlarına üzerine etkisinin araştırılması amaçlanmıştır. Araştırmada, Kızıltan 91 makarnalık ve Obala ekmeklik buğday çeşitleri kullanılarak, 0, 4, 8, 12, 16 ve 20 kg da⁻¹ azot doz uygulaması yapılmıştır. Çalışma, Kahramanmaraş-Göksun ilçesi koşullarında Kasım-Temmuz ayları arasında yürütülmüştür. Deneme bölünmüş parseller deneme deseninde 20 cm sıra aralığının da, 6 sıralı, m² 500 tohum düşecek şekilde elle ekim yapılmıştır. Kızıltan 91 makarnalık ve Obala ekmeklik buğday çeşitlerinin kardeş sayısı, bitki boyu, bayrak yaprak uzunluğu, bayrak yaprak genişliği, hektolitreye ağırlığı, fertil başakçık sayısı, tane verimi özellikleri incelenmiştir. İncelenen özelliklerden bitki boyu, bayrak yaprak uzunluğu, bayrak yaprak genişliği, tane verimi yönünden çeşitler arasında istatistiksel önemli farklılıklar kaydedilmiştir. Gübre dozları incelenen tüm özellikler üzerinde pozitif etkide bulunduğu ve istatistiksel önemli farklılıklar oluşturduğu belirlenmiştir. En yüksek dekara tane verimi Kızıltan 91 makarna ve Obala ekmeklik buğday çeşitleri sırasıyla 493, 508 kg ile 20 kg da⁻¹ azot doz uygulamasından elde edilmiştir. Obala ekmeklik buğday çeşidi 16 kg da⁻¹ azot doz uygulamasından 502 kg dekara tane verimi elde edildiği ve 20 kg da⁻¹ azot doz uygulaması arasında istatistiksel fark oluşturmadığı kaydedilmiştir. Kızıltan 91 makarnalık çeşitte 418 kg da⁻¹, Obala ekmeklik çeşitten 464 kg da⁻¹ tane verimi alınmıştır.

Anahtar Kelimeler: ekmeklik, makarnalık, buğday, azot dozları, verim, verim unsurları

Giriş

Dünya üzerinde yaşayan canlıların beslenme kaynaklarından, buğday en önde gelen bitkilerden biridir. Buğday, ekim ve üretim bakımından da ilk sırada yer alan, stratejik öneme sahip bir bitkidir. Uygun ve ucuz besleme değeri yanı sıra üretim, taşınma, depolanma, işlenme kolaylığı ve geniş adaptasyon yeteneğiyle, birçok ülkenin temel besini durumundadır (Kün, 1988). Buğday dünyanın birçok yerinde beslenme amacıyla kullanılan besin türlerinin ana ürünüdür. Dünyanın tarihi buluşu olan buğday başağının 12 bin yıl öncesinden beri tarımının yapıldığı ve Anavatanın Türkiye olduğu Göbekli Tepe'nin keşfiyle kayıtlara girmiştir (Karahan ve Yücekaya, 2020). Öğütülerek ekme yapılıp öncü ürün olarak kullanılan buğdayın önemi sürekli artarak sürdürülebilir bitki durumunu korumaktadır. Buğdayın geçmişten gelen stratejik önemi gelecekte de devam edeceği aşikardır. İnsanlar



günlük enerji ihtiyaçlarının yarısına yakını buğdaydan sağlamaktadırlar. Buğday, insan yaşamını ekonomik ve kültürel olarak etkilerken, buğdayın evrimi üzerine insan topluluklarının da büyük katkısı olmuştur. Ekmek ve makarnalık olarak kullanılan buğdayda kullanım amacı yönüyle büyük farklılıklar bulunmaktadır. Verim ve kaliteyi sınırlayan bölgelerde ise sınırlayıcı faktörlerin giderilmesi yönünde araştırmaların yapılması gerekmektedir. Buğday tarımında ekim zamanını belirleyici olan en önemli faktörlerden biri tohum yatağının toprak sıcaklığıdır. Toprak sıcaklığının 8-10 C olduğu dönem ekim yapılırsa kök gelişmesi hızlı olur. Bu uygun zaman aralığında yapılan ekim, soğuğa ve kurağa karşı dayanıklılığı artırmaktadır. Hem erken ekim, hem de geç ekim kış dönemindeki şiddetli soğuklardan bitkinin zarar görmesine neden olacağından sakıncalıdır. Ekmeklik buğdaylar -35°C dereceye kadar olan kısa süreli soğuklara dayanabilir. Makarnalık buğdaylar ise -15°C dereceden itibaren zarar görür. Makarnalık buğdaylar daha seçicidirler. Toprakta verimlilik ve su kapasitesinin yüksek olarak bulunmasını isterler. Bu sebep ile taban ve yarı taban arazilerde makarnalık çeşitler üretilmelidir. Türkiye iklim koşulları yönünden makarnalık buğday üretiminde birçok ülkeye oranla avantajlı olması ve makarnalık buğdayın gen merkezi olmasına rağmen, makarna sanayisinin hammadde ihtiyacının ithalat yoluyla karşılanması, makarnalık buğday üzerinde çalışmaların gerekliliğini göstermektedir (Taşcı ve ark., 2022). Dünyada ve Türkiye’de çok önemli bir yere sahip olan buğday üzerinde çok değişik konularda çalışmalar yapılmaktadır. Yapılan bu araştırmalarda, temel araştırma niteliğinde olması nedeniyle, öncelikle yöreye uygun çeşitlerin belirlenmesine çalışılmaktadır. Bir yöreye uygun çeşitlerin belirlenmesine yönelik çalışmalarda ise; kardeş sayısı, metrekaresindeki başak sayısı, bin dane ağırlığı, hektolitre ağırlığı, başaktaki dane sayısı, başaktaki dane ağırlığı, başaktaki başakçık sayısı, başak uzunluğu, bitki boyu, hasat indeksi, biyolojik verim ve dane verimi gibi kriterlere yer verilmekte ve yöreye en uygun çeşidin seçilmesine çalışılmaktadır.

Bitki verimliliğini artırmada; gübre seçimi, uygulama zamanı, yöntemi ve gübre uygulama miktarı, topraktan azot kayıplarını en aza indirme gibi hususlar dikkate alınması gereken önemli konulardır (Rhezali ve Lahlali, 2017). Azot gübresi uygulama yöntemlerinden biri verimin uygulanan azot gübresi miktarına oranı olarak tanımlanmaktadır (Lopez-Bellido, Lopez-Bellido, 2001), N oranı toprak organik madde içeriğine uyarlanması ve mineralizasyon potansiyeli (Setiyono ve ark., 2011) gibi çevresel faktörlere göre değişmektedir. N oranı, tahıl verimini ve biyokütle üretim verimliliğini önemli ölçüde etkilemektedir. Azottan buğday veriminde farklılığın oluşmasında mevsimsel iklim koşullarına (<%85) ve buna bağlı işel toprak özellikleri etkili olmaktadır. Çeşitler arasındaki ortalama tahıl tane verimi %15,75 ve biyokütleydi %12 olarak değişkenlik göstermektedir (Kostic ve ark., 2021). Tahıl yetiştirilmesinde arzu edilen verimin alınmasında, gübre uygulaması mutlak kullanılması gereken besin elementidir. Buğday bitkisine verilecek fazla azot gübresi bitkinin fazla gelişmesini sağlayarak bitkinin yatmasına, hastalıklara karşı direncinin düşmesine neden olmaktadır. Azot gübresinin azaltılması ise verimin ve kalitenin düşürerek ekonomik üretimden uzaklaştırmaktadır (Çiftçi ve Doğan, 2013). Yöremizde de buğday yetiştiriciliğinde kültürel uygulamalar sırasında ortaya çıkan sıkıntıların başında uygun gübre miktarı ve kullanılan çeşit gelmektedir. Azot, üretimde normal bitki gelişimini sınırlayan en önemli besin elementidir. Artan azot gübre uygulamaları her zaman tane verimi artışı sağlamaz, azalmaya da neden olabilir. Doğru miktarda azot uygulaması, başak sayısını ve başak başına tohum sayısını artırarak daha yüksek verime katkıda bulunur (Abedi ve ark., 2011; Si ve ark., 2020). Bitkinin gerek duyduğu azot miktarı ve zamanının iyi yönetilmemesi çevreye zarar oluşturması yanı sıra dolaylı olarak insan ve hayvan sağlığı üzerinde de olumsuz bir etkiye sahiptir. Buğday üretiminde uygulanan toplam N gübresinin yaklaşık %67’si (NH₃) denitrifikasyon, sızma, buharlaşma ve (N₂O, NO veya NO₂) sera gazı emisyonları gibi doğal süreçlerle kaybolabilmektedir (Raun ve ark. 2002). Tarım ve çevre koruma politikaları birbirleriyle uyumlu ve birbirini tamamlayıcı olmalıdır. Tarım sektörü, ekolojik prensipleri ve doğal çevrenin korunmasını dikkate alarak sürdürülebilir tarım yaklaşımı güçlendirmelidir. Aşırı kimyasal gübre ve tarım ilacı kullanılan yoğun tarım uygulamalarından vaz geçerek, doğayı çevreyi koruyucu ve enerji kaybını önleyici tarımsal uygulamalara geçilmelidir. Bu nedenle Kahramanmaraş Göksun ilçe koşullarında Kızıltan 91 makarnalık ve Obala ekmeklik buğday çeşitleri uygun azot dozu belirlemek için altı farklı azot doz uygulaması araştırılmıştır.

Materyal ve Yöntem

Kızıltan 91 makarnalık ve Obala ekmeklik buğday çeşitleri deneme materyali olarak, 0, 4, 8, 12, 16, 20 kg da⁻¹ azot gübre dozları uygulama faktörü olarak kullanılmıştır. Araştırma Kahramanmaraş Göksun ilçesinde bölünmüş parseller deneme deseninde yürütülmüştür. Araştırma Göksun (Kahramanmaraş) ilçesinde yürütülmüştür. Ekim elle 5 m uzunluğunda 20 cm sıra aralığında 6 sıralı, m² 500 tohum gelecek şekilde, tesadüf bloklarında bölünmüş parseller deneme deseninde, Kasım ayının sonunda 2020 yılına ekilmiştir. Ekimde ana parsellere çeşitler, alt parsellere gübre dozları gelecek şekilde yapılmıştır. Taban gübresi olarak dekara 5 kg fosfor (triple süper fosfat) ekimle birlikte uygulanmıştır. Uygulanacak azot dozlarının yarısı ekimle birlikte, diğer yarısı da sapa kalma döneminde uygulanmıştır. İncelenen özellikler için her bir parseli temsil edecek on bitki örneği alınmıştır. Hasat işlemi 2021-Temmuz ayının son haftasında parsel biçer döver ile yapılmıştır. Deneme alanının toprakları killi-tınlı, nört pH’lı, orta düzeyde organik yapıya sahip, potasyum yönünden yüksek, fosfor yönünden düşük, tuzsuz ve orta kireçli yapıya sahip olarak belirlenmiştir (Anonim, 2022). Yürütülen çalışmanın ekimi 2020-



Kasım ayının son haftasında elle yapılmış, hasat ise parsel biçer döveri ile 2021-Temmuz ayının son haftası yapılmıştır. Göksun ilçesinde minimum sıcaklıkları Kasım ayından Nisan ayına kadar sıfırın altında, Nisan ayından (3.8°C) itibaren sıfırın üzerinde gerçekleşmiştir. Ortalama sıcaklık değerleri Mart, Nisan, Mayıs, Haziran ve Temmuz aylarında sırasıyla 3.2, 10.2, 15.5, 17.4, 22.5 °C, aylık yağış değerleri ise 131.4, 38.4, 26.1, 25.9 ve 6.1 mm olarak gerçekleşmiştir. Denemenin yürütüldüğü bölgede karasal iklimin hakim sürmüştür (Anonim, 2024). Araştırmada Kızıltan 91 makarnalık ve Obala ekmeçlik buğday çeşitlerinin kardeş sayısı, bitki boyu (cm), bayrak yaprak uzunluğu (cm), bayrak yaprak genişliği (cm), hektolitreye ağırlığı (kg), fertil başakçık sayısı (adet), tane verimi(kg da⁻¹) özellikleri incelenmiştir. Araştırmada elde edilen gözlemler ve ölçüm sonuçlarının ortalama değerlerine ait istatistiksel analizlerde JMP 13 paket programı kullanılmış, Duncan çoklu karşılaştırma testi ile ortalamaların karşılaştırılması yapılmıştır (JMP, 2013).

Bulgular ve Tartışma

Kızıltan 91 makarnalık ve Obala ekmeçlik buğday kullanılarak yürütülen çalışmada verilerin istatistiki analiz sonucunda elde edilen kardeş sayısı, bitki boyu, bayrak yaprak uzunluğuna ait ortalamlar ve grupları Çizelge 1’de verilmiştir.

Yürütülen araştırmada, Obala ekmeçlik buğday çeşidi 3.75 adet kardeş sayısı ile Kızıltan-91 makarnalık (3.37 adet) buğday çeşidinden kardeş sayısı yönünden istatistiki olarak önemli farklılık oluşturmadığı kaydedilmiştir. Uygulanan farklı gübre dozlarına göre buğday çeşitleri kardeş sayısı yönünden aralarında istatistiksel olarak birbirinden farklı 6 grup oluştuğu kaydedilmiştir. Gübre dozlarına göre en yüksek kardeş sayısı 4.56 adet ile 20 kg da⁻¹ azot dozundan elde edildiği ve diğer uygulamalardan istatistiki olarak önemli farklılık oluşturduğu görülmüştür. İkinci sırada kardeş sayısı 4.12 adet ile 16 kg da⁻¹ azot dozundan elde edildiği ve onu sırasıyla 12 (3.71 adet) ve 8 (3.375 adet) ve 4 (2.937 adet) kg da⁻¹ azot uygulamasının izlediği ve kendi aralarında istatistiki olarak önemli farklılık oluşturduğu belirlenmiştir. En düşük kardeş sayısı 2.67 adet ile 0 kg da⁻¹ azot dozunda elde edildiği ve diğer azot doz uygulamalarından istatistiksel olarak önemli farklılıklar oluşturduğu tespit edilmiştir. Kardeş sayısı yönünden buğday çeşitleri ile azot dozları interaksiyonlarını arasında istatistiksel olarak farklılık görülmediği kaydedilmiştir. ÇeşitXdoz interaksiyonlarında en yüksek kardeş sayısı 4.82 adet ile Obala ekmeçlik çeşidinin 20 kg da⁻¹ azot uygulamasından, en düşük 2.65 adet ile Kızıltan-91 makarnalık çeşidin 0 kg da⁻¹ azot doz uygulamasından elde edilmiştir. (Çizelge 1.). Gezahegn ve ark. (2022), iki buğday çeşidine farklı gelişme zamanlarında azot gübre uygulamasında verimli kardeş sayısının 3.61-6.24 adet arasında değiştiği kaydetmişlerdir. Assefa ve ark. (2023) tarafından 0 azot dozu ile 270 kg ha⁻¹ N karşılaştırıldığında, toplam kardeşlenme %89, etkili kardeşlenme %101 artış gösterdiği kaydedilmiştir. Yürütülen araştırmada da azot dozunun artması buğdayın kardeş sayısında da önemli artış oluşturmuştur.

Çizelge 1’den, Obala ekmeçlik buğday çeşidi 64.85 cm bitki boyu değeri ile Kızıltan-91 makarnalık (49.54 cm) buğday çeşidinden farklı gruplarda yer alarak, istatistiki olarak önemli farklılık oluşturduğu görülmektedir. Yürütülen araştırmada uygulanan farklı gübre dozlarına göre buğday çeşitleri bitki boyu yönünden aralarında istatistiksel olarak birbirinden farklı 6 grup oluştuğu kaydedilmiştir. Gübre dozlarına göre en yüksek bitki boyu 63.10 cm ile 20 kg da⁻¹ azot dozundan elde edildiği ve diğer uygulamalardan istatistiki olarak önemli farklılık oluşturduğu görülmüştür. İkinci sırada bitki boyu 60.47 cm ile 16 kg da⁻¹ azot dozundan elde edildiği ve onu sırasıyla 12 (58.47 cm) ve 8 (55.96 cm) ve 4 (54.05 cm) kg da⁻¹ azot uygulamasının izlediği ve kendi aralarında istatistiki olarak önemli farklılık oluşturduğu belirlenmiştir. En düşük bitki boyu 51.12 cm ile 0 kg da⁻¹ azot dozunda elde edildiği ve diğer azot doz uygulamalarından istatistiksel olarak önemli farklılıklar oluşturduğu tespit edilmiştir. Bitki boyu yönünden buğday çeşitleri ile azot dozları interaksiyonlarını arasında istatistiksel olarak farklılık görülmediği kaydedilmiştir. Çeşitxdoz interaksiyonlarında en yüksek bitki boyu 70.87 cm ile Obala ekmeçlik çeşidinin 20 kg da⁻¹ azot uygulamasından, en düşük 44.52 ile Kızıltan-91 makarnalık çeşidin 0 kg da⁻¹ azot doz uygulamasından elde edilmiştir. Diğer interaksiyonlarda bitki boyu 68.47-46.47 cm arasında değişim gösterdiği kaydedilmiştir (Çizelge 1.). Sönmez ve Kırıl (2004), Tokat ilinin Erbaa ilçesinde 9 adet makarnalık buğday çeşitleriyle yaptığı çalışmada bitki boyu 79-82 cm, Çifci ve Doğan (2013), Bursa koşullarında, makarnalık ve ekmeçlik buğday çeşitlerine uygulanan 0, 15, 20, 25, 30, 35 kg da⁻¹ azot dozlarında bitki boyunun 80.40-86,25 cm, Kara ve ark (2016), Kahramanmaraş koşullarında 17 ekmeçlik buğday çeşidinde bitki boyu 77.8-95.5 cm, Ulupınar ve Akgün (2020), Isparta ekolojik koşullarında makarnalık buğday çeşidine uygulan farklı azot dozlarında bitki boyunun 76.97 -98.48 cm, Gezahegn ve ark. (2022), iki buğday çeşidine, iki farklı bölgede bitki boyunun 69-84 cm, Göy (2023), Tokat-Zile koşullarında kuru ve sulu koşullarda bitki boyunun 66,2 ve 70,7 cm, Ekin ve Kendal (2023), Mardin-Kızıltepe ilçesi 3 adet makarnalık buğday çeşidinde bitki boyu 97-107 cm, Sebnie ve ark. (2024), Ethiopia ekmeçlik buğdaylarına uygulanan 0, 46, 69 ve 92 kg ha⁻¹ azot dozunda bitki boyları 62.41-76.60 cm arasında değiştiğini kaydetmişlerdir. Daha önceki çalışmalardan makarnalık ve ekmeçlik olarak kullanılan buğdaylarda gübre dozuna, uygulanan faktörlere ve bölgelere göre değişkenlik gösterdiği anlaşılmaktadır. Yürütülen araştırmada bitki boyunun önceki araştırmalara göre daha kısa olmasında çeşit karakteri yanı sıra, bölgenin iklim koşullarında büyük etkisinin olduğu düşünülmüştür. Gübre dozlarının artışı bitki boyunda pozitif yönde artış gösterdiği belirlenmiştir.



Ekmeklik ve makarnalık buğday çeşitleriyle yapılan çalışmadan bayrak yaprak uzunluğuna yönünden çeşitler arasında istatistiki olarak önemli farklılığın olduğu Çizelge 1'den görülmektedir. Obala ekmeklik buğday çeşidinde 21.27 cm sayısı ile Kızıltan-91 makarnalık (20.01 cm) buğday çeşidinin bayrak yaprak uzunluğunun daha yüksek değere sahip olarak farklı gruplarda yer aldığı belirlenmiştir. Makarnalık ve ekmeklik buğday çeşitleri uygulanan gübre dozlarına göre bayrak yaprak uzunluğu yönünden istatistiksel olarak (a, d, e) birbirlerinden farklı üç ayrı grubun oluştuğu ve üç de geçiş (ab, bc, cd) grubunun oluştuğu tespit edilmiştir. Gübre dozlarına göre en yüksek bayrak yaprak uzunluğuna 22.45 cm ile 20 kg da⁻¹ azot dozundan elde edildiği 16 kg da⁻¹ azot doz uygulaması (21.58 cm) hariç, diğer gübre uygulamalarından istatistiksel olarak önemli farklılıklar oluşturduğu belirlenmiştir. Gübre doz uygulamalarında 8 ve 12 kg da⁻¹ uygulamasında bayrak yaprak uzunluğu sırasıyla 20.57, 21.07 cm olduğu ve istatistiki olarak kendi aralarında farklılık oluşturmadığı tespit edilmiştir. Bayrak yaprak uzunluğu en düşük değer olarak 18.58 cm ile kontrol uygulamasından elde edilmiştir. Onu 19.93 cm ile ikinci sırada 4 kg da azot uygulamasının izlediği aralarında bayrak yaprak uzunluğu yönünden istatistiksel önemli farklılık oluşurken, 8 kg da azot uygulaması arasında önemli farklılık oluşturmadığı belirlenmiştir. Bayrak yaprak uzunluğu yönünden buğday çeşitleri ile azot dozları etkileşimlerini arasında istatistiksel olarak farklılık görülmediği kaydedilmiştir. Çeşitxdoz etkileşimlerinde en yüksek bayrak yaprak uzunluğuna 23.35 cm ile Obala ekmeklik çeşidinin 20 kg da⁻¹ azot uygulamasından, en düşük 18.05 cm ile Kızıltan-91 makarnalık çeşidinin 0 kg da⁻¹ azot doz uygulamasından elde edilmiştir. Diğer etkileşimlerde bayrak yaprak uzunluğu 19.06-22.50 cm adet arasında değişim gösterdiği belirlenmiştir (Çizelge 1.). Doğan (2013) Kırklareli koşullarında buğday ve yem bezelyesi ile yapılan çalışmada buğday bitkisinin ortalama, bayrak yaprak uzunluğunun 47.07 cm olduğunu tespit etmişlerdir. Yaraşır (2018) Buğday bitkisine uygulanan beş farklı dozda (0, 1, 2, 3, 4 t/da) sıvı biyogaz atıkları ile üç farklı (0, 9, 18 kg/da) mineral azot dozunda bayrak yaprak alanının en yüksek 18 kg da⁻¹ mineral azot dozunda elde edildiğini belirtmiştir. Bayrak yaprağının diğer yapraklara göre verime verim unsurlarına katkısı daha fazla olduğu bilinmektedir (Racz ve ark 2022). Yürütülen çalışmada bayrak yaprağın artan azot dozlarında olumlu tepki gösterdiği ve artış gerçekleştirdiği kaydedilmiştir.

Kızıltan 91 makarnalık ve Obala ekmeklik buğday kullanılarak yürütülen çalışmada verilerin istatistiki analiz sonucunda elde edilen yaprak genişliği, hektolitreye ağırlığı, fertil başakçık sayısına ait ortalamalar ve grupları Çizelge 2'de verilmiştir.

Çizelge 1. Farklı dozda azot uygulanan makarnalık ve ekmeklik buğday çeşitlerinin kardeş sayısına (adet), bitki boyuna (cm), bayrak yaprak uzunluğuna (cm) ait ortalama değerler ve Duncan testine göre oluşan gruplar
Table 1. Mean values of tiller number (unit), plant height (cm), flag leaf length (cm) and groups formed according to Duncan test for durum and bread wheat varieties applied with different nitrogen doses.

	Kardeş sayısı			Bitki boyu			Bayrak yaprak uzunluğu		
	Kızıltan	Obala	Ortalamalar	Kızıltan	Obala	Ortalamalar	Kızıltan	Obala	Ortalamalar
Gübre dozları	91	Obala		91	Obala		91	Obala	
0	2.65	2.70	2.67 f	44.52	57.72	51.125 f	18.05	19.06	18.55 e
4	2.77	3.10	2.93 e	46.47	61.62	54.050 e	19.64	20.22	19.93 d
8	3.12	3.62	3.37 d	48.02	63.90	55.962 d	19.80	21.35	20.57 cd
12	3.50	3.92	3.71 c	50.45	66.50	58.475 c	20.36	21.77	21.07 bc
16	3.90	4.35	4.12 b	52.47	68.47	60.475 b	20.36	22.50	21.58 ab
20	4.30	4.82	4.56 a	55.32	70.87	63.100 a	21.55	23.35	22.45 a
Orta.	3.37	3.75	3.56	49.54 b	64.85	57.197	20.01 b	21.27	20.69
					a			a	

Çizelge 2. Farklı dozda azot uygulanan makarnalık ve ekmeklik buğday çeşitlerinin yaprak genişliği (cm), hektolitreye ağırlığı (cm), fertil başakçık sayısına (adet) ait ortalama değerler ve Duncan testine göre oluşan gruplar.
Table 2. Mean values of leaf width (cm), hectolitre weight (cm), and number of fertile spikelets (pieces) of durum and bread wheat varieties treated with different nitrogen doses, and groups formed according to Duncan test.

	Yaprak genişliği			Hektolitreye ağırlığı			Fertil başakçık sayısı		
	Kızıltan	Obala	Ortalamalar	Kızıltan	Obala	Ortalamalar	Kızıltan	Obala	Ortalamalar
Gübre dozları	91	Obala		91	Obala		91	Obala	
0	1.01	1.16	1.08 c	66.67	68.32	67.50 f	21.77 f	22.70 ef	22.23 e
4	1.02	1.21	1.12 bc	69.07	71.05	70.06 e	24.55 de	24.75 cd	24.65 d
8	1.05	1.27	1.16 bc	70.57	72.35	71.46 d	26.50 cd	26.92 cd	26.21 c
12	1.07	1.27	1.17 bc	71.81	74.22	73.02 c	29.67 b	26.65 c	28.16 b
16	1.12	1.29	1.20 b	73.05	76.15	74.60 b	32.72 a	28.92 b	30.82 a
20	1.25	1.49	1.37 a	74.37	77.30	75.83 a	33.50 a	30.37 b	31.96 a
Orta.	1.09 b	1.28 a	1.18	70.92	73.23		28.12	26.55	27.34



Çizelge 2. incelendiğinde Obala ekmeklik buğday çeşidinin 1.28 adet yaprak genişliği Kızıltan 91 makarnalık buğday (1.09 cm) çeşidinden daha fazla yaprak genişliğine sahip olduğu görülmektedir. Uygulanan azot dozlarına göre yaprak genişliğinde birbirinden farklı 3 (a, b, c) grup ve birde geçiş (bc) grubu oluşturmuştur. En yüksek yaprak genişliği 1.18 ile 20 kg da⁻¹ azot doz uygulamasından elde edildiği ve diğer uygulanan gübre dozlarından istatistiksel olarak önemli farklılıklar oluşturduğu kaydedilmiştir. Yaprak genişliği yönünden 16 kg da⁻¹ gübre uygulaması, en yüksek ikinci sıra değerini sahip olmuştur. En düşük yaprak genişliği 1.08 cm ile 0 kg da⁻¹ azot dozu uygulamasında elde edilmiştir. Yaprak genişliği 4, 8, 12 kg da⁻¹ azot doz uygulamasında istatistiksel olarak aynı (bc) geçiş grubunu oluşturmuştur. Yaprak genişliği yönünden istatistiki olarak aynı geçiş grubunda yer alan 4, 8, 12 kg da⁻¹ azot uygulaması, kontrol uygulaması ile 16 kg da⁻¹ azot uygulaması arasında yer almıştır. Yaprak genişliği ait çeşit x azot dozu interaksyonda en yüksek değerler 1.49 cm ile Obala çeşidinde 20 kg da⁻¹ azot uygulamasında, en düşük ise Kızıltan 91 çeşidinde 1.01 adet ile 0 kg da⁻¹ azot dozu uygulamasından elde edilmiştir. Diğer çeşit x azot dozu interaksyonunda yaprak genişliği değerleri 1.29-1.02 cm arasında değişim gösterdiği ve istatistiki olarak önemli farklılıklar oluşturmadığı kaydedilmiştir (Çizelge 2.). Doğan (2013) Kırklareli koşullarında buğday ve yem bezelyesi ile yapılan çalışmada buğday bitkisinin ortalama bayrak yaprak eninin 1.58 cm olduğunu tespit etmiştir. Yaraşır (2018) Buğday bitkisine uygulanan beş farklı dozlarda (0, 1, 2, 3, 4 t/da) sıvı biyogaz atıkları ile üç farklı (0, 9, 18 kg/da) mineral azot doz uygulamasında bayrak yaprak alanının en yüksek 18 kg da⁻¹ mineral azot dozunda elde edildiğini belirtmiştir. Yürütülen araştırmada da ve daha önceki çalışmalardan da anlaşılabacağı üzere bayrak yaprak genişliğini uygulanan azot dozları ve besin elementlerinin artırdığı anlaşılmaktadır.

Farklı azot dozlarını araştırıldığı çalışmada, hektolitre ağırlığı Kızıltan 91 makarnalık buğday çeşidinde 70.92 kg, Obala ekmeklik buğday çeşidinde 73.23 kg olduğu ve hektolitre ağırlığı yönünden buğday çeşitleri arasında istatistiksel farklılığın olmadığı kaydedilmiştir. Gübre dozlarına göre en yüksek hektolitre ağırlığı 75.38 kg ile 20 kg da⁻¹ azot dozundan elde edildiği ve diğer uygulamalardan istatistiki olarak önemli farklılık oluşturduğu görülmüştür. Onu sırasıyla İkinci sırada 74.60 kg ile 16 kg da⁻¹ azot dozunun, 12, 8 ve 4 kg da⁻¹ azot doz uygulamaları sırasıyla 73.02, 71.46, 70.06 kg ile izlediği ve kendi aralarında istatistiki olarak önemli farklılık oluşturduğu belirlenmiştir. En düşük hektolitre ağırlığına 67.50 kg ile kontrol uygulamasından elde edildiği ve diğer uygulamalara arasında hektolitre ağırlığı yönünden istatistiki önemli farklılıklar oluşturduğu tespit edilmiştir. Hektolitre ağırlığına yönünden buğday çeşitleri ile azot dozları interaksyonlarını arasında istatistiksel olarak farklılık görülmediği kaydedilmiştir. ÇeşitXdoz interaksyonlarında en hektolitre ağırlığına 77.30 kg ile Obala ekmeklik çeşidinin 20 kg da⁻¹ azot uygulamasından, en düşük 66.67 kg ile Kızıltan-91 makarnalık çeşidin 0 kg da⁻¹ azot doz uygulamasından elde edilmiştir. Diğer interaksyonlarda hektolitre ağırlığına 68.32-66.15 kg arasında değişim gösterdiği belirlenmiştir (Çizelge 2). Ottman ve ark. (2000), yaptıkları araştırmada, makarnalık buğdaya çiçeklenmeye yakın dönemde uygulanan 0, 3.4 ve 6.7 g m⁻² saf azot dozlarının hektolitre ağırlığını artırdığını bildirmişlerdir. Öztürk ve Çağlar (2001), bazı makarnalık buğday çeşitlerinin Erzurum koşullarında hektolitre ağırlığının 74.5- 79.9 kg, Sönmez ve Kırıl (2004), Tokat ilinin Erbaa ilçesinde 9 adet makarnalık buğday çeşitlerinde hektolitre ağırlığının 74.8-79.1 kg, Kara ve ark (2016), Kahramanmaraş koşullarında 17 ekmeklik buğday çeşidinde hektolitre ağırlığının 74.9-79.2 kg, Göy (2023), Tokat-Zile koşullarında kuru ve sululu koşullarda hektolitre ağırlığının 80.4 ve 81.0 kg, Ekin ve Kendal (2023), Mardin-Kızıltepe ilçesi 3 adet makarnalık buğday çeşidinde sıvı azot gübre uygulamasında hektolitre ağırlığının 81.6-83.8 kg/hl, arasında olduğu tespit etmişlerdir. Yürütülen araştırmada hektolitre ağırlığının ekmeklik ve makarnalık oluşlarına göre farklılıklar oluşturduğu, uygulanan azot dozlarının artmasıyla pozitif yönde artışı kaydedilmiştir. Daha önceki yapılan çalışmalardan da çeşide, bölgeye ve uygulama faktörlerinin hektolitre ağırlığına etkili olacağı anlaşılmaktadır.

Kahramanmaraş-Göksun koşullarında ekmeklik ve makarnalık buğday buğday çeşitleriyle yapılan çalışmadan Obala ekmeklik buğday çeşidinde 26. 55 adet, Kızıltan-91 makarnalık buğday çeşidi de 28.12 fertil başakçık sayısına sahip olduğu ve kendi aralarında istatistiki farklılıkların oluşturmadığı kaydedilmiştir. Yürütülen araştırmada uygulanan farklı gübre dozlarına göre buğday çeşitlerinin fertil başakçık sayısı yönünden aralarında istatistiksel olarak birbirinden farklı 6 grup olduğu kaydedilmiştir. Gübre dozlarına göre en yüksek fertil başakçık sayısı 31.96 adet ile 20 kg da⁻¹ azot dozundan elde edildiği ve diğer uygulamalardan istatistiki olarak önemli farklılık oluşturduğu görülmüştür. İkinci sırada fertil başakçık sayısı 30.82 adet ile 16 kg da⁻¹ azot dozundan elde edildiği ve onu sırasıyla 12 (28.16 adet) ve 8 (26.21 adet) ve 4 (24.65 adet) kg da⁻¹ azot uygulamasının izlediği ve kendi aralarında istatistiki olarak önemli farklılık oluşturduğu belirlenmiştir. En düşük fertil başakçık sayısı 22.33 adet ile 0 kg da⁻¹ azot dozunda elde edildiği ve diğer azot doz uygulamalarından istatistiksel olarak önemli farklılıklar oluşturduğu tespit edilmiştir. Fertil başakçık sayısı yönünden buğday çeşitleri ile azot dozları interaksyonlarını arasında istatistiksel olarak 0.01 düzeyinde önemli farklılık bulunmuştur. ÇeşitXdoz interaksyonlarında en yüksek fertil başakçık sayısı sırasıyla 33.55 ve 32.72 adet ile Kızıltan 91 makarnalık çeşidinin 20 ve 16 kg da⁻¹ azot doz uygulamalarından elde edildiği, istatistiksel olarak aynı grupta yer alarak, diğer interaksyon uygulamasından farklı grupta yer aldığı belirlenmiştir. Obala ekmeklik buğday çeşidinin 20, 16 kg da⁻¹ azot uygulaması ile Kızıltan 91 çeşidinin 12 kg da⁻¹ azot doz uygulaması diğer bir istatistik grubu oluşturarak, diğer interaksyonlardan fertil başakçık sayısı yönünden önemli farklılıklar oluşturmuştur. Fertil başakçık sayısı yönünden Kızıltan 91 makarnalık çeşidinin 8 kg da⁻¹ azot doz uygulaması ile Obala çeşidinin 4 ve 8 kg da azot



uygulanması aynı geçiş grubunda yer aldığı, Kızıltan 91 çeşidinin 4 kg da⁻¹ ve Obala çeşidinin 12 kg da⁻¹ azot uygulamaları hariç diğer interaksyonu uygulamalarından istatistiki olarak önemli farklılık oluşturduğu kaydedilmiştir. En düşük fertil başakçık sayısı 21.77 adet ile Kızıltan-91 makarnalık çeşidinin 0 kg da⁻¹ azot doz uygulamasından elde edildiği ve Obala çeşidinin 0 kg da⁻¹ azot doz uygulaması hariç diğerlerinden önemli derecede farklılıklar oluşturduğu kaydedilmiştir (Çizelge 2.). Yaraşır (2018) Buğday bitkisine uygulanan beş farklı dozlarda (0, 1, 2, 3, 4 t/da) sıvı biyogaz atıkları ile üç farklı (0, 9, 18 kg/da) mineral azot dozu uygulamasında, en fazla başak tane sayısının 9-18 kg da⁻¹ minerel azot dozunda etde ettiklerinin belirtmiştir. Gezahegn ve ark. (2022), iki buğday çeşidine, iki farklı bölgede başaktaki tane sayısının 29.75-42.52 adet, Göy (2023), Tokat-Zile koşullarında kuru ve sulu koşullarda başakta tane sayısı 26,6 ve 29,7 adet, Sebnie ve ark. (2024), Ethiopia ekmeklik buğdaylarına uygulanan 0, 46, 69 ve 92 kg ha⁻¹ azot dozlarında başaktaki tohum sayısı 25.85-44.45 adet arasında değiştiğini rapor etmişlerdir. Daha önceki çalışmalardan da görüldüğü gibi fertil başakçık sayısının çevreye koşullarına ve uygulanan gübre dozlarına göre değiştiği görülmüştür. Yürütülen araştırmada da elde edilen sonuçlar fertil başakçık sayısı üzerinde gübre dozlarının etkili olduğu kaydedilmiştir.

Kızıltan 91 makarnalık ve Obala ekmeklik buğday kullanılarak yürütülen çalışmada verilerin istatistiki analiz sonucunda elde edilen tane verimine ait ortalamalar ve grupları Çizelge 3’de verilmiştir.

Çizelge 3. Farklı dozda azot uygulanan makarnalık ve ekmeklik buğday çeşitlerinin tane verimine (kg da⁻¹) ait ortalama değerler ve Duncan testine göre oluşan gruplar.

Table 3. Mean values of grain yield (kg da⁻¹) of durum and bread wheat varieties applied with different nitrogen doses and the groups formed according to Duncan test.

Gübre dozları	Tane verimi		
	Kızıltan 91	Obala	Ortalamalar
0	345.12 h	383.58 fg	364.35 f
4	375.80 g	445.84 de	410.82 e
8	399.58 f	461.77 cd	430.79 d
12	436.90 e	484.72 bc	460.81 c
16	461.89 cd	502.25 ab	482.07 b
20	493.99 ab	508.76 a	501.38 a
Orta.	418.92 b	464.49 a	441.70

Çizelge 3’den görüldüğü gibi, Obala ekmeklik buğday çeşidi 464.49 kg da⁻¹ tane verimi ile Kızıltan-91 makarnalık buğday çeşidinden (418.92 kg da⁻¹) tane verimi yönünden daha yüksek değere sahip olarak farklı gruplarda yer almışlardır. Uygulanan farklı gübre dozlarına göre buğday çeşitleri bin tane ağırlığı aralarında istatistiksel olarak birbirinden farklı altı grup oluştuğu kaydedilmiştir. Gübre dozlarına göre en yüksek tane verimi 501.38 kg da⁻¹ ile 20 kg da⁻¹ azot doz uygulamasından ve en düşük tane verimi 364.35 kg da⁻¹ ile 0 kg da⁻¹ azot doz uygulamasından elde edildiği, kendi aralarında ve diğer uygulamalardan istatistiki olarak önemli farklılık oluşturduğu görülmüştür. Gübre doz uygulamalarının artmasıyla tane veriminin artışı ve artan gübre dozlarına göre tane verim artışın da istatistiksel olarak önemli farklılıkların oluştuğu kaydedilmiştir. Çeşit/doz interaksyonlarında en yüksek tane verim 508.76 kg da⁻¹ Obala 20 kg da⁻¹ azot doz uygulamalarından, onu ikinci sırada 502.25 kg da⁻¹ ile Obala çeşidinin 16 kg da⁻¹ azot doz uygulaması, üçüncü sırada 461.89 kg da⁻¹ ile Kızıltan 91 makarnalık buğday çeşidinin izlediği ve kendi aralarında istatistiksel farklılıkların oluşturmadığı tespit edilmiştir. En düşük tane verimi 345.12 kg da⁻¹ ile Kızıltan 91 makarnalık çeşitten elde edildiği ve diğer interaksyon uygulamalarından istatistiksel olarak önemli farklılıklar oluşturduğu kaydedilmiştir. Çeşit azot doz interaksyonunda Kızıltan 91 makarnalık çeşide uygulanan 4 ve 8 kg da⁻¹ azot doz uygulaması tane verimi yönünden birbirinden farklı iki (f, g) grup oluştururken, Obala ekmeklik çeşidin 0 kg da⁻¹ azot doz uygulaması geçiş (fg) grubunda yer almıştır. Tane verimi yönünden Kızıltan 91 makarnalık çeşidin 16 kg da⁻¹ azot doz uygulaması ile Obala çeşidin 8 kg da⁻¹ azot doz uygulaması istatistiki olarak farklılıklar oluşturmayıp aynı geçiş grubunda yer aldığı görülmüştür. Kızıltan 91 makarnalık çeşidin 12 kg da⁻¹ azot doz uygulaması ile Obala çeşidin 4 kg da⁻¹ azot doz uygulaması istatistiki olarak farklılıklar oluşturmadığı kaydedilmiştir. Çeşit doz interaksyonunda Obala ekmeklik çeşidin Kızıltan makarnalık çeşide göre tane verimi yönünden tepkisinin daha pozitif olduğu anlaşılmaktadır (Çizelge 3). Ottman ve ark. (2000), makarnalık buğdaya çiçeklenmeye yakın dönemde uygulanan 0, 3.4 ve 6.7 g m⁻² saf azot dozlarının tane verimi arttığını bildirmişlerdir. İbrikiçi ve ark. (2001), Çukurova koşullarında dört buğday çeşidine uygulanan 0- 5-10-15-20-25-30 kg/da azot dozlarının iki çeşitte 20 kg da⁻¹ N dozundan sonra verimde azalma gerçekleşirken, azot dozlarının diğer iki çeşitte verimi artırdığı tespit edilmiştir. Öztürk ve Çağlar (2001), bazı makarnalık buğday çeşitlerinin Erzurum koşullarında tane verimi 68.4-175.6 kg da⁻¹ arasında bulmuşlardır. Ducsay ve Lozek, (2004), Sladkovicovo-Novy’da kışlık buğdayda 40, 120, kg ha⁻¹ azot doz uygulamasında, en yüksek tane veriminin 120 kg ha⁻¹ dozundan elde edildiğini kaydedilmiştir. Sönmez ve Kırıl (2004), Tokat ilinin Erbaa ilçesinde 9 adet makarnalık buğday çeşitlerinde tane verimini 434.0-578.0 kg da⁻¹, Çokkızgın ve Çölkesen (2006), farklı makarnalık buğday çeşitlerinde 0, 4, 8, 12, 16, 20 ve 24 kg da⁻¹ azot doz uygulamalarında tane verimini 265.8 - 808 kg da⁻¹, Yılmaz ve Şimşek (2012), Sivas ekolojik koşullarda Amonyum



nitrat % 33 N, Amonyum sülfat % 21 N, Üre % 46 gübre çeşidinin 0, 4, 8, 12 ve 16 kg da⁻¹ doz uygulamasında, Gerek-79 ekmeklik buğday çeşidinin tane veriminin 85.9-130.2 kg da⁻¹ arasında değiştiğini, en yüksek tane veriminin 16 kg N da⁻¹ amonyum sülfat formunun ve üre formunun uygulamalarından elde edildiğini kaydetmişlerdir. Kara ve ark (2016), Kahramanmaraş koşullarında 17 ekmeklik buğday çeşidinde tane verimi 383.5-550.9 kg da⁻¹, Özkan (2016) Harran koşullarında 5 makarnalık ve 5 ekmeklik buğday çeşidine uygulanan 6, 10, 14, 18, 22 kg da⁻¹ azot doz uygulamasında tane verimini 416-593 kg da⁻¹ arasında değiştiğini bildirmişlerdir. Irmak (2019) tarafından, Edirne ekolojik koşullarda yaygın olarak üretilen ekmeklik buğday çeşitlerine uygulanan farklı gübre çeşitleri, farklı zamanlar ve farklı azot doz uygulamalarında; bitkilerin sapa kalkma, başaklanma ve taneye besin taşınma dönemlerini kapsayan Nisan ve Mayıs aylarında yağış miktarındaki farklılıklar, azotlu üst gübre uygulamalarına karşı, buğday çeşitlerinin tepkilerinin farklı olduğu belirtilmiştir. Erdem ve ark. (2020) tane veriminin 149-383 kg da⁻¹, Kubar ve ark. (2020), Çin’de beş azot dozunu farklı zamanlarda bölerek yapılan uygulamada en iyi sonuçların dekara uygulanan 22,5 kg azot doz uygulamasında tane veriminin 445-731 kg da⁻¹, Zheng ve ark (2021), Çin’de iki buğday çeşidine uygulanan (0, 12, 18, 24 kg da⁻¹) gübre dozunda tane veriminin 226-994 kg da⁻¹, Gezahegn ve ark. (2022), iki buğday çeşidine, iki farklı bölgede dekara 9.2 kg azot dozu, sekiz farklı gelişme düzeyinde farklı oranlarda uygulamada tane veriminin 229-528 kg da⁻¹, Göy (2023), Tokat-Zile koşullarında kuru ve sulu koşullarda tane veriminin 252,8 ile 315,9 kg da⁻¹, Ekin ve Kendal (2023), Mardin-Kızıltepe koşullarında, 3 adet makarnalık buğday çeşidinde sıvı gübre uygulamasında tane veriminin 536,7-628,9 kg/da⁻¹, Cui ve ark. (2023), İki buğday çeşidi üzerinde farklı gübre formları tane veriminin 456-856 kg da⁻¹, Sebnie ve ark. (2024), Ethiopia ekmeklik buğdaylarına uygulanan 0, 46, 69 ve 92 kg ha⁻¹ azot dozlarının tane veriminin 119.07-298.02 kg da⁻¹ arasında değiştiğini kaydetmişlerdir.

Sonuç

Kızıltan 91 makarnalık ve Obala ekmeklik buğday çeşitleri Kahramanmaraş-Göksun ilçesi koşullarında attı farklı azot dozu uygulanarak, azot dozlarının etkisi araştırılmıştır. Farklı azot gübre dozlarının buğday çeşitlerinin kardeş sayısı, bitki boyu, bayrak yaprak uzunluğu, bayrak yaprak genişliği, hektolitre ağırlığı (kg), fertil başakçık sayısı, tane verimi özellikleri üzerindeki etkisi incelenmiştir. Obala ekmeklik buğday çeşidi bitki boyu, bayrak yaprak uzunluğu, bayrak yaprak genişliği, tane verimi yönünden Kızıltan 91 makarnalık buğdaydan daha yüksek değerler gösterdiği ve istatistiksel önemli farklılık oluşturduğu kaydedilmiştir. İncelenen tüm özellikler azot doz artışıyla artışı belirlenmiştir. Uygulanan 0, 4, 8, 12, 16 ve 20 kg da⁻¹ azot dozları incelenen tüm özelliklerde istatistiki önemli farklılıklar oluşturmuştur. Yürütülen çalışma sonucunda Göksun ilçesi gibi karasal iklim bölgelerinde Kızıltan 91 makarnalık buğday için 20 kg da⁻¹ azot doz uygulamasının, Obala ekmeklik çeşit için 16 kg da⁻¹ azot doz uygulamasının uygun olacağı sonucuna varılmıştır. Elde edilen sonuçların daha sonra yapılacak çalışmalar için kaynak oluşturması ve çiftçiler açısından önemli olacağı düşünülmüştür.

Beyanlar

Yazar Katkı Beyanı

L.İ: Proje yönetimi, danışmanlık, kavramsallaştırma, metodoloji, gözden geçirme, kayıt, raporlama, yazma, yorumlama, düzenleme.

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Yazarlar arasında herhangi bir çıkar çatışması yoktur.

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Potato Virus Epidemiology and the Emerging Role of Alternative Weed Hosts

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Abstract

Potato viruses remain a serious constraint to worldwide potato production. They cause a serious yield losses deterioration of tuber quality and seed degeneration of worldwide. Among the most economically important pathogens, potato leafroll virus (PLRV) and potato virus Y (PVY) continue to spreading geographically. The Expansion has been associated to increased monoculture system, changes in the ecology of aphid vectors due to climate change and the emergence of recombinant viral strains. Despite the progress made in disease management, current epidemiological frameworks still underestimate the main role of weed reservoirs in virus persistence, inoculum carryover and secondary transmission in potato agroecosystems. Recent molecular metagenomic, and landscape scale studies increasingly identify weed communities as active epidemiological studies rather than incidental alternative hosts. weed species such as *Chenopodium album* & *solanum nigrum* can harbor potato viruses, and preserve an asymptomatic infection, sometimes leading to the maintenance of potato viruses in the weed species for a season, and also support aphid vector survival. These reservoirs can carry viral inoculum between cropping cycles and intensify next season transmission in the potato crop. Emerging virome surveillance has also revealed hidden viral diversity within non crop vegetation including the identification of recombinant and undetected viral variants. Recent evidence indicate that weed mediated persistence is more central role in the initiation outbreak and seed degeneration dynamics than previously recognized. This review summarizes the most recent potato virus epidemiology and re evaluates the ecological significance of weed reservoirs under rapidly changing agroecosystems. Particular emphasis is placed on virus vector weed interactions, recombinant viral evolution, climate vector response migration and landscape connectivity influencing disease emergence. The review concludes that sustainable virus management are insufficient to depend solely on certified seed systems and vector suppression strategies. Instead, integrated surveillance system combining weed ecology, molecular epidemiology, and climate-based predication are essential for improving outbreak predication and strengthening long term potato health resilience.

Keywords: *Potato viruses, Weed hosts, Virus epidemiology, Vector ecology*





Optimization of *Saccharomyces boulardii* Fermentation Conditions in Sunflower Meal Hydrolysate

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Abstract

In this study, acid and enzymatic hydrolysis pretreatments were applied to sunflower meal in order to degrade its lignocellulosic structure, and the obtained hydrolysate was sterilized and used as a fermentation medium for *Saccharomyces boulardii*. Previous studies showed that 96 h fermentation in sunflower meal hydrolysate achieved comparable performance to commercial Yeast Extract-Peptone-Malt Extract (YPM) medium, despite the absence of external nutrient supplementation. Based on these findings, the present study focused on optimizing fermentation conditions. Optimization experiments were designed using the Central Composite Design (CCD) approach through Design-Expert software, and 30 different fermentation conditions were evaluated. Initial pH (2.5–8.5), temperature (25–47.5°C), aeration rate (80–150 rpm), and inoculum ratio (2.5–12.5%, v/v) were selected as independent variables. OD600 values, viable cell counts, and sugar consumption were analyzed as response variables. The results indicated that the optimum growth conditions were achieved at 25–33°C, pH 5.5–6.0, inoculum ratio of 7–9%, and aeration rate of 110–130 rpm. The highest sugar consumption (25.1 g/L) was obtained at 25°C, pH 4, 10% inoculum ratio, and 80 rpm. Viable cell counts increased from an initial range of 6.60–7.26 log CFU/mL to 6.80–8.48 log CFU/mL at the end of fermentation. The highest cell growth was observed at 32.5°C, pH 5.5, 2.5% inoculum ratio, and 115 rpm, corresponding to an increase of approximately 1.63 log CFU/mL. Model validation experiments were conducted at three selected conditions and the differences between predicted and experimental values remained low (0.12–8.14%), indicating that the model accurately predicted cell growth. Overall, the findings demonstrated that sunflower meal hydrolysate could serve as a sustainable and cost-effective substrate for probiotic fermentation processes.

Keywords: Sunflower meal hydrolysate, *Saccharomyces boulardii*, Fermentation optimization, Central Composite Design (CCD)



Factors Affecting Milk Quality in Small Ruminants

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Abstract

Small ruminants are of significant importance in terms of meat and milk production, especially in rural areas. The quality of milk obtained from these animals directly affects both milk yield and the nutritional value and processability of dairy products. Milk quality is evaluated through various parameters such as fat, protein, somatic cell count, and microbiological characteristics. This study addresses the genetic, environmental, and flock management factors that affect milk quality in small ruminants, with genetic factors significantly determining milk composition through breed and individual characteristics, where some sheep and goat breeds tend to produce milk with higher fat content; environmental factors such as nutrition, climatic conditions, and housing systems play a crucial role, particularly the energy and protein balance of the ration directly influencing milk yield and quality, while heat stress may reduce both; and flock management practices including milking hygiene, milking frequency, and udder health are also key determinants, especially as diseases like mastitis increase somatic cell count and negatively affect milk quality. In conclusion, milk quality in small ruminants is shaped by the contribution of multiple factors, and proper management of these factors is essential for improving milk yield and obtaining high-quality dairy products.

Keywords: Sheep, Goats, Milk Quality, Genetics, Feeding

Küçükbaş Hayvanlarda Süt Kalitesini Etkileyen Faktörler

Özet

Küçükbaş hayvanlar özellikle kırsal bölgelerde et ve süt üretimi açısından önemli bir yere sahiptir. Bu hayvanlardan elde edilen sütün kalitesi hem süt verimliliğini hem de süt ürünlerinin besin değeri ve işlenebilirliğini doğrudan etkilemektedir. Süt kalitesi yağ, protein, somatik hücre sayısı, mikrobiyolojik özellikler gibi çeşitli parametrelerle değerlendirilmektedir. Bu çalışmada küçükbaş hayvanlarda süt kalitesini etkileyen genetik, çevresel ve sürü yönetimi uygulamaları gibi faktörler ele alınmıştır. Genetik faktörler, hayvanın ırkı ve bireysel özellikleri üzerinden süt bileşimini önemli ölçüde belirlemektedir. Örneğin bazı koyun ve keçi ırkları daha yüksek yağ oranına sahip süt üretme eğilimindedir. Çevresel faktörler arasında beslenme, iklim koşulları ve barınma şartları öne çıkmaktadır. Özellikle rasyonun enerji ve protein dengesi süt verimi ve kalitesi üzerinde doğrudan etkilidir. Sıcaklık stresi gibi iklimsel faktörler ise süt veriminde ve kalitesinde düşüşe neden olabilmektedir. Sürü yönetimi uygulamaları da süt kalitesi üzerinde önemli rol oynamaktadır. Sağım hijyeni, sağım sıklığı ve meme sağlığı gibi unsurlar süt kalitesini belirleyen temel faktörler arasındadır. Özellikle mastitis gibi meme hastalıkları somatik hücre sayısını artırarak süt kalitesini olumsuz etkilemektedir. Sonuç olarak küçükbaş hayvanlarda süt kalitesi çok sayıda faktörün etkileşimi ile şekillenmektedir. Bu faktörlerin doğru şekilde yönetilmesi hem süt veriminin artırılması hem de kaliteli süt ürünleri elde edilmesi açısından büyük önem taşımaktadır.

Anahtar Kelimeler: Koyun, Keçi, Süt Kalitesi, Genetik, Besleme

Giriş

Süt ve süt ürünleri, sağlıklı beslenmenin bir parçası olarak yaygın bir şekilde tavsiye edilmekte olup inek, keçi, koyun gibi memeli hayvanlardan elde edilir. Besin içeriğince zengin, yüksek biyolojik değerlere sahip olan bir besin maddesidir. Şekil 1’de küçükbaş hayvanlarda süt sağımı görülmektedir.

Sütün ana bileşenleri su, yağ, protein, laktoz ve mineraller olup süt yaklaşık %88.32 su, %4.52 karbonhidrat, %3.22 protein, %3.25 yağ, %0.69 kül içermektedir (USDA-ARS, 2004).

Süt Kalitesi Üzerine Etkili Faktörler

Süt kalitesi üzerine başlıca etkili faktörler aşağıda verilmiştir.

- Genetik Yapı ve Irk
- Besleme
- Çevre Faktörleri
- Laktasyon Sayısı ve Yaş
- Hastalıklar
- Somatik Hücre Sayısı



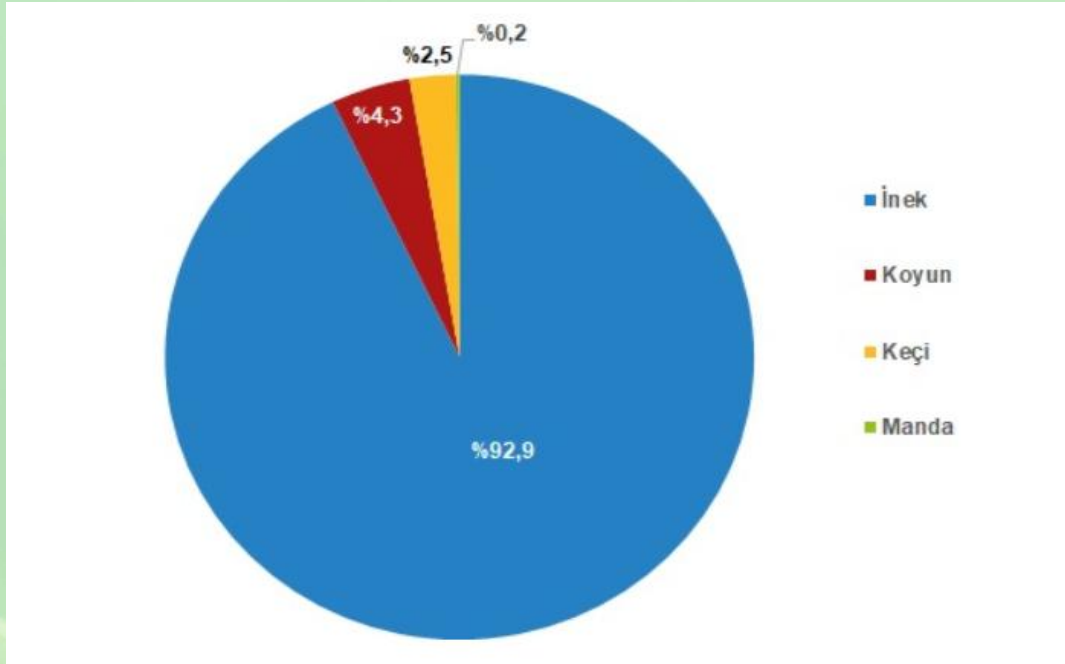
Tablo 1 ve Şekil 2 incelendiğinde Türkiye’de süt üretimi büyükbaş hayvancılığın etkisiyle artış göstermiştir. İnek sütü üretimi toplam üretimin en büyük kısmını oluştururken yükselişini sürdürdüğü görülmektedir.



Şekil 1. Süt Sağımı

Tablo 1. Türkiye Süt Üretimi (Ton) (TÜİK, 2026)

Yıl	Toplam	İnek	Manda	Koyun	Keçi
2020	23 503 790	21 749 342	63 767	1 101 065	589 617
2021	23 200 306	21 370 116	63 643	1 143 762	622 785
2022	21 563 492	19 912 135	43 589	1 067 342	540 426
2023	21 481 567	19 961 908	43 025	933 576	543 058
2024	22 487 757	21 040 442	58 122	906 945	482 247



Şekil 2. 2023 Yılı Çiğ Süt Üretiminin Hayvan Türlerine Göre Dağılımı

Genetik Yapı ve Irk

Kalıtım derecesi, karakterlerin ortaya çıkmasında genlerin etki payı olup kalıtım derecesinin değeri arttıkça özelliğin ortaya çıkmasında genetik yapının etki payının yüksek olduğu anlaşılır.

Süt veriminin kalıtım derecesi tahmininin ortalama 0.32, süt yağının kalıtım derecesinin ortalama 0.56, süt proteininin kalıtım derecesinin ise yaklaşık 0.53 olduğunu söyleyebiliriz. Bu bağlamda, süt yağ ve protein varyasyonunun yaklaşık %55’inin genetik yapıdan, %45’inin ise diğer faktörlerinden kaynaklandığı ifade edilebilir (Schroeder, 2012). Dolayısıyla, çevre şartları ne kadar iyileştirilirse iyileştirilsin ırkın genetik yapısında kodlanmış süt yağ ve protein miktarından daha fazla protein ve yağ elde etmek mümkün değildir. Aynı şekilde, genetik yapıda kodlanmış süt protein ve yağ miktarı ne kadar iyi olursa olsun eğer bakım ve besleme şartları en iyi şekilde sağlanmazsa genetik yapının müsaade ettiği en üst seviyeden protein ve yağ elde etmek mümkün değildir.

Sütçü koyun ırkı denildiğinde özellikle süt verimi anlamında gelişmiş ve yüksek süt verimine sahip koyun ırkları anlaşılmaktadır. Bu ırklar genellikle süt üretimi odaklı yetiştirilir ve süt endüstrisi için tercih edilir. Sütçü



koyun ırkları yüksek kalitede ve miktarda süt üretimi ile ön plana çıkar. Süt verimi ve kalitesini ırk ile beraber genetik, bakım, beslenme, yaş gibi diğer faktörlerde etkilemektedir (Anonim, 2026a)

Doğu Friz koyunu, sütçü koyun ırkı denildiğinde dünyada akla ilk gelen ırklar arasında yer alır. Oldukça yüksek süt üretimine ve uzun emzirme süresine sahiptir. Doğu Friz koyunu 200 ile 300 gün süren laktasyon döneminde yaklaşık 300 ila 600 litre süt üretimine sahiptir. Kuzuların emdiği sütler de dahil olmak üzere bazı koyunların süt veriminin 900 litreye ulaştığı görülmektedir. Süt yağ oranı laktasyonun zirve döneminde %5-6 civarındayken, geç laktasyonda %9-10 civarına çıkmaktadır.

İvesi koyunu, Güney Batı Asya’da oldukça popüler olan, Suriye ve Arap çöllerinde ortaya çıkmış yerel bir koyun ırkıdır. Ülkemizde de oldukça yaygındır. Özellikle kurak koşullara uyum sağlama yeteneği onu sütçü ırklar arasında tercih sebebi yapmaktadır. İvesi koyununun 180 günlük laktasyon döneminde ortalama süt verimi 200 ile 300 litre arasında değişmektedir. Fakat bu ırk çoğunlukla çok iyi bakım ve besleme koşullarına sahip olmayan yerlerde yetiştirildiği için bu tarz üretimde verim laktasyon başına 60 litreye kadar düşebilmektedir. İyi yönetilen, bakım ve beslemenin iyi olduğu bir üretim sistemi ile gelişmiş bir İvesi koyunu 214 gün laktasyon süresinde 504 litre süt verebilmektedir.

Sakız koyunu, ülkemizde özellikle Marmara ve Ege bölgesinde en yaygın olarak karşımıza çıkan ırklardan birisidir. Kökeni tam olarak bilinmemek ile beraber Sakız adasının yerel koyunları ile Anadolu’daki Kıvrıcık ve Dağlıç ırkları arasındaki melezlemenin sonucu ortaya çıktığı düşünülmektedir. Sakız koyununun 220 günlük laktasyon döneminde ortalama süt verimi 250 ile 320 litre arasında değişmektedir. Bu değerler ideal bakım koşullarındaki değerlerdir. Kaydedilen en yüksek süt üretimi ise 272 günlük laktasyon döneminde 597 litredir. Bu ırkın süt verimi çok üst seviyelerde olmasa da ülkemizdeki en yaygın bulunan sütçü koyun ırklarından birisidir ve ülkemize iyi bir şekilde adapte olmuştur.

Türk Saanen keçisi, yetiştirme alanı; Marmara ve Ege Bölgesi, verim yönü; kombine, süt ve döl, genel tanımı; saf Saanen keçileri ve bölgede bulunan Maltız ve Kıl keçilerinin melezlenmesi ile oluşturulmuştur. Kıl uzunluğu oldukça kısa ve parlaktır. Deri esnek ve yumuşak olup sütçü bir yapıyı temsil eden niteliktedir. Vücut narin, dişilik özelliklerini gösterir tipte, boyun ince ve uzun, baş narin ve göğüs kafesi geniş ve sağlam yapıdadır. Sağrı eğimi çok düşük olmayıp hafif eğimdedir (Anonim, 2026b). Irka Özgü Ayırıcı Özellikler: Irkın temel karakteristiklerinden birisi kulak yapısıdır. Kulaklar kısa, dik ve oldukça hareketlidirler. Erkek ve dişiler boynuzlu veya boynuzsuz olabilecekleri gibi küpeli veya küpesiz de olabilirler. Erken gelişen bir ırktır. Döl ve süt verimi yüksektir. Adaptasyon yeteneği düşüktür. Yetiştirme koşulları; uysal olan bu ırktan keçilerin yönetimi kolay olup sürü halinde veya bireysel yetiştirmeye uygun hayvanlardır. Türk Saanen keçilerinin süt verimleri ortalama 500 kg/laktasyon düzeyinde olup, bakım şartlarının iyileştirilmesi ile aynı sürüde 800 kg’a kadar süt üreten hayvanlara rastlanabilmektedir. Süt keçileri 200-300 gün sağlatabilmektedir.

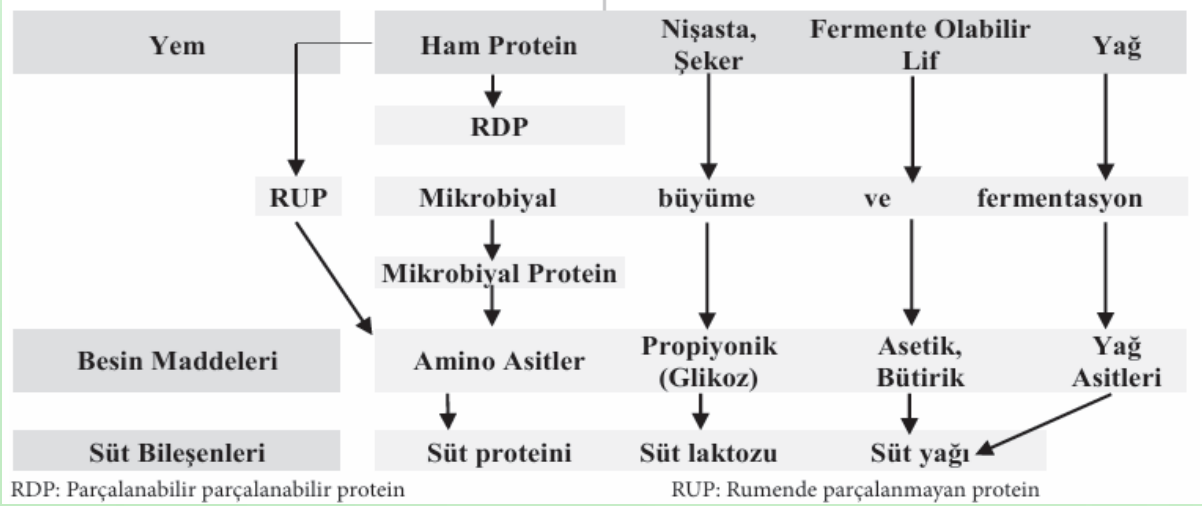
Kilis Keçisi; yayılma alanı Kilis, Gaziantep, Adıyaman ve Hatay’dır. Irka özgü ayırıcı özellikler; sağlam vücut yapılı, engebeli arazilerde uzun yürüyüş kabiliyetli, sıcak ve soğuğa dayanıklı ve hastalıklara karşı dirençlidir. Sütü özellikle Maraş dondurması üreticileri tarafından tercih edilir. Gelişmiş bir meme yapısına ve sütçü tip görünümüne sahiptirler. Erkekler 50-60 kg, dişiler 35-45 kg canlı ağırlığa sahiptirler. Laktasyon süreleri 210-260 gün, süt verimleri 200-300 kg’dır. İyi bakım ve besleme koşullarında süt verimleri 400-500 kg’a kadar çıkar.

Besleme

Beslenme hemen hemen tüm vücut sistemlerini etkilemektedir. Beslenmeye bağlı besleme aralığı, karbonhidratlar, yağlar, proteinler, somatik hücre sayısı, vitaminler, mineraller, su ve yem katkı maddeleri gibi faktörlere bağlıdır. Beslenmeye bağlı protein, laktoz, su, mineraller ve yağlar gibi birçok faktör süt kompozisyonunu etkiler (Dündar ve Küçükersan, 2021). Beslenme veya rasyon formülasyonunda yapılan değişiklikler, süt proteininden daha çok süt yağıyla güçlü bir ilişki içindedir. Beslenme ve besleme yönetimi, genetik dışındaki yağ ve protein sorunlarına en iyi çözüm olarak kabul edilir (Bequette ve ark., 1998).

Beslemenin süt bileşimi üzerinde önemli etkisi bulunmaktadır. Ön midelerdeki milyarlarca mikroorganizma yardımıyla rasyonun fermente edilmesi sonucu açığa çıkan farklı fermentasyon ürünleri süt proteini, süt laktozu ve süt yağı dâhil olmak üzere sütün bileşimini belirlemektedir.





Şekil 3. Rumende yem besin maddelerinin işlenmesi sonucu açığa çıkan süt bileşenleri (Sniffen ve Herd, 1991)

Çevre Faktörleri

Süt endüstrisinde, yetiştiricilikte sürü performansını artırmak için etkili çevre faktörlerin incelenmesi önemlidir. Mevsim; Süt yağ ve protein içeriği, kış ve sonbahar aylarında en yüksek ilkbahar ve yaz aylarında ise en düşük düzeyde seyreder (Jenkins ve McGuire, 2006; Gabriella ve Virginia, 2007). Bu durumun esas sebebi mevsime bağlı olarak değişen yem içeriği ve iklimsel çevre şartlarıdır.

Hayvanlar ilkbahar ve yaz aylarında merada otladıklarında ve sıcağa maruz kaldıklarında süt yağ oranları düşer. Çünkü yüksek çevre sıcaklığı ve yüksek nem süt yağ ve protein yüzdesini düşürmektedir (Fegan, 1979). Süt yağ ve protein yüzdesindeki bu düşüş, sıcaklık ve nem nedeniyle kuru madde tüketiminin ve dolayısıyla enerji alımının aksamasından kaynaklanmaktadır. Ayrıca yüksek sıcaklık süt yağ asidi kompozisyonunu da etkileyebilmektedir (Sharma ve ark., 1988; Gabriella ve Virginia, 2007; Heck ve ark., 2009).

Laktasyon Sayısı ve Yaş

Süt yağ ve protein içeriği, laktasyon safhasına bağlı olarak değişiklik göstermektedir. Ağız sütünde en yüksek düzeyde bulunan yağ ve protein oranı doğumu takip eden birinci ayda düşmeye başlayarak süt veriminin en yüksek olduğu safhada en düşük seviyede bulunur. Daha sonra laktasyonun ilerleyen safhalarında yavaş yavaş artmaya başlar (Craninx ve ark., 2008; Stoop ve ark., 2009; Gabriella ve Virginia, 2007). Genel olarak laktasyon sayısı arttıkça süt verimi belirli bir döneme kadar yükselir, daha sonraki dönemlerde ise düşüş gösterebilir.

Laktasyon sayılarının ilerlemesine paralel olarak, koyunların/keçilerin süt verimlerinde artış olur. İlk laktasyonda düşük olan süt verimi her geçen yıl artar. Bu artış 4. laktasyona yani 6-7 yaşına kadar sürer. 4. laktasyondan sonra süt verimi tekrar azalmaya başlar (Demirci, 2013).

Süt yağ içeriği ilerleyen yaşla birlikte nispeten sabit kalırken süt protein içeriği ilerleyen yaşla birlikte tedricen düşüş göstermektedir. Süt protein içeriği, beşinci laktasyonda %10-15 civarında düşüş gösterebilmektedir (Craninx ve ark., 2008; Stoop ve ark., 2009; Gabriella ve Virginia, 2007).

Laktasyon süresi uzadıkça süt üretimi de artacağı için sütçü ırk koyunlarda/keçilerde laktasyonun uzun olması genel olarak istenen bir özelliktir. Laktasyon süresi uygun sınırlar içerisinde olmalıdır. Sürü içerisindeki koyunların/keçilerin laktasyon sürelerinin farklılık göstermesi nedeniyle laktasyon süt verimleri de farklılık göstermektedir. Bu nedenle koyunların/keçilerin ferdi olarak laktasyon süt verimlerinin belirlenmesi için laktasyon süresinin standardize edilmesi gerekmektedir.

Hastalıklar

Hastalıklar, ruminant hayvanlarda süt verimi, kalitesi ve kompozisyonunu etkilemektedir. Süt kompozisyonuna etkisiyle ilgili olarak üzerinde en çok çalışma yapılan hastalık mastitis olup bu hastalığın genellikle süt yağını düşürdüğü ve süt yağ kompozisyonunu değiştirdiği bilinmektedir (Heinrichs ve ark., 2005; Gabriella ve Virginia, 2007). Mastitis nedeniyle süt yağındaki düşüş yaklaşık %10, süt kazein ve laktoz muhtevastaki düşüş ise %15 civarında olmaktadır. Bu miktardaki değişim peynir üretimi ve peynir üretim tipinin de değişmesine sebep olabilmektedir. Mastitis süt kalitesini doğrudan etkileyen somatik hücre sayısını arttıran önemli bir hastalıktır (Looper, 2012). Eğer sütteki somatik hücre sayısı 500 bin hücre/ml seviyesinden fazla ise sütün mayalanma süresi ve peynir kalitesi düşmektedir (Harmon, 1994).



Somatik Hücre Sayısı

Süt kalitesinin ve meme sağlığının iyi bir göstergesi olan diğer unsurda somatik hücre sayısı (meme epitel hücreleri + lökositler = SHS)'dır. Süt verimi ile SHS arasında negatif bir ilişki bulunmakta; SHS düzeyinin artışında süt veriminde düşüşlere sebep olmaktadır. Sütteki somatik hücre sayısı, son yıllarda sağlıklı ve kaliteli süt üretiminde en çok üzerinde durulan özelliklerden biridir. Sütteki somatik hücre sayısının belirlenmesindeki amaçlardan biri, uygun olmayan sütlerin insan tüketimine sunulmasının önlemesidir. Sütteki somatik hücre sayısının artması sütün içerdiği laktoz, kazein ve yağ içeriğinin azalmasına bunun sonucunda da süt ürünlerinin işlenmesinde kaliteyle ilgili sorunlar yaşanmasına (Barbano ve ark., 1991) ve ürünün raf ömrünün azalmasına (Ma ve ark., 2000) neden olmaktadır. Bu sebeplerden ve mastitisin teşhisinde belirleyici bir unsur (Tsenkova ve ark., 2001) olarak kullanılmasından ötürü somatik hücre sayısı önem teşkil etmektedir.

Avrupa Birliği'nin ilgili mevzuatına (Health and Hygiene Directive 92/46/EEC) göre, çiğ ve ısıtılmış sütlerde SHS'nın 1 mililitrede 400,000' den, süt ürünlerinde ise 500,000' den fazla olmaması gerekmektedir. ABD'de ise sığır sütünde somatik hücre sayısı mililitrede 750,000 ve koyun ve keçi sütünde ise mililitrede 1,000,000 adet bulunması tüketim açısından kabul edilebilir sınırlar olarak belirtilmektedir (Paape ve ark., 2007).

Sonuç

Süt kompozisyonu, süt kalitesi ve sütün fiyatlandırılmasında en önde gelen hususlardandır. Küçükbaş hayvanlarda süt kalitesi; genetik yapıdan beslemeye, çevresel koşullardan sağım hijyenine kadar birçok faktörün etkileşimi sonucunda şekillenmektedir. Kaliteli süt üretimi için dengeli besleme programları uygulanmalı, hayvan sağlığı düzenli olarak kontrol edilmeli ve hijyen kurallarına titizlikle uyulmalıdır. Bu faktörlerin bütüncül şekilde yönetilmesi hem üretici hem de tüketici açısından büyük önem taşımaktadır.

Beyanlar

Yazar Katkı Beyanı

Yazarlar çalışmaya eşit oranda katkı sunmuştur.

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Yazarlar herhangi bir çıkar çatışması olmadığını beyan eder.

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Occupational Health and Safety in the Livestock Industry

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Abstract

Livestock farming is a hazardous activity that involves many potential contributing factors that may lead to worker injuries and even fatalities. However, farm workers generally do not perceive livestock farming as a source of danger. The aim of this study is to identify the main occupational health and safety risks encountered in the livestock industry, evaluate the causes of occupational accidents, and present preventive measures to improve worker safety. Today, working in the livestock industry continues to be considered one of the most dangerous occupations among all professions. Occupational health and safety in this industry is of great importance because workers are exposed to physical, chemical, biological, and ergonomic risks. Aggressive animal behavior, improper handling techniques, and lack of hygiene may lead to occupational accidents, while zoonotic diseases and manure gases can cause serious health problems. In addition, the unconscious use of chemical disinfectants and medications may result in respiratory and skin diseases, whereas heavy lifting and repetitive movements increase musculoskeletal disorders. A large proportion of occupational accidents occur due to direct contact with animals, improper equipment use, and lack of hygiene. Raising workers' awareness regarding the use of personal protective equipment, providing ergonomic working environments, and establishing emergency action plans are of vital importance. Occupational health and safety in animal production, as in many other industries, is highly important. In conclusion, the effective implementation of occupational health and safety practices in the livestock industry is necessary for the protection of workers and the sustainability of production.

Keywords: Livestock, Occupational Health, Occupational Safety, Occupational Accident

Hayvancılık Sektöründe İş Sağlığı ve Güvenliği

Özet

Hayvancılık, çalışanların yaralanmasına ve hatta ölümüne yol açabilecek birçok potansiyel katkıda bulunan faktörü içeren tehlikeli sınıfta olan bir faaliyettir. Bununla birlikte, çiftlik çalışanları genellikle hayvancılığı bir tehlike kaynağı olarak görmezler. Bu çalışmada amaç, hayvancılık sektöründe karşılaşılan başlıca iş sağlığı ve güvenliği risklerini belirlemek, iş kazalarının nedenlerini değerlendirmek ve çalışanların güvenliğini artırmaya yönelik koruyucu önlemleri ortaya koymaktır. Günümüzde de hayvancılık sektöründe çalışmak, tüm meslekler arasında en tehlikeli işler arasında yer almaya devam etmektedir. Bu sektörde iş sağlığı ve güvenliği, çalışanların fiziksel, kimyasal, biyolojik ve ergonomik risklere maruz kalması nedeniyle büyük önem taşımaktadır. Hayvanların saldırgan davranışları, yanlış taşıma teknikleri ve hijyen eksikliği iş kazalarına yol açarken, zoonoz hastalıklar ve gübre gazları ciddi sağlık sorunlarına neden olabilmektedir. Kimyasal dezenfektanlar ve ilaçların bilinçsiz kullanımı solunum yolu ve cilt hastalıklarına sebep olurken, ağır yük kaldırma ve tekrarlayan hareketler kas-iskelet sistemi rahatsızlıklarının artmasına yol açmaktadır. İş kazalarının büyük bir kısmı, hayvanlarla doğrudan temas, yanlış ekipman kullanımı ve hijyen eksikliği nedeniyle meydana gelmektedir. Çalışanların kişisel koruyucu donanım kullanımı konusunda bilinçlendirilmesi, ergonomik çalışma ortamlarının sağlanması ve acil durum planlarının oluşturulması hayati öneme sahiptir. Hayvansal üretimde iş sağlığı ve güvenliği konusu, diğer birçok alanda olduğu gibi çok önemlidir. Sonuç olarak, hayvancılık sektöründe iş sağlığı ve güvenliği uygulamalarının etkin biçimde yürütülmesi, çalışanların korunması ve sürdürülebilir üretimin devamlılığı açısından gereklidir.

Anahtar Kelimeler: Çiftlik Hayvanları, İş Sağlığı, İş Güvenliği, İş Kazası

Giriş

İş sağlığı ve güvenliği; İş kazaları ve meslek hastalıkları tüm dünyada ve ülkemizde çalışma hayatının en önemli sorunlarından biridir. Meslek hastalığı; 155 sayılı Uluslararası Çalışma Örgütü'nün İş Sağlığı ve Güvenliği Sözleşmesi ile 2002 yılı hazırlanan ILO protokolü çerçevesinde, "işyeri ortamında oluşan risk faktörlerine maruz kalma sonucunda meydana gelen hastalıklar" şeklinde ifade edilmektedir (Şener ve ark., 2024). İş sağlığı ve güvenliği, çalışma hayatında bireylerin temel yaşam haklarını koruma ve iş yerlerinde güvenli bir ortam oluşturma çabalarının en önemli bileşenlerinden biridir (Karabal, 2021).



İş sağlığı ve güvenliğinin amacı; Teknolojik ilerlemeler ve iş yerlerindeki dinamikler, iş sağlığı ve güvenliği uygulamalarının sürekli olarak gelişimini zorunlu kılmıştır. Türkiye’de İş Sağlığı ve Güvenliği Kanunu (6331 Sayılı) gibi yasal düzenlemeler, işverenlerin ve çalışanların bu alandaki sorumluluklarını net bir şekilde belirlemiştir. Bu bağlamda, işverenlerin mesleki riskleri azaltma, çalışanları koruma ve iş yerlerinde güvenli çalışma ortamları sağlama yükümlülüğü hem bireysel hem de toplumsal bir sorumluluk olarak karşımıza çıkmaktadır (İnci ve ark., 2024). İş sağlığı ve güvenliğinin amacı, bireylerin yaşam hakkını tehdit eden riskleri ve tehlikeleri ortadan kaldırmak, önceden tespit edilen tehlikeler için gerekli önlemleri alarak güvenli bir çalışma ortamı sağlamaktır (Dizdar ve Önder, 2023). İş sağlığı ve güvenliği kanunu; 6331 sayılı kanun, işyerlerinde çalışanların sağlık ve güvenliğini sağlamak ve iş kazalarını önlemek amacıyla çıkarılmıştır (Anonim, 2026).

Tarımsal Üretimde İş Sağlığı ve Güvenliği

Tarım sektöründe çalışanlar yaptıkları işleri çoğunlukla tek başlarına gerçekleştirmekte ve iş sağlığı ve güvenliği açısından uzun süre korumasız olarak çalışmaktadır (Akpınar ve Özyıldırım, 2015). Uzun çalışma saatleri, hafta sonu çalışma gibi durumlar tarım sektöründe çalışanlar için dinlenme imkanlarının olmamasına sebebiyet vermektedir. Aynı zamanda uygun olmayan çalışma ve barınma koşulları da çalışanlarda çeşitli rahatsızlıklara neden olmaktadır (Özel ve Güğçerçin 2020).

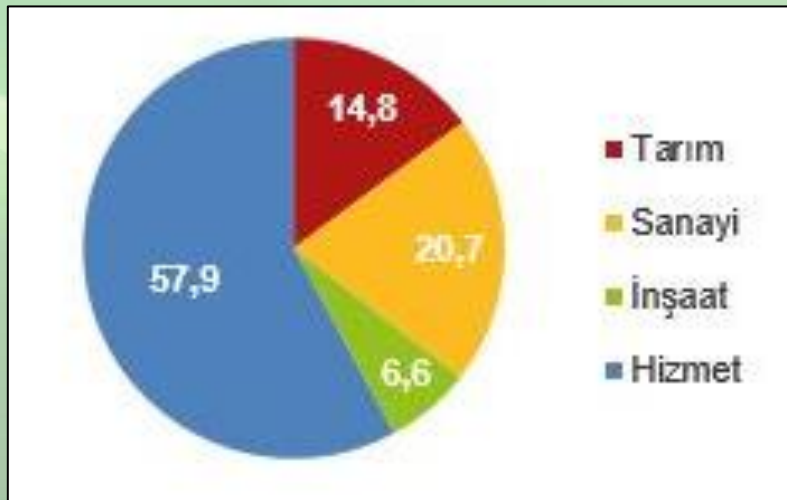
Hayvancılıkta İş Sağlığı ve Güvenliği

Tarımsal üretim içerisinde yer alan gerek bitkisel üretim gerekse hayvansal üretim kapsamında gerçekleştirilen faaliyetlerin neredeyse tümü tehlikeli sınıfta tanımlanmıştır. Bitkisel, hayvansal üretim içerisinde bu uğraşlar açık, kapalı ya da yarı açık alanlarda sürdürülmektedir. Kapalı alanlardaki faaliyetler ise tarım ve tarıma dayalı sanayii de içermektedir.

Tarımsal faaliyetler tehlike sınıfları içerisinde çok tehlikeli, tehlikeli ve az tehlikeli olmak üzere tüm tehlike sınıflarını içerisinde bulundurmaktadır. Tüm iş kolları içerisinde tarımsal faaliyetler NACE (Nomenclature of Economic Activities) kodlarına göre ayrı ayrı incelendiğinde, kullanılan materyalden, çevre koşullarından kaynaklanan etkenler yönü ile de kendi içerisinde gizli kalmış birçok farklı risk ve tehlikeyi barındırdığı anlaşılmaktadır. Tarım sektöründe çalışanların çeşitli kimyasallara, pestisitlere, partikül maddelere, zoonoz hastalıklara ve iş kazalarına maruz kalmalarından dolayı diğer iş sektörlerine oranla tarım sektöründe meslek hastalıkları ve iş kazaları daha fazla görülmektedir. Bu nedenle, Dünya genelinde en tehlikeli iş kolların biri olarak görülmektedir (Molina-Guzmán ve Ríos-Orsorio, 2020).

Hayvanların saldırgan davranışları, yanlış taşıma teknikleri ve hijyen eksikliği iş kazalarına yol açarken, zoonoz hastalıklar ve gübre gazları ciddi sağlık sorunlarına neden olabilmektedir. İş kazalarının büyük bir kısmı, hayvanlarla doğrudan temas, yanlış ekipman kullanımı ve hijyen eksikliği nedeniyle meydana gelmektedir. Çalışanların kişisel koruyucu donanım kullanımı konusunda bilinçlendirilmesi, ergonomik çalışma ortamlarının sağlanması ve acil durum planlarının oluşturulması hayati öneme sahiptir (Serap ve İkbāl, 2020).

Şekil 1’de 2024 Yılı Türkiye’de İstihdamın Sektörel Dağılımı (%) verilmiştir. 2024 yılında 4 milyon 827 bin kişi tarım sektöründe, 6 milyon 746 bin kişi sanayi sektöründe, 2 milyon 162 bin kişi inşaat sektöründe, 18 milyon 886 bin kişi hizmet sektöründe istihdam edildi. Bir önceki yıl ile karşılaştırıldığında istihdam edilenlerin sayısı tarım sektöründe 132 bin, sanayi sektöründe 35 bin, inşaat sektöründe 165 bin, hizmet sektöründe 656 bin kişi artmıştır.



Şekil 1. 2024 Yılı Türkiye’de İstihdamın Sektörel Dağılımı (%)



Tablo 1. 2024 Yılı İş Kazası-Meslek Hastalığı İstatistikleri

Yıl	İş Kazası Sayısı	İş Kazası Sonucu Ölüm Sayısı	Meslek Hastalığı Sayısı	Meslek Hastalığı Sonucu Ölüm	İş Kazası Sıklık Hızı	İş Kazası Ağırlık Hızı
2012	74.871	745	395	1	0,55	0,32
2013	191.389	1360	351	0	1,32	0,41
2014	221.366	1626	494	0	1,47	0,41
2015	241.547	1252	510	0	1,52	0,45
2016	286.068	1405	597	0	1,78	0,53
2017	359.653	1633	691	0	2,24	0,778
2018	430.985	1541	1044	0	2,42	1,007
2019	422.463	1147	1088	0	2,42	0,438
2020	384.262	1236	908	5	2,44	0,455
2021	511.084	1382	1207	35	2,76	0,426
2022	588.823	1517	953	8	2,80	0,423
2023	681.401	1966	945	0	3,18	0,451
2024	733.646	1897	888	3	3,37	0,441

Tablo 1’de 2024 Yılı İş Kazası-Meslek Hastalığı İstatistikleri verilmiştir. SGK 2024 yılı iş kazası-meslek hastalığı istatistiklerine göre; 2024 yılında bir önceki yıla göre %7,67 artışla 733.646 iş kazası meydana gelmiş ve iş kazaları sonucu %3,51 azalışla 1.897 çalışanımızı kaybetmişiz. En çok ölüm İSG Kanunundan sonraki 12 yılda olduğu gibi inşaat sektöründe meydana gelmiştir. Meydana gelen iş kazalarının %22,73’ü ve ölümlerin %53,98’i 50’den az çalışanı olan işyerlerinde meydana gelmiştir. Bitkisel ve hayvansal üretim ile avcılık ve ilgili hizmet faaliyetleri alanında ise 4.143 iş kazası meydana gelmiştir.

Hayvancılık Sektörü İçin İş Sağlığı ve Güvenliği Önlemleri

Hayvancılık sektörü için iş sağlığı ve güvenliği önlemleri 2 başlık altında incelenmiştir (Demirhan ve ark., 2016).

- Hastalıklar
- Kazalar

Hastalıklar

Zoonoz Hastalıklar; Omurgalı hayvanlardan insanlara, doğal olarak geçebilen hastalıklar veya enfeksiyonlar olarak tanımlanabilir. Zoonozlar, bakteriyel, paraziter, viral ve mantar kaynaklı olabilmektedir. Ayrıca bulaşması sadece kene pire gibi arthropodlar aracılığı ile olabilen bazı zoonoz hastalıklar arthropodal kökenli zoonozlar olarak tanımlanmaktadır. Bu etkenler hayvanlarda değişik şekillerde hastalığa neden olurlar ve farklı yollarla insanlara bulaşabilirler.

Solunum Yolu Hastalıkları; Yapılan araştırmalara göre hayvancılık sektöründe çalışanların %25’i bir çeşit solunum yolu rahatsızlığı geçirmektedir. Bu oran, solunum yolu rahatsızlıklarını, hayvancılık sektöründe çalışanlarda en sık görülen hastalıklar sınıflandırmasında ilk sıralara yerleştirmektedir.

Görülen hastalıkların en önemli nedenleri tozlar, gazlar, tarımsal kimyasallar ve enfeksiyona neden olan etmenlerdir. Tozlar değerlendirilirken 2 gruba ayırmak olasıdır. İlk grup organik bileşenlerden oluşan tozlar, ikinci grup ise inorganik bileşenlerden oluşan tozlardır. İnorganik tozların en önemli kaynağı otlaklar ve yeşil alanlardır. Hastalıkların en önemli kaynağı ise mikropları içinde barındıran tarımsal organik tozlardır. Bronşit ve astım en sık rastlanan rahatsızlıklardır.

Gazlar da hayvancılık sektöründe karşılaşılan solunum yolu hastalıklarının önemli nedenlerindendir. Sığırların ve diğer büyükbaş hayvanların beslendiği büyük kapalı alanlarda ve kümeslerde amonyak düzeylerinin yüksek olması bazı tehlikeleri beraberinde getirmektedir.

Cilt Hastalıkları; kontakt dermatit, güneş kaynaklı, enfeksiyon kaynaklı ya da böcek kaynaklı olmak üzere sınıflandırılabilir. Tarım sektöründe karşılaşılan hastalıkların neredeyse %70’inin cilt kaynaklı olduğu tahmin edilmektedir. Gübreler, bitkiler, yemler, pestisitler ve yemlere konulan antibiyotikler de cilt hastalıklarına neden olmaktadır. Güneşe uzun süreler maruz kalmak da oldukça ciddi cilt hastalıklarına neden olmaktadır. Aktinik keratoz ve cilt kanserleri bu cilt hastalıklarının en önemlileridir (Demirhan ve ark., 2016).

Kazalar

Hayvancılık sektöründe görülen iş kazalarının çok önemli bir bölümü beslenen hayvanlarla kurulan birebir fiziksel temastan kaynaklanmaktadır. Hayvanların çifte atması, itmesi, hırçınlaşarak saldırması ve ısırması yaralanmalara neden olmaktadır. ABD’de National Traumatic Injury Surveillance of Farmers (NIOSH)’in yaptığı belirlemeye göre hayvancılık da içinde olmak üzere bütün tarımsal sektörlerde, yaralanmaların önemli bir kısmı hayvanlarla fiziksel temastan kaynaklanmakta ve sadece sığır ve koyunların neden olduğu olaylar bütün içinde %18’i teşkil etmektedir.



Aynı zamanda bu yaralanmalar geçici iş görememe konusunda en çok işgünü kaybına neden olan olaylar olarak ortaya çıkmaktadır. Bunlara ilave olarak fiziksel etmenlerden kaynaklanan sağlık sorunlarının başında; duyma kaybı, makinaların neden olduğu travmalar, kas ve iskelet sistemi rahatsızlıkları ile karşılaşmaktadır (Demirhan ve ark., 2016).

Hayvancılık Sektörü İçin İş Sağlığı ve Güvenliği Önlemleri

- Hayvan barınaklarının temizlenmesi, bakımı, hayvan taşınması sırasında oluşabilecek düşme, kırık, yumuşak doku travmaları, kafa travmaları vb. fiziksel travma risklerine karşı, çalışanlara ilk yardım eğitimi verilmelidir.
- İşin türüne göre risk değerlendirme rehberleri hazırlanmalı ve denetimleri yapılmalıdır.
- Hayvancılık sektöründe çalışan nüfusun kayıt altına alınmasının sağlanması ve mesleki eğitimleri yapılmalıdır.
- Çalışanlar; eldiven, ayakkabı, koruyucu iş elbisesi, göz, yüz ve solunum koruyucularını kullanmalı ve çalışırken çıkarmamalıdır.
- Koruyucuları temiz tutmalı, temiz ortamda saklamalı ve eskimiş, aşınmış veya kullanım süresi dolmuş koruyucuları değiştirmelidirler.
- Bulaşıcı hastalıkların engellenmesi amacı ile çalışanların bilinçlendirilmesi gerekmektedir.
- Çalışanlara hijyen eğitimi kapsamında gerekli eğitimler verilmelidir.
- Patojen mikroorganizma ve parazit temasını azaltmak amacı ile çalışanların uygun Kişisel Koruyucu Donanımları kullanılması sağlanmalıdır.
- Normal olmayan görünüm, koku veya davranış olması durumunda temas etmeden ya da aynı ortamda uzun süre kalınmadan yetkili hekime haber verme bilinci sağlanmalıdır.

Sonuç

Hayvancılık sektöründe iş sağlığı ve güvenliği, çalışanların sağlığını korumak ve iş kazalarını önlemek açısından büyük önem taşımaktadır. Risklerin doğru şekilde belirlenmesi, gerekli önlemlerin alınması ve çalışanların bilinçlendirilmesi ile daha güvenli ve verimli bir çalışma ortamı oluşturulabilir. Bu nedenle iş sağlığı ve güvenliği uygulamalarının sürekli geliştirilmesi gerekmektedir.

Hayvancılık sektöründe iş sağlığı ve güvenliği konusunda ciddi eksiklikler bulunmaktadır. Ayrıca, hayvancılık sektörü ile iş sağlığı ve güvenliği arasındaki ilişkiye yönelik yeterli farkındalık henüz oluşmamıştır. Bu nedenle, Çalışma ve Sosyal Güvenlik Bakanlığı ile Tarım ve Orman Bakanlığı'nın işçi sağlığı ve güvenli çalışma koşulları konusunda ortak çalışmalar yürütmesi büyük önem taşımaktadır. Gerekli önlemlerin alınmasıyla birlikte hayvansal üretim sürecinde meydana gelen iş kazaları ve meslek hastalıkları en aza indirilebilir.

Beyanlar

Yazar Katkı Beyanı

Yazarlar çalışmaya eşit oranda katkı sunmuştur.

Çıkar Çatışması

Yazarlar herhangi bir çıkar çatışması olmadığını beyan eder.

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Effect of Dietary *Parquetina nigrescens* Leaf Extract on Growth Performance, Activities of Digestive Enzymes, Serum Biochemical Profile and Antioxidative Status of African Catfish (*Clarias gariepinus*)

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Abstract

The current study sought to determine how dietary *Parquetina nigrescens* leaf (PNL) affected the performance of *Clarias gariepinus*. Ethanol extract of PNL was included at 0.0 (control), 0.5, 1.0, and 1.5 g/kg diet for *C. gariepinus* juveniles. The fish (n = 240) were fed the assigned diets for eight weeks to apparent satiation, twice daily in three replicates to determine the growth performance, nutrient utilization and activities of intestinal digestive enzymes. Thereafter, samples of blood were withdrawn from the fish to determine the serum biochemical and anti-oxidative parameters. One-way analysis of variance was used to analyze the data generated at $P < 0.05$. In comparison to the fish fed other diets, fish fed 1.0-1.5 g PNL showed considerable increase in weights, specific growth rate, protein efficiency ratio and reduced feed conversion ratio. Higher fish survival and fish productivity index were obtained at 1.0 g PNL. The fish fed 1.0-1.5 g PNL had higher activities of maltase, lipase, chymotrypsin, and pepsin. Additionally, blood proteins were enhanced, while liver enzymes reduced with dietary PNL. The activities of serum catalase, glutathione peroxidase, glutathione-S-transferase, superoxide dismutase were also boosted in the fish on 1.0-1.5 g PNL. Ultimately, the growth performance of *C. gariepinus*, as well as its serum biochemical and antioxidative status were enhanced with dietary PNL at 1.0-1.5 g. Hence, PNL inclusion at 1.0 g/kg diet is recommended, as organic supplement, for healthy production performance of the fish.

Keywords: *Clarias gariepinus*, *Parquetina nigrescens*, growth performance, serum biochemical, antioxidant enzymes

Introduction

Production of aquatic animals is increasing due to their high nutritional value and contribution to healthy diet, food security and economic development. Globally, inland aquaculture contributes about 84% to global inland fish production (FAO, 2024). African catfish, *Clarias gariepinus*, is one of the highly reared and priced inland food fishes in Africa and other continents. The fish is intensively, widely and mostly cultured in Nigeria because of its attributes, including high consumers' acceptance, market value, fast growth rate, as well as its high adaptability to adverse rearing, water quality and environment conditions (Adeniyi et al., 2025). The use of natural additives with growth and health-promoting effects are nonnegotiable and fundamental to economic viability, sustainable production and food security without compromising quality diets to meeting the requirements of the fish for essential nutrients and safety of the consumers. One category of such natural additives is herbs.

Medicinal herbs are recognized for possession of diverse bioactive compounds, which are the bases for their wide usage. Additionally, it is opined that herbs as natural additives are ecofriendly, renewable, sustainable and relatively safe for animal use. Investigations on the usage of herbs in the culture of aquatic animals are rising owing to its diverse roles. The roles of herbal additives in aquafeeds, including promotion of growth, antioxidant capacity, fish immunity and resistance against disease-causing organisms have been attested in many recent studies (Garg et al., 2021; Promprom et al., 2024; Adeniyi et al., 2023a, 2025; Paray et al., 2025).

Parquetina nigrescens is a woody perennial shrub with smooth twining stem and wide leaves, in the family Apocynaceae and subfamily Periplocoideae. It is rich in flavonoids (Ayoola et al., 2019; Kayode et al. 2022), while many compounds such as octadecatrienoate, hexadecanoic acid, octadecanoate, squalene, mannose, iophene, phytol, decanoic acid, 5-ethyl-2-furaldehyde have been identified in reasonable quantities from the leaves (Adeyomoye and Adeoye, 2018; Adase et al., 2022). The plant possesses several biological properties, including: antibacterial, antioxidant, antidiabetic, anti-helminthic, anti-inflammatory, anti-ulcerative, antipyretic, hepatoprotective and immuno-stimulating properties (Saba et al., 2010; Banwo et al., 2020; Ojuade et al., 2021; Adeniyi et al., 2023a; Akinduko et al., 2024). The rich phytochemical compounds and diverse biological properties of *P. nigrescens* leaf could have led to its wide and effective utilization for ethnomedicinal purposes (Daramola et al., 2022; Kayode et al., 2022; Olumide et al., 2022). Despite the potentials of this plant, there is limited information on its usage for farmed aquatic animals. Therefore, this study purposed to evaluate how dietary *P. nigrescens* leaf extract would affect the growth performance, digestive enzymes, serum biochemical indices and antioxidative capacity of *Clarias gariepinus*.



Materials and Methods

Source and preparation *Parquetina nigrescens* leaf extract

Fresh *P. nigrescens* leaves were obtained, cleaned with tap water, allowed to air-dry at ambient temperature and ground into meal using an electric blender. Ethanol was used as the solvent in a ratio of 1:5 (Plant: ethanol, weight/volume) to extract the herbal meal. To ensure sufficient homogenization and extraction, the *P. nigrescens* leaf meal was dissolved in ethanol using a glass rod and shaken on electrical orbital shaker (DLAB, SK033pro, UK) at 250 rpm intermittently within the 48 hours of extraction. After that, muslin cloth and filter paper were used to sieve and filter the mixture, respectively. The solvent was removed from the filtrate, using rotary evaporator, to produce concentrated *P. nigrescens* leaf extract (PNL), which was preserved in refrigerator (-4 °C) until when it was included in the diet (Adeniyi et al., 2023a).

Experimental fish and feeding

Juveniles of *Clarias gariepinus* were acquired from a reliable farm and given a commercial feed (Bluecrown, Nigeria; 2 mm size; 42% crude protein, 12% lipid) for 2 weeks during which the fishes adjusted to the rearing conditions. The juveniles (240; 17.74 ± 0.23) were then divided at random into four treatments of three replicates. The fish were reared in twelve experimental plastic aquaria of 80 L-capacity, using a renewal method of 72-hour water replenishment. The ingredients listed on Table 1 were used to produce four 2 mm diets, with PNL {0.0 (control), 0.5, 1.0 and 1.5 g / kg diet} added by spraying. The pellets of each diet were immediately air-dried and put in labeled polythene bags. During the eight-week feeding trial, the designated diets were offered to the fish daily, at 08:30-9:30 am and 4:30 – 5:30 pm, till they appeared satiated.

Growth performance

The fish were batch-weighted prior and after the feeding trial to estimate the initial and final weights. The sum of the weights of feed offered and consumed by the fish in each aquarium was taken as feed intake. The fish weight gain (WG), specific growth rate (SGR), feed conversion ratio (FCR), protein efficiency ratio (PER), fish survival (FS) and fish productivity index (FPI) were calculated from the data obtained as shown below:

- i. $WG (g) = \text{Final weight (FW)} - \text{Initial weight (IW)}$
- ii. $SGR (\%/day) = 100 \times (\ln FW - \ln IW) / \text{Time of feeding trial (days)}$
- iii. $FCR = \text{Feed intake (FI)} / WG$
- iv. $PER = WG / \text{Protein intake}$
(Protein intake = Crude protein in diet $\times$ FI)
- v. $FS (\%) = 100 (\text{Number of survived fish} / \text{number of fish stocked})$
- vi. $FPI = (\text{Weight gain} \times \text{Fish survival}) / (FCR \times 10)$

Analysis of digestive enzymes

To avoid contamination with endogenous enzymes, feeding was stopped 24 hours before the removing the guts. Thereafter, guts of two fishes were removed, from each replicate and labeled appropriately in a sample bottle. The guts were cleansed with ice-cold and then homogenized with ice-cold deionized water (1:10); centrifugation of the homogenate was performed at 5,000 g for 15 min; and the supernatants of the samples were used as enzyme extracts for the digestive enzymes assay on the activities of lipase, chymotrypsin, pepsin, and maltase, following the standard procedures described by Ogunbiyi and Okon (1976) and Fagbenro *et al.* (2005).

For lipase, mixture of 1.0 mL each of enzyme extract and 25% olive oil emulsion (at pH 7.0) were simultaneously incubated with the control (blank) in a water bath at 37 °C for an hour. After incubation, 3.0 mL of 95% ethanol and two drops of phenolphthalein were added to produce a reaction mixture that was titrated against 0.05N sodium hydroxide. The difference in titre values of control and extract was recorded as lipase activity (Ogunbiyi and Okon, 1976). To estimate the activities of pepsin and chymotrypsin, mixture 0.5 mL of enzyme extract, 10 mg of hide powder azure as substrate, and 2.0 mL phosphate buffer (pH 8.0 for chymotrypsin and pH 2.0 for pepsin) were incubated at 37 °C for an hour along with control samples. Thereafter, 3.0 mL of ice-cold phosphate buffer was added, the mixture was filtered and the absorbance read at 595 nm (Fagbenro *et al.*, 2005). Maltase activity was analyzed by heating mixture of 0.2 mL of the intestinal enzyme extract, 0.4 mL of 1 % substrate (0.112 μ M maltose), 0.2 mL phosphate buffer (pH 7.0), and 1.6 mL of alkaline 3, 5-dinitrosalicylic acid reagent (DNSA) for 30 minutes in a water bath at 100 °C. The mixture was made up to 4.0 mL by adding distilled water and absorbance was measured at 540 nm (Fagbenro *et al.*, 2005).

Blood collection, biochemical and antioxidant analyses

Following the feeding trial, samples of blood were collected from the fish's caudal vein using a 2 mL plastic syringe in plain bottles, left at ambient temperature for 30 minutes allowed to allow it to clot and then transported to the laboratory on ice, where the serum were separated using centrifuge, properly labeled in eppendorf tubes and store in freezer for serum biochemical and antioxidant analyses. Blood proteins, cholesterol, triglycerides, total



bilirubin, creatinine, blood urea nitrogen (BUN), aspartate aminotransferase (AST), alanine aminotransferase (ALT), and alkaline phosphatase (ALP) were determined with Randox kit, following the standard procedure of the manufacturer. The concentration of malondialdehyde (MDA), hydrogen peroxide, reduced glutathione (GSH) and activities of glutathione peroxidase (GPx), glutathione-s-transferase (GST), catalase, and superoxide dismutase (SOD) were also evaluated using commercial assay kit (Cayman).

Table 1: Gross composition (g/kg diets) of experimental diets containing *Parquetina nigrescens* leaf (PNL) extract for *Clarias gariepinus*

Ingredients	Levels of inclusion (g/kg)			
	0.0	0.5	1.0	1.5
Fish meal	280	280	280	280
Soya bean meal	256	256	256	256
Groundnut cake	191	191	191	191
Maize flour	179.5	179.5	179.5	179.5
Fish oil	50	50	50	50
Di-calcium phosphate	6	6	6	6
Premix	20	20	20	20
Starch	15	14.5	14.0	13.5
PNL extract	0.0	0.5	1.0	1.5
Methionine	0.5	0.5	0.5	0.5
Table salt	2	2	2	2

*Premix (per kg premix): Vitamin A, 22,000IU; vitamin B1, 20mg; vitamin B2, 25mg; vitamin B6, 10mg; vitamin B12, 0.05mg; vitamin C, 300mg; vitamin D3, 5,000IU; vitamin E, 300mg; vitamin K3, 10mg; niacin, 120mg; folic acid, 5mg; biotin, 1mg; inositol, 50mg; calcium pantothenate, 60mg; choline chloride, 500mg; manganese, 30mg; iron, 35mg; zinc, 45mg; copper, 3mg; cobalt, 2mg; iodine, 5mg; selenium, 0.15mg

Statistical analysis

Using one-way analysis of variance, the data from the study were presented as mean $\pm$ standard error (SE). The differences among means of the treatments were analyzed with Duncan multiple range tests at $P < 0.05$, using statistical package for social sciences (SPSS), version 25.

Results

Fish growth performance and nutrient utilization

Table 2 presents the growth performance of *C. gariepinus* fed different levels of PNL extract and the control diet. In comparison to the control treatment, the final weight, weight gain, specific growth rate of the fish fed 1.0 - 1.5 g PNL extract/kg increased ($P < 0.05$). The feed intake of the fish did not vary significantly among the treatments, but lower ($P < 0.05$) feed conversion ratio and higher protein efficiency ratio were obtained in *C. gariepinus* fed 1.0 and 1.5 g PNL extract, in relation to the fish fed other diets. Fish survival (100%) was significantly higher at 1.0 g PNL, than the control treatment. On the overall, dietary PNL at 1.0 g PNL/kg diet enhanced fish productivity index significantly.

Activities of digestive enzymes

The effect of dietary PNL extract on activities of digestive enzymes in *C. gariepinus* is shown on Table 3. Higher ($P < 0.05$) lipase activity was recorded in treatments fed PNL extract, reaching the peak at 1.0 g inclusion level. Also, the activities of pepsin, chymotrypsin and maltase in the fish rose as the levels of dietary PNL extract increased.

Table 2: Growth performance of *Clarias gariepinus* juveniles fed diets containing *Parquetina nigrescens* leaf extract for eight weeks

Parameters	PNL inclusion level (g/kg diet)			
	0.0	0.5	1.0	1.5
Initial weight (g/fish)	17.72 $\pm$ 0.14 ^a	17.76 $\pm$ 0.15 ^a	17.63 $\pm$ 0.07 ^a	17.87 $\pm$ 0.07 ^a
Final weight (g/fish)	120.28 $\pm$ 1.80 ^c	130.96 $\pm$ 0.65 ^b	135.38 $\pm$ 1.62 ^a	138.38 $\pm$ 0.70 ^a
Weight gain (g/fish)	102.57 $\pm$ 1.69 ^c	113.20 $\pm$ 0.61 ^b	117.76 $\pm$ 1.56 ^a	120.51 $\pm$ 0.54 ^a
SGR (%/day/fish)	3.42 $\pm$ 0.02 ^c	3.57 $\pm$ 0.02 ^b	3.64 $\pm$ 0.02 ^a	3.66 $\pm$ 0.01 ^a
Feed intake (g/fish)	140.22 $\pm$ 0.49 ^{bc}	143.70 $\pm$ 0.84 ^a	139.75 $\pm$ 0.33 ^c	142.35 $\pm$ 1.12 ^{ab}
Feed conversion ratio	1.37 $\pm$ 0.01 ^a	1.27 $\pm$ 0.02 ^b	1.19 $\pm$ 0.01 ^c	1.18 $\pm$ 0.02 ^c
Protein efficiency ratio	1.83 $\pm$ 0.03 ^c	1.97 $\pm$ 0.02 ^b	2.11 $\pm$ 0.02 ^a	2.12 $\pm$ 0.02 ^a
Fish survival (%)	95.00 $\pm$ 0.00 ^b	96.67 $\pm$ 1.67 ^{ab}	100.00 $\pm$ 0.00 ^a	96.67 $\pm$ 1.67 ^{ab}
Fish productivity index	713.10 $\pm$ 22.83 ^c	862.61 $\pm$ 26.78 ^b	992.65 $\pm$ 16.91 ^a	986.22 $\pm$ 27.08 ^a

Means $\pm$ SE along a row with different superscript differ significantly at $P < 0.05$. SGR - Specific growth rate



Table 3: Activities of digestive enzymes in *Clarias gariepinus* juveniles fed diets containing *Parquetina nigrescens* leaf extract (PNL) for eight weeks

Parameters	PNL inclusion levels (g/kg diet)			
	0.0	0.5	1.0	1.5
Lipase	38.58 ± 0.24 ^c	40.18 ± 0.5 ^b	44.53 ± 0.91 ^a	42.59 ± 0.84 ^a
Pepsin	0.05 ± 0.00 ^c	0.06 ± 0.00 ^{bc}	0.07 ± 0.00 ^b	0.09 ± 0.01 ^a
Chymotrypsin	0.63 ± 0.01 ^c	0.65 ± 0.00 ^{bc}	0.71 ± 0.00 ^b	0.88 ± 0.03 ^a
Maltase	0.33 ± 0.01 ^d	0.45 ± 0.01 ^c	0.51 ± 0.01 ^b	0.73 ± 0.03 ^a

Means ± SE along a row with different superscript differ significantly at P < 0.05.

Fish biochemical profile

Table 4 shows the result of serum biochemistry profile of *C. gariepinus* fed with PNL extract. Dietary PNL extract enhanced the blood proteins (P<0.05). Concentration of AST and ALP reduced in all the fish fed with PNL-supplemented diets, with the lowest values obtained at 1.0 g inclusion level. The treatment fed 1.0 g PNL had the lowest (P<0.05) ALT, compared to others. There were no significant variations (P>0.05) in the concentrations of BUN, creatinine, and total bilirubin. Lower (P<0.05) cholesterol and triglyceride were obtained at 1.0-1.5 g PNL and 1.5 g PNL, respectively, compared to other treatments. Similarly, dietary PNL also reduced glucose levels at 1.0-1.5 g PNL dosage.

Antioxidative status

The effect of PNL extracts on the anti-oxidative status of *C. gariepinus* infected with *A. hydrophila* is shown in Table 4. There was significant reduction in the concentration of serum MDA and hydrogen peroxide (H₂O₂) of *C. gariepinus* fed 1.0 g PNL / kg diet, compared to those fed the control diet. Significantly higher GSH (Reduced glutathione) was exhibited in fish on 1.0 g PNL extract, compared to those fed other diets. The activities of antioxidant enzymes _CAT, GPx, and GST_ were also boosted in the fish fed PNL-based diets, especially at 1.0-1.5 g inclusion levels, compared to the fish on control diet.

Table 4: Serum biochemical profile of *Clarias gariepinus* juveniles fed diets containing *Parquetina nigrescens* leaf extract for eight weeks

Parameters	PNL inclusion levels (g/kg diet)			
	0.0	0.5	1.0	1.5
Total Protein (g/dL)	4.88±0.05 ^b	5.06±0.04 ^a	5.11±0.04 ^a	5.12±0.04 ^a
Albumin (g/dL)	1.08±0.02 ^b	1.04±0.03 ^a	1.18±0.03 ^a	1.11±0.04 ^a
Globulin (g/dL)	3.80±0.04 ^b	4.01±0.03 ^a	3.93±0.03 ^a	4.01±0.03 ^a
AGR	0.28±0.00 ^{ab}	0.26±0.01 ^b	0.30±0.01 ^a	0.28±0.01 ^{ab}
AST (UI/L)	316.67±1.92 ^a	307.00±3.62 ^b	282.81±2.69 ^c	301.56±2.52 ^b
ALT (UI/L)	50.44±0.87 ^a	51.44±1.02 ^a	45.11±0.89 ^b	49.78±1.00 ^a
ALP (UI/L)	601.56±1.39 ^a	562.67±8.77 ^b	544.78±1.85 ^c	564.67±2.36 ^b
BUN (mg/dl)	6.41±0.11	6.43±0.08	6.21±0.07	6.44±0.03
Creatinine (mg/dl)	0.56±0.02	0.58±0.01	0.53±0.02	0.57±0.02
Cholesterol (mg/dL)	185.89±1.33 ^a	188.00±1.87 ^a	178.78±1.21 ^b	171.00±0.83 ^{ab}
Triglycerides (mg/dL)	60.11±0.96 ^a	62.78±0.36 ^a	63.11±0.68 ^a	50.11±0.70 ^b
Glucose (mg/dL)	321.33±1.13 ^a	317.78±2.37 ^a	298.00±0.71 ^c	307.00±1.49 ^b

Means ± SE along a row with different superscript differ significantly at P < 0.05. AGR – Albumin globulin ratio; AST - Aspartate aminotransferase; ALT - alanine aminotransferase; ALP - Alkaline phosphatase (ALP); BUN – Blood urea nitrogen

Table 5: Antioxidative status of *Clarias gariepinus* juveniles fed diets containing *Parquetina nigrescens* leaf extract for eight weeks

Parameters	PNL inclusion levels (g/kg diet)			
	0.0	0.5	1.0	1.5
MDA (μmol/mg protein)	3.04 ± 0.02 ^a	1.05 ± 0.01 ^b	1.02 ± 0.03 ^b	1.06 ± 0.01 ^b
H ₂ O ₂ (μmol/mg protein)	7.39 ± 0.13 ^a	5.85 ± 0.06 ^b	4.60 ± 0.07 ^c	4.09 ± 0.05 ^d
GSH (U/mg protein)	516.28 ± 3.75 ^d	618.07 ± 1.92 ^b	626.37 ± 1.28 ^a	607.08 ± 1.34 ^c
GPX (U/mg protein)	12.36 ± 0.42 ^b	12.90 ± 0.58 ^b	16.09 ± 0.36 ^a	15.61 ± 0.25 ^a
GST (U/mg protein)	55.75 ± 0.34 ^c	57.91 ± 0.18 ^c	63.82 ± 1.43 ^b	85.31 ± 0.81 ^a
Catalase	2.94 ± 0.13 ^d	3.31 ± 0.06 ^c	3.60 ± 0.05 ^b	3.86 ± 0.06 ^a
SOD (U/mg protein)	3.92 ± 0.06 ^b	6.47 ± 0.04 ^a	6.41 ± 0.06 ^a	6.34 ± 0.04 ^a

Means ± SE along a row with different superscript differ significantly at P < 0.05. MDA - Malondialdehyde; H₂O₂ - Hydrogen peroxide; GSH - Reduced glutathione; SOD - Superoxide dismutase; GPx - glutathione peroxidase; GST - Glutathione-s-transferase



Discussion

Dietary PNL has been shown to enhance feed efficiency, growth performance, survival, productivity index, and the activities of the digestive enzymes of African catfish in this study. Similarly, many phyto-additives have been reported to promote growth in diverse farm aquatic animals, including *Chenopodium album* (Amhamed et al., 2018), *Apium graveolens* (Sutthi et al., 2020), *Mitracarpus scaber* (Adeshina et al., 2021), moringa (Adeniyi et al., 2023b), paulownia (El-Refiae et al., 2024), ivy (Fadaei et al., 2025) leaf extracts. Digestive enzymes _amylases, proteases and lipases_ catalyze the breakdown of carbohydrates, protein, and lipids into absorbable nutrients that are utilized for growth, repairs of worn out cells and tissues and energy for diverse fish's metabolic activities. Hence, the growth-promoting effects of PNL diets in the current study could be linked with the enhanced digestion of feed by the digestive enzymes and nutrients' absorption. Similar observations on the enhanced activities of digestive enzymes in fishes on dietary herbs have been published in previous studies (Amhamed et al., 2018; Naiel et al., 2021; Fadaei et al., 2025; Li et al., 2026).

Blood biochemical parameters are vital indicators for the evaluation and screening of dietary supplements on the physiological, nutritional benefit, health and general welfare of farm fishes (Adeniyi et al., 2023b). The significant increase in the blood proteins and lower liver enzymes (AST, ALT, and ALP) suggest that PNL enhanced protein metabolism and promote healthy liver function. Liver enzymes are common biomarkers for assessing the impact of extrinsic factors and their effects on the animal and higher level of these enzymes could indicate pathological stress due to hepatic injuries detrimental to the hepatocytes (Tennant and Center, 2008). Similarly, the lower concentrations of cholesterol, triglycerides and glucose recorded at 1.0 or 1.5 g PNL could be related to the roles PNL in improving fat and carbohydrate metabolism at these dosages. The current observations on the biochemical profiles of fish align with the recent similar studies (Adeniyi et al., 2023b; Fadaei et al., 2025; Li et al., 2026).

Plant-based natural antioxidants have been proven to be efficacious agents that mitigate peroxidation of lipids in feeds and other substrates, and scavenge free radicals. They provide effective defense against oxidative stress and damage by boosting endogenous non-enzymatic (GSH) and enzymatic antioxidants (catalase, GPx, GST, and SOD) for sustainable production of healthy aquatic species (Adeshina et al., 2021; Adeniyi et al., 2024, 2025; Hu et al., 2025). The significant lower concentration of serum MDA and H₂O₂ with corresponding increase in GSH, catalase, GPx, GST and SOD in this study could be associated with the antioxidant activity of dietary PNL mitigating against oxidative stress in the fish. Previous in vitro (Ayoola et al., 2011; Banwo et al., 2020) and recent in vivo studies in rat (Akinduko et al., 2024; Bamisaye et al., 2026) also demonstrated antioxidant activities of PNL and this might be attributed to its flavonoid content (Ayoola et al., 2019; Kayode et al., 2022). In agreement with the present study, many herbal leaves have been reported as effective natural antioxidants in different aquatic species (Adeniyi et al., 2018; Maldonado-Garcia et al., 2019; Naiel et al., 2021; Adeniyi et al., 2024, 2025; Paray et al., 2025).

In conclusion, the study determined the effects of *P. nigrescens* leaf extract performance of *C. gariepinus*. The extract promoted the fish weight gain, specific growth rate, protein efficiency ratio, fish productivity index, activities of lipase, pepsin and chymotrypsin and maltase, reduced feed conversion ratio, as well as improved the serum biochemical and antioxidative status of the fish at 1.0-1.5 g. Hence, PNL inclusion at 1.0 g/kg diet is recommended for healthy production performance of the fish.

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Evaluation of the Phytochemical Properties and Therapeutic Potential of *Crocus sativus* L. (Saffron) in Light of Current Approaches

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Abstract

Saffron (*Crocus sativus* L.), belonging to the Iridaceae family, is an important medicinal plant that attracts attention in both traditional and modern medicine due to its high economic value and rich phytochemical content. The main bioactive components of saffron, crocin, crocetin, picrocrocin, and safranal, are responsible for the plant's color, aroma, and taste characteristics, as well as its pharmacological effects (Rios et al., 1996; Pitsikas, 2016). Throughout history, saffron has been used in the treatment of digestive system diseases, pain, insomnia, depression, and various inflammatory conditions (Mousavi and Bathaie, 2011; Ceylan, 2005).

In this study, the phytochemical properties of saffron and its therapeutic effects on different disease groups were evaluated in line with current scientific data. Research shows that saffron exhibits strong antioxidant effects and can reduce cellular damage caused by oxidative stress (Amin et al., 2011; Sadeghnia et al., 2017). Furthermore, it has been reported to exhibit positive effects in mental health issues such as depression, anxiety, and sleep disorders; some studies have shown similar efficacy to standard antidepressants such as fluoxetine (Noorbala et al., 2005; Marx et al., 2019). In neurodegenerative diseases, compounds such as crocin and safranal are stated to have shown neuroprotective effects and beneficial results in Alzheimer's disease (Hatziagapiou et al., 2019; Hadipour et al., 2020).

Studies on the anticancer effects of saffron show that this plant may be effective in various types of cancer by suppressing cell proliferation, inducing apoptosis, and reducing oxidative stress (Ashktorab et al., 2019; Lambrianidou et al., 2020). In conclusion, saffron is considered an important natural resource in the development of new pharmaceutical products in the future thanks to its multifaceted biological activities.

Keywords: Saffron (*Crocus sativus* L.) has antioxidant activity, neuroprotective effects, and anticancer activity.

Crocus sativus L. (Safran)'ın Fitokimyasal Özellikleri ve Terapötik Potansiyelinin Güncel Yaklaşımlar Işığında Değerlendirilmesi

Özet

Safran (*Crocus sativus* L.), Iridaceae familyasına ait, yüksek ekonomik değeri ve zengin fitokimyasal içeriği nedeniyle hem geleneksel hem de modern tıpta dikkat çeken önemli bir tıbbi bitkidir. Safranın başlıca biyoaktif bileşenleri olan krosin, krosetin, pikrokrosin ve safranal; bitkinin renk, aroma ve tat özelliklerinin yanı sıra farmakolojik etkilerinden de sorumludur (Rios ve ark., 1996; Pitsikas, 2016). Tarihsel süreç boyunca safran; sindirim sistemi hastalıkları, ağrı, uykusuzluk, depresyon ve çeşitli inflamatuvar durumların tedavisinde kullanılmıştır (Mousavi ve Bathaie, 2011; Ceylan, 2005).

Bu çalışmada, safranın fitokimyasal özellikleri ve farklı hastalık grupları üzerindeki terapötik etkileri güncel bilimsel veriler doğrultusunda değerlendirilmiştir. Yapılan araştırmalar, safranın güçlü antioksidan etkiler gösterdiğini ve oksidatif stres kaynaklı hücresel hasarı azaltabildiğini ortaya koymaktadır (Amin ve ark., 2011; Sadeghnia ve ark., 2017). Ayrıca depresyon, anksiyete ve uyku bozuklukları gibi ruh sağlığı sorunlarında olumlu etkiler sergilediği; bazı çalışmalarda fluoksetin gibi standart antidepresanlarla benzer etkinlik gösterdiği bildirilmiştir (Noorbala ve ark., 2005; Marx ve ark., 2019). Nörodejeneratif hastalıklarda ise krosin ve safranal gibi bileşiklerin nöroprotektif etki göstererek Alzheimer hastalığı üzerinde yararlı sonuçlar ortaya koyduğu belirtilmektedir (Hatziagapiou ve ark., 2019; Hadipour ve ark., 2020).

Safranın antikanser etkileri üzerine yapılan çalışmalar, bu bitkinin hücre proliferasyonunu baskılama, apoptozu indüklemeye ve oksidatif stresi azaltma yoluyla çeşitli kanser türlerinde etkili olabileceğini göstermektedir (Ashktorab ve ark., 2019; Lambrianidou ve ark., 2020). Sonuç olarak safran, çok yönlü biyolojik aktiviteleri sayesinde gelecekte yeni farmasötik ürünlerin geliştirilmesinde önemli bir doğal kaynak olarak değerlendirilmektedir.

Anahtar Kelimeler: Safran (*Crocus sativus* L.), antioksidan aktivite, nöroprotektif etki, antikanser aktivite



Giriş

Safran (*Crocus sativus* L.), Iridaceae familyasına ait, ekonomik değeri oldukça yüksek olan ve tarih boyunca hem tıbbi hem de gıda amaçlı kullanılan önemli bir tıbbi bitkidir. Bitkinin çiçeklerinden elde edilen kırmızı renkli stigmalar, içerdiği krosin, krosetin, pikrokrosin ve safranal gibi biyoaktif bileşikler sayesinde karakteristik renk, aroma ve farmakolojik özellikler göstermektedir. Bu bileşikler, safranın yalnızca baharat olarak değil aynı zamanda doğal bir tedavi ajanı olarak da değerlendirilmesini sağlamıştır.

Safranın kullanımına ilişkin kayıtlar Mezopotamya, Eski Mısır, Antik Yunan ve Roma uygarlıklarına kadar uzanmaktadır. Tarih boyunca sindirim sistemi hastalıkları, göz rahatsızlıkları, yara tedavisi, ağrı kontrolü ve ruhsal bozukluklar başta olmak üzere birçok hastalıkta geleneksel tedavi amacıyla kullanılmıştır. Osmanlı tıp yazmalarında da "za'feran" adıyla yer almakta ve özellikle baş ağrısı, uykusuzluk, göz hastalıkları ve cinsel fonksiyon bozukluklarının tedavisinde önerilmektedir.

Günümüzde doğal ürünlere olan ilginin artmasıyla birlikte safran üzerine gerçekleştirilen deneysel ve klinik çalışmalar da önemli ölçüde artmıştır. Araştırmalar, safranın güçlü antioksidan özelliklerinin yanı sıra antienflamatuvar, antikanser, nöroprotektif, antidepresan, antihipertansif ve immünomodülatör etkiler gösterebildiğini ortaya koymaktadır. Özellikle oksidatif stres ve kronik inflamasyonun rol oynadığı hastalıklarda, safranın içerdiği biyoaktif bileşiklerin koruyucu ve tedavi edici etkileri dikkat çekmektedir.

Son yıllarda Alzheimer hastalığı, Parkinson hastalığı, depresyon, anksiyete bozuklukları, çeşitli kanser türleri, kardiyovasküler hastalıklar ve metabolik hastalıklar üzerinde yürütülen çalışmalar, safranın çok yönlü farmakolojik özelliklere sahip olduğunu göstermektedir. Bununla birlikte mevcut araştırmaların önemli bir kısmı deneysel düzeyde olup, klinik kullanımın yaygınlaştırılabilmesi için daha geniş örneklemli ve uzun süreli klinik çalışmalara ihtiyaç duyulmaktadır.

Bu derlemenin amacı, *Crocus sativus* L.'nin botanik özellikleri, fitokimyasal bileşenleri ve geleneksel kullanım alanlarının yanı sıra, güncel literatür doğrultusunda antioksidan, antikanser, nöroprotektif, psikiyatrik ve diğer farmakolojik etkilerini kapsamlı biçimde değerlendirmek ve safranın gelecekteki terapötik potansiyeline ilişkin güncel bilgileri bir araya getirmektir.

Genel Bilgiler

Safran Bitkisinin Genel Özellikleri

Safran (*Crocus sativus* L.), Iridaceae familyasına ait çok yıllık, geofit karakterde bir kültür bitkisidir. Bitkinin ekonomik değerini oluşturan kısmı, çiçeklerinde bulunan kırmızı renkli stigma yapılarıdır. Her çiçekte üç adet stigma bulunmakta olup, safran üretiminde yalnızca bu kısım kullanılmaktadır. Üretimin tamamen elle gerçekleştirilmesi ve çok sayıda çiçekten az miktarda ürün elde edilmesi nedeniyle safran, dünyanın en değerli baharatlarından biri olarak kabul edilmektedir.

Safranın anavatanı kesin olarak bilinmemekle birlikte uzun yıllardır başta İran olmak üzere Akdeniz ülkeleri ve Asya'nın çeşitli bölgelerinde yetiştirilmektedir. Türkiye'de ise özellikle Safranbolu çevresinde yetiştiriciliği yapılmakta olup, tarihsel ve kültürel açıdan önemli bir yere sahiptir. Günümüzde artan doğal ürün ve fitoterapi ilgisiyle birlikte safran, yalnızca baharat olarak değil, farmasötik ve fonksiyonel gıda alanlarında da değerlendirilen önemli bir bitki hâline gelmiştir.

Taksonomisi

Safranın bilimsel sınıflandırması aşağıdaki gibidir:

- Alem: Plantae
- Bölüm: Magnoliophyta
- Sınıf: Liliopsida
- Takım: Asparagales
- Familya: Iridaceae
- Cins: *Crocus*
- Tür: *Crocus sativus* L.

Crocus cinsi çok sayıda tür içermekle birlikte, ticari değere sahip ve baharat olarak kullanılan tek tür *Crocus sativus* L.'dir. Bitki steril triploid yapıda olduğundan tohum oluşturmaz ve üretimi yalnızca soğan (korm) ile vejetatif olarak gerçekleştirilmektedir. Bu özellik, bitkinin genetik devamlılığının korunmasını sağlamakla birlikte üretimin tamamen insan kontrolüne bağlı olmasına neden olmaktadır.

Botanik Özellikleri

Safran sonbaharda çiçeklenen, yer altında korm adı verilen depo organına sahip çok yıllık otsu bir bitkidir. Yaprakları dar, uzun ve şerit şeklinde olup koyu yeşil renklidir. Mor tonlarında çiçeklere sahip olan bitkinin her çiçeğinde üç adet parlak kırmızı stigma ve bunları taşıyan ince stilus yapısı bulunmaktadır.



Bitkinin yaşam döngüsü büyük ölçüde çevresel koşullardan etkilenmektedir. Yaz aylarında dinlenme dönemine giren kormlar, sonbaharda yeniden gelişmeye başlamakta ve kısa süre içerisinde çiçeklenmektedir. Hasat döneminde çiçekler tek tek toplanmakta, ardından stigmalar dikkatli bir şekilde ayrılarak kurutulmaktadır. Ürünün kalite özellikleri; yetiştirme koşulları, hasat zamanı ve kurutma yöntemlerine bağlı olarak değişebilmektedir.

Fitokimyasal Bileşenleri

Safranın farmakolojik ve duyuşal özellikleri içerdiği biyoaktif bileşiklerden kaynaklanmaktadır. En önemli bileşenleri krosin, krosetin, pikrokrosin ve safranaldır.

Krosin, safrana karakteristik koyu kırmızı rengini veren temel karotenoid türevidir ve güçlü antioksidan özellik göstermektedir. Krosetin ise krosinin aglikon formu olup antioksidan ve çeşitli biyolojik etkilerinden sorumlu önemli bileşiklerden biridir. Pikrokrosin safranının kendine özgü acı tadını oluştururken, kurutma işlemi sırasında parçalanarak safranalin oluşumuna katkı sağlamaktadır. Safranald ise bitkiye karakteristik aromasını kazandıran uçucu bileşik olup aynı zamanda çeşitli farmakolojik etkiler göstermektedir.

Bu temel bileşiklerin yanı sıra safranda flavonoidler, fenolik bileşikler ve çeşitli karotenoidler de bulunmaktadır. Söz konusu fitokimyasal içerik, safranının antioksidan, antienflamatuvar, nöroprotektif ve antikanser etkilerinin temelini oluşturmaktadır.

Geleneksel Kullanımı

Safran, tarih boyunca farklı uygarlıklarda hem tedavi edici hem de günlük yaşamda kullanılan değerli bir bitki olmuştur. Antik Mısır, Yunan ve Roma dönemlerinde sindirim sistemi rahatsızlıkları, yara tedavisi, göz hastalıkları ve ağrıların giderilmesinde kullanıldığı bildirilmektedir. Ayrıca aromatik yağlar, merhemler ve çeşitli ilaç hazırlamalarında da önemli bir bileşen olarak yer almıştır.

Osmanlı tıp yazmalarında "za'feran" adıyla geçen safran; baş ağrısı, göz hastalıkları, uykusuzluk, sindirim sistemi rahatsızlıkları ve cinsel fonksiyon bozukluklarının tedavisinde önerilmiştir. Geleneksel halk hekimliğinde ise yatıştırıcı, iştah açıcı, sindirimi kolaylaştırıcı ve afrodizyak özelliklerinden yararlanılmıştır.

Tıbbi kullanımının yanı sıra safran, gıda sektöründe doğal renklendirici ve aroma verici olarak yaygın biçimde kullanılmaktadır. Çay, tatlı, pilav, hamur işleri, sütü ürünler, et yemekleri ve çeşitli içeceklerde karakteristik renk ve aroma sağlaması nedeniyle gastronomide önemli bir yere sahiptir. Ayrıca tekstil boyamacılığı, kozmetik ve parfümeri alanlarında da tarih boyunca doğal bir hammadde olarak değerlendirilmiştir.

Safranın geleneksel kullanımı ile modern bilimsel çalışmalar birlikte değerlendirildiğinde, tarihsel bilgi birikiminin günümüzde elde edilen farmakolojik bulgular tarafından büyük ölçüde desteklendiği görülmektedir. Bu durum, bitkinin doğal tedavi ajanı olarak önemini artırmakta ve yeni terapötik uygulamalar açısından umut verici bir kaynak olduğunu göstermektedir.

Safran Bitkisinin Tıbbi Kullanımı

Safran (*Crocus sativus* L.), geleneksel tıptan günümüz modern tıbbına kadar geniş kullanım alanına sahip önemli bir tıbbi bitkidir. İçeriğinde bulunan krosin, krosetin, pikrokrosin ve safranald gibi biyoaktif bileşikler sayesinde antioksidan, antienflamatuvar, antikanser, nöroprotektif, antidepresan ve kardiyoprotektif etkiler göstermektedir. Son yıllarda gerçekleştirilen deneysel ve klinik çalışmalar, safranının farklı hastalıkların önlenmesi ve tedavisinde destekleyici bir doğal ajan olarak değerlendirilebileceğini ortaya koymaktadır.

Antioksidan Etki

Safranın en dikkat çekici farmakolojik özelliklerinden biri güçlü antioksidan kapasitesidir. Bu etkinin temelinde, içerdiği karotenoidler ve fenolik bileşiklerin serbest radikalleri nötralize ederek oksidatif stresi azaltması yer almaktadır. Yapılan deneysel çalışmalarda safran ekstraktının karaciğer, böbrek, akciğer ve kalp dokularında oluşan oksidatif hasarı azalttığı, antioksidan savunma sistemini güçlendirdiği ve doku hasarına karşı koruyucu etki gösterdiği bildirilmiştir. Ayrıca safranalin toplam antioksidan kapasiteyi artırdığı ve iskemi-reperfüzyon hasarına karşı nöroprotektif özellik gösterdiği belirlenmiştir. Bu bulgular, safranının oksidatif stresle ilişkili birçok hastalıkta destekleyici tedavi potansiyeline sahip olduğunu göstermektedir.

Ürojenekolojik Fonksiyonlar Üzerine Etkisi

Safranın üreme sağlığı üzerindeki etkileri son yıllarda çok sayıda klinik araştırmada değerlendirilmiştir. Çalışmalar, safranının özellikle erektil disfonksiyon tedavisinde olumlu sonuçlar verdiğini ve semen parametrelerini iyileştirebildiğini göstermektedir. Kadınlarda ise cinsel işlev bozuklukları, premenstrüel sendrom ve menopoz semptomları üzerinde yararlı etkiler bildirilmiştir. Safran kullanımının duyuş durum değişiklikleri, anksiyete, sıcak basmaları ve yaşam kalitesi üzerinde olumlu sonuçlar oluşturduğu belirtilmektedir. Ayrıca deneysel çalışmalarda krosinin afrodizyak etki gösterdiği, buna karşın safranalin bu etkiyi belirgin biçimde oluşturmadığı rapor edilmiştir. Elde edilen veriler, safranının kadın ve erkek üreme sağlığının desteklenmesinde doğal bir seçenek olabileceğini düşündürmektedir.



Ruh Sağlığına Etkisi

Depresyon ve anksiyete gibi ruhsal hastalıklar üzerinde safranın etkileri birçok klinik çalışmada araştırılmıştır. Bulgular, safranin hafif ve orta şiddette depresyon belirtilerini azaltabildiğini ve bazı çalışmalarda fluoksetin gibi antidepresan ilaçlarla benzer etkinlik gösterebildiğini ortaya koymaktadır. Safranın bu etkisinin serotonin ve diğer nörotransmitter sistemleri üzerindeki düzenleyici etkilerinden kaynaklandığı düşünülmektedir. Ayrıca doğum sonrası depresyon, uyku bozuklukları ve yaşam kalitesi üzerine gerçekleştirilen çalışmalarda da safran kullanımının güvenli ve etkili sonuçlar sağlayabileceği bildirilmiştir. Uyku kalitesini artırması ve ruh hâlini iyileştirmesi nedeniyle safran, psikiyatrik hastalıklarda destekleyici fitoterapötik ajanlar arasında değerlendirilmektedir.

Nörodejeneratif Hastalıklara Etkisi

Nörodejeneratif hastalıkların patogenezinde oksidatif stres ve kronik inflamasyon önemli rol oynamaktadır. Safranın içerdiği krosin, krosetin ve safranal gibi bileşikler, güçlü antioksidan özellikleri sayesinde sinir hücrelerinin oksidatif hasardan koruyabilmektedir. Yapılan çalışmalar, safranın Alzheimer hastalarında plaseboya göre daha etkili sonuçlar verdiğini ve donepezil ile memantin gibi ilaçlarla benzer klinik etkinlik gösterebildiğini ortaya koymuştur. Bunun yanında β -amiloid birikimini azaltması, kolinerjik sistemi desteklemesi ve nöronal apoptozu baskılaması safranın nöroprotektif etkilerinin temel mekanizmaları arasında gösterilmektedir. Retina kaynaklı nörodejeneratif hastalıklarda da olumlu etkiler bildirilmiş olup, safranın nörolojik hastalıkların tedavisinde umut vadeden doğal bir ajan olduğu düşünülmektedir.

Kanserde Etkisi

Safranin antikanser etkileri, içerdiği krosin, krosetin ve safranal gibi bileşiklerin hücre çoğalmasını baskılaması, apoptozu indüklemesi ve oksidatif stresi azaltması ile ilişkilendirilmektedir. İn vitro ve in vivo çalışmalar; akciğer, meme, mide, kolon ve prostat kanseri başta olmak üzere birçok kanser türünde safran ve aktif bileşenlerinin tümör hücrelerinin proliferasyonunu azalttığını göstermektedir. Ayrıca kemoterapötik ilaçlarla birlikte kullanıldığında bazı kanser hücrelerinde tedaviye duyarlılığı artırabildiği bildirilmektedir. Sağlıklı hücreler üzerinde düşük toksisite göstermesi, safranın gelecekte destekleyici antikanser tedavilerinde değerlendirilebilecek doğal bir kaynak olduğunu ortaya koymaktadır. Bununla birlikte mevcut bulguların büyük bölümü deneysel çalışmalara dayandığından, klinik kullanım için daha kapsamlı araştırmalara ihtiyaç bulunmaktadır.

Kardiyovasküler Sistem Üzerindeki Etkisi

Safranin kardiyovasküler sistem üzerinde koruyucu etkiler gösterdiği çeşitli deneysel ve klinik çalışmalarla desteklenmektedir. Özellikle krosetinin serum kolesterol düzeylerini azaltabildiği ve lipoprotein oksidasyonunu baskıladığı bildirilmiştir. Bunun yanı sıra iskemik kalp hastalıklarında biyokimyasal ve histopatolojik açıdan koruyucu etkiler gösterdiği belirtilmektedir. Retinal dolaşım ve göz fonksiyonları üzerindeki olumlu etkileri de safranin vasküler koruyucu özelliklerini desteklemektedir.

Kan Basıncı Üzerindeki Etkisi

Safran ekstraktlarının antihipertansif etkileri deneysel modellerde ayrıntılı olarak araştırılmıştır. Yapılan çalışmalarda hem sulu hem de etanolik ekstraktların kan basıncını doza bağlı olarak düşürdüğü belirlenmiştir. Bu etkinin özellikle periferik damar direncinin azalması ve damar düz kasları üzerindeki gevşetici etkilerden kaynaklandığı düşünülmektedir. Ayrıca safranin sempatik sinir sistemi aracılığıyla oluşan kasılmaları baskılayabildiği gösterilmiş olup, antihipertansif tedavilere destek olabilecek doğal ürünler arasında değerlendirilmektedir.

Antitüssif Etki

Safranin stigma ekstrektı ile temel bileşenlerinden biri olan safranalın öksürük üzerine etkileri deneysel çalışmalarda incelenmiştir. Araştırmalar, özellikle etanolik stigma ekstrektı ve safranal uygulamalarının öksürük sayısını anlamlı düzeyde azalttığını göstermektedir. Buna karşılık taç yaprağı ekstrektları ile krosinin belirgin bir antitüssif etki oluşturmadığı bildirilmiştir. Bu bulgular, safranin özellikle stigma kısmından elde edilen bileşenlerin solunum sistemi hastalıklarında destekleyici olarak değerlendirilebileceğini göstermektedir.

Tartışma

Bu derlemede incelenen çalışmalar, *Crocus sativus* L.'nin yalnızca geleneksel tedavi uygulamalarında kullanılan bir bitki olmadığını, aynı zamanda modern tıp açısından da önemli farmakolojik özelliklere sahip doğal bir kaynak olduğunu ortaya koymaktadır. Son yıllarda gerçekleştirilen deneysel ve klinik araştırmalar, safranin farklı hastalık gruplarında çok yönlü biyolojik etkiler gösterebildiğini desteklemektedir.

Safranin en belirgin özelliklerinden biri güçlü antioksidan kapasitesidir. Oksidatif stresin kanser, nörodejeneratif hastalıklar ve kardiyovasküler hastalıklar başta olmak üzere birçok kronik hastalığın gelişiminde



önemli rol oynadığı düşünüldüğünde, safranın içerdiği krosin, krosetin ve safranal gibi biyoaktif bileşiklerin serbest radikal oluşumunu baskılaması önemli bir avantaj sağlamaktadır. Bu bileşiklerin antioksidan savunma sistemini desteklemesi, safranın koruyucu ve tedaviye destekleyici etkilerini açıklayan temel mekanizmalardan biri olarak değerlendirilmektedir.

Ruh sağlığı üzerine gerçekleştirilen klinik çalışmalar incelendiğinde, safranın özellikle depresyon ve anksiyete belirtilerinin azaltılmasında olumlu sonuçlar ortaya koyduğu görülmektedir. Bazı araştırmalarda standart antidepresan ilaçlarla benzer etkinlik göstermesi, bitkinin psikiyatrik hastalıklarda tamamlayıcı tedavi seçeneği olarak değerlendirilebileceğini düşündürmektedir. Bunun yanında uyku kalitesini artırıcı etkileri de yaşam kalitesinin iyileştirilmesine katkı sağlamaktadır.

Kanser üzerine yürütülen çalışmalar ise safranın hücre proliferasyonunu baskılayıcı, apoptozu uyarıcı ve oksidatif stresi azaltıcı etkilerini ortaya koymaktadır. Bununla birlikte mevcut araştırmaların büyük bölümü hücre kültürü ve deney hayvanı modellerinde gerçekleştirilmiştir. Bu nedenle klinik etkinliğin kesin olarak ortaya konulabilmesi için geniş örneklemli ve kontrollü insan çalışmalarına ihtiyaç duyulmaktadır.

Nörodejeneratif hastalıklar, kardiyovasküler sistem hastalıkları, hipertansiyon ve ürojenekolojik fonksiyonlar üzerine elde edilen bulgular da safranın çok hedefli etki mekanizmalarına sahip olduğunu göstermektedir. Ancak terapötik dozların standardizasyonu, uzun dönem güvenlik verileri ve ilaç etkileşimleri konusunda daha kapsamlı çalışmalar yapılması gerekmektedir.

Genel olarak değerlendirildiğinde, geleneksel kullanım bilgileri ile güncel bilimsel araştırmaların büyük ölçüde birbirini desteklediği görülmektedir. Bu durum, safranın gelecekte fitoterapi ve ilaç geliştirme çalışmalarında önemli doğal kaynaklardan biri olabileceğini göstermektedir.

Sonuç

Safran (*Crocus sativus* L.), zengin fitokimyasal içeriği ve çok yönlü farmakolojik özellikleri sayesinde günümüzde üzerinde en fazla araştırma yürütülen tıbbi bitkiler arasında yer almaktadır. Bu derlemede değerlendirilen çalışmalar, safranın antioksidan, antikanser, nöroprotektif, antidepresan, kardiyoprotektif ve antihipertansif etkiler başta olmak üzere geniş bir biyolojik aktivite spektrumuna sahip olduğunu göstermektedir.

Safranın içerdiği krosin, krosetin, pikrokrosin ve safranal gibi temel biyoaktif bileşiklerin, farklı hastalıkların patogeneğinde rol oynayan oksidatif stres, inflamasyon ve hücre hasar mekanizmalarını düzenleyebildiği bildirilmektedir. Bu özellikleri nedeniyle safran, mevcut tedavilere destek sağlayabilecek doğal bir terapötik ajan olarak dikkat çekmektedir.

Her ne kadar elde edilen bulgular oldukça umut verici olsa da mevcut literatürün önemli bir bölümünü deneysel çalışmalar oluşturmaktadır. Klinik uygulamaların yaygınlaştırılabilmesi için standart dozların belirlenmesi, uzun dönem güvenlik çalışmalarının yapılması ve geniş hasta gruplarında kontrollü klinik araştırmaların gerçekleştirilmesi gerekmektedir.

Sonuç olarak, geleneksel kullanım bilgileri ile bilimsel araştırmalardan elde edilen veriler birlikte değerlendirildiğinde *Crocus sativus* L.'nin gelecekte yeni farmasötik ürünlerin geliştirilmesi ve fitoterapötik uygulamaların yaygınlaştırılması açısından önemli bir doğal kaynak olduğu değerlendirilmektedir.

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Relationship of *CTLA-4* gene polymorphism to increased risk of Hepatocellular Carcinoma**Areeha Naveed¹, Sidra Zafar², Haris Khurram³, Saba Zafar^{1*}**¹*The Women University, Faculty of Life Sciences, Department of Biochemistry and Biotechnology, 60000, Multan, Pakistan.*²*Bahauddin Zakariya University, Faculty of Biological Sciences, Institute of Molecular Biology and Biotechnology, 60000, Multan, Pakistan.*³*National University of Computer and Emerging Sciences, Chiniot-Faisalabad Campus, Faculty of Sciences, ²Department of Sciences and Humanities, Chiniot, Pakistan***Abstract**

Cancer is a disease characterized by the uncontrolled growth and spread of abnormal cells through the circulatory and lymphatic systems. It is one of the leading causes of death worldwide, accounting for approximately 2–2.5 million deaths annually. Several factors contribute to cancer development, including genetic mutations, environmental exposure, tobacco use, obesity, alcohol consumption, hormonal imbalance, radiation, and carcinogens. Liver cancer is a major type of cancer associated with risk factors such as Hepatitis B virus (HBV), Hepatitis C virus (HCV), cirrhosis, alcohol intake, aflatoxin exposure, non-alcoholic steatohepatitis, and smoking. Liver cancer is classified into primary and secondary types, with hepatocellular carcinoma (HCC) being the most common primary liver cancer, accounting for nearly 90% of cases. Around 85% of cirrhotic patients eventually develop HCC. Current treatment options include liver transplantation, chemotherapy, immunotherapy, and local ablative therapies.

Cancer-related genes are broadly divided into tumor suppressor genes and oncogenes. Genes implicated in liver cancer include *TP53*, *CTNNB1*, *CCND1*, *VEGFA*, *HGF*, *NFE2L2*, *KEAP1*, and others. The present study focused on the *CTLA-4* gene as a candidate gene to investigate its association with hepatocellular carcinoma. Two SNPs, rs3087243 and rs5742909, were analysed along with demographic and clinical factors such as diabetes, smoking, BMI, exercise, HBV, and HCV infection.

A total of 100 blood samples were collected, including 50 liver cancer patients and 50 healthy controls. Genotyping was performed using TETRA-ARMS PCR followed by agarose gel electrophoresis. Statistical analysis using SPSS and logistic regression revealed that BMI, diabetes, smoking, and HBsAg positivity significantly increased liver cancer risk. In contrast, *CTLA-4* variants and several haplotypes appeared to have a protective role, with haplotype GACC showing a significant association with liver cancer susceptibility.

Keywords: Liver Cancer, Single Nucleotide Polymorphism, *CTLA-4*, Logistic regression.

Neurotoxic Components in Aromatic Plant Essential Oils Literature-Based Review

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Abstract

Essential oils are natural secondary metabolites obtained from plants and are rich in monoterpenes, sesquiterpenes, and aromatic compounds. They have been widely used throughout history for medicinal, cosmetic, and aromatherapeutic purposes (Ceylan, 1987; Chávez-González et al., 2016). With the increasing interest in natural products, the use of essential oils has expanded considerably; however, toxic effects associated with improper and uncontrolled use have become an important health concern (Posadzki et al., 2012). Certain lipophilic monoterpenes are capable of crossing the blood-brain barrier, thereby causing neurotoxic effects on the central nervous system (Güneş, 2022).

In this thesis, the chemical structures, mechanisms of action, toxicological profiles, and clinical risks of neurotoxic constituents found in essential oils were evaluated based on the literature. Particular emphasis was placed on monoterpene compounds with neurotoxic potential such as thujone, camphor, α -terpinene, and 1,8-cineole (Pelkonen et al., 2013; Santos et al., 2015). Essential oils obtained from plants including *Salvia officinalis*, *Artemisia absinthium*, *Tanacetum vulgare*, and *Thuja occidentalis* were reported to cause severe toxic effects such as convulsions, epileptiform seizures, and hepatotoxicity due to their high thujone content (Lachenmeier et al., 2006; Abass et al., 2011). Similarly, essential oils containing camphor and α -terpinene were shown to induce neurological disorders, memory impairment, and neuromuscular hyperactivity at high doses (Baldișsera et al., 2016; Liebelt et al., 1993).

In conclusion, although essential oils possess significant therapeutic properties, they may also present serious neurotoxic risks. Therefore, standardization, accurate dosing, controlled duration of use, and pharmacist supervision are considered essential for their safe use.

Keywords: Essential oil, Neurotoxicity, Monoterpenes, Aromatherapy, Thujone.

Aromatik Bitki Uçucu Yağlarında Nörotoksositeye Yol Açan Bileşenlerin Literatür Tabanlı İncelenmesi

Özet

Uçucu yağlar; monoterpenler, seskiterpenler ve çeşitli aromatik bileşikler bakımından zengin, bitkilerden elde edilen doğal sekonder metabolitlerdir ve tarih boyunca tıbbi, kozmetik ve aromaterapötik amaçlarla kullanılmıştır (Ceylan, 1987; Chávez-González ve ark., 2016). Günümüzde doğal ürünlere olan ilginin artmasıyla birlikte uçucu yağların kullanım alanı genişlemiş, ancak bilinçsiz kullanımına bağlı toksik etkiler de önemli bir sağlık sorunu hâline gelmiştir (Posadzki ve ark., 2012). Özellikle lipofilik özellik gösteren bazı monoterpenlerin kan-beyin bariyerini aşabilmesi, merkezi sinir sistemi üzerinde nörotoksik etkilerin ortaya çıkmasına neden olabilmektedir (Güneş, 2022).

Bu çalışmada; uçucu yağlarda bulunan nörotoksik bileşenlerin kimyasal yapıları, etki mekanizmaları, toksikolojik profilleri ve klinik riskleri literatür verileri doğrultusunda değerlendirilmiştir. Çalışmada özellikle tüyon, kafur, α -terpinen ve 1,8-sineol gibi nörotoksik potansiyel taşıyan monoterpene bileşikler üzerinde durulmuştur (Pelkonen ve ark., 2013; Santos ve ark., 2015). *Salvia officinalis*, *Artemisia absinthium*, *Tanacetum vulgare* ve *Thuja occidentalis* gibi bitkilerden elde edilen uçucu yağların yüksek tüyon içeriği nedeniyle konvülsiyon, epileptiform nöbet ve hepatotoksosite gibi ciddi toksik etkilere yol açabileceği bildirilmiştir (Lachenmeier ve ark., 2006; Abass ve ark., 2011). Benzer şekilde kafur ve α -terpinen içeren uçucu yağların yüksek dozlarda nörolojik bozukluklar, bellek kaybı ve nöromusküler aşırı aktivite oluşturabildiği gösterilmiştir (Baldișsera ve ark., 2016; Liebelt ve ark., 1993).

Sonuç olarak uçucu yağların terapötik etkilerinin yanında ciddi nörotoksik riskler de taşıdığı; bu nedenle standardizasyon, doğru dozlama, uygun kullanım süresi ve eczacı danışmanlığının güvenli kullanım açısından kritik öneme sahip olduğu değerlendirilmiştir.

Anahtar Kelimeler: Uçucu yağ, Nörotoksosite, Monoterpenler, Aromaterapi, Tüyon



Giriş

Bitkilerin bazı kısımlarından elde edilen, kimyasal bileşenlerinin büyük kısmını monoterpenler, seskiterpenler, aromatik bileşikler, azot ve kükürt taşıyan bileşikler, fenilpropan türevleri ve diterpenler oluşturan uçucu yağlar (Ceylan, 1987; Chávez-González ve ark., 2016; György ve ark., 2020), tarih boyunca çeşitli alanlarda kullanılmıştır. Günümüzde ise sahip oldukları biyolojik aktiviteler dolayısıyla antiinflamatuvar ve antimikrobiyal amaçlarla yaygın olarak kullanılmaktadır (Chávez-González ve ark., 2016; György ve ark., 2020).

Günümüzde kullanımı artan uçucu yağlarla birlikte önemli bir güvenlik riski de ortaya çıkmaktadır (Posadzki ve ark., 2012). İçerdikleri lipofilik karakterli moleküller sayesinde özellikle kan-beyin bariyerini aşabilmeleri, merkezi sinir sistemi üzerinde beklenmedik ve bazen geri dönüşümsüz komplikasyonlara yol açabilmektedir.

Bu çalışma; nörotoksik bileşenler içeren uçucu yağların kimyasal profillerini, moleküler düzeydeki etki mekanizmalarını ve literatürdeki vaka raporları ile klinik risklerini ele almayı hedeflemektedir.

Genel Bilgiler

Uçucu Yağlar

Uçucu yağlar bitkilerin çiçek, kök, kabuk, yaprak, tohum, meyve ve gövde gibi kısımlarından genelde damıtma (distilasyon) yolu ile elde edilen aromatik, kolaylıkla kristalleşebilen, genellikle renksiz veya açık sarı renkli, uçucu olan doğal sekonder metabolitlerdir (Ceylan, 1987; Halcón, 2014). Uçucu yağların farmasötik endüstride ya da tedavide ana kullanım alanını aromaterapi oluşturmaktadır. Sentetik ilaçların istenmeyen etkileri, bakteri direnci ve doğal ürünlerin tercih edilmesi gibi nedenlerle aromaterapiye olan ilgi zamanla artmıştır (Chávez-González ve ark., 2016; György ve ark., 2020).

Uçucu yağların aromaterapide oral ya da diğer yollarla uygulanmaları nedeniyle, sağlık personeline danışılmadan yanlış kullanımları toksik etkilere yol açabilmektedir (Posadzki ve ark., 2012).

Uçucu yağların eldesi

Uçucu yağ elde edilmesinde kullanılacak yöntemin hangisi olacağı uçucu yağın miktarına, cinsine veya bitkinin morfolojik yapısına bağlıdır (Bayrak, 2006; Toroğlu ve ark., 2006; Kaya ve ark., 2015; Coelho ve ark., 2012).

Sıvıların kaynama noktası farkından yararlanma prensibiyle yapılan ayırma işlemine distilasyon denmektedir. Distilasyonun su distilasyonu, buhar distilasyonu, hidrodiffüzyon, vakum distilasyonu ve fraksiyonel distilasyon gibi çeşitleri bulunmaktadır (Kılıç, 2008). Bitkilerden elde edilen uçucu yağın ayrıştırılmasında çoğu zaman kullanılan geleneksel yöntem su distilasyonudur. Kaynama esnasında su buharı ile sürüklenen yağ molekülleri yoğunlaşarak faz farkı sayesinde sudan ayrılmaktadır (Linskens ve ark., 1997).

Geleneksel ekstraksiyon yöntemlerinde bitki materyali organik çözücüler kullanılarak ekstre edilmektedir (Kılıç, 2008). Basınçlı Solvent Ekstraksiyonu, Mikrodalga Destekli Ekstraksiyon, Süperkritik Akışkan Ekstraksiyonu ve Ultrason Destekli Ekstraksiyon ise kısa ekstraksiyon süresi ve düşük çözücü tüketimi nedeniyle günümüzde tercih edilen gelişmiş yöntemler arasında yer almaktadır (Benthin ve ark., 1999; Başer, 2010; Carabias-Martinez ve ark., 2005; Büyüktuncel, 2012; Lavilla ve ark., 2017).

Terpenler ve Terpenoidler

Terpenler; bitkiler, hayvanlar, mikroorganizmalar, böcekler ve deniz canlıları gibi çeşitli doğal kaynaklardan elde edilen bileşiklerdir. Birincil metabolitlerin enzimatik süreçler sonunda farklılaşmasıyla oluşan bu yapılar ikincil metabolitler olarak adlandırılmaktadır. İkincil metabolitler arasında en geniş grubu terpenler oluşturmaktadır (Perveen ve ark., 2018).

Terpenler, beş karbonlu izopren birimlerinden meydana gelmekte olup doğal ürünlerin en kapsamlı sınıfını oluşturmaktadır. (Oldfield ve ark., 2012). Yapılarındaki izopren birimi sayısına göre hemiterpenler, monoterpenler, seskiterpenler, diterpenler, sesterterpenler, triterpenler ve tetraterpenler olarak sınıflandırılmaktadır (Perveen ve ark., 2018).

Monoterpenler, iki izopren biriminden oluşmakta olup uçucu yağların temel bileşenlerini meydana getirmektedir. Yapısal özelliklerine göre asiklik, monosiklik ve bisiklik monoterpenler olarak sınıflandırılmaktadır (Zielińska-Błajet ve ark., 2020).

Seskiterpenler, üç izopren biriminden oluşan ve bitkilerde yaygın olarak bulunan terpen grubudur. Uçucu yağların önemli bileşenleri arasında yer almakta olup çeşitli biyolojik aktivitelere sahiptir (Perveen ve ark., 2018).

Diterpenler, dört izopren biriminden oluşan doğal bileşiklerdir ve bitkilerde yaygın olarak bulunmaktadır. Yapılarındaki çeşitlilik nedeniyle farklı biyolojik özellikler göstermektedirler (Perveen ve ark., 2018).

Sesterterpenler, beş izopren biriminden oluşmakta olup doğada daha az rastlanan terpen gruplarından (Perveen ve ark., 2018).

Triterpenler, altı izopren biriminden meydana gelmekte olup bitkilerde yaygın olarak bulunan önemli doğal bileşikler arasında yer almaktadır (Perveen ve ark., 2018).



Nörotoksik Bileşenler

Nörotoksosite, doğal veya sonradan yapılan toksik maddelere maruz kalmanın sonucu olarak beyne veya periferik sinir sisteminde oluşan hasara denilmektedir. Nörotoksositeye sebep olan nörotoksinler, sinir sisteminde kritik işlevleri bulunan nöronal ve glial hücrelerde dejenerasyona veya hücre ölümüne yol açarak sistemin işleyişini temelden değiştirebilmektedir. Nöronlar, sahip oldukları yüksek metabolik hız nedeniyle nörotoksinlerin indüklediği hasara karşı en duyarlı hücre grubunu oluşturmaktadır (Güneş, 2022).

Kimyasalların sinir sistemi üzerindeki etkileri mekanizmasal olarak farklılık gösterir; bazı toksinler doğrudan sinir hücrelerini hedef alırken, bazıları ise metabolik süreçlere müdahale ederek dolaylı yoldan zarar vermektedir (Spencer ve ark., 2024). Polar olmayan maddeler, lipidlerdeki yüksek çözünürlükleri sayesinde kan-beyin bariyerini daha kolay aşarak sinir dokusuna nüfuz edebilmektedir (Güneş, 2022).

Uçucu Yağlardaki Nörotoksik Bileşenler

Tuyon

Tuyon, pek çok bitkide farklı oranlarda bulunan doğal bir monoterpen ketondur (Pelkonen ve ark., 2013). Özellikle *Salvia officinalis*, *Artemisia absinthium*, *Tanacetum vulgare* ve *Thuja occidentalis* gibi bitkilerde yoğun olarak bulunur (Scientific Committee on Food, 2003). Tuyonun nörotoksik etkisi, GABA-A reseptörleri üzerinden inhibitör nörotransmisyonu baskılaması sonucu aşırı nöronal uyarılabilirliğe neden olması ile ilişkilidir. Bu nedenle yüksek dozlarda kullanımı epileptojenik nöbetlere ve konvülsif durumlara yol açabilmektedir (Abass ve ark., 2011; Bonkovsky ve ark., 1992; Lachenmeier ve ark., 2010).

Salvia officinalis bitkisinden elde edilen uçucu yağ

Salvia officinalis yapraklarından elde edilen uçucu yağın başlıca bileşenleri α -, β -tuyon, 1,8-sineol, kamfer ve borneoldür (Zeybek ve ark., 2002). Uçucu yağdaki tuyon oranı %30–50 olup, içerdiği tuyon nedeniyle yüksek dozlarda kullanımı uygun değildir (Baytop, 1999; Zeybek ve ark., 2002).

Artemisia absinthium bitkisinden elde edilen uçucu yağ

Pelinotunda bulunan tuyon, bitkinin farmakolojik ve toksikolojik etkilerinden başlıca sorumlu bileşik olarak kabul edilmektedir. Tuyon, pelinotunda bulunan toksik bir bileşik olup farmakolojik ve toksikolojik etkilerinden başlıca sorumlu madde olarak kabul edilmektedir. Pelinotu uçucu yağdaki α - ve β -tuyon oranının %1,6–2,3 arasında olduğu bildirilmiştir (Patocka ve ark., 2003).

Tanacetum vulgare bitkisinden elde edilen uçucu yağ

T. vulgare uçucu yağının başlıca bileşenlerinden biri tuyondur. Avrupa Birliği'nde tuyonun toksik etkileri nedeniyle gıda ve diğer ürünlerde kullanım miktarı sınırlandırılmıştır (Baranauskiene ve ark., 2014; Nemeth ve ark., 2020; Nurzynska-Wierdak ve ark., 2022).

Thuja occidentalis bitkisinden elde edilen uçucu yağ

Thuja occidentalis yapraklarından elde edilen uçucu yağın başlıca bileşenleri arasında tuyon, izotuyon, fenkon, sabinen türevleri ve α -pinen bulunmaktadır (Biswas ve ark., 2011).

Kafur

Kafur, uçucu yağlarda bulunan doğal bir monoterpen ketondur. Organizmaya dermal temas, oral yol veya inhalasyon yoluyla alınabilmektedir (Santos ve ark., 2015). Monoterpenlerin nörotoksik etkileri üzerine yapılan çalışmalar, bu bileşiklerin nikotinik asetilkolin reseptörlerini inhibe ettiğini ve bu mekanizmaya bağlı olarak katekolamin salgılanmasında azalmaya yol açtığını göstermektedir (Park ve ark., 2001). Yüksek dozlarda kafur içeren uçucu yağların tonik-klonik konvülsiyonlara ve ölüme neden olabileceği bildirilmiştir (Millet ve ark., 1981).

Cinnamomum camphora bitkisinden elde edilen uçucu yağ

Cinnamomum camphora Lauraceae familyasına ait olup Japonya, Tayvan ve Çin gibi Asya ülkelerinde doğal olarak yetişmektedir. Uçucu yağı ahşabının damıtılmasıyla elde edilmekte olup doğal kafurun temel kaynağını oluşturmaktadır (Van Wyk ve ark., 2009; USDA, 2013). Başlıca uçucu yağ bileşenlerini kafur, linalool, borneol, kamfen, ökaliptol, terpinen-4-ol, limonen ve safrol oluşturmaktadır (Chelliah, 2008).

Ocimum kilimandscharicum bitkisinden elde edilen uçucu yağ

Ocimum kilimandscharicum, Lamiaceae familyasına ait olup başlıca bileşenleri kafur, linalool, limonen, metil öjenol oluşturmaktadır (Opiyo, 2022).

α -Terpinen

Doğada yaygın olarak bulunan ve önemli bir monoterpen olan α -Terpinen (1-izopropil-4-metil-1,3-sikloheksadien), pek çok aromatik bitkinin uçucu yağ kompozisyonunda yer almaktadır (Baldissera ve ark., 2016; Brahim ve ark., 2015).

Çoğu monoterpen güvenli kabul edilse de α -Terpinen gibi bazı bileşiklerin belirli dozlarda ciddi bozukluklara yol açabileceği bildirilmiştir. Hamile farelere oral yolla uygulanan α -Terpinenin embriyofetotoksik etkilere neden olduğu rapor edilmiştir (Wojtunik, 2014; Wojtunik-Kulesza ve ark., 2017; Araujo ve ark., 1996). α -Terpinenlerin nörotoksitesi üzerine yapılan deneyde deneklere farklı dozlarda α -Terpinen verilmiştir. 10 gün boyunca α -



Terpinen verilen deneklerde anksiyete veya lokomotor bozukluk yaratmasa da tüm doz seviyelerinde bellek bozukluğuna yol açtığını gözlemlenmiştir (Baldissera ve ark., 2016).

Chenopodium ambrosioides bitkisinden elde edilen uçucu yağ

Chenopodium ambrosioides uçucu yağının başlıca bileşenlerinin α -Terpinen, p -simen ve askaridol olduğu tespit edilmiştir (Gupta ve ark., 2002). Uçucu yağının içinde bulunan α -Terpinen bileşiğinin nörotoksitesi dolayısıyla uygun dozda kullanımı önerilmektedir (Baldissera ve ark., 2016).

Melaleuca alternifolia bitkisinden elde edilen uçucu yağ

Melaleuca alternifolia bitkisi Myrtaceae familyasına ait olup tıp, kozmetik, gıda ve tarım alanlarında kullanılmaktadır (Hammer, 2015; Homeyer ve ark., 2015; Raymond ve ark., 2017; Sharifi-Rad ve ark., 2017). Uçucu yağının başlıca bileşenleri Terpinen-4-ol, γ -Terpinen ve α -Terpinendir (Zhang ve ark., 2018). Uçucu yağının temel bileşenlerinden birinin α -Terpinen olması nedeniyle doza dikkat edilerek kullanılması gerekmektedir (Sharififar ve ark., 2007).

Ökaliptol (1,8-sineol)

Aromatik özellikleriyle tanımlanan monosiklik bir monoterpen eter olan 1,8-sineol (ökaliptol), ökaliptüs uçucu yağlarının yaklaşık %83'ünü oluşturmaktadır. Myrtaceae, Lauraceae ve *Artemisia* gibi çeşitli botanik familyalarında bol miktarda bulunmaktadır (Xavier ve ark., 2020; Rather ve ark., 2017). Ökaliptol, sahip olduğu bu terapötik etkilerinin yanı sıra başlıca toksik bileşen olduğu solunum sorunları, konvülsiyonlar ve merkezi sinir sistemi depresyonuna sebep olduğu olduğu çalışmalarda gösterilmiştir. Şiddetli zehirlenme vakalarında koma, status epileptikus ve aspirasyon pnömonisi gibi etkilere yol açabilirken, hafif zehirlenmelerde bulantı, kusma, baş dönmesi ve ataksi şeklinde komplikasyonlara sebep olmaktadır (Flaman ve ark., 2001; Tibballs, 1995).

Eucalyptus globulus bitkisinden elde edilen uçucu yağ

Eucalyptus globulus, Myrtaceae familyasına ait olup uçucu yağının başlıca bileşeni 1,8-sineoldür. Uçucu yağ geleneksel olarak solunum yolu hastalıklarında, antiseptik ve ekspektoran amaçlarla kullanılmaktadır (Gamal Mohamed ve ark., 2007). Bununla birlikte, uçucu yağın yüksek miktarda 1,8-sineol içermesi nedeniyle özellikle çocuklarda bilinçsiz ve yüksek doz kullanımından kaçınılmalıdır (Dhakad ve ark., 2018; Salvatori ve ark., 2023).

Safrol

Safrol, fenilpropanoid yapısında doğal bir bileşik olup başta *Sassafras albidum* ve *Piper betle* olmak üzere çeşitli bitkilerin uçucu yağlarında bulunmaktadır. Safrol, DNA adüktü oluşumu yoluyla oral skuamöz hücreli karsinom ve hepatoselüler karsinom gelişimi için temel risk bileşiklerinden biridir (Chung ve ark., 2008; Chen ve ark., 1999). Uluslararası Kanser Araştırma Ajansı (IARC, 1976) tarafından, kemirgenlerde kanserojenliği kanıtlanmış bir madde olması dolayısıyla Grup 2B kanserojen olarak sınıflandırılmıştır.

Makrofaj aktivasyonu yoluyla artan ROS üretimi karsinojenik süreçlerin yanı sıra merkezi sinir sisteminde ROS tarafından lipid peroksidasyonuna ve membran akışkanlığının ciddi seviyede azalmasına sebep olur (Phaniendra ve ark., 2015). Bu durumda safrolün nörotoksik potansiyeli taşıdığını gösterebilir.

Sassafras albidum Nutt. bitkisinden elde edilen uçucu yağ

Lauraceae familyasında yer alan *Sassafras albidum* uçucu yağının temel bileşeni safrol olup geçmişte aroma verici ve geleneksel tedavi amacıyla yaygın olarak kullanılmıştır. Uçucu yağın ana bileşenlerini ise safrol (%82,04) ve metil öjenol (%3,03) oluşturmaktadır (Kamdem ve Gage, 1995).

Piper betle L. bitkisinden elde edilen uçucu yağ

Piper betle bitkisinin çiçek durumu, 15 mg/g gibi yüksek bir konsantrasyonda safrol içerir (Hwang ve ark., 1992) ve çiçek durumu ile betel çiğnenmesi tükürükte 420 μ M seviyesinde yüksek safrol üretimine neden olur (Wang ve Hwang, 1993).

Miristisin

Miristisin (1-allil-3,4-metilendioksi-5-metoksibenzen), muskat, maydanoz, havuç ve karabiberin aktif bileşenlerinden biri olup literatürde hem koruyucu hem de toksik etkileriyle bilinen bir fenilpropanoiddir (Salzer, 1977). Miristisin vücutta birikmesi veya oksidasyonunun azalması durumunda halüsinasyon gibi psikofarmakolojik etkiler ortaya çıkabilmektedir (Hallstrom ve Thuvander, 1997). Miristisin merkezi sinir sistemi üzerinde belirgin etkileri olduğu, sub-hipnotik hegzobarbital dozlarıyla kombine edildiğinde uyku süresini uzattığı; ayrıca antikolinergik ve psikotropik etkilere sahip olduğu bildirilmiştir (Shin ve ark., 1988; Abernethy ve Becker, 1992). Miristisin metabolitlerinden biri olan MMDA'nın meskalin benzeri güçlü halüsinojenik etkiye sahip olduğu belirtilmiştir (Stein ve ark., 2001).

Myristica fragrans Houtt. bitkisinden elde edilen uçucu yağ

Myristica fragrans bitkisinden elde edilen uçucu yağ, kendine has baharatlı bir kokuya sahip olup temel bileşenlerini monoterpenler, fenilpropenler (öjenol, metil öjenol ve **miristisin**) ile seskiterpenler oluşturmaktadır (Atta-ur-Rahman ve ark., 2000; Dupuy ve ark., 2013; Francis ve ark., 2019). Yapraklarında da başlıca bileşenler arasında miristisin bulunmaktadır (Ashokkumar ve ark., 2022).



Pinokamfon

Pinokamfon, *Hyssopus officinalis* L. bitkisinin ana bileşenlerinden biri olup konvülsiyona neden olan oksijenli monoterpenler arasında yer almaktadır (De Martino ve ark., 2009; Schütte, 1984). Bu bileşiğin epileptojenik özellikleri hem *in vivo* hem de *in vitro* hayvan çalışmalarıyla ortaya konmuştur (Cadéac ve Meunier, 1889; Millet ve ark., 1981; Steinmetz ve ark., 1987). Wistar sıçanlarına uygulanan *Hyssopus officinalis* uçucu yağının düşük dozlarda generalize yüksek voltajlı spike deşarjlarına, yüksek dozlarda ise tonik-klonik nöbetlere ve ölümcül konvülsif status tablosuna yol açtığı bildirilmiştir (Millet ve ark., 1981).

Hyssopus officinalis bitkisinden elde edilen uçucu yağ

Hyssopus officinalis uçucu yağının başlıca bileşenlerinden biri pinokamfondur (De Martino ve ark., 2009). Uçucu yağın içerdiği pinokamfon nedeniyle nörotoksik ve epileptojenik etki gösterebildiği, bu nedenle kullanımında doza dikkat edilmesi gerektiği bildirilmektedir (Millet ve ark., 1981).

Sonuç

Bu çalışma kapsamında incelenen veriler, uçucu yağların sadece aromatik ve terapötik ajanlar olmadığını, aynı zamanda merkezi sinir sistemi üzerinde ciddi farmakolojik ve toksikolojik etkilere sahip kompleks karışımlar olduğunu açıkça ortaya koymaktadır. Günümüzde artan "doğal olan güvenlidir" görüşüne rağmen, uçucu yağların içerdiği düşük molekül ağırlıklı lipofilik bileşenlerin kan-beyin bariyerini aşabilmesi, bu maddelerin nörotoksik potansiyellere sahip olduğu ve nörotoksik bileşen içeren uçucu yağların kullanımının göz ardı edilmemesi gerektiğini kanıtlamaktadır.

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Green Synthesis, Characterization, and Multifunctional Bioactivity Evaluation of *Cymbopogon citratus*-Mediated ZnO, CuO, and ZnO–CuO Nanoparticles

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Abstract

Cymbopogon citratus, commonly known as lemongrass, is an aromatic medicinal plant rich in flavonoids, phenolic compounds, essential oils, and other phytochemicals with important pharmacological properties. In this study, zinc oxide, copper oxide, and zinc oxide–copper oxide nanoparticles were synthesized using *Cymbopogon citratus* leaf extract through an eco-friendly green synthesis approach. The aim of this research was to characterize the synthesized nanoparticles and evaluate their antioxidant, antibacterial, antidiabetic, photocatalytic, and cytotoxic activities for potential biomedical and environmental applications. The synthesized nanoparticles were characterized using UV-visible spectroscopy, Fourier transform infrared spectroscopy, dynamic light scattering, scanning electron microscopy, and X-ray diffraction to determine their optical properties, functional groups, particle size, morphology, and crystalline nature. Antioxidant activity was evaluated using the DPPH free radical scavenging assay and reducing power assay, with ascorbic acid as the reference standard. Among the tested nanoparticles, ZnO–CuO nanoparticles showed the highest antioxidant potential. Antibacterial activity was assessed by the agar well diffusion method against *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Staphylococcus epidermidis*, using an antibiotic disc as the positive control. ZnO nanoparticles showed the strongest inhibition against *E. coli*, *K. pneumoniae*, and *P. aeruginosa*, whereas CuO nanoparticles were most effective against *S. aureus*. ZnO–CuO nanoparticles exhibited the highest antibacterial activity against *S. epidermidis*. The antidiabetic activity was investigated using alpha-amylase and alpha-glucosidase inhibition assays, with acarbose as the standard drug. ZnO–CuO nanoparticles demonstrated the highest inhibitory activity in both assays. Photocatalytic activity was evaluated through methylene blue dye degradation, where ZnO nanoparticles showed superior efficiency compared with CuO and ZnO–CuO nanoparticles. Cytotoxicity results indicated promising effects of all nanoparticles against cancer cells. Overall, these findings suggest that *Cymbopogon citratus*-mediated nanoparticles have significant therapeutic, diagnostic, and environmental potential.

Keywords: *Cymbopogon citratus*; Green synthesis; Zinc oxide nanoparticles; Copper oxide nanoparticles; Antibacterial activity



Monitoring the Suitability of Pusacak Pond (Amasya) for Drinking and Irrigation Purposes Using Various Water Quality Indices and Piper Diagram

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Abstract

This study was conducted to evaluate the water quality and pollution status of Pusacak Pond, located in the Gümüşhacıköy district of Amasya Province, during the period from October 2024 to September 2025. Within the scope of the study, 17 physicochemical parameters and concentrations of 7 heavy metals were analyzed in water samples collected monthly from three different sampling stations representing the integrity of the pond ecosystem. The findings revealed that the annual average water quality parameters of the pond remained below the threshold values specified in the WHO (2021) guidelines. According to the evaluation based on SWQR (2016) criteria, copper concentrations exceeded the permissible limits and indicated potential pollution, whereas all other parameters remained within the acceptable limits.

To determine the suitability of the pond water for drinking and irrigation purposes, several water quality indices were calculated. The Water Quality Index (WQI) and Sodium Adsorption Ratio (SAR) indicated “excellent” water quality, while Sodium Percentage (%Na) was classified as “good,” Kelley’s Ratio (KR) as “suitable,” Residual Sodium Carbonate (RSC) as “safe,” and Permeability Index (PI) as “moderate.” In contrast, Magnesium Hazard (MH) values indicated that the water was “unsuitable” for irrigation purposes. The fact that MH values exceeded the recommended threshold reported in the literature suggests that caution should be exercised in agricultural applications. According to the Piper diagram analysis, the pond water was characterized by the dominant Ca^{2+} – Mg^{2+} – HCO_3^- hydrochemical facies.

Overall, the results emphasize the importance of regular monitoring programs and effective environmental management strategies to preserve the general water quality of Pusacak Pond and ensure ecological sustainability.

Keywords: Amasya, Pusacak Pond, Water Quality Index, Irrigation Water Quality

Pusacak Göleti’nin (Amasya) İçme ve Sulama Suyu Uygunluğunun Çeşitli Kalite İndeksleri ve Piper Diyagramı ile İzlenmesi

Özet

Bu çalışma, Ekim 2024 - Eylül 2025 döneminde Amasya ili Gümüşhacıköy ilçesinde yer alan Pusacak Göleti’nin su kalitesini ve kirlilik durumunu değerlendirmek amacıyla yürütülmüştür. Bu kapsamda, göletin bütünlüğünü temsil eden üç farklı örnekleme istasyonundan aylık periyotlarla alınan su numunelerinde 17 fizikokimyasal parametre ile 7 ağır metal konsantrasyonu analiz edilmiştir. Elde edilen bulgular, göletin yıllık ortalama su kalitesi WHO (2021) rehberlerinde belirtilen sınır değerlerin altında olduğunu göstermiştir. SWQR (2016) kriterlerine göre yapılan değerlendirmede ise gölet suyunun bakır içeriğinin sınır değerleri aşarak kirlilik göstergesi oluşturduğu, bakır dışında kalan tüm parametrelerin ise sınır değerlerin altında kaldığı tespit edilmiştir. Gölet suyunun içme ve sulama açısından uygunluğunu belirlemek amacıyla gerçekleştirilen indeks hesaplamalarında Su Kalitesi İndeksi (WQI) ve Sodyum Adsorpsiyon Oranı (SAR) “mükemmel”, Sodyum Yüzdesi (%Na) “İyi”, Kelley Oranı (KR) “Uygun”, Kalıcı Sodyum Karbonatlar (RSC) bakımından “Güvenli” ve Geçirgenlik İndeksi (PI) bakımından “Orta” kalitede belirlenmiştir. Buna karşın Magnezyum Tehlikesi (MH) bakımından “Uygun Değil”, kalitede olduğu tespit edilmiştir. MH değerinin literatürde belirtilen sınır değerinin üzerinde yer alarak sulama açısından “uygun değil” sınıfında yer alması, tarımsal kullanımda dikkatli olunması gerektiğini göstermektedir. Piper diyagramı sonuçlarına göre gölet suyunun Ca^{2+} – Mg^{2+} – HCO_3^- baskın su tipinde yer aldığı belirlenmiştir. Sonuç olarak araştırma bulguları, Pusacak Göleti’nin genel su kalitesinin korunması ve ekolojik sürdürülebilirliğin sağlanması adına düzenli izleme çalışmalarının ve etkin çevresel yönetim stratejilerinin yürütülmesinin önemini vurgulamaktadır.

Anahtar Kelimeler: Amasya, Pusacak Göleti, Su Kalite İndeksi, Sulama Suyu Kalitesi.





Plant and Microbial Polysaccharides as Sustainable Wall Materials for Probiotic Microencapsulation: Structural Properties and Protection Mechanisms

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Abstract

Probiotics are live microorganisms that offer crucial health benefits, such as regulating gut microbiota and immune responses, provided they reach the host intestine at an effective concentration typically between one million and one billion viable colony-forming units per gram. However, probiotics suffer severe activity losses due to metabolite accumulation during production, as well as adverse conditions during processing, storage, and digestion, making it difficult to achieve desired therapeutic outcomes. Currently, encapsulation technology using plant and microbial extracellular polysaccharides serves as the primary method to maintain probiotic viability by providing exceptional gelation, film-forming, and biocompatible wall materials that protect organisms from destruction and enhance colon stability. This review systematically evaluates recent breakthroughs in food-grade microencapsulation technology, focusing specifically on the structure-function relationships of plant and microbial extracellular polysaccharide wall materials, their structural characteristics, and application trends. Furthermore, the scope of this work encompasses an overview of emerging delivery technologies, including material modification strategies and genetic engineering approaches, alongside the current applications and industrial challenges of polysaccharide-based encapsulation in foods. In conclusion, while broad encapsulation technologies exist, this review highlights the integration of novel material modifications and genetic engineering to understand polysaccharide structures. It serves as a comprehensive resource for researchers developing next-generation probiotic delivery systems, ultimately promoting further technological innovation and addressing market demands for functional synbiotic products.

Keywords: Plant Polysaccharides, Microbial Polysaccharides, Probiotic Microencapsulation, Wall Materials, Structural Characteristics



Effects of a blended supplementation of *Piliostigma thonningii* and *Daniella oliveri* essential oils on reproductive performance, semen quality, and fertility indices in Bunaji bulls.

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Abstract

This study investigated the effects of a blended essential oil formulation derived from *Piliostigma thonningii* (camel's foot) and *Daniella oliveri* on the reproductive performance of Bunaji bulls. The combination was selected based on the complementary phytochemical profiles of both plants, which are rich in phenolics, flavonoids, and terpenoids with documented antioxidant, antimicrobial, and endocrine-modulating activities. These bioactive compounds are associated with improved testicular function, enhanced spermatogenesis, and better semen quality. In addition, both plants are widely distributed in tropical savanna ecosystems, making their combined use a cost-effective and sustainable phyto-genic strategy for reproductive enhancement in livestock. A completely randomized design was used, involving fifteen clinically healthy Bunaji bulls (22–24 months old; 156.32 ± 0.70 kg average body weight), which were allocated into three dietary treatment groups. Over a 16-week experimental period, bulls received a basal diet supplemented with 0 ml/kg (T1, control), 10 ml/kg (T2), or 20 ml/kg (T3) of the blended essential oil mixture. The results indicated that dietary treatments had no significant effect ($P > 0.05$) on semen pH or colour, which remained consistently creamy white across all groups. However, supplementation with the blended essential oil significantly improved ($P < 0.05$) sperm concentration and ejaculate volume, with the highest values observed in T3. Likewise, sperm motility, percentage of live sperm, and live-to-dead sperm ratio were significantly enhanced ($P < 0.05$) in the supplemented groups compared with the control. In contrast, bulls in the highest supplementation group exhibited the lowest proportions of dead and morphologically abnormal sperm cells ($P < 0.05$). Although most specific sperm abnormality traits, including midpiece droplet, coiled tail, detached head, free tail, and bent tail, were not significantly influenced by dietary treatment ($P > 0.05$), scrotal length and circumference increased significantly ($P < 0.05$) with supplementation, with the greatest improvement recorded in T3. In conclusion, supplementation with the blended *Piliostigma thonningii* and *Daniella oliveri* essential oil mixture at 20 ml/kg improved testicular development and semen quality without adverse effects, demonstrating its potential as a natural and sustainable phyto-genic alternative to synthetic reproductive enhancers in bull production systems.

Keywords: *Piliostigma thonningii* and *Daniella oliveri* essential oil, Bunaji bulls, Reproductive performance, Semen quality, Scrotal traits, Natural feed additive

Introduction

There is a persistent shortage of animal protein across Africa, driven by multiple constraints affecting ruminant production systems in small-, medium-, and large-scale operations, particularly in West Africa (Anaso and Chibuogwu, 2026; Anaso & Olafadehan, 2025; Olafadehan et al., 2023; Anaso, 2025a). The Food and Agriculture Organization reported an average per capita animal protein intake of approximately 4.5 g/day in sub-Saharan Africa, which is far below the recommended 35 g/day (FAO, 2001; Anaso and Anaso, 2025). Current projections indicate that demand for animal protein will continue to rise due to population growth, increasing income levels, and evolving dietary preferences (FAO, 2009; Anaso & Salihu, 2025; Anaso, 2026a-d). However, livestock productivity in tropical regions remains limited by poor feed quality, heat stress, and the inherently low reproductive efficiency and growth performance of indigenous breeds (Anaso, 2025b, c). These factors collectively impair feed utilization, metabolic efficiency, and reproductive performance, especially in breeding males.

Essential oils (EOs) are volatile, aromatic plant-derived compounds obtained from seeds, leaves, bark, and roots, and are increasingly recognized for their bioactive roles in animal nutrition (Anaso et al., 2025c). In this context, mixed essential oil formulations derived from *Piliostigma thonningii* (camel's foot) and *Daniella oliveri* have gained attention due to their complementary phytochemical composition and synergistic bioactivity. *Piliostigma thonningii* is a leguminous savannah tree characterized by bilobed leaves and nutrient-rich seeds, while *Daniella oliveri* is a widely distributed savannah species known for its medicinal and phytochemical richness. Both plants contain phenolics, flavonoids, terpenoids, and other bioactive constituents with antioxidant, antimicrobial, anti-inflammatory, and immunomodulatory properties (Anaso, 2023a,b). Their combined essential oil formulation has shown potential to enhance rumen fermentation, oxidative balance, and reproductive physiology in animal systems.



Several studies have reported the benefits of phytogetic feed additives, including essential oils, in improving nutrient utilization, health status, and productive performance in ruminants (Kholif et al., 2017, 2020; Morsy et al., 2018; Anaso et al., 2025d–g). More recent evidence highlights their multifunctional properties, including antimicrobial activity, antioxidant effects, and improved feed palatability, positioning them as viable natural alternatives to synthetic growth promoters (Anaso, 2023a,b; Anaso and Alagbe, 2025a–c). The global restriction on antibiotic growth promoters due to antimicrobial resistance concerns has further intensified interest in plant-based feed additives capable of sustaining productivity while ensuring food safety (Soultos et al., 2009; Koné et al., 2016; Tufarelli et al., 2017; Anaso et al., 2021a,b; Anaso et al., 2024d; Anaso and Dikki, 2025; Anaso, 2026a,b). Consequently, mixed essential oil formulations such as those derived from *P. thonningii* and *D. oliveri* are increasingly being explored for their antibacterial, antioxidant, and immunomodulatory potential (Miguel, 2010; Negi, 2012; Ahmed & Abdallah, 2020; Anaso et al., 2025a,b; Anaso et al., 2026).

Although individual essential oils from *Piliostigma thonningii* and *Daniella oliveri* have been evaluated in rabbits and small ruminants (Anaso, 2023a,b; Anaso et al., 2023; Anaso et al., 2024a–d; Anaso, 2025a–e; Anaso et al., 2025a–g), limited information exists on the effects of their combined essential oil supplementation on reproductive performance in large ruminants. In particular, data on semen quality, testicular development, and fertility indices in Nigerian White Fulani (Bunaji) bulls remain scarce. Given the need to enhance male reproductive efficiency under tropical production constraints, it is important to investigate the potential synergistic effects of these mixed essential oils as natural reproductive enhancers.

Therefore, the present study was designed to:

1. Evaluate the semen characteristics of White Fulani bulls fed diets supplemented with the mixed essential oil formulation.
2. Determine the semen morphology of bulls under mixed essential oil supplementation.
3. Assess the scrotal parameters of bulls receiving diets supplemented with the mixed essential oil blend.

Materials And Methods

Preparation of Mixed Essential Oil Formulation

Seeds of *Piliostigma thonningii* (Milne-Redh.) were collected from naturally occurring stands in the Federal Capital Territory, Nigeria, within the Southern Guinea Savanna agro-ecological zone. The seeds were air-dried under shade to preserve thermolabile bioactive constituents and prevent phytochemical degradation. After drying to constant weight, the seeds were milled into a fine powder and stored at ambient temperature prior to essential oil extraction.

Essential oil extraction was carried out using steam distillation. A total of 100 g of the powdered seed material was immersed in 700 mL of distilled water and heated at 100 °C for 3 hours in a stainless-steel distillation apparatus fitted with a condenser. Volatile oil fractions were collected using a Clevenger-type apparatus following the procedures described by Anaso and Alagbe (2025a) and Anaso et al. (2025c). The yield of *P. thonningii* seed essential oil was 1.42% (v/w, dry matter basis).

Gas chromatography–mass spectrometry (GC–MS) analysis (Table 1, Anaso, 2023b) revealed a terpene-rich profile dominated by β -pinene (25.02%), β -limonene (17.85%), and α -muurolene (9.63%), alongside other monoterpenes and sesquiterpenes with known antioxidant, antimicrobial, and metabolic regulatory activities.

In addition, fresh mature leaves of *Daniella oliveri* were harvested from the same agro-ecological zone. The leaves were authenticated at the Forestry Research Institute of Nigeria, thoroughly washed, air-dried to constant weight, and milled into fine powder. A 250 g portion of the powdered leaves was macerated in 1000 mL of 80% ethanol (BDH) for 48 hours in an airtight container. The extract was filtered using Whatman No. 1 filter paper and stored at 4 °C for subsequent use (Anaso, 2025a,b).

Preparation of Piliostigma–Daniella Mixed Essential Oil (PDEO)

The *P. thonningii* seed essential oil was blended with the ethanolic leaf extract of *D. oliveri* to formulate a mixed essential oil system designated as PDEO (*Piliostigma–Daniella Essential Oil*). This formulation was designed to integrate the terpene-rich profile of *P. thonningii* with the phenolic- and flavonoid-rich bioactive constituents of *D. oliveri*, thereby enhancing antioxidant potential, antimicrobial activity, and reproductive functionality. The resulting PDEO was used as a composite phytogetic additive in evaluating reproductive performance in Bunaji bulls.

Mixed Essential Oil Formulation

The *P. thonningii* seed essential oil (MSEO) and the ethanolic leaf extract of *D. oliveri* were subsequently combined to form a blended phytogetic formulation. This mixed essential oil/extract system was designed to harness potential synergistic interactions between the terpene-rich seed oil of *P. thonningii* and the bioactive phenolic-rich extract of *D. oliveri*, with the aim of enhancing reproductive performance, antioxidant status, and metabolic efficiency in Bunaji bulls.



Table 1. Bioactive compounds of *Piliostigma thonningii* essential oil detected by the gas chromatography-mass spectrometry

Compounds	Percentage area	Mass peak
Azulene	0.42	25, 40, 42, 57
Beta myrcene	6.05	25, 72, 102, 106, 110
Beta limonene	17.85	25, 41, 43, 57
Cis- linaloxide	0.21	25, 39, 47, 49, 55
Alpha cymene	0.15	25, 44, 48
Beta ocimene	0.06	25, 88, 106
Trans beta ocimene	0.30	25, 39, 66, 70
4-methylpropiohenone	0.12	25, 88, 106, 109
1,3 dimethyl-4-Isopropylbenzene	3.11	25, 48, 51, 58, 69
Dodecane	0.19	25, 41, 43
Tridecane	1.20	60, 68, 77, 103
2,3-dimethylnephtalene	0.71	25, 44, 68, 92
1,8-dimethylnephtalene	0.22	25, 81, 87, 102, 117
Alpha thujene	0.19	25, 29, 38, 44
Beta pinene	25.02	25, 62, 68, 100
Terpinen-4-ol	2.60	25, 42, 47, 58
Alpha terpineol	3.70	25, 88, 93, 106
Gamma terpineol	5.11	25, 71, 79, 100
Alpha cubebene	2.09	25, 63, 69
Alpha yiangene	1.02	25, 41, 55, 108, 127
Alpha selinene	1.10	25, 40, 48, 51
Compounds	Percentage area	Mass peak
Chrysathenine	0.08	25, 47, 57,63
Alpha allyltoluene	0.29	25, 39, 47, 58
Borneol	1.44	25, 33, 39
Hexenyl acetate	2.83	25, 28, 37, 108
Camhene	1.50	25, 63, 68, 101
n-Nonanol	0.04	25, 69, 104
Trans-pinocarveol	0.62	25, 27, 29, 41, 55, 67
Cis pinocarveol	1.77	25, 41, 55, 67, 81, 104
Fenchol	0.96	25, 41, 58, 138
Alpha murolene	9.63	25, 39, 51, 105, 109

Reference; Anaso (2023b) and Anaso et al. (2024d)

Table 2. Bioactive compounds of *Daniellia oliveri* essential oil detected by the gas chromatography-mass spectrometry

Compound	Relative Abundance (%)
α -Pinene	18.40
β -Pinene	12.70
Limonene	9.60
Sabinene	7.30
Myrcene	6.50
Terpinen-4-ol	5.80
α -Terpineol	4.90
β -Caryophyllene	8.10
Germacrene D	6.20
Caryophyllene oxide	3.40

Reference; Anaso (2025)

Experimental site

In collaboration with the Co-Farms Green Aid Revolution Ruminant Research Unit, the experimental trial was conducted at Morugo Farms. The study site is located within Nigeria's Southern Guinea Savanna agro-ecological zone, positioned between latitudes 08°51' and 09°37' N and longitudes 07°20' and 07°51' E (Anaso et al., 2025e). The area experiences a tropical climate characterized by annual rainfall ranging from 1,145 to 1,631 mm, with distinct wet and dry seasons. Relative humidity averages approximately 60% during the rainy season and 30% during the dry season, while ambient temperatures range from 25.8 to 30.2 °C in the wet season and 36 to 42 °C in the dry season.



The vegetation is predominantly derived savanna, consisting mainly of grasses interspersed with scattered shrubs, legumes, and browsable forbs that serve as feed resources for ruminants. Common browse species include *Leucaena leucocephala*, *Piliostigma thonningii*, and *Daniella oliveri*, while dominant grass species comprise *Panicum maximum*, *Andropogon gayanus*, and *Hyparrhenia rufa*. The soils are predominantly well-drained sandy loams with moderate fertility, supporting both livestock grazing and forage production.

This ecological environment provides a representative semi-intensive ruminant production system suitable for evaluating the physiological, nutritional, and reproductive responses of animals to dietary supplementation with the mixed *Piliostigma–Daniella* essential oil formulation (PDEO).

Experimental animals, management and diets

In this study, fifteen clinically healthy Bunaji (White Fulani) bulls with an average body weight of 156.32 ± 0.70 kg and aged 22–24 months were used. The experiment comprised a 20-day acclimation period followed by a 120-day feeding trial, giving a total duration of 140 days. The bulls were sourced from a reputable commercial farm in North-Central Nigeria (Anaso et al., 2024b) and housed in a 20×30 m corral equipped with 18.6 m^2 individual pens.

Prior to animal arrival, all pens and surrounding facilities were thoroughly cleaned and disinfected using Morigad® (a broad-spectrum antibiotic disinfectant) and Hypo® (a sodium hypochlorite-based disinfectant containing demineralized water and caustic soda) to ensure strict biosecurity conditions.

Upon arrival, the bulls underwent a two-week quarantine period during which standard prophylactic measures were implemented. Each animal received an intramuscular injection of long-acting oxytetracycline hydrochloride (10 mL/100 kg body weight) for bacterial prophylaxis, a subcutaneous administration of Avomec® (1 mL/50 kg body weight) for ecto- and endoparasite control, and an oral dose of Vitalyte® to mitigate transport and environmental stress. All treatments were administered in accordance with manufacturer guidelines under the supervision of a qualified veterinarian.

Diets were formulated in line with the nutritional requirements for cattle as recommended by the National Research Council (NRC, 2007) (Table 2). Bulls were fed at 5% of their body weight on a dry matter basis, with weekly adjustments made based on changes in body weight (Anaso et al., 2021a,b; Olafadehan et al., 2021). Clean water was provided ad libitum, and feeding was conducted twice daily at 08:00 and 16:00 h.

The experimental treatments consisted of a basal diet alone for the control group (T1), while bulls in T2 and T3 received the basal diet supplemented with the mixed essential oil formulation (PDEO) at inclusion levels of 10 mL/kg and 20 mL/kg of feed, respectively. The PDEO was thoroughly mixed with a portion of the morning ration and administered immediately to ensure uniform intake, after which the remaining feed was offered. This procedure was adopted to minimize volatilization losses, enhance palatability, and ensure consistent delivery of the mixed essential oil across treatment groups.

Table 3. Ingredient composition of the experimental diets (% DM)

Ingredient (DM basis)	Quantity (kg)
Panicum Maximum (hay)	30
Maize	28
Biodegraded sugarcane scrapings (BDSS)	15
Groundnut Cake	12
Cowpea husk	7
Cassava peels	3
Molasses	2
Salt	0.5
Limestone	2
Vitamin–mineral premix	0.5
Total	100

Testicular and semen parameters

Semen analyses and scrotal measurements were performed in accordance with accepted standard practices. In accordance with Akpa et al. (2012) and Anaso and Chibuogwu (2026), scrotal length (SL), which is the distance along the caudal surface of the scrotum from the place of attachment at the perineum to the distal tip, was measured once a week using a flexible measuring tape. According to Akpa et al. (2012), scrotal circumference (SC) was calculated as the biggest circumference around the pendulous scrotum following a gentle push of both testes to the bottom of the scrotal sac.

Following the protocols described by Zemjanis (1970), semen was extracted from all experimental bulls by electro-ejaculation using an automatic electro-ejaculator (Autojact, Neovet) running at 12 V and 5 A. A series of 1–35 electrical shocks were given to the bulls over a period of 30 seconds to 5 minutes while they were held in a standing position inside a chute in order to induce ejaculation (Anaso et al., 2024b). The volume of ejaculate



(measured in milliliters) was promptly recorded from the calibrated collection vial. Following that, samples were kept in a water bath at 37 °C, and further tests were carried out in compliance with the recommendations of the CBRA (1998).

Semen Evaluation Procedures

While pH was instantly evaluated by dipping a narrow-range litmus paper into the semen and watching for a color shift, ejaculate volume was measured straight from the graduated collection tube (Anaso et al., 2023). Semen appearance (color and consistency) was evaluated visually and classified as watery, thick milky, creamy marble, or creamy (Anaso et al., 2023). As soon as possible after collection, the initial fructose content was measured using Mann's technique (1948). For additional microscopic evaluation, thin smears of every sample were made, allowed to air dry, appropriately labeled, and kept (Anaso et al., 2024b).

Sperm Motility and Concentration

By diluting 10 µL of semen in 1 mL of Tris buffer (which contains 3.0 g hydroxymethylaminomethane, 2.0 g sodium citrate, and 1.0 g fructose), progressive motility was assessed. A 100× magnification light microscope was used to examine a 10 µL aliquot of this mixture that had been sandwiched between a coverslip and a glass slide that had been preheated to 37 °C. The percentage of progressively motile spermatozoa was used to express the results.

A Neubauer hemocytometer, which has 25 large squares that are further divided into 16 smaller squares (for a total of 400), was used to measure the concentration of sperm. In accordance with Rekwot et al. (1997), sperm cells were counted diagonally over five large squares (equivalent to 80 small squares). Semen samples were diluted 1:100 in formaldehyde solution to immobilize the sperm cells before counting. To make sure there were no air bubbles, a drop of the diluted sample was put into the counting chamber. The sperm concentration per milliliter of semen was then calculated by extrapolating the quantity of sperm cells (Anaso et al., 2024b).

Sperm Morphology and Viability

Smears stained with 7.5% Giemsa solution (Doles Laboratory) diluted in distilled water were used for morphological evaluation. To distinguish between normal and aberrant spermatozoa, slides were submerged for two hours, allowed to air dry upright, and then inspected under a microscope. Morphological anomalies were categorized using Barth and Oko's (1989) criteria. Percentages of total spermatozoa were used to express the results.

The eosin–nigrosine staining method was used to calculate the live-to-dead sperm ratio (Hancock, 1951; Anaso et al., 2024b). On a sterile glass slide, a drop of semen and an equal drop of eosin-nigrosine stain were carefully combined. Another slide was used to create a thin smear at a 45° angle, which was then labeled and allowed to air dry. Dead spermatozoa absorbed the dye and turned pink or crimson under the microscope, whereas healthy spermatozoa appeared unstained.

Statistical analyses

A completely randomized design (CRD) was used to analyze data on reproductive and scrotal parameters using a one-way analysis of variance (ANOVA), with nutrition therapy acting as the fixed effect. The SPSS program (version 22.0; IBM Corp., Armonk, NY, USA) was used for all statistical analyses. Duncan's Multiple Range Test (DMRT) was used to compare treatment means, and differences were deemed statistically significant when $P < 0.05$. The statistical model used for the analysis is expressed as:

$$Y_{ij} = \mu + t_i + e_{ij} \quad Y_{ij} = \mu + t_i + e_{ij}$$

where:

- $Y_{(ij)}$ = observed value of the dependent variable,
- μ = overall mean common to all observations,
- t_i = fixed effect of the i^{th} dietary treatment ($i = 3$), and
- e_{ij} = random error term associated with each observation.

A strong statistical foundation for evaluating treatment differences was provided by this analytical method, which made sure that observed changes in scrotal features and reproductive success were due to treatment effects rather than chance experimental error.

Results And Discussions

Semen characteristics of bulls supplemented with the mixed Piliostigma–Daniella essential oil formulation

Table 4 presents the semen characteristics of Bunaji bulls fed diets supplemented with the mixed *Piliostigma–Daniella* essential oil formulation (PDEO). Semen colour remained consistently creamy white across all treatment groups. This uniform appearance is indicative of normal seminal plasma integrity and adequate sperm concentration, as creamy-white semen is generally associated with good fertilizing capacity, whereas altered coloration may suggest reduced sperm density or underlying reproductive dysfunction (Anaso et al., 2025d; Ososanyo et al., 2013; Bitto et al., 1988; Oyeyemi et al., 2011). The consistent semen colour across treatments indicates that PDEO supplementation did not adversely affect seminal quality or reproductive health.



Semen pH was not significantly affected by PDEO supplementation. Maintenance of physiological semen pH is essential for optimal sperm motility, metabolic activity, and fertilization potential, while deviations may reflect infection or metabolic imbalance (Anaso et al., 2025d; Zhou et al., 2015; Anaso et al., 2024a). The lack of treatment effect on semen pH suggests that PDEO did not disrupt the acid–base equilibrium of the seminal environment, consistent with reports that phytogetic additives and essential oils may not necessarily alter seminal pH (Ahmed and Abdallah, 2020; Abdel-Wareth and Metwally, 2021; Elratel et al., 2021; Anaso et al., 2023).

Ejaculate volume increased in bulls receiving PDEO supplementation compared with the control group. This parameter, which reflects the functional activity of the accessory sex glands and contributes to sperm transport efficiency, is often influenced by nutritional status and physiological condition. The observed improvement suggests a positive stimulatory effect of the mixed essential oil on reproductive secretory activity.

Sperm concentration was significantly enhanced in PDEO-supplemented bulls, indicating improved spermatogenic activity and testicular function. Higher sperm concentration is directly associated with improved fertility potential, as it increases the probability of successful fertilization. The response observed in supplemented groups suggests that PDEO may enhance nutrient utilization and antioxidant protection within the testes, thereby supporting normal sperm production and maturation.

Similarly, sperm motility and live sperm percentage were significantly improved in bulls receiving PDEO. Progressive motility is a key determinant of sperm transport through the female reproductive tract, while sperm viability reflects membrane integrity and cellular health. The elevated values recorded in supplemented bulls indicate improved functional competence of spermatozoa and enhanced reproductive efficiency.

In contrast, the proportion of dead sperm cells and morphologically abnormal spermatozoa was higher in the control group but reduced in PDEO-supplemented bulls. The reduction in sperm abnormalities suggests improved stability of spermatogenesis and enhanced protection against oxidative stress-induced cellular damage during sperm development.

Overall, the improvements observed in semen volume, sperm concentration, motility, and viability, alongside reduced sperm abnormalities in PDEO-supplemented bulls, are consistent with previous findings on phytogetic and essential oil-based feed additives (Anaso and Chibuogwu, 2026; Anaso et al., 2024b, 2023; Abdel-Wareth and Metwally, 2021). These beneficial effects are likely attributable to the synergistic bioactive constituents of the mixed essential oil formulation, which may enhance antioxidant defense mechanisms, protect spermatozoa from oxidative damage, and support overall reproductive efficiency.

Table 4. Semen characteristics of Bunaji bulls fed diets supplemented with the mixed *Piliostigma–Daniella* essential oil formulation

Parameter	T1	T2	T3	SEM
Semen colour	Creamy white	Creamy white	Creamy white	
pH	6.48	6.50	6.50	0.04
Semen volume (ml)	1.93 ^c	2.26 ^b	2.37 ^a	0.03
Motility (%)	79.03 ^b	91.04 ^a	91.37 ^a	0.29
Semen concentration (x10 ⁶)	308.58 ^c	358.82 ^b	366.94 ^a	9.12
Abnormalities (%)	12.40 ^a	10.95 ^b	9.81 ^c	0.43
Live spermatozoa (%)	60.21 ^b	80.40 ^a	83.46 ^a	0.72
Dead spermatozoa (%)	39.79 ^a	19.59 ^b	18.54 ^b	0.72
Live dead ratio	1.58 ^b	3.86 ^a	4.12 ^a	0.39

Means with different superscripts within the same row differ significantly (P < 0.05). T1, control (0 mL/kg diet of mixed *Piliostigma–Daniella* essential oil formulation, PDEO); T2, 10 mL/kg diet of PDEO; T3, 20 mL/kg diet of PDEO.

Sperm morphology of bulls supplemented with the mixed Piliostigma–Daniella essential oil formulation

Table 5 presents the effects of the mixed *Piliostigma–Daniella* essential oil formulation (PDEO) on sperm morphology in Bunaji bulls. Key morphological parameters including; mid-piece droplet, coiled tail, detached head, free tail, bent tail, and the proportion of normal sperm cells did not differ significantly among treatment groups. These traits are critical indices of spermatogenic efficiency, structural integrity of spermatozoa, and overall fertilizing capacity in breeding bulls, as morphological defects are known to impair motility, disrupt energy metabolism, and reduce oocyte penetration potential.

The evaluated abnormalities, which included mid-piece droplets, coiled tails, detached heads, free tails, and bent tails, alongside the proportion of normal sperm cells, are routinely used in the diagnosis of teratozoospermia, a condition associated with reduced male fertility. The absence of significant differences among treatments indicates that PDEO supplementation did not exert adverse effects on sperm morphological integrity.

The mid-piece region, which contains the mitochondrial sheath responsible for ATP production and sustained motility, showed no treatment-related disruption. This suggests that mitochondrial structure and energy-generating capacity of sperm cells were maintained in bulls receiving PDEO.



Coiled tail abnormalities, often associated with oxidative stress, microbial contamination, or membrane instability, were also unaffected by dietary treatments. This implies that the mixed essential oil formulation did not induce physiological or oxidative stress sufficient to compromise tail structure or sperm motility.

Detached head defects, commonly linked to impaired spermiogenesis or testicular dysfunction, remained unchanged across treatments, suggesting that PDEO did not interfere with testicular architecture or germ cell development. Likewise, free tail and bent tail abnormalities, which are typically associated with epididymal stress, thermal load, or nutritional imbalance, showed no treatment-induced variation. The stability of these parameters indicates that the bulls maintained normal physiological and environmental homeostasis throughout the trial.

The proportion of morphologically normal sperm cells, an overall indicator of semen quality and reproductive potential, was highest in bulls receiving the highest level of PDEO supplementation, although differences were not statistically significant. This pattern suggests a favourable trend toward improved spermatogenic efficiency and reduced cellular abnormalities with PDEO inclusion.

The maintenance of normal sperm morphology may be attributed to the synergistic bioactive constituents of the mixed essential oil formulation, including monoterpenes and sesquiterpenes such as β -pinene, β -myrcene, α -pinene, and β -caryophyllene, as well as lipid-associated compounds. These phytochemicals are known to enhance membrane stability, reduce lipid peroxidation, and protect developing germ cells from oxidative damage.

Table 5. Sperm morphology of bulls supplemented with mixed *Piliostigma–Daniella* essential oil formulation

Parameter (%)	T1	T2	T3	SEM
Middle piece defect	0.05	0.02	0.01	0.01
Coiled tail	13.21	8.40	6.92	0.51
Detached head	6.33	3.56	3.05	0.60
Free tail	9.18	6.18	5.95	1.01
Bent tail	7.04	5.26	5.00	1.00
Normal cells	69.69	76.11	79.77	3.58

Means with different superscripts within the same row differ significantly (P < 0.05). T1, control (0 mL/kg diet of mixed *Piliostigma–Daniella* essential oil formulation, PDEO); T2, 10 mL/kg diet of PDEO; T3, 20 mL/kg diet of PDEO.

Scrotal parameters of bulls supplemented with the mixed *Piliostigma–Daniella* essential oil formulation

Table 6 presents the scrotal characteristics of Bunaji bulls fed diets supplemented with the mixed *Piliostigma–Daniella* essential oil formulation (PDEO). Scrotal measurements were assessed as non-invasive indicators of testicular development, spermatogenic capacity, and overall breeding soundness in bulls. Scrotal length increased in bulls receiving PDEO supplementation compared with the control group, with the lowest values recorded in the control and higher values observed in the supplemented groups. Bulls receiving the higher level of PDEO showed the greatest scrotal length, although values between the supplemented groups were comparable.

Similarly, scrotal circumference followed the same pattern, with the control group recording lower values, while PDEO-supplemented bulls exhibited improved measurements. The highest scrotal circumference was observed in bulls receiving the higher level of the mixed essential oil formulation.

Scrotal length is a key reproductive trait reflecting testicular elongation and parenchymal development, which are directly associated with seminiferous tubule density and daily sperm production. The lower values observed in the control group suggest comparatively reduced testicular growth potential, whereas the improved measurements in PDEO-supplemented bulls indicate enhanced testicular development and functional maturation.

Scrotal circumference is widely recognized as one of the most reliable predictors of sperm output, semen quality, and fertility potential in breeding bulls. It is positively associated with testicular weight, sperm concentration, and earlier attainment of sexual maturity. The higher scrotal circumference recorded in PDEO-supplemented bulls suggests improved spermatogenic capacity and reproductive efficiency, consistent with the superior semen quality observed in these animals.

The increase in both scrotal length and circumference in bulls receiving PDEO indicates that the mixed essential oil formulation promoted testicular growth and functional development. This response may be attributed to the synergistic bioactive constituents of *Piliostigma thonningii* and *Daniella oliveri*, which are known to enhance antioxidant status, support endocrine balance, and improve metabolic efficiency required for optimal testicular function.

Reduced scrotal dimensions are often associated with delayed sexual maturity, lower sperm production, and diminished semen quality, whereas improved scrotal traits are consistently linked to enhanced reproductive performance. Nutritional and phytogenic modulation remains a key strategy for improving male fertility in livestock production systems. The present findings therefore suggest that dietary inclusion of the mixed *Piliostigma–Daniella* essential oil formulation can effectively enhance scrotal development and reproductive potential in Bunaji bulls.



Table 6. Scrotal parameters of bulls supplemented with mixed *Piliostigma–Daniella* essential oil formulation

Parameter (%)	T1	T2	T3	SEM
Scrotal length	12.39 ^b	15.57 ^a	17.45 ^a	0.47
Scrotal circumference	27.11 ^c	31.20 ^b	34.62 ^a	0.40

Means with different superscripts within the same row differ significantly (P < 0.05). T1, control (0 mL/kg diet of mixed *Piliostigma–Daniella* essential oil formulation, PDEO); T2, 10 mL/kg diet of PDEO; T3, 20 mL/kg diet of PDEO.

Conclusion

In summary, dietary supplementation with the mixed *Piliostigma–Daniella* essential oil formulation (PDEO) significantly improved testicular development, sperm viability, and overall semen quality in Bunaji bulls, particularly at the higher inclusion level, without eliciting any adverse physiological effects.

These findings indicate that PDEO has strong potential to enhance male fertility, likely driven by the synergistic action of its diverse bioactive constituents with antioxidant, antimicrobial, and endocrine-modulating properties derived from both *Piliostigma thonningii* and *Daniella oliveri*.

Overall, the mixed essential oil formulation presents a promising, safe, and sustainable phytogetic alternative to conventional synthetic reproductive enhancers, with practical applications for improving breeding soundness and fertility performance in tropical bull production systems.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the research, authorship, or publication of this manuscript.

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Mitigation of Carbon Emissions and Enhancement of Lactational and Physiological Indices in West African Dwarf Does Using *Daniella oliveri* Essential Oil-Based Diets

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Abstract

This study evaluated the effects of *Daniella oliveri* essential oil (DOE) supplementation on enteric methane production, milk yield, immune response, and oxidative stress indicators in lactating West African Dwarf (WAD) does. Twenty-one does with comparable initial body weights (10.55 ± 0.60 kg) were randomly allotted to three dietary treatment groups ($n = 7$) using a completely randomized design over a 50-day feeding period. Dietary supplementation with DOE significantly improved ($P < 0.05$) milk yield, serum immunoglobulins (IgG, IgA, and IgM), triiodothyronine (T3), and superoxide dismutase (SOD) activity, with the highest responses observed in does fed the highest DOE inclusion level (T3). Antioxidant status was also enhanced, as evidenced by significant increases ($P < 0.05$) in catalase, glutathione peroxidase, glutathione reductase, and total antioxidant capacity in the T2 and T3 groups. Conversely, enteric methane emissions, malondialdehyde (MDA), and cortisol concentrations were significantly reduced in DOE-supplemented animals relative to the control group ($P < 0.05$). The results indicate that DOE supplementation enhances lactational performance, strengthens immune function, and improves oxidative stability while concurrently reducing methane emissions, demonstrating its potential as a climate-smart nutritional strategy for sustainable dairy goat production. Based on the observed responses, supplementation at 10 ml DOE/kg diet was considered the optimal inclusion level for improving productivity and physiological wellbeing in WAD does.

Keywords: Small ruminants, dairy goats, tropical phytogetic, climate smart agriculture, methane, immune status.

Introduction

Over the last decade, the application of essential oils (EOs), which are aromatic plant-derived extracts, has increased considerably in animal health and production systems (Anaso et al., 2021a,b; 2025c; Anaso and Olafadehan, 2025; Elazab et al., 2025). These oils contain biologically active compounds, particularly polyphenolics, which have been reported to modulate ruminal fermentation and enhance nutrient utilization in ruminants (Kholif et al., 2018; Anaso et al., 2025a-g). Studies investigating the effects of EOs on milk production in dairy cattle have produced variable outcomes, ranging from a 6.7% reduction to a 5% improvement compared with control diets (Patra, 2011). Positive effects including increased energy-corrected milk yield and feed efficiency (Kholif et al., 2018; Elcoso et al., 2019), improved milk yield and composition (Matloup et al., 2017; Kholif et al., 2018; 2021), as well as marginal responses (Blanch et al., 2016), have been documented. These observations suggest that terpenes and other antioxidant constituents transferred into milk may improve its oxidative stability. In addition, EO supplementation has been associated with elevated concentrations of unsaturated fatty acids (UFAs) and conjugated linoleic acid (CLA) isomers in milk (Kholif and Olafadehan, 2021; Anaso and Chibuogwu, 2026), thereby enhancing the nutritional quality of milk for both animals and consumers.

Essential oils have further been shown to influence ruminal starch and protein degradation, ammonia production, volatile fatty acid (VFA) synthesis, and methane (CH_4) emissions through their antimicrobial activities against methanogenic archaea and hyper-ammonia-producing bacteria (Kholif and Olafadehan, 2021; Anaso and Ajogi, 2026). However, these beneficial effects may sometimes be accompanied by reduced fiber degradability (Patra and Yu, 2012).

Recent studies have identified essential oils as promising natural alternatives to synthetic growth promoters in livestock production (Anaso et al., 2024a-d). *Daniella oliveri*, a multipurpose medicinal tree commonly found in the savannah regions of West Africa, has attracted increasing scientific interest because of its rich phytochemical composition and therapeutic potential. The essential oil derived from *D. oliveri* contains numerous bioactive compounds with antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory properties (Anaso and Alagbe, 2025a-c; Anaso, 2026a,b). Previous phytochemical analyses have revealed that the oil is rich in terpenoids and other secondary metabolites capable of exerting beneficial physiological effects in animals (Anaso et al., 2024c). Compounds such as limonene, β -pinene, γ -terpineol, camphene, and related monoterpenes contribute to the oil's antioxidant and aromatic properties, while also exhibiting antimicrobial and health-promoting activities (Anaso et al., 2024a,d). Nevertheless, excessive concentrations of certain phytoconstituents may pose toxicological



risks, thereby necessitating proper dosage evaluation before inclusion in animal diets (SCLabs, 2016; Anaso et al., 2023).

In response to the increasing global concern over antimicrobial resistance and restrictions on the use of antibiotics in livestock production, attention has shifted toward the development of effective phytogetic feed additives (Anaso, 2023a,b). Although the beneficial effects of several plant essential oils on animal productivity and health have been documented, information regarding the influence of Daniella oliveri essential oil (DOE) on lactational performance, oxidative stress biomarkers, immunological responses, and enteric methane emissions in dairy goats remains limited. Therefore, this study was designed to evaluate carbon emissions, lactational performance, oxidative stress indices, and immunological parameters in West African Dwarf does fed diets supplemented with Daniella oliveri essential oil.

Materials and Methods

Collection of Daniella oliveri Seeds and Extraction of Essential Oil

Seeds of Daniella oliveri were collected from the Federal Capital Territory, located within the southern Guinea savannah agro-ecological zone of Nigeria. The harvested seeds were air-dried under shade to preserve their phytochemical constituents and bioactive properties. After adequate drying, the seeds were milled into a fine powder and stored at room temperature prior to essential oil extraction (Anaso, 2025a,b).

For the extraction procedure, 100 g of the powdered seed sample was subjected to steam distillation. The powdered material was mixed with 700 mL of distilled water and heated at 100 °C for 3 h using a stainless-steel distillation apparatus equipped with a condenser. This process enabled the volatilization of the essential oil, which was subsequently condensed into liquid form. The resulting essential oil was collected as droplets using a Clevenger-type apparatus according to the procedures described by Anaso (2023b) and Anaso and Alagbe (2025).

Experimental site

The experimental trial was carried out at the Co-farms Green Aid Revolution and Morugo Farms experimental station, geographically positioned between latitudes 08°51' and 09°37' North and longitudes 07°20' and 07°51' East. This location experiences an annual rainfall range between 1,145 mm and 1,631 mm. Seasonal temperature patterns show that during the wet season, ambient temperatures fluctuate between 25.8°C and 30.2°C, while in the dry season, temperatures soar to between 36°C and 42°C (Anaso et al., 2024b). Relative humidity, as reported by Anaso (2025b), averages approximately 60% during the rainy season and drops to about 30% in the dry season (Anaso and Alhassan, 2025).

Experimental animals, management and diets

Twenty-one clinically healthy West African Dwarf (WAD) does with similar initial body weights (28.73 ± 0.40 kg) were randomly assigned to three dietary treatment groups, with seven animals per treatment, using a completely randomized design. The animals were housed individually in standard pens measuring 1.9 m² within a larger corral structure measuring 10 × 15 × 8 m. Prior to the commencement of the experiment, the housing facility was thoroughly disinfected to maintain optimal sanitary and biosecurity conditions.

The feeding trial lasted for 84 days and was conducted in accordance with the nutritional recommendations of the National Research Council (NRC, 2007) for growing sheep. The composition of the experimental diets is presented in Table 1. Feed was offered at 5% of the animals' body weight on a dry matter basis, with weekly adjustments made according to changes in body weight. Feed intake was carefully monitored to ensure accuracy and minimize wastage. Animals were fed twice daily at 8:00 a.m. and 4:00 p.m., and clean drinking water was provided ad libitum throughout the study.

The does were randomly allotted to one of three dietary treatments. Group T1 served as the control and received the basal diet without supplementation, whereas Groups T2 and T3 received diets supplemented with Daniella oliveri essential oil (DEO) at inclusion levels of 5 mL/kg and 10 mL/kg feed, respectively.

Milk yield

Goats were machine milked twice daily at 07:00, and 16:00 h. Milk yield for individual does was recorded daily.

Immune function was assessed by quantifying immunoglobulin classes (IgA, IgG, and IgM), also using Stanbio-specific kits per Elghalid et al. (2020).

Oxidative stress markers evaluated included triiodothyronine (T3), total antioxidant capacity (TAC), and the enzymatic activities of malondialdehyde (MDA), superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione reductase (GR), and cortisol. These were likewise analyzed using the aforementioned commercial kits and standardized methodologies.

Methane production was calculated by the equation of Wolin (1960): $CH_4 = (\text{acetic} + (2 \times \text{propionic})) - \text{fermentative } CO_2$; where fermentative $CO_2 = (\text{acetic}/2) + (\text{propionic}/4) + (1.5 \times \text{butyric})$.



Results and Discussion

Table 1 presents the effects of *Daniella oliveri* essential oil supplementation on milk yield, enteric methane emissions, immunological parameters, and oxidative stress indices in West African Dwarf does. Supplementation with *Daniella oliveri* essential oil (DEO) significantly increased ($P < 0.05$) milk yield, serum concentrations of immunoglobulins G, A, and M, triiodothyronine (T3), and superoxide dismutase (SOD), with the highest values observed in does fed the highest DEO inclusion level (T3). Antioxidant defense capacity, as evidenced by elevated activities of catalase, glutathione peroxidase, glutathione reductase, and total antioxidant capacity, was significantly improved in the T2 and T3 groups ($P < 0.05$). Conversely, enteric methane emissions, malondialdehyde (MDA), and cortisol concentrations were significantly reduced in DEO-supplemented groups relative to the control ($P < 0.05$).

Milk yield progressively increased across the treatment groups. Essential oils are known to influence milk production in ruminants, although their effects largely depend on the type, dosage, and chemical composition of the oil used (Kholif and Olafadehan, 2021). The observed improvement in milk yield may be attributed to enhanced feed utilization, increased nutrient availability, and improved energy efficiency, as well as the selective inhibition of pathogenic microorganisms while promoting beneficial rumen microbes, thereby optimizing ruminal fermentation (Kholif et al., 2018; Anaso et al., 2025b; Anaso and Alagbe, 2025c).

The calculated methane (CH₄) values indicated that DEO supplementation reduced enteric methane production. Essential oils exert varying effects on methanogenesis depending on their phytochemical composition. They may directly suppress methanogenic archaea and/or indirectly decrease methane production by inhibiting microbial metabolic pathways associated with methanogenesis (Beauchemin and McGinn, 2006; Kholif and Olafadehan, 2021; Anaso et al., 2025b). In addition, EOs may alter the structure of archaeal communities and interfere with methanogenic activity, ultimately lowering methanogen abundance and methane output (Ohene-Adjei et al., 2008). Similarly, Wang et al. (2009) reported that supplementation of sheep diets with oregano-derived essential oil reduced methane production.

Immunoglobulins, particularly IgG, IgM, and IgA, are major components of the adaptive immune system and function as the first line of humoral defense by neutralizing toxins, binding pathogens, and preventing microbial attachment to mucosal surfaces (Anaso et al., 2025a; Anaso, 2025). The elevated concentrations of these immunoglobulins in the DEO-supplemented groups (T2 and T3) indicate enhanced immune responsiveness, likely due to the antioxidative and immunomodulatory bioactive compounds present in the essential oil. These findings corroborate the observations of Anaso et al. (2025d), who reported improved immunoglobulin profiles following dietary supplementation with essential oils.

Triiodothyronine (T3), an important thyroid hormone involved in metabolic regulation, growth, development, and thermoregulation, was also significantly increased in DEO-supplemented does, suggesting improved metabolic activity and physiological efficiency (Anaso et al., 2025a).

Malondialdehyde (MDA), a widely recognized biomarker of lipid peroxidation and cellular membrane damage, was significantly reduced in T2 and T3, indicating lower oxidative stress levels in these groups. This reduction may be attributed to the free radical scavenging activities of phenolic compounds present in DEO. These phytochemicals, including ketone derivatives, catechins, and volatile oils, have been reported to inhibit oxidative damage through the neutralization of superoxide and hydroxyl radicals (Anaso et al., 2025a; Anaso et al., 2025d).

The antioxidative effects observed may further be linked to the bioactive constituents of DEO, including limonene, α -pinene, β -caryophyllene, oleic acid, heptadecanoic acid, and related monoterpenes and sesquiterpenes, which possess antimicrobial, anti-inflammatory, and antioxidant activities. These compounds may also contribute to the reduction in cortisol concentration, a stress-related hormone released during physiological stress and hypoglycemia, thereby reflecting improved physiological stability in DEO-fed does (Anaso, 2023a; 2023b).

Superoxide dismutase (SOD), an essential antioxidant enzyme responsible for converting toxic superoxide radicals into hydrogen peroxide and molecular oxygen, was significantly elevated in T2 and T3. This increase suggests an enhanced antioxidant defense system and is consistent with earlier reports by Anaso et al. (2025a,b), who documented improved antioxidant enzyme activities following dietary supplementation with herbal and essential oil additives. However, the optimal activity of SOD depends largely on adequate micronutrient availability in the diet (Anaso et al., 2025d).

Glutathione-related activities, measured through glutathione peroxidase (GPx) and glutathione reductase (GR), were also significantly increased in the treatment groups, indicating enhanced intracellular protection against reactive oxygen species (ROS). Glutathione plays a crucial role in maintaining cellular integrity by preventing oxidative damage to lipids, proteins, and nucleic acids, while also stabilizing apolipoprotein B (Anaso et al., 2025a). The increased glutathione activity observed in T2 and T3 therefore suggests that DEO supplementation improved redox balance and strengthened cellular antioxidant defenses.

Furthermore, the bioactive phytochemicals present in DEO may function as natural acetylcholinesterase inhibitors, thereby preserving acetylcholine required for smooth muscle contractions, including gastrointestinal motility. This mechanism may contribute to enhanced digestion and nutrient absorption efficiency (Anaso et al., 2025a).



Activities of antioxidant enzymes such as catalase, glutathione peroxidase, and glutathione reductase were significantly enhanced in the DEO-supplemented groups. These enzymes are essential in detoxifying hydrogen peroxide and other reactive oxygen species by catalyzing their conversion into water and oxygen, thereby protecting tissues against oxidative injury and maintaining cellular homeostasis (Anaso et al., 2025a).

Table 1: Effects of Daniella oliveri Essential Oil Supplementation on Milk Yield, Methane Emissions, Immunological Responses, and Oxidative Stress Indices in West African Dwarf Does

Parameter	T1	T2	T3	SEM
Milk yield (g/day)	226 ^c	291 ^b	378 ^a	30.03
Methane emission	6.55 ^a	2.28 ^b	2.21 ^b	0.16
Immunoglobulin G (mg/100 mL)	4998.22 ^c	6740.82 ^b	6857.27 ^a	101.50
Immunoglobulin A (mg/mL)	0.30 ^c	0.38 ^b	0.54 ^a	0.06
Immunoglobulin M (mg/mL)	3.72 ^c	5.09 ^b	5.63 ^a	0.69
Triiodothyronine (nmol/L)	1.99 ^c	6.09 ^b	6.63 ^a	0.99
Malondialdehyde (nmol/L)	0.82 ^a	0.38 ^b	0.36 ^b	0.08
Superoxide dismutase (nmol/mL)	787.55 ^c	979.51 ^b	1063.91 ^a	13.07
Catalase (U/gHb)	2860.47 ^b	3090.82 ^a	3206.66 ^a	21.85
Glutathione peroxidase (U/gHb)	283.60 ^b	301.01 ^a	305.01 ^a	3.59
Cortisol (ng/mL)	18.71 ^a	9.56 ^b	9.08 ^b	0.20
Total antioxidant capacity (nmol)	1.04 ^b	1.52 ^a	1.62 ^a	0.04
Glutathione reductase (IU/10 ¹¹ RBC)	2.38 ^b	3.08 ^a	3.27 ^a	0.60

Conclusion

The results indicate that dietary supplementation with Daniella oliveri essential oil (DEO) enhances lactational performance, strengthens immune function, and improves oxidative stability in West African Dwarf does, while concurrently reducing enteric methane emissions. Collectively, these responses underscore its potential as a climate-smart feed additive for improving productivity and environmental sustainability in dairy goat production systems. Based on the observed physiological and productive responses, a supplementation level of 10 mL DEO/kg diet was identified as the most effective dose for optimizing performance and health status in WAD does.

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Transformation of the Concept of Coffee Quality in the Third Wave Coffee Movement: A Literature Review on Brewing Methods

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Abstract

Coffee consumption has undergone a significant transformation in recent years, evolving beyond being merely a beverage into a phenomenon with social, cultural, and experiential dimensions. The third wave coffee movement has played a pivotal role in this transformation by redefining coffee as a specialty product evaluated not only through its sensory characteristics but also through its production process, brewing techniques, and consumption experience. The aim of this study is to examine the transformation of the concept of coffee quality within the context of the third wave coffee movement and to reveal the role of alternative brewing methods in this process. The study was conducted using document analysis, one of the qualitative research methods, through a comprehensive review of national and international academic literature. The findings indicate that, with the emergence of the third wave coffee movement, the concept of quality has evolved from a product-oriented perspective into a multidimensional construct encompassing sensory attributes, production processes, and consumer experience. Furthermore, alternative brewing methods such as V60, Chemex, AeroPress, and French Press were found to have a significant influence on the aroma, flavor, and overall sensory characteristics of coffee, thereby directly affecting consumers' perception of quality. Consequently, it is concluded that the third wave coffee movement has transformed coffee consumption into an experiential and symbolic practice, leading to a fundamental redefinition of the concept of coffee quality.

Keywords: Third wave coffee, coffee quality, brewing methods, consumer culture, coffee experience, sensory analysis

Üçüncü Dalga Kahve Akımında Kalite Anlayışının Dönüşümü: Demleme Yöntemleri Üzerine Bir Literatür Değerlendirmesi

Özet

Kahve tüketimi son yıllarda önemli bir dönüşüm geçirerek yalnızca bir içecek olmanın ötesine geçmiş ve sosyal, kültürel ve deneyimsel boyutlar kazanan bir olgu haline gelmiştir. Bu dönüşümde üçüncü dalga kahve akımı belirleyici bir rol oynamış, kahveyi standart bir tüketim ürününden çıkararak üretim süreci, demleme teknikleri ve tüketim deneyimi ile birlikte değerlendirilen nitelikli bir içecek olarak konumlandırmıştır. Bu çalışmanın amacı, üçüncü dalga kahve akımı ile birlikte kahvede kalite anlayışında meydana gelen dönüşümü incelemek ve alternatif demleme yöntemlerinin bu süreçteki rolünü ortaya koymaktır. Araştırma kapsamında nitel araştırma yöntemlerinden doküman analizi kullanılmış ve konuya ilişkin ulusal ve uluslararası akademik çalışmalar incelenmiştir. Elde edilen bulgular, üçüncü dalga kahve akımı ile birlikte kalite kavramının yalnızca ürün odaklı olmaktan çıkarak duyuşal özellikler, üretim süreci ve tüketim deneyimi gibi unsurları içeren çok boyutlu bir yapıya dönüştüğünü göstermektedir. Ayrıca V60, Chemex, Aeropress ve French Press gibi alternatif demleme yöntemlerinin kahvenin aroma, tat ve genel duyuşal özellikleri üzerinde belirleyici olduğu ve bu durumun kalite algısını doğrudan etkilediği tespit edilmiştir. Sonuç olarak üçüncü dalga kahve akımının, kahve tüketimini deneyimsel ve sembolik bir yapıya dönüştürdüğü ve bu dönüşümün kahvede kalite anlayışını yeniden şekillendirdiği sonucuna ulaşılmıştır.

Anahtar Kelimeler: Üçüncü dalga kahve, kahve kalitesi, demleme yöntemleri, tüketim kültürü, kahve deneyimi, duyuşal analiz

Giriş

Kahve, dünya genelinde en yaygın tüketilen içeceklerden biri olmasının yanı sıra ekonomik, kültürel ve sosyal açıdan stratejik öneme sahip tarımsal ürünlerden biridir. Tarihsel süreç içerisinde yalnızca temel bir tüketim ürünü olarak değerlendirilen kahve, değişen tüketici beklentileri, gelişen üretim teknikleri ve küresel kahve kültüründeki dönüşümün etkisiyle farklı bir anlam kazanmıştır. Günümüzde kahve; üretildiği coğrafya, çekirdek türü, işleme yöntemi, kavurma profili ve demleme tekniği gibi çok sayıda değişken üzerinden değerlendirilen, nitelik odaklı bir gastronomi ürünü olarak kabul edilmektedir (Pendergrast, 2019; Hoffmann, 2023).



Son yıllarda kahve sektöründe yaşanan dönüşüm, kalite kavramının yeniden ele alınmasını gerekli kılmıştır. Geleneksel anlayışta kalite çoğunlukla ürünün fiziksel özellikleri, standart üretim kriterleri ve marka değeri ile ilişkilendirilirken, günümüzde kalite; duysal özellikler, sürdürülebilir üretim, izlenebilirlik, etik ticaret ve tüketici deneyimini kapsayan çok boyutlu bir yapı olarak değerlendirilmektedir (Garvin, 1984; Folmer, 2017). Bu değişim, yalnızca üretim süreçlerini değil, tüketicilerin kahveye yönelik beklentilerini ve tüketim alışkanlıklarını da önemli ölçüde etkilemiştir.

Kahve kültüründe yaşanan bu dönüşüm, literatürde genel olarak birinci, ikinci ve üçüncü dalga kahve hareketleri çerçevesinde açıklanmaktadır. Birinci dalga kahve hareketi, kahvenin geniş kitlelere ulaştırılmasını ve günlük tüketimin yaygınlaştırılmasını amaçlayan endüstriyel üretim anlayışını temsil ederken, ikinci dalga kahve hareketi kahveyi sosyal bir deneyim ve yaşam tarzı unsuru olarak konumlandırmıştır. Özellikle espresso bazlı içeceklerin yaygınlaşması ve uluslararası kahve zincirlerinin büyümesiyle birlikte tüketiciler farklı kahve çeşitleri ve hazırlama yöntemleriyle tanışmıştır. Bununla birlikte, standartlaştırılmış ürünlerin yaygınlaşması zaman içerisinde tüketicilerin daha özgün, izlenebilir ve yüksek kaliteli kahve arayışını da beraberinde getirmiştir (Telli Danışmaz, 2021; Türkyılmaz, 2020).

Bu arayışın bir sonucu olarak 2000'li yıllardan itibaren gelişim gösteren üçüncü dalga kahve hareketi, kahvenin değerlendirilme biçiminde önemli bir paradigma değişimi yaratmıştır. Üçüncü dalga yaklaşımı, kahveyi yalnızca tüketilen bir içecek olarak değil; yetiştirildiği coğrafya, rakım, iklim koşulları, çekirdek türü, hasat ve işleme yöntemleri, kavurma profili ile demleme parametrelerinin birlikte şekillendirdiği nitelikli bir ürün olarak ele almaktadır. Bu yaklaşım, üretimden fincana kadar uzanan tüm sürecin kalite değerlendirmesinin ayrılmaz bir parçası olduğunu savunmakta ve kahvenin izlenebilirliği, sürdürülebilirliği ve duysal özelliklerini kalite kavramının merkezine yerleştirmektedir (Specialty Coffee Association, 2023; Hoffmann, 2023).

Kahveye ilişkin literatür incelendiğinde, üçüncü dalga kahve hareketi, specialty coffee yaklaşımı, tüketici davranışları ve alternatif demleme yöntemleri üzerine çok sayıda araştırmanın gerçekleştirildiği görülmektedir (Telli Danışmaz, 2021; Türkyılmaz, 2020; Kement et al., 2022). Bununla birlikte, bu çalışmaların önemli bir kısmının söz konusu kavramları birbirinden bağımsız olarak ele aldığı, üçüncü dalga kahve hareketinin kalite anlayışında meydana getirdiği dönüşümü demleme yöntemleri ekseninde bütüncül bir bakış açısıyla değerlendiren çalışmaların ise sınırlı olduğu dikkat çekmektedir (Kement et al., 2022; Hoffmann, 2023). Özellikle kalite algısının yalnızca duysal özellikler üzerinden değil; üretim süreçleri, sürdürülebilirlik, izlenebilirlik ve tüketici deneyimiyle birlikte ele alınmasının konuya ilişkin daha kapsamlı değerlendirmeler yapılmasına katkı sağlayacağı düşünülmektedir (Folmer, 2017; Specialty Coffee Association, 2023).

Bu çalışmanın amacı, üçüncü dalga kahve akımı kapsamında kahvede kalite anlayışında meydana gelen dönüşümü literatür doğrultusunda incelemek ve alternatif demleme yöntemlerinin bu dönüşüm üzerindeki etkisini değerlendirmektir. Bu doğrultuda kahvede kalite kavramının tarihsel gelişimi, üçüncü dalga kahve hareketinin temel özellikleri, specialty coffee yaklaşımı ve yaygın olarak kullanılan alternatif demleme yöntemlerinin kalite algısı üzerindeki etkileri ulusal ve uluslararası literatür ışığında analiz edilmiştir. Çalışma, literatür taramasına dayalı bir derleme araştırması olarak hazırlanmış olup, konuya ilişkin ulusal ve uluslararası akademik yayımlar, bilimsel makaleler, kitaplar ve sektörel raporlar sistematik biçimde incelenmiş; elde edilen bulgular karşılaştırmalı olarak değerlendirilerek üçüncü dalga kahve hareketi, kahvede kalite anlayışı ve alternatif demleme yöntemleri arasındaki ilişki bütüncül bir bakış açısıyla yorumlanmıştır. Çalışmada V60, Chemex, Kalita Wave, AeroPress, French Press, Syphon ve Espresso gibi yaygın demleme yöntemlerinin kahvenin duysal özellikleri ve tüketici kalite algısı üzerindeki rolleri değerlendirilmiş; üçüncü dalga kahve hareketinin kalite anlayışına etkileri sürdürülebilirlik, izlenebilirlik, duysal değerlendirme ve tüketici deneyimi ekseninde tartışılmıştır. Bu yönüyle çalışmanın gastronomi alanındaki akademik bilgi birikimine katkı sağlaması ve gelecekte gerçekleştirilecek araştırmalar için kuramsal bir kaynak oluşturması hedeflenmektedir.

Materyal ve Yöntem

Bu çalışma, üçüncü dalga kahve hareketinin kahvede kalite anlayışı üzerindeki etkisini alternatif demleme yöntemleri çerçevesinde değerlendirmeyi amaçlayan nitel bir derleme araştırmasıdır. Araştırmada veri toplama yöntemi olarak doküman analizi kullanılmıştır. Doküman analizi, belirli bir konuya ilişkin yazılı kaynakların sistematik biçimde incelenmesi, sınıflandırılması ve yorumlanmasına dayanan nitel araştırma yöntemlerinden biridir. Bu kapsamda konuya ilişkin ulusal ve uluslararası akademik makaleler, kitaplar, lisansüstü tezler, bilimsel raporlar ve sektörel yayımlar incelenmiştir.

Literatür tarama sürecinde üçüncü dalga kahve, kahvede kalite anlayışı, specialty coffee, alternatif demleme yöntemleri, tüketici davranışları ve kahve deneyimi konularını ele alan ulusal ve uluslararası akademik çalışmalar sistematik olarak incelenmiştir. Kaynak seçiminde hakemli dergilerde yayımlanan akademik çalışmalar ile alan yazında kabul gören temel eserlerin kullanılmasına özen gösterilmiştir. Ayrıca Specialty Coffee Association (SCA) ve International Coffee Organization (ICO) tarafından yayımlanan güncel rapor ve standartlardan da yararlanılmıştır.



Elde edilen veriler betimsel analiz yaklaşımıyla değerlendirilmiştir. İncelenen çalışmalar; üçüncü dalga kahve hareketinin gelişimi, kahvede kalite kavramı, alternatif demleme yöntemlerinin özellikleri ve bu yöntemlerin kalite algısı üzerindeki etkileri açısından karşılaştırmalı olarak analiz edilmiştir. Araştırma kapsamında herhangi bir deneysel uygulama, anket, görüşme veya gözlem gerçekleştirilmemiştir; çalışma yalnızca mevcut literatürden elde edilen verilerin sistematik olarak incelenmesi ve değerlendirilmesi esasına dayandırılmıştır. Bu doğrultuda ulaşılan bulgular bütüncül bir bakış açısıyla değerlendirilerek üçüncü dalga kahve hareketinin kalite anlayışında meydana getirdiği dönüşüm ortaya konulmuştur.

Bulgular ve Tartışma

Kalite kavramı, farklı disiplinlerde çeşitli biçimlerde tanımlanmakla birlikte, genel olarak bir ürün veya hizmetin belirlenen gereksinimleri karşılama ve tüketici beklentilerine cevap verebilme düzeyi olarak ifade edilmektedir. Özellikle gıda sektöründe kalite yalnızca ürünün fiziksel ve kimyasal özellikleriyle sınırlı olmayıp; güvenilirlik, duysal özellikler, besin değeri, üretim koşulları ve tüketici memnuniyeti gibi çok boyutlu unsurları kapsamaktadır (Garvin, 1984; Crosby, 1979; Deming, 1986). Bu nedenle kalite, hem objektif ölçütlerle değerlendirilebilen teknik bir kavramı hem de tüketicilerin algı ve deneyimlerinden etkilenen öznel bir yapıyı ifade etmektedir (Grunert, 2005; Zeithaml, 1988).

Kahve özelinde kalite kavramı değerlendirildiğinde ise ürünün yalnızca fiziksel özellikleriyle açıklanmasının yeterli olmadığı görülmektedir. Kahvenin yetiştirildiği coğrafi bölge, rakım, iklim koşulları, kullanılan Coffea türü, hasat yöntemi, işleme tekniği, kavurma profili ve demleme parametreleri nihai ürünün kalitesini doğrudan etkileyen temel faktörler arasında yer almaktadır (Illy & Viani, 2005; Folmer, 2017; Hoffmann, 2023). Bunun yanı sıra tüketicilerin kahveyi algılama biçimi; aroma, asidite, gövde, tatlılık, denge ve genel içim deneyimi gibi duysal özelliklerden önemli ölçüde etkilenmektedir. Bu durum, kahvede kalite değerlendirmesinin yalnızca üretim süreçlerine değil, aynı zamanda tüketici deneyimine de dayanan çok boyutlu bir yaklaşım gerektirdiğini göstermektedir (Specialty Coffee Association [SCA], 2023; Samoggia & Riedel, 2019).

Kalite kavramının kahve sektöründe yeniden tanımlanmasında en önemli kırılma noktalarından biri üçüncü dalga kahve hareketinin ortaya çıkışı olmuştur. Kahve tüketim kültürünün tarihsel gelişimi genel olarak birinci, ikinci ve üçüncü dalga olmak üzere üç temel dönem çerçevesinde ele alınmaktadır. Birinci dalga kahve hareketi, kahvenin endüstriyel üretim teknikleriyle geniş tüketici kitlelerine ulaştırılmasını amaçlamış ve erişilebilirliği ön plana çıkarmıştır. İkinci dalga kahve hareketi ise kahveyi yalnızca günlük tüketilen bir içecek olmaktan çıkarak sosyal bir deneyim ve yaşam tarzı unsuru hâline getirmiş, espresso bazlı içeceklerin yaygınlaşması ve uluslararası kahve zincirlerinin büyümesiyle birlikte tüketicilerin kahveye yönelik beklentilerini önemli ölçüde değiştirmiştir (Pendergrast, 2019; Hoffmann, 2023; Telli Danışmaz, 2021).

Üçüncü dalga kahve hareketi ise önceki dönemlerden farklı olarak kahveyi standart bir ticari ürün yerine kendine özgü niteliklere sahip bir tarım ürünü olarak değerlendirmektedir. Bu yaklaşımda kahvenin üretildiği bölge, rakım, toprak yapısı, iklim koşulları, çekirdek çeşidi, hasat zamanı, işleme yöntemi, kavurma profili ve demleme tekniği gibi birçok unsur nihai kaliteyi belirleyen temel değişkenler arasında kabul edilmektedir (Specialty Coffee Association [SCA], 2023; Folmer, 2017; Illy & Viani, 2005). Böylece kalite kavramı yalnızca standart üretim ölçütleriyle değil, üretimden tüketime kadar uzanan tüm sürecin değerlendirilmesiyle açıklanmaya başlanmıştır. Bu dönüşüm, tüketicilerin kahveyi değerlendirme biçimini de değiştirmiş; aroma çeşitliliği, izlenebilirlik, sürdürülebilir üretim ve duysal deneyim gibi unsurlar kalite algısının ayrılmaz bileşenleri hâline gelmiştir (Samoggia & Riedel, 2019; Hoffmann, 2023).

Üçüncü dalga kahve hareketinin kalite anlayışına kazandırdığı en önemli yaklaşımlardan biri, kahvenin yalnızca çekirdeğin sahip olduğu özelliklerle değerlendirilmemesi gerektiği düşüncesidir. Bu yaklaşım doğrultusunda kahvenin nihai kalitesinin; üretim aşamasından kavurma sürecine, öğütme derecesinden demleme yöntemine kadar birbirini tamamlayan çok sayıda değişkenin etkileşimi sonucunda ortaya çıktığı kabul edilmektedir (Illy & Viani, 2005; Folmer, 2017). Dolayısıyla aynı kahve çekirdeği farklı demleme teknikleri kullanılarak hazırlandığında, elde edilen fincanın aroma profili, gövdesi, asiditesi, tatlılığı ve genel duysal özellikleri önemli ölçüde değişebilmektedir (Hoffmann, 2023; Specialty Coffee Association [SCA], 2023). Bu durum, demleme yöntemlerinin yalnızca hazırlama sürecinin bir parçası olmadığını, aynı zamanda tüketicinin kalite algısını doğrudan etkileyen temel faktörlerden biri olduğunu göstermektedir.

Alternatif demleme yöntemlerinin yaygınlaşmasıyla birlikte tüketicilerin kahveyi değerlendirme biçiminde de önemli değişiklikler yaşanmıştır. Özellikle V60, Chemex, AeroPress, Kalita Wave ve French Press gibi yöntemler, kahvenin farklı duysal özelliklerini ön plana çıkararak aynı çekirdeğin farklı karakteristikler sergilemesine olanak tanımaktadır. Örneğin filtre tabanlı demleme yöntemleri daha temiz ve belirgin aroma profilleri sunarken, metal filtre kullanılan yöntemlerde gövde ve yoğunluk daha fazla hissedilmektedir. Benzer şekilde demleme süresi, su sıcaklığı, öğütme kalınlığı ve ekstraksiyon oranı gibi değişkenler de fincandaki tat dengesini doğrudan etkilemektedir. Bu nedenle üçüncü dalga kahve anlayışında kalite değerlendirmesi yalnızca kullanılan çekirdeğin niteliğine değil, demleme sürecinin bilimsel ilkeler doğrultusunda yönetilmesine de bağlıdır (Hoffmann, 2023; Rao, 2014; Illy & Viani, 2005; Folmer, 2017).



Üçüncü dalga kahve hareketinin yaygınlaşmasıyla birlikte alternatif demleme yöntemleri, kahvenin duysal özelliklerini ortaya çıkarmada önemli araçlar olarak değerlendirilmeye başlanmıştır. Bu yöntemlerin ortak amacı, kahvenin kendine özgü aroma ve tat özelliklerini mümkün olduğunca koruyarak tüketiciye aktarmaktır. Bununla birlikte her demleme yönteminin ekstraksiyon süresi, filtre yapısı, suyun kahve yatağıyla temas biçimi ve akış hızı gibi teknik özellikleri birbirinden farklı olduğundan, aynı kahve çekirdeği kullanılsa dahi elde edilen fincan profili değişebilmektedir (Hoffmann, 2023; Rao, 2014; Folmer, 2017). Bu durum, demleme yöntemlerinin kalite değerlendirmesinde yalnızca teknik bir tercih olmadığını, aynı zamanda tüketicinin duysal deneyimini şekillendiren temel unsurlardan biri olduğunu göstermektedir.

Literatürde özellikle V60, Chemex, AeroPress, Kalita Wave ve French Press gibi yöntemlerin farklı aroma profilleri oluşturduğu vurgulanmaktadır. V60 ve Chemex gibi kâğıt filtre kullanılan yöntemler daha temiz, parlak ve belirgin tat profilleri sunarken; French Press gibi metal filtre kullanılan yöntemlerde kahvenin yağları ve çözünmeyen partikülleri fincana daha fazla geçtiği için gövde hissi ve yoğunluk artmaktadır (Illy & Viani, 2005; Hoffmann, 2023). AeroPress ise kısa demleme süresi ve basınç uygulamasını bir araya getirmesi sayesinde dengeli asidite, belirgin tatlılık ve kontrollü ekstraksiyon sağlaması nedeniyle hem profesyonel baristalar hem de nitelikli kahve tüketicileri tarafından tercih edilen yöntemlerden biri olarak öne çıkmaktadır (Rao, 2014; Hoffmann, 2023). Bu farklılıklar, tüketicilerin kaliteyi tek tip bir ölçüt üzerinden değil; tercih ettikleri duysal özellikler doğrultusunda değerlendirdiklerini ortaya koymaktadır (Samoggia & Riedel, 2019; Specialty Coffee Association [SCA], 2023).

Literatürde demleme yöntemlerinin kahve kalitesi üzerindeki etkisi değerlendirildiğinde, araştırmacıların ortaklaştığı temel nokta, kaliteli bir kahve deneyiminin yalnızca nitelikli çekirdek kullanımına bağlı olmadığıdır. Kahvenin üretim sürecinde gösterilen özenin, uygun kavurma profili ve doğru demleme tekniğiyle desteklenmediği durumlarda çekirdeğin sahip olduğu potansiyel duysal özelliklerin tam olarak ortaya çıkarılamadığı belirtilmektedir (Illy & Viani, 2005; Folmer, 2017). Bu nedenle üçüncü dalga kahve anlayışında kalite, üretimden tüketime kadar uzanan tüm süreçlerin bütüncül biçimde değerlendirilmesini gerektiren dinamik bir kavram olarak ele alınmaktadır (Specialty Coffee Association [SCA], 2023). Araştırmalar, demleme sürecinde kullanılan ekipmanların ve uygulanan parametrelerin kahvenin ekstraksiyon verimini doğrudan etkilediğini ortaya koymaktadır. Özellikle öğütme derecesi, su sıcaklığı, demleme süresi, kahve-su oranı ve suyun mineral yapısı gibi değişkenlerde meydana gelen küçük farklılıklar dahi fincandaki aroma, tatlılık, asidite ve gövde dengesini önemli ölçüde değiştirebilmektedir (Hoffmann, 2023; Rao, 2014). Bu durum, üçüncü dalga kahve işletmelerinde demleme sürecinin standart tariflerden ziyade bilimsel ölçütler doğrultusunda yönetilmesini gerekli kılmıştır. Böylece kalite anlayışı yalnızca son ürünün değerlendirilmesiyle sınırlı kalmayıp, fincana ulaşınca kadar geçen tüm süreçlerin sistematik biçimde yönetilmesini kapsayan bütüncül bir yaklaşıma dönüşmüştür.

Diğer taraftan, tüketicilerin kalite algısının da demleme yöntemlerine bağlı olarak değiştiği görülmektedir. Samoggia ve Riedel (2019), nitelikli kahve tüketicilerinin aroma çeşitliliği, tat dengesi ve fincandaki berraklığı kalite göstergeleri arasında değerlendirdiğini belirtirken; Hoffmann (2023), doğru demleme yönteminin çekirdeğin karakteristik özelliklerini ortaya çıkararak tüketicinin kahve deneyimini önemli ölçüde geliştirdiğini ifade etmektedir. Benzer şekilde SCA standartları, kaliteli kahvenin yalnızca çekirdek özellikleriyle değil, kontrollü ekstraksiyon ve doğru demleme uygulamalarıyla birlikte değerlendirilmesi gerektiğini vurgulamaktadır (Specialty Coffee Association [SCA], 2023). Bu bulgular birlikte değerlendirildiğinde, üçüncü dalga kahve hareketinin kalite anlayışını ürün odaklı bir yaklaşımdan süreç odaklı bir kalite anlayışına dönüştürdüğü söylenebilir.

Alternatif demleme yöntemlerinin yaygınlaşması, kahve kalitesine ilişkin değerlendirme ölçütlerinin yeniden şekillenmesine önemli katkı sağlamıştır. Geleneksel kahve tüketim anlayışında kalite çoğunlukla kahvenin tazeliği veya markası üzerinden değerlendirilirken, üçüncü dalga kahve yaklaşımıyla birlikte demleme yönteminin de kaliteyi belirleyen temel unsurlardan biri olduğu kabul edilmeye başlanmıştır (Hoffmann, 2023; Folmer, 2017). Bu yaklaşım doğrultusunda aynı kahve çekirdeğinin farklı demleme yöntemleriyle hazırlanması sonucunda ortaya çıkan duysal farklılıklar, kalite değerlendirmesinde dikkate alınan önemli kriterlerden biri hâline gelmiştir.

Literatürde özellikle filtre demleme yöntemlerinin, kahvenin özgün karakteristik özelliklerini daha belirgin biçimde ortaya çıkardığı ifade edilmektedir. V60 ve Chemex gibi kâğıt filtre kullanılan yöntemler, kahve yağlarının ve ince partiküllerin büyük ölçüde filtrelenmesini sağlayarak daha temiz, berrak ve dengeli bir fincan profili oluşturmaktadır. Bu durum meyvemsi aromaların, çiçeksi notaların ve çekirdeğe özgü tat özelliklerinin daha kolay algılanmasına olanak tanımaktadır (Illy & Viani, 2005; Hoffmann, 2023). Buna karşılık French Press gibi metal filtre kullanılan demleme yöntemlerinde kahve yağlarının fincana geçmesi gövde hissini artırırken, daha yoğun ve dolgun bir içim deneyimi sunmaktadır (Illy & Viani, 2005; Rao, 2014). Bu farklılıklar, herhangi bir yöntemin diğerinden daha kaliteli olduğu anlamına gelmemekte; aksine kalite algısının tüketicinin duysal beklentileri ve tercihleri doğrultusunda şekillendiğini göstermektedir.

Benzer şekilde AeroPress ve Kalita Wave gibi alternatif yöntemler de ekstraksiyon sürecini daha kontrollü hâle getirerek farklı duysal profiller elde edilmesine olanak sağlamaktadır. Özellikle AeroPress'in kısa demleme süresi ve kontrollü basınç uygulaması sayesinde dengeli asidite ve belirgin tatlılık sağlayabildiği; Kalita Wave'in ise düz tabanlı filtre yapısı sayesinde daha homojen ekstraksiyon oluşturduğu belirtilmektedir (Rao, 2014; Hoffmann, 2023). Bu özellikler, üçüncü dalga kahve işletmelerinde demleme yöntemlerinin yalnızca operasyonel bir tercih



olarak değil, kahvenin potansiyel kalitesini ortaya çıkaran stratejik bir unsur olarak değerlendirilmesine neden olmuştur (Specialty Coffee Association [SCA], 2023).

Üçüncü dalga kahve hareketiyle birlikte kalite anlayışındaki dönüşüm yalnızca üretim ve demleme süreçleriyle sınırlı kalmamış, tüketicilerin kahveyi değerlendirme biçiminde de önemli değişikliklere neden olmuştur. Geleneksel kahve tüketiminde kalite çoğunlukla markaya, fiyat düzeyine veya ürünün fiziksel özelliklerine bağlı olarak değerlendirilirken, üçüncü dalga kahve anlayışında tüketiciler kahvenin üretim hikâyesi, yetiştirildiği bölge, çiftlik bilgisi, işleme yöntemi ve sürdürülebilir üretim uygulamaları gibi unsurları da kalite değerlendirmesinin bir parçası olarak görmeye başlamıştır (Samoggia & Riedel, 2019; Specialty Coffee Association [SCA], 2023). Böylece kalite kavramı yalnızca ürünün kendisini ifade eden bir ölçüt olmaktan çıkmış, üretimden tüketime kadar uzanan tüm süreci kapsayan bütüncül bir yapıya dönüşmüştür.

Bu dönüşümde specialty coffee yaklaşımı önemli bir rol üstlenmektedir. Nitelikli kahve anlayışı, yalnızca kusursuz çekirdek elde edilmesini değil, aynı zamanda üretici, kavurucu, barista ve tüketici arasında kurulan bilgi paylaşımını da kalite sürecinin önemli bir bileşeni olarak değerlendirmektedir (Folmer, 2017; Hoffmann, 2023). Bu nedenle üçüncü dalga kahve işletmelerinde tüketicilere kahvenin kökeni, yetiştigi rakım, işleme yöntemi, kavurma tarihi ve önerilen demleme teknikleri hakkında ayrıntılı bilgi sunulması yaygın bir uygulama hâline gelmiştir. Böylece tüketiciler yalnızca kahve tüketen bireyler olmaktan çıkmakta, tükettikleri ürünün özelliklerini değerlendirebilen ve kaliteyi bilinçli biçimde yorumlayabilen aktif katılımcılar hâline gelmektedir.

Literatürde, tüketici deneyiminin kalite algısı üzerindeki belirleyici etkisi giderek daha fazla vurgulanmaktadır. Kahvenin hazırlanış sürecinin gözlemlenebilmesi, demleme ekipmanlarının görünürlüğü, baristanın teknik bilgi düzeyi ve tüketiciyle kurduğu iletişim, kahve deneyiminin algılanan değerini artıran unsurlar arasında gösterilmektedir (Pine & Gilmore, 1999; Samoggia & Riedel, 2019). Bu bağlamda üçüncü dalga kahve işletmeleri yalnızca kaliteli kahve sunan işletmeler değil, aynı zamanda tüketicilere eğitim, deneyim ve etkileşim sağlayan gastronomik mekânlar olarak değerlendirilmektedir. Dolayısıyla kalite anlayışı ürün odaklı bir değerlendirmeden uzaklaşarak deneyim odaklı bir yapıya evrilmiş ve kahve tüketimi kültürel, sosyal ve duysal boyutları bulunan bütüncül bir deneyim olarak ele alınmaya başlanmıştır.

Literatürde yer alan çalışmalar birlikte değerlendirildiğinde, üçüncü dalga kahve hareketinin kahvede kalite anlayışını tek boyutlu bir değerlendirme yaklaşımından uzaklaştırarak çok boyutlu bir yapıya dönüştürdüğü görülmektedir. Geleneksel kalite anlayışında fiziksel ürün özellikleri ve standart üretim süreçleri ön planda tutulurken, günümüzde kalite; çekirdeğin yetiştirildiği çevresel koşullar, hasat ve işleme yöntemleri, kavurma profili, demleme tekniği, duysal değerlendirme ve tüketici deneyiminin birlikte ele alındığı kapsamlı bir kavram olarak değerlendirilmektedir (Folmer, 2017; Hoffmann, 2023; Specialty Coffee Association [SCA], 2023). Bu değişim, kahvenin yalnızca ticari bir ürün değil, üretim sürecinin her aşamasında özen gerektiren nitelikli bir gastronomi ürünü olarak algılanmasına katkı sağlamıştır.

Araştırmalar incelendiğinde, kaliteli kahve deneyiminin oluşmasında tek bir unsurun belirleyici olmadığı, aksine birbirini tamamlayan birçok değişkenin birlikte değerlendirilmesi gerektiği vurgulanmaktadır. Kahve çekirdeğinin türü ve yetiştigi bölgenin sahip olduğu doğal özellikler kadar uygulanan işleme yöntemi, kavurma derecesi, öğütme kalınlığı, kullanılan suyun kimyasal özellikleri ve tercih edilen demleme yöntemi de fincandaki duysal kaliteyi doğrudan etkilemektedir (Illy & Viani, 2005; Rao, 2014; Hoffmann, 2023). Bu nedenle üçüncü dalga kahve hareketinde kalite, yalnızca son ürün üzerinden değerlendirilen bir kavram olmaktan çıkarak üretim zincirinin tamamını kapsayan bütüncül bir süreç yönetimi anlayışına dönüşmüştür.

Bununla birlikte, üçüncü dalga kahve hareketinin tüketiciler üzerinde oluşturduğu farkındalık da kalite anlayışındaki dönüşümün önemli bileşenlerinden biri olarak değerlendirilmektedir. Günümüzde tüketiciler kahvenin yalnızca tadını değil; hangi ülkede üretildiğini, hangi çiftlikten geldiğini, hangi yöntemle işlendiğini, hangi tarihte kavrulduğunu ve hangi demleme yöntemiyle hazırlandığını da kalite değerlendirmesinin bir parçası olarak görmektedir. Bu durum, tüketicilerin kahveye ilişkin bilgi düzeyinin artmasına katkı sağlarken aynı zamanda kahve işletmelerinin şeffaflık, sürdürülebilirlik ve izlenebilirlik konularına daha fazla önem vermesine neden olmuştur (Samoggia & Riedel, 2019; Pine & Gilmore, 1999). Dolayısıyla üçüncü dalga kahve hareketi yalnızca kahve hazırlama tekniklerini değil, üretici, işletme ve tüketici arasındaki ilişkiyi de yeniden şekillendirerek kalite anlayışının kapsamını önemli ölçüde genişletmiştir.

Üçüncü dalga kahve hareketinin gelişmesiyle birlikte demleme yöntemleri yalnızca kahvenin hazırlanma biçimini belirleyen teknik uygulamalar olarak değil, aynı zamanda kalite değerlendirme sürecinin ayrılmaz bir parçası olarak görülmeye başlanmıştır. Literatürde, demleme yöntemlerinin ekstraksiyon verimi üzerinde doğrudan etkili olduğu ve ekstraksiyon sürecinde meydana gelen farklılıkların kahvenin duysal özelliklerini önemli ölçüde değiştirdiği belirtilmektedir (Rao, 2014; Hoffmann, 2023). Bu nedenle üçüncü dalga kahve anlayışında kaliteli bir fincan kahvenin elde edilmesi, yalnızca nitelikli çekirdek kullanımına değil; çekirdeğin özelliklerine uygun demleme yönteminin seçilmesine ve demleme parametrelerinin doğru yönetilmesine bağlıdır (Illy & Viani, 2005; Folmer, 2017).

Özellikle V60 demleme yöntemi, üçüncü dalga kahve işletmelerinde en yaygın kullanılan manuel demleme tekniklerinden biri olarak öne çıkmaktadır. Konik filtre yapısı ve kontrollü su akışı sayesinde ekstraksiyon sürecinin büyük ölçüde barista tarafından yönetilebilmesi, bu yöntemin en önemli avantajlarından biri olarak



değerlendirilmektedir. Hoffmann (2023), V60 ile gerçekleştirilen kontrollü demlemelerde kahvenin meyvemsi ve çiçeksi aroma bileşenlerinin daha belirgin hissedildiğini, berraklık ve tat dengesi açısından başarılı sonuçlar elde edildiğini ifade etmektedir. Benzer şekilde Rao (2014), kontrollü su döküşü ve uygun öğütme derecesinin ekstraksiyon kalitesini artırarak kahvenin karakteristik özelliklerinin daha net ortaya çıkmasını sağladığını belirtmektedir. Bu bulgular, V60 yönteminin özellikle tek orijinli kahvelerin duyuşal özelliklerini ön plana çıkarmada önemli bir araç olduğunu göstermektedir.

Chemex yöntemi de benzer şekilde filtre demleme prensibine dayanmakla birlikte, kullanılan kalın kâğıt filtre sayesinde kahve yağlarının ve ince partiküllerin büyük ölçüde tutulmasını sağlamaktadır. Literatürde Chemex ile hazırlanan kahvelerin daha temiz, dengeli ve berrak bir içim profiline sahip olduğu; özellikle asidite ve aroma bileşenlerinin daha belirgin hissedildiği ifade edilmektedir (Illy & Viani, 2005; Hoffmann, 2023). Bununla birlikte bazı araştırmacılar, kalın filtre yapısının gövde hissini azalttığını ve bu nedenle daha yoğun kahve deneyimi arayan tüketiciler açısından farklı değerlendirmelere neden olabileceğini belirtmektedir (Folmer, 2017). Bu durum, kalite kavramının tek tip bir ölçüt üzerinden değerlendirilmediğini; tüketicilerin beklentileri doğrultusunda farklı demleme yöntemlerinin farklı kalite algıları oluşturabildiğini ortaya koymaktadır.

Kalita Wave ise düz tabanlı filtre yapısı sayesinde daha homojen ekstraksiyon sağlamayı amaçlayan alternatif demleme yöntemlerinden biridir. Literatürde, suyun kahve yatağına daha dengeli dağılması nedeniyle ekstraksiyon hatalarının azaltıldığı ve farklı kullanıcılar tarafından benzer sonuçlar elde edilebildiği belirtilmektedir (Hoffmann, 2023; Rao, 2014). Bu özelliği sayesinde özellikle standart kaliteyi korumayı hedefleyen üçüncü dalga kahve işletmelerinde tercih edilen yöntemlerden biri hâline gelmiştir. Demleme sürecinde standardizasyonun sağlanması, kalite anlayışının yalnızca duyuşal değerlendirme ile değil, aynı zamanda süreç yönetimiyle de ilişkili olduğunu göstermektedir.

Alternatif demleme yöntemlerinin yaygınlaşması, üçüncü dalga kahve hareketinin temel ilkelerinden biri olan bireyselleştirilmiş kahve deneyiminin gelişmesine de önemli katkı sağlamıştır. Geleneksel kahve hazırlama anlayışında tüketicilere büyük ölçüde standart ürünler sunulurken, üçüncü dalga kahvecilik yaklaşımı her kahve çekirdeğinin kendine özgü karakteristik özelliklerinin farklı demleme teknikleriyle en uygun şekilde ortaya çıkarılabileceğini savunmaktadır (Hoffmann, 2023; Folmer, 2017). Bu nedenle demleme yöntemi seçimi, yalnızca teknik bir tercih olmaktan çıkmış; kahvenin duyuşal potansiyelini ortaya koyan stratejik bir uygulama olarak değerlendirilmeye başlanmıştır.

French Press yöntemi, metal filtre kullanımı nedeniyle kahvenin doğal yağlarının ve çözünmeyen partiküllerinin fincana geçmesine olanak tanımaktadır. Bu durum gövde hissini artmasına ve daha yoğun bir içim deneyimi oluşmasına katkı sağlarken, bazı tüketiciler tarafından kalite göstergesi olarak değerlendirilen dolgunluk hissini de ön plana çıkarmaktadır (Illy & Viani, 2005; Hoffmann, 2023). Buna karşılık kâğıt filtre kullanılan yöntemlerde daha temiz ve berrak bir fincan profili elde edilmesi, kalite değerlendirmesinde farklı duyuşal beklentilerin ortaya çıkmasına neden olmaktadır. Dolayısıyla literatürde herhangi bir demleme yönteminin diğerlerinden üstün olduğu yönünde ortak bir görüş bulunmamakta; her yöntemin farklı duyuşal özellikleri ön plana çıkardığı ve kalite algısının tüketici beklentileri doğrultusunda şekillendiği ifade edilmektedir (Samoggia & Riedel, 2019; Hoffmann, 2023).

Benzer şekilde AeroPress yöntemi de kısa demleme süresi, kontrollü basınç uygulaması ve farklı reçetelere uyarlanabilmesi sayesinde üçüncü dalga kahve kültüründe önemli bir yere sahiptir. AeroPress ile hazırlanan kahvelerde ekstraksiyon sürecinin daha kontrollü ilerlemesi, acılık oluşumunun sınırlandırılması ve tatlılık ile asidite arasında dengeli bir yapı oluşturulabilmesi yöntemin öne çıkan özellikleri arasında gösterilmektedir (Rao, 2014; Hoffmann, 2023). Bu esneklik, farklı kahve çekirdeklerinin karakteristik özelliklerinin daha başarılı şekilde ortaya çıkarılmasına olanak tanımakta ve kalite değerlendirmesinde standart reçeteler yerine çekirdeğin özelliklerine uygun demleme yaklaşımının benimsenmesini desteklemektedir.

Syphon ve espresso gibi farklı demleme yöntemleri de kalite anlayışının çeşitlenmesine katkı sağlamaktadır. Vakum prensibiyle çalışan Syphon yöntemi, aromatik bileşenlerin korunması ve berrak içim profiliyle dikkat çekerken; espresso ise yüksek basınç altında gerçekleştirilen kısa ekstraksiyon süreci sayesinde yoğun gövde, belirgin aroma ve karakteristik krema yapısıyla farklı bir kalite deneyimi sunmaktadır (Illy & Viani, 2005; Folmer, 2017). Bu farklılıklar, üçüncü dalga kahve hareketinin kaliteyi tek tip bir ürün standardı olarak değil, farklı demleme teknikleri aracılığıyla ortaya çıkan çeşitli duyuşal deneyimlerin bütünü olarak değerlendirdiğini göstermektedir.

Üçüncü dalga kahve hareketinin kalite anlayışına kazandırdığı en önemli yeniliklerden biri, kalite değerlendirmesinin yalnızca fincandaki duyuşal özelliklerle sınırlandırılmamasıdır. Günümüzde kalite; kahvenin yetiştirildiği çevresel koşullar, üretim sürecinde uygulanan etik yaklaşımlar, sürdürülebilir tarım uygulamaları ve ürünün üreticiden tüketiciye kadar izlenebilir olması gibi unsurları da kapsayan çok boyutlu bir kavram olarak ele alınmaktadır (Specialty Coffee Association [SCA], 2023; Folmer, 2017). Bu yaklaşım, üçüncü dalga kahve hareketinin kaliteyi yalnızca sonuç odaklı değil, süreç odaklı değerlendirdiğini göstermektedir.

İzlenebilirlik (traceability), üçüncü dalga kahve anlayışının temel bileşenlerinden biri olarak kabul edilmektedir. Kahvenin üretildiği ülkenin yanı sıra bölgesi, çiftliği, rakımı, yetiştirildiği iklim koşulları, hasat dönemi ve uygulanan işleme yönteminin tüketiciyle paylaşılması, kaliteli kahvenin önemli göstergeleri arasında



değerlendirilmektedir (Hoffmann, 2023; Illy & Viani, 2005). Bu bilgiler yalnızca ürün hakkında teknik veri sunmamakta; aynı zamanda tüketicinin kahvenin üretim sürecini anlamasını sağlayarak kalite algısını güçlendirmektedir. Böylece kalite kavramı yalnızca fincanda hissedilen tat ile değil, ürünün sahip olduğu hikâye ve üretim sürecinin şeffaflığı ile de ilişkilendirilmektedir.

Sürdürülebilirlik ise üçüncü dalga kahve hareketinin kalite anlayışını etkileyen bir diğer önemli unsur olarak öne çıkmaktadır. Literatürde sürdürülebilir üretim uygulamalarının yalnızca çevresel etkileri azaltmakla kalmadığı, aynı zamanda uzun vadede ürün kalitesinin korunmasına da katkı sağladığı belirtilmektedir (International Coffee Organization [ICO], 2024; Folmer, 2017). Üreticilerin adil ticaret uygulamalarına yönelmesi, doğal kaynakların bilinçli kullanılması ve üretim süreçlerinde çevresel sürdürülebilirliğin gözetilmesi, kaliteli kahve üretiminin temel bileşenleri arasında değerlendirilmektedir. Bu nedenle üçüncü dalga kahve hareketi kaliteyi yalnızca duyuşal mükemmellik üzerinden değil; etik, çevresel ve ekonomik sürdürülebilirlik ilkeleri doğrultusunda şekillenen bütüncül bir değer olarak ele almaktadır.

Bu yaklaşım, tüketicilerin satın alma davranışlarını da önemli ölçüde etkilemektedir. Özellikle nitelikli kahve tüketicilerinin, satın aldıkları kahvenin kökenine, üretim koşullarına ve sürdürülebilir üretim ilkelerine ilişkin bilgi edinmeye daha fazla önem verdikleri; bu durumun ise algılanan kaliteyi ve tüketici memnuniyetini olumlu yönde etkilediği ifade edilmektedir (Samoggia & Riedel, 2019). Böylece üçüncü dalga kahve hareketi, kalite anlayışını yalnızca ürün özellikleriyle açıklayan geleneksel yaklaşımdan uzaklaştırarak üretici, işletme ve tüketiciyi aynı değer zinciri içerisinde değerlendiren yeni bir kalite perspektifi geliştirmiştir.

Üçüncü dalga kahve hareketinin kalite anlayışını dönüştüren unsurlardan biri de kahvenin hazırlanma sürecinde görev alan baristanın bilgi ve becerisine verilen önemin artmasıdır. Geleneksel kahve üretim ve servis anlayışında baristanın görevi çoğunlukla standart reçeteleri uygulamakla sınırlıyken, üçüncü dalga kahvecilik yaklaşımında barista; kahve çekirdeğinin özelliklerini analiz eden, uygun demleme yöntemini belirleyen ve ekstraksiyon sürecini yöneten önemli bir kalite unsuru olarak değerlendirilmektedir (Hoffmann, 2023; Specialty Coffee Association [SCA], 2023). Bu durum, kalite anlayışının yalnızca kullanılan ürünlerle değil, insan faktörü ve teknik uzmanlıkla da doğrudan ilişkili olduğunu göstermektedir.

Literatürde, demleme sürecinde gerçekleştirilen küçük uygulama farklılıklarının dahi fincandaki kaliteyi önemli ölçüde etkileyebileceği belirtilmektedir. Öğütme derecesindeki küçük değişimler, su sıcaklığındaki birkaç derecelik farklılık, demleme süresinin uzaması ya da kısalması ve kahve-su oranındaki değişiklikler ekstraksiyon verimini doğrudan etkileyerek aroma, gövde, asidite ve tatlılık dengesinde belirgin farklılıklar oluşturabilmektedir (Rao, 2014; Hoffmann, 2023). Bu nedenle üçüncü dalga kahve işletmelerinde demleme süreci deneyime dayalı uygulamalardan ziyade bilimsel ölçütler doğrultusunda yönetilmekte; tekrar edilebilir kalite standartlarının oluşturulması hedeflenmektedir.

Bununla birlikte kalite anlayışındaki dönüşüm yalnızca teknik süreçlerle sınırlı kalmamış, tüketicilerin kahve tüketiminden beklentilerini de önemli ölçüde değiştirmiştir. Günümüzde tüketiciler yalnızca iyi hazırlanmış bir kahve talep etmekle kalmamakta; kullanılan çekirdeğin özellikleri, uygulanan demleme yöntemi, kavurma profili ve hazırlanış süreci hakkında bilgi edinmeyi de kaliteli hizmetin bir parçası olarak değerlendirmektedir (Samoggia & Riedel, 2019). Bu durum, kahve tüketiminin yalnızca fizyolojik bir ihtiyaç olmaktan çıkarak bilgi, deneyim ve etkileşim temelli gastronomik bir deneyime dönüşüğünü göstermektedir.

Araştırmalar birlikte değerlendirildiğinde üçüncü dalga kahve hareketinin kalite anlayışını çok yönlü biçimde yeniden şekillendirdiği görülmektedir. Kalite artık yalnızca çekirdeğin fiziksel özellikleriyle açıklanamamakta; üretim süreci, sürdürülebilirlik, izlenebilirlik, kavurma uygulamaları, demleme yöntemi, baristanın teknik yeterliliği ve tüketici deneyiminin birlikte değerlendirilmesiyle anlam kazanmaktadır (Folmer, 2017; Hoffmann, 2023; Specialty Coffee Association [SCA], 2023). Dolayısıyla üçüncü dalga kahve yaklaşımı, kaliteyi tek bir değişkene bağlı olarak açıklayan geleneksel anlayıştan uzaklaşarak üretimden tüketime kadar uzanan tüm süreci kapsayan bütüncül bir kalite modeli ortaya koymaktadır.

Üçüncü dalga kahve hareketiyle birlikte kalite değerlendirmesinde duyuşal analiz yöntemlerinin önemi önemli ölçüde artmıştır. Geleneksel kalite değerlendirmelerinde fiziksel özellikler ve temel ürün standartları ön planda tutulurken, günümüzde kahvenin aroma, tat, gövde, asidite, tatlılık, denge ve genel içim deneyimi gibi duyuşal özellikleri kalite değerlendirmesinin temel bileşenleri arasında yer almaktadır (Specialty Coffee Association [SCA], 2023; Folmer, 2017). Bu yaklaşım, kalite kavramının yalnızca üretim sürecine değil, tüketicinin fincanda deneyimlediği duyuşal özelliklere de dayandığını göstermektedir.

Duyuşal analiz süreci, kahvenin belirli standartlar doğrultusunda değerlendirilmesini sağlayan sistematik bir uygulama olarak tanımlanmaktadır. Özellikle Specialty Coffee Association tarafından geliştirilen kalite değerlendirme sistemi; aroma, lezzet, asidite, gövde, denge, son tat, tatlılık, homojenlik ve genel değerlendirme gibi birçok kriteri birlikte ele almaktadır (Specialty Coffee Association [SCA], 2023). Bu sistem sayesinde kalite değerlendirmesi yalnızca bireysel tüketici beğenisine dayanmamakta, belirli standartlar çerçevesinde gerçekleştirilen duyuşal analizlerle desteklenmektedir. Böylece üçüncü dalga kahve hareketi kalite kavramını daha nesnel ve karşılaştırılabilir ölçütlerle değerlendirmeyi amaçlamaktadır.

Literatürde duyuşal analiz sonuçlarının demleme yöntemlerine bağlı olarak değişebildiği sıklıkla vurgulanmaktadır. Aynı kahve çekirdeği farklı ekstraksiyon yöntemleri kullanılarak hazırlandığında aroma



yoğunluğu, asidite düzeyi, gövde hissi ve tat dengesi açısından belirgin farklılıklar oluşabilmektedir (Hoffmann, 2023; Rao, 2014). Bu nedenle demleme yöntemi seçiminde yalnızca teknik uygunluk değil, çekirdeğin duysal potansiyelini en iyi şekilde ortaya çıkaracak yaklaşımın belirlenmesi de önem taşımaktadır. Üçüncü dalga kahve işletmelerinde uygulanan standart reçeteler ve kontrollü demleme teknikleri, duysal analiz sonuçlarının tutarlılığını artırmayı ve tüketicilere her fincanda benzer kalite deneyimi sunmayı amaçlamaktadır.

Bu gelişmeler doğrultusunda kalite anlayışı yalnızca "iyi kahve" üretme hedefinden uzaklaşarak ölçülebilir, değerlendirilebilir ve sürekli geliştirilebilir bir yapıya dönüşmüştür. Duyusal analiz yöntemlerinin yaygınlaşması, kalite değerlendirmelerinde bilimsel yaklaşımın benimsenmesini desteklemiş; üreticiler, kavurucular, baristalar ve tüketiciler arasında ortak bir kalite dili oluşmasına katkı sağlamıştır (Folmer, 2017; Hoffmann, 2023). Böylece üçüncü dalga kahve hareketi, kaliteyi yalnızca algılanan bir özellik olmaktan çıkararak uluslararası standartlarla desteklenen sistematik bir değerlendirme süreci hâline getirmiştir.

Literatürde üçüncü dalga kahve hareketinin kalite anlayışına etkisi incelendiğinde, araştırmacıların ortak olarak vurguladığı noktalardan biri kalite kavramının standart bir ürün özelliği olmaktan çıkarak dinamik bir değerlendirme sürecine dönüşmüş olmasıdır. Geleneksel kalite anlayışında ürünün belirli teknik özellikleri yeterli görülürken, üçüncü dalga kahve yaklaşımında kalite; kahve çekirdeğinin sahip olduğu özelliklerin uygun kavurma profili ve doğru demleme yöntemiyle desteklenmesi sonucunda ortaya çıkan bütüncül bir değer olarak ele alınmaktadır (Folmer, 2017; Hoffmann, 2023). Bu doğrultuda kalite değerlendirmesi yalnızca fincandaki son ürün üzerinden değil, üretimden tüketime kadar uzanan tüm süreç dikkate alınarak gerçekleştirilmektedir.

Araştırmalar, aynı kahve çekirdeğinin farklı demleme yöntemleriyle hazırlanmasının tüketicilerin kalite algısını belirgin biçimde değiştirebildiğini ortaya koymaktadır. Bunun temel nedeni, her demleme yönteminin ekstraksiyon sürecini farklı şekilde yönetmesi ve buna bağlı olarak kahvenin aroma, asidite, gövde, tatlılık ve son tat gibi duysal özelliklerini farklı düzeylerde ortaya çıkarmasıdır (Rao, 2014; Illy & Viani, 2005). Dolayısıyla kalite değerlendirmesinde belirleyici olan unsur yalnızca kullanılan kahve çekirdeği değil, çekirdeğin karakteristik özelliklerini en doğru şekilde yansıtabilecek demleme yönteminin tercih edilmesidir. Bu yaklaşım, üçüncü dalga kahve hareketinin kalite anlayışını ürün odaklı bir bakış açısından süreç odaklı bir kalite yönetimi anlayışına dönüştürdüğünü göstermektedir.

Bununla birlikte literatürde kalite algısının yalnızca teknik değişkenlerle açıklanamayacağı da vurgulanmaktadır. Tüketicilerin önceki deneyimleri, kahve bilgisi, duysal beklentileri ve demleme yöntemlerine ilişkin farkındalık düzeyleri de kalite değerlendirmesini etkileyen önemli unsurlar arasında yer almaktadır (Samoggia & Riedel, 2019). Bu nedenle üçüncü dalga kahve işletmeleri yalnızca nitelikli kahve sunmayı değil, aynı zamanda tüketicileri kahve hakkında bilgilendirmeyi, farklı demleme yöntemlerini deneyimleme fırsatı sunmayı ve kahve kültürünü geliştirmeyi de kalite anlayışının bir parçası olarak değerlendirmektedir. Böylece kalite kavramı fiziksel ürün özelliklerinin ötesine geçerek bilgi, deneyim ve duysal farkındalıkla desteklenen çok boyutlu bir yapıya dönüşmektedir.

Literatürde üçüncü dalga kahve hareketine ilişkin çalışmalar incelendiğinde, araştırmacıların büyük çoğunluğunun kalite anlayışındaki dönüşümün tek bir değişkenle açıklanamayacağı konusunda ortak görüşe sahip olduğu görülmektedir. Bununla birlikte, kaliteyi belirleyen unsurların öncelik sıralaması konusunda farklı yaklaşımlar bulunmaktadır. Bazı araştırmalar kahve çekirdeğinin kökeni, yetiştirilme koşulları ve işleme yönteminin kalite üzerinde belirleyici olduğunu savunurken (Illy & Viani, 2005; Folmer, 2017), bazı araştırmalar ise aynı çekirdeğin farklı demleme teknikleriyle hazırlanması sonucunda duysal özelliklerin önemli ölçüde değişebildiğini ve bu nedenle demleme yönteminin kalite algısı üzerinde en az çekirdek kadar etkili olduğunu belirtmektedir (Hoffmann, 2023; Rao, 2014). Bu durum, üçüncü dalga kahve hareketinin kaliteyi tek boyutlu bir bakış açısıyla değerlendirmedikçe, aksine birbirini tamamlayan birçok faktörün etkileşimi sonucunda oluşan bütüncül bir yapı olarak ele aldığını göstermektedir.

Benzer şekilde, tüketici kalite algısına ilişkin çalışmalar da kalite değerlendirmesinin kişisel deneyimlerden bağımsız düşünülemeyeceğini ortaya koymaktadır. Özellikle nitelikli kahve tüketicileri üzerinde gerçekleştirilen araştırmalarda, kahve hakkında bilgi düzeyi arttıkça tüketicilerin demleme yöntemleri arasındaki duysal farklılıkları daha kolay ayırt edebildiği ve kalite değerlendirmelerini daha bilinçli gerçekleştirdiği belirtilmektedir (Samoggia & Riedel, 2019). Buna karşın kahve kültürüyle yeni tanışan tüketicilerin kaliteyi daha çok marka algısı, fiyat ve genel beğeni üzerinden değerlendirdiği ifade edilmektedir. Bu bulgular, kalite algısının yalnızca ürün özelliklerinden değil, tüketicinin bilgi birikimi ve deneyim düzeyinden de etkilendiğini göstermektedir.

Üçüncü dalga kahve hareketinin gelişmesiyle birlikte tüketicilerin demleme yöntemlerine yönelik ilgisinin artması, işletmelerin hizmet anlayışını da değiştirmiştir. Günümüzde birçok üçüncü dalga kahve işletmesi, aynı kahve çekirdeğini farklı demleme yöntemleriyle sunarak tüketicilerin duysal farklılıkları deneyimlemesine olanak sağlamaktadır. Bu uygulama, kalite değerlendirmesinin standart bir reçete üzerinden değil, farklı demleme tekniklerinin ortaya çıkardığı aroma, gövde, asidite ve tat profillerinin karşılaştırılması yoluyla yapılmasını teşvik etmektedir (Specialty Coffee Association [SCA], 2023; Hoffmann, 2023). Böylece kalite anlayışı, tek bir doğru demleme yönteminin bulunduğu düşüncesinden uzaklaşarak, kahvenin karakteristik özelliklerini en başarılı şekilde ortaya çıkarabilen yöntemin tercih edilmesi anlayışına dönüşmektedir.



Bu değerlendirmeler doğrultusunda literatürde oluşan genel görüş, üçüncü dalga kahve hareketinin kalite kavramını yeniden tanımladığı yönündedir. Kalite artık yalnızca fiziksel ürün özellikleri veya standart üretim kriterleriyle açıklanmamakta; kahve çekirdeğinin sahip olduğu potansiyelin uygun kavurma profili, doğru demleme yöntemi, teknik bilgi, duyuşal değerlendirme ve tüketici deneyimiyle birlikte ele alındığı çok boyutlu bir sistem olarak değerlendirilmektedir (Folmer, 2017; Hoffmann, 2023; Specialty Coffee Association [SCA], 2023). Bu yaklaşım, kalite anlayışının geleneksel kahve üretim ve tüketim alışkanlıklarından önemli ölçüde farklılaştığını ve üçüncü dalga kahve hareketinin gastronomi alanındaki kalite algısını yeniden şekillendirdiğini ortaya koymaktadır.

Kalite anlayışındaki dönüşümün temelinde, kahvenin standart bir tüketim ürünü olarak görülmesinden uzaklaşarak nitelikli bir gastronomi ürünü olarak değerlendirilmeye başlanması yer almaktadır. Üçüncü dalga kahve hareketi, kahvenin yalnızca fiziksel özellikleriyle tanımlanmasının yeterli olmadığını; ürünün üretim sürecinden tüketiciye ulaşmaya kadar geçen tüm aşamaların kaliteyi doğrudan etkilediğini ortaya koymuştur (Folmer, 2017; Hoffmann, 2023). Bu yaklaşım doğrultusunda kalite değerlendirmesi yalnızca nihai ürün üzerinden yapılmamakta; üretim koşulları, işleme yöntemleri, kavurma uygulamaları, demleme tekniği ve duyuşal analiz sonuçları birlikte ele alınmaktadır. Böylece kalite kavramı statik bir özellik olmaktan çıkarak sürekli geliştirilebilen ve yönetilebilen dinamik bir süreç hâline gelmiştir.

Bu dönüşümün en önemli sonuçlarından biri, kahve sektöründe standart kalite anlayışının yerini farklı kalite beklentilerine bırakmasıdır. Literatürde, her kahve çekirdeğinin kendine özgü duyuşal karakteristiklere sahip olduğu ve bu özelliklerin farklı demleme yöntemleriyle farklı biçimlerde ortaya çıkabildiği ifade edilmektedir (Illy & Viani, 2005; Rao, 2014). Bu nedenle üçüncü dalga kahve hareketinde kalite, tüm kahveler için tek tip bir standart oluşturmaktan ziyade, her kahvenin potansiyelini en doğru şekilde ortaya çıkarabilme başarısı olarak değerlendirilmektedir. Başka bir ifadeyle, kaliteli kahve anlayışı belirli bir reçetenin uygulanmasından çok, çekirdeğin karakterine uygun üretim ve demleme kararlarının alınmasını gerektirmektedir.

Araştırmalar, bu yaklaşımın tüketicilerin kahveye yönelik beklentilerini de önemli ölçüde değiştirdiğini göstermektedir. Günümüzde tüketiciler yalnızca lezzetli bir kahve tüketmeyi değil; tükettikleri ürünün nasıl üretildiğini, hangi koşullarda işlendiğini ve neden belirli bir demleme yönteminin tercih edildiğini öğrenmeyi de kaliteli hizmet anlayışının bir parçası olarak değerlendirmektedir (Samoggia & Riedel, 2019; Specialty Coffee Association [SCA], 2023). Bu durum üçüncü dalga kahve işletmelerinin yalnızca ürün sunan işletmeler olmaktan çıkarak bilgi paylaşımı yapan, tüketici farkındalığını artıran ve kahve kültürünün gelişimine katkı sağlayan gastronomik mekânlar hâline gelmesine katkıda bulunmuştur.

Bu bağlamda değerlendirildiğinde üçüncü dalga kahve hareketinin kalite anlayışına getirdiği en önemli katkının, kaliteyi yalnızca ürün odaklı bir kavram olmaktan çıkararak bilgi, deneyim, teknik yeterlilik ve sürdürülebilirlik ilkeleriyle bütünleşen çok boyutlu bir yapı hâline dönüştürmesi olduğu söylenebilir. Literatürde farklı araştırmaların ulaştığı ortak sonuçlar da bu dönüşümün yalnızca üretim süreçlerini değil, tüketici davranışlarını, işletme uygulamalarını ve kahve kültürünü de önemli ölçüde etkilediğini ortaya koymaktadır (Folmer, 2017; Hoffmann, 2023; Samoggia & Riedel, 2019).

Literatürde yer alan çalışmalar karşılaştırmalı olarak değerlendirildiğinde, üçüncü dalga kahve hareketinin kalite anlayışını yeniden şekillendirdiği konusunda genel bir görüş birliği bulunduğu görülmektedir. Bununla birlikte araştırmacılar, kaliteyi belirleyen unsurların önem derecesi konusunda farklı yaklaşımlar ortaya koymaktadır. Bazı çalışmalar, kahve kalitesinin temel belirleyicisinin çekirdeğin genetik özellikleri, yetiştirildiği coğrafya ve uygulanan işleme yöntemi olduğunu savunurken (Illy & Viani, 2005; Folmer, 2017), diğer araştırmalar demleme sürecinin ve ekstraksiyon parametrelerinin nihai kalite algısını doğrudan etkilediğini vurgulamaktadır (Hoffmann, 2023; Rao, 2014). Bu farklı yaklaşımlar birbirini dışlayan görüşler olarak değil, kaliteyi oluşturan sürecin farklı aşamalarını açıklayan tamamlayıcı değerlendirmeler olarak ele alınmalıdır.

Benzer şekilde, tüketici odaklı araştırmalar kalite algısının yalnızca ürünün fiziksel özellikleriyle açıklanamayacağını göstermektedir. Tüketicilerin kahveye ilişkin bilgi düzeyleri, demleme yöntemlerine olan aşinalıkları, duyuşal deneyimleri ve kahve kültürüyle kurdukları ilişki, kalite değerlendirmelerinde belirleyici rol oynamaktadır (Samoggia & Riedel, 2019). Bu durum özellikle üçüncü dalga kahve işletmelerinde tüketici eğitimi, barista-tüketici iletişimi ve ürün hakkında şeffaf bilgi paylaşımı gibi uygulamaların önem kazanmasına katkı sağlamıştır. Böylece kalite anlayışı yalnızca üreticinin sunduğu bir değer olmaktan çıkmış, üretici, işletme ve tüketicinin birlikte oluşturduğu dinamik bir süreç olarak değerlendirilmeye başlanmıştır.

Araştırmaların ortaklaştığı bir diğer önemli nokta ise kalite anlayışının sürekli gelişen ve değişen bir yapı olduğudur. Kahve üretim teknolojilerindeki ilerlemeler, kavurma tekniklerinin gelişmesi, alternatif demleme yöntemlerinin çeşitlenmesi ve duyuşal analiz standartlarının yaygınlaşması, kalite değerlendirmelerinde yeni ölçütlerin ortaya çıkmasına neden olmuştur (Specialty Coffee Association [SCA], 2023; Hoffmann, 2023). Bu gelişmeler doğrultusunda kalite, yalnızca belirli standartları karşılayan bir ürün özelliği olmaktan çıkarak, bilimsel bilgi, teknik uzmanlık ve tüketici beklentileri doğrultusunda sürekli yeniden tanımlanan bir kavram hâline gelmiştir. Dolayısıyla üçüncü dalga kahve hareketi yalnızca yeni demleme yöntemlerini yaygınlaştırmamış; aynı zamanda kahve sektöründe kaliteye ilişkin düşünce biçimini de önemli ölçüde dönüştürmüştür.



Genel olarak değerlendirildiğinde, literatürde yer alan çalışmalar üçüncü dalga kahve hareketinin kahvede kalite anlayışını önemli ölçüde dönüştürdüğünü ortaya koymaktadır. Bu dönüşüm yalnızca alternatif demleme yöntemlerinin yaygınlaşmasıyla sınırlı kalmamış; kahvenin üretiminden kavrulmasına, demleme sürecinden tüketici deneyimine kadar uzanan tüm aşamalarda kalite kavramının yeniden tanımlanmasına katkı sağlamıştır. İncelenen çalışmalar, kaliteli kahvenin yalnızca nitelikli çekirdek kullanımına bağlı olmadığını; uygun kavurma profili, doğru demleme yöntemi, kontrollü ekstraksiyon, duyuşal değerlendirme, sürdürülebilir üretim anlayışı ve bilinçli tüketici yaklaşımının birlikte ele alınması gerektiğini göstermektedir (Folmer, 2017; Hoffmann, 2023; Specialty Coffee Association [SCA], 2023). Bu doğrultuda üçüncü dalga kahve hareketinin, kaliteyi tek boyutlu teknik ölçütlerle açıklayan geleneksel yaklaşımdan uzaklaşarak üretici, işletme ve tüketiciyi aynı kalite zinciri içerisinde değerlendiren bütüncül bir anlayış geliştirdiği söylenebilir.

Sonuç

Bu çalışmada, üçüncü dalga kahve hareketinin kahvede kalite anlayışı üzerindeki etkisi alternatif demleme yöntemleri çerçevesinde literatür doğrultusunda değerlendirilmiştir. İncelenen çalışmalar, üçüncü dalga kahve hareketinin yalnızca kahve hazırlama tekniklerinde değil, kalite kavramının tanımlanması ve değerlendirilmesinde de önemli bir dönüşüm oluşturduğunu ortaya koymaktadır. Geleneksel kalite anlayışında ürünün fiziksel özellikleri ve standart üretim kriterleri ön planda tutulurken, üçüncü dalga kahve yaklaşımı kaliteyi üretim süreci, kavurma uygulamaları, demleme yöntemi, duyuşal değerlendirme, sürdürülebilirlik ve tüketici deneyimini kapsayan bütüncül bir yapı olarak ele almaktadır.

Literatürden elde edilen bulgular, kaliteli kahvenin yalnızca nitelikli çekirdek kullanımına bağlı olmadığını, çekirdeğin karakteristik özelliklerinin uygun kavurma profili ve doğru demleme yöntemiyle desteklenmesi gerektiğini göstermektedir. Özellikle V60, Chemex, AeroPress ve French Press gibi alternatif demleme yöntemlerinin ekstraksiyon sürecini farklı biçimlerde yönlendirmesi; aroma, asidite, gövde ve tat dengesi üzerinde belirleyici rol oynamaktadır. Bu durum, demleme yöntemlerinin yalnızca kahve hazırlama teknikleri olmadığını; aynı zamanda tüketicilerin kalite algısını şekillendiren temel değişkenlerden biri olduğunu ortaya koymaktadır.

Araştırma kapsamında incelenen çalışmalar, üçüncü dalga kahve hareketiyle birlikte tüketicilerin kaliteye ilişkin beklentilerinin de değiştiğini göstermektedir. Günümüzde tüketiciler kahvenin kökeni, üretim koşulları, işleme yöntemi, kavurma tarihi ve kullanılan demleme tekniği gibi unsurları kalite değerlendirmesinin ayrılmaz bir parçası olarak görmektedir. Buna bağlı olarak kalite anlayışı yalnızca ürün odaklı bir değerlendirme olmaktan çıkmış; bilgi, deneyim, şeffaflık ve sürdürülebilirlik ilkeleriyle desteklenen çok boyutlu bir yapıya dönüşmüştür.

Bu çalışmanın en önemli katkısı, üçüncü dalga kahve hareketi, kalite anlayışı ve alternatif demleme yöntemleri arasındaki ilişkiyi literatür doğrultusunda bütüncül bir bakış açısıyla değerlendirmesidir. Elde edilen bulgular, demleme yöntemlerinin kahvenin duyuşal özelliklerini ortaya çıkarmada ve tüketici kalite algısını şekillendirmede önemli bir role sahip olduğunu göstermektedir.

Bu çalışma, literatür taramasına dayalı bir derleme araştırması olduğundan, elde edilen değerlendirmeler incelenen akademik yayınların kapsamıyla sınırlıdır. Çalışmada uygulamalı araştırmalara yer verilmemesi, bulguların doğrudan deneysel verilerle desteklenmesini sınırlandırmaktadır. Bu nedenle gelecekte gerçekleştirilecek araştırmalarda alternatif demleme yöntemlerinin tüketici kalite algısı üzerindeki etkisinin deneysel çalışmalar, duyuşal analiz uygulamaları ve farklı tüketici grupları üzerinde yapılacak araştırmalarla desteklenmesi, konuya ilişkin literatüre daha kapsamlı katkılar sağlayacaktır.

Sonuç olarak üçüncü dalga kahve hareketi, kahvede kalite anlayışını yalnızca ürün odaklı bir yaklaşımdan uzaklaştırarak üretim süreçleri, demleme teknikleri, duyuşal değerlendirme ve tüketici deneyimini birlikte ele alan bütüncül bir kalite anlayışına dönüştürmüştür. Bu dönüşüm, kahve sektöründe kaliteye ilişkin değerlendirme ölçütlerinin yeniden şekillenmesine katkı sağlamış; alternatif demleme yöntemlerini kalite algısının temel bileşenlerinden biri hâline getirerek üçüncü dalga kahve anlayışının kaliteye yönelik bütüncül yaklaşımını güçlendirmiştir.

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Post-Harvest Resilience of Microbial Activity in Bacterially Inoculated Soils Under Drought Stress**Emine Nur Tuncer¹, Ali Sarioğlu¹**¹*Harran University Faculty of Agriculture Department of Soil Science and Plant Nutrition, Haliliye/Şanlıurfa, Türkiye.***Abstract**

The effects of microbial inoculation strategies on plant development in agricultural ecosystems are widely known. However, the "legacy effects" left on the soil after the main crop is harvested are not fully known. This study was conducted to examine the permanent effects of different *Bradyrhizobium japonicum* inoculation methods (seed and soil) on microbial stability during the 10-day plant-free incubation period after soybean (*Glycine max* L.) harvest in soils with a history of drought stress. In the study, soil respiration (CO₂), dehydrogenase activity (DHA), microbial biomass carbon (MBC) and metabolic (qCO₂) and specific (qD) ecophysiological indices were evaluated with multivariate statistical analyzes (PCA and Correlation). The findings showed that the "nutrient shock" caused by the cessation of post-harvest root exudates led to severe metabolic stress and carbon wastage from cellular respiration in the uninoculated control group. While drought stress (WS) suppressed microbial biomass and enzyme activities, inoculation from soil under stress (WS+A2) compensated for these losses in an extraordinary way. While basal respiration (CO₂) decreased dramatically by approximately 40% in WS+A2 application in the post-harvest period; The increase in microbial biomass (MBC) and enzyme activity (DHA) by 119.4% and 91.3%, respectively, compared to the stress group, proved that the microbial community maintained its cellular potential by reducing unnecessary carbon expenditure. As a result, it has been determined that bacterial inoculation from the soil goes beyond the existence of the plant and creates a high ecological resistance (resilience) in the soil microbiota against post-harvest hunger and drought shocks and prepares the ecosystem for the next production season by preserving carbon with maximum efficiency.

Keywords: *Aftereffect, Microbial ecology, Bradyrhizobium japonicum, Drought stress, Ecophysiological indices.*

Introduction

Severe drought periods triggered by global climate change not only limit crop production but also put the soil microbiological health, which forms the basis of the agricultural ecosystem, under a long-term threat (Liu et al., 2022; Seleiman et al., 2021). It is widely reported in the literature that plant growth-promoting rhizobacteria (PGPR) improve growth parameters and physiological defense mechanisms in plants under drought stress (Glick, 2014; Vacheron et al., 2013). In our preliminary research conducted in this context, it was successfully demonstrated that *Bradyrhizobium japonicum* inoculation alleviates oxidative stress in soybean (*Glycine max* L.), protects photosynthetic capacity and significantly supports plant development, and the targeted study outcomes have been completed (Tuncer and Sarioğlu., 2026, under review).

However, the sustainability of agricultural ecosystems directly depends not only on microbial interactions during the period when the plant exists, but also on the "legacy effects" remaining in the soil in the post-harvest period (de Vries et al., 2018; Matthews et al., 2023). When the plant is harvested, root exudates, which are the main source of energy and carbon for soil microorganisms, are suddenly cut off (Bais et al., 2006). This creates a secondary source of "nutrient shock" and metabolic stress for microbial communities, especially in soil conditions where abiotic stresses such as drought persist (Naylor & Coleman-Derr, 2018). Although the effects of PGPR applications on the plant have been extensively studied in the literature, there is still a large gap in how long and at what efficiency these bacteria applied after the plant is removed from the soil can maintain soil microbial dynamics (Ibarra et al., 2020; Wu et al., 2016).

The main aim of this study is to examine the permanent effects of drought stress and different inoculation methods (seed and soil) on soil microbial stability during the 10-day plant-free incubation period after soybean harvest. Current research goes beyond classical enzyme activities; It interrogates the "metabolic health" of the soil through ecophysiological coefficients such as microbial biomass carbon (MBC), microbial metabolic fraction (qCO₂) and specific dehydrogenase activity (qD). The findings aim to reveal the role of microbial interventions made directly in the soil in preparing the soil ecosystem for the next production season and its microbial resistance capacity, even after the main crop is withdrawn from the field.



Materials and Methods

This study was conducted to examine the legacy effects of drought stress and different *Bradyrhizobium japonicum* inoculation methods (seed and soil) on the rhizosphere of soybean (*Glycine max* L., cv. GAPSOY 16). The direct effects of the preliminary trial on plant physiology and growth parameters were reported in detail in the main study (Tuncer and Sarioğlu., 2026, under review). The aforementioned preliminary experiment was set up according to the randomized block trial design in controlled greenhouse conditions, in pots filled with soil with high clay content, calcareous soil and pH value between 7.5-8.0. Two different irrigation regimes were applied throughout plant development: full irrigation (100% of field capacity) and water stress (50% of field capacity); The inoculation factor is designed as control, seed inoculation and pulverized inoculation directly into the soil.

Post-Harvest Incubation and Soil Sampling

After the soybean plants were harvested during the flowering period and their roots were carefully removed from the soil, the soil remaining in the pots constituted the main material of the current experiment. In this new period, when microorganisms were deprived of root secretions (the main carbon source), the soils were incubated in pots for 10 days in order to observe the permanent effects of stress and inoculation methods on the microbial flora. During this process, soil moisture was kept constant at harvest levels (according to the relevant irrigation regime). At the end of the incubation period, homogenized soil samples taken from each pot were prepared for laboratory analysis.

Examined Soil Microbiological Parameters

Soil Respiration (CO₂ Output): CO₂ output, which is a general indicator of soil microbial activity, was determined according to the closed jar incubation and titration method (Isermeyer, 1952). **Soil Dehydrogenase Activity (DHA):** It was determined by treating soil samples with TTC (triphenyltetrazolium chloride) and reading the formed formazan spectrophotometrically at 546 nm, in accordance with the method of Thalmann, (1968) for the determination of active microbial respiration and enzyme viability.

Microbial Biomass Carbon (MBC): MBC analysis in soil was performed according to the method of Öhlinger, (1996). A 50 g soil sample was taken and brought to field capacity. Samples were placed in a desiccator containing a beaker containing 50 mL of chloroform. The air in the desiccator was evacuated using a vacuum pump. After a 24-hour waiting period, the samples were removed. The extracted samples were mixed with potassium sulfate solution at a ratio of 1:5 and left to shake for 30 minutes. After shaking, the samples were filtered and organic matter was determined.

Microbial Metabolic Quotient (qCO₂): Calculated by dividing daily CO₂ output to microbial biomass carbon (CO₂-C/MBC) in order to determine the tolerance of soil microorganisms to environmental stress and energy use efficiency (Anderson & Domsch, 1990).

Specific Dehydrogenase Activity (qD): In order to determine the dehydrogenase enzyme activity per unit carbon of microbial biomass (microbial physiological state), it was calculated by dividing the measured DHA value to the microbial biomass carbon and incubation time (µgTPF/mgC/h⁻¹) (Anderson & Domsch, 1990).

Statistical Analysis

The data obtained were subjected to two-way (irrigation level x inoculation method) analysis of variance (ANOVA). Differences between applications were evaluated with Duncan's multiple comparison test (p<0.05). Additionally, Principal Component Analysis (PCA) was used to see the multidimensional relationship between microbial dynamics in the post-harvest period.

Results

Soil Respiration (CO₂) and Dehydrogenase Activity (DHA)

Following the 10-day incubation period after harvesting the soybean plant and removing the roots, statistically significant differences (p<0.05) were detected between the treatments in CO₂ release and dehydrogenase (DHA) enzyme activity, which are indicators of microbial activity in the soil.

In soils incubated under full irrigation conditions, *Bradyrhizobium japonicum* inoculations from seed (A1) and soil (A2) increased CO₂ output (Figure 1A) by 23.8% and 38.1%, respectively, compared to the control group. However, CO₂ output in pots with a history of drought stress (WS) decreased by 56.9% compared to the control group. Although bacterial inoculations performed under stress conditions increased CO₂ output by 22.6% in the WS+A1 application and 36.4% in the WS+A2 application compared to the WS group, they were statistically in the same group with WS.

When dehydrogenase (DHA) enzyme activity was examined (Figure 1B), a different picture emerged. Under normal irrigation conditions, A1 and A2 applications increased DHA activity by 12.5% and 14.6%, respectively, compared to the control. Water stress (WS) application caused a sharp decrease in enzyme activity by 51.9% compared to the control group.



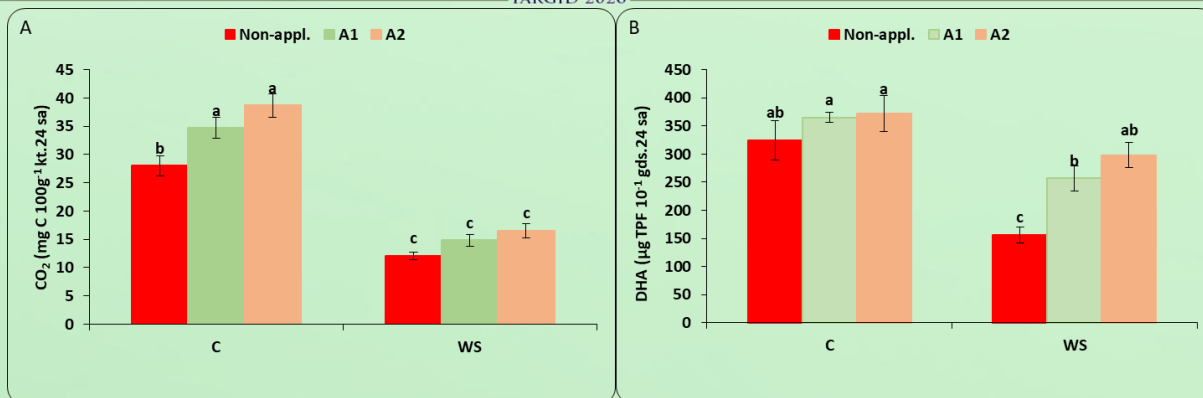


Figure 1: Soil respiration [CO₂ (A)] and Dehydrogenase enzyme activity [DHA (B)] Soybean plant under water stress (WS) of not inoculation (non-appl.), inoculation from seed (A1) and inoculation from soil (A2) application (Mean ± S.E.). C: treatment with water alone; WS: irrigation 50%

It was determined that vaccinations administered under drought stress kept DHA levels significantly higher during the 10-day incubation period. Seed grafting (WS+A1) increased the DHA value by 64.6% compared to the WS group. In the soil inoculated stress group (WS+A2), this increase was much higher and enzyme activity increased by 91.3% compared to the WS group. According to the statistical analysis results, the DHA activity of WS+A2 application was found to be no different (in the same statistical group) with the control soil that had not received any stress.

Microbial Biomass Carbon (MBC) and Ecophysiological Indices (qCO₂ and qD)

Statistically significant differences ($p < 0.05$) were determined between applications in microbial biomass carbon (MBC) values, which express the size of the live microbial population in the soil. Bacterial inoculations applied from seed (A1) and soil (A2) under normal irrigation conditions increased the amount of MBC (Figure 2A) by 145.6% and 158.3%, respectively, compared to the control (C) group. In contrast, drought stress (WS) treatment reduced live microbial biomass by 36.2% compared to the control group. Grafting practices under drought stress significantly compensated for these biomass losses. While seed grafting (WS+A1) increases the MBC value by 99.7% compared to the stress group (WS); Soil inoculation (WS+A2) increased this increase to 119.4%. Remarkably, the biomass value reached by WS+A2 application under stress was found to be 39.9% higher than the MBC value of the control group without stress.

A different picture was observed when ecophysiological indices (qCO₂ and qD) reflecting the energy use efficiency and physiological state of the microbial population were examined. In microbial metabolic carbon (qCO₂) values (Figure 2B), the control group was statistically at the highest level. All remaining stress and inoculation treatments (A1, A2, WS, WS+A1 and WS+A2) exhibited significantly lower qCO₂ values compared to the control group.

The highest value in the specific dehydrogenase activity (qD) parameter (Figure 2C), which expresses the dehydrogenase enzyme activity per unit microbial biomass, was also measured in the control group. Drought stress (WS) and grafting applications under stress (WS+A1 and WS+A2) reduced qD values by 23.7%, 38.6% and 35.5%, respectively, compared to the control group. The lowest qD values were determined in A1 and A2 applications under normal irrigation conditions.

Multivariate Statistical Analyzes (Correlation and PCA)

As a result of Pearson correlation analysis (Figure 3), which was performed to determine the relationships between post-harvest soil microbial parameters, statistically significant ($p < 0.05$ and $p < 0.01$) relationships were detected between the variables. Strong positive correlations ($r = 0.880$ to 0.839) were found between CO₂, DHA and MBC, which are key activity indicators in soil. In contrast, a negative relationship was observed between microbial biomass (MBC) and ecophysiological stress indices; In particular, a statistically significant and very strong negative correlation ($r = -0.817$, $p < 0.05$) was detected between MBC and specific dehydrogenase activity (qD). Additionally, a near-perfect positive relationship ($r = 0.968$, $p < 0.01$) was determined between qCO₂, which expresses microbial stress, and qD.

In the Principal Components Analysis (PCA) biplot plot (Figure 3), which was performed to visualize the holistic effect of treatments on microbial parameters, the first two principal components (PC1 and PC2) explained 97.3% of the total variance (70.7% and 26.6%, respectively). While the PC1 axis represents high biomass and enzyme activity (MBC, CO₂, DHA) in a positive direction; PC2 axis reflected metabolic stress indices (qCO₂, qD). In the PCA space, applications are clearly separated. Inoculation treatments (A1 and A2) under normal irrigation conditions exhibited the highest microbial health profile, positioned to the far right of PC1. While water stress (WS) application is isolated at the negative end of PC1; inoculums under stress (WS+A1 and WS+A2) shifted towards the center, showing that stress was alleviated. The control (C) group showed a sharp positive separation on the PC2 axis and was located in the same region as the qCO₂ and qD vectors.



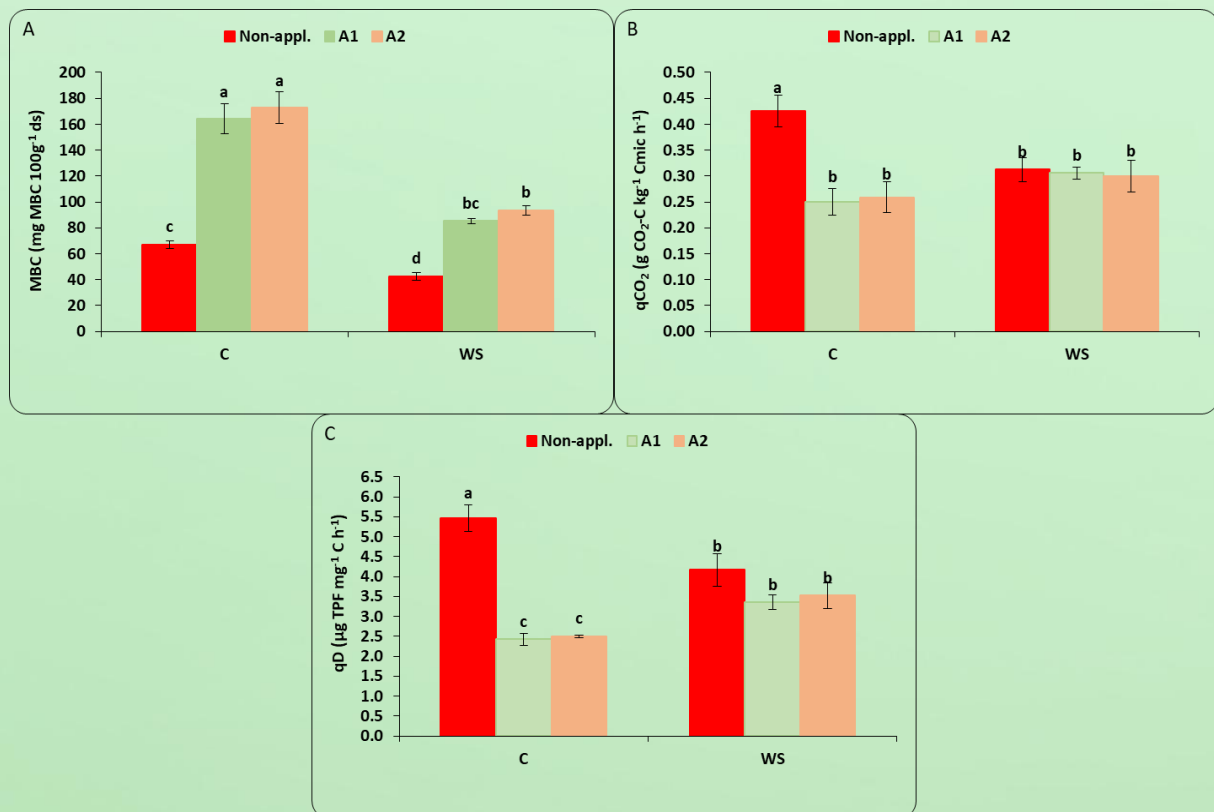


Figure 2: Microbial biomass carbon [MBC (A)], microbial metabolic coefficient [qCO₂ (B)] and microbial biomass conversion [qD (C)] Soybean plant under water stress (WS) of not inoculation (non-appl.), inoculation from seed (A1) and inoculation from soil (A2) application (Mean ± S.E.). C: treatment with water alone; WS: irrigation 50%

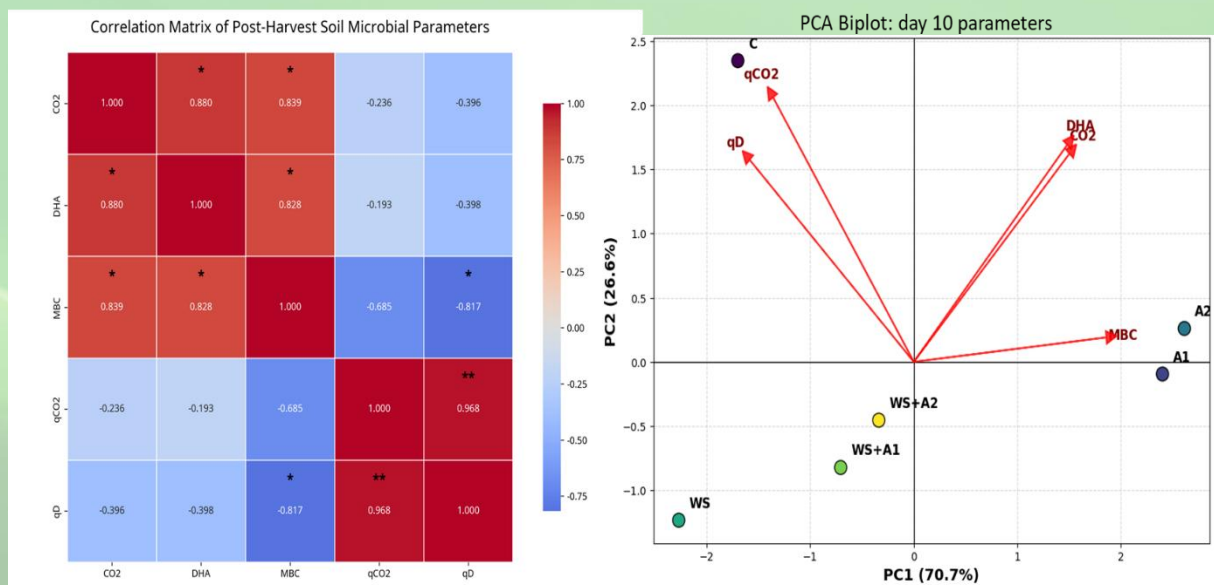


Figure 3: Correlation matrix and PCA analysis of the results

Discussion

The post-harvest period is a critical transitional phase for soil microbial communities when the flow of fresh carbon from plant roots is abruptly interrupted and existing populations face “nutrient shock.” When the data obtained at the time of harvest in our main study (Tuncer and Sarıoğlu., 2026, under review) were compared with the findings obtained after 10 days of plant-free incubation, a clear ecological decoupling was detected in the responses of the applications to this shock.



As expected, removal of the plant from the field caused a general metabolic slowdown in all groups. In the (A2) group inoculated from soil under normal irrigation conditions, CO₂ output and DHA activity showed a balanced decrease of 12.1% and 13.5%, respectively, compared to the time of harvest. In contrast, the almost no decrease in CO₂ respiration in the unvaccinated control (C) group (minimal decrease of 0.9%) may seem like stability at first glance, but this actually reflects a severe metabolic stress. It is understood that the native flora, whose food source has been cut off, continues to engage in high rates of cellular respiration (carbon waste) in order to survive. As a matter of fact, Hartman & Richardson, (2013) reported that soil microorganisms under nutrient limitation increase basal respiration in order to maintain their energy balance, and this leads to a carbon loss that negatively affects ecosystem health in the long term. The peak of qCO₂ values in the control group also confirms this carbon waste.

The most striking finding of our study is the microbial adaptation strategy observed after harvest in inoculated soils (WS+A1 and WS+A2) with a history of drought stress. With the removal of plant roots, CO₂ output decreased dramatically by 40.7% in the WS+A2 application. However, this sharp decline does not represent microbial deaths, but rather a successful protection mechanism (survival state) developed by the inoculated *Bradyrhizobium japonicum* strains. In the same group, the decrease in specific enzyme activity (DHA), which is the main indicator of cellular viability and potential, was limited to only 8.8%. This proves that in extreme conditions where drought and nutrient shock are combined, the microbial community engages in respiratory-enzyme decoupling (CO₂ output) by stopping unnecessary carbon expenditure (CO₂ output) and successfully protects the main cellular metabolism.

Recent studies in the literature support this finding. (Xiao et al., 2023) reported that rhizosphere bacteria under severe drought and nutrient deficiency protect intracellular enzyme systems by suppressing general respiration and thus increase ecological resistance. Similarly, (Shi et al., 2025) emphasized that successful microbial inoculations maximize carbon use efficiency by reducing basal respiration during stress.

As a result, when the harvest period findings obtained in the main study and the 10th day results of the current study are integrated; It has been proven that soil inoculation (A2 and WS+A2) creates a strong legacy effect that can transfer cellular potential to the next season by promoting microbial activity in the presence of plants, while protecting the ecosystem from carbon waste in the absence of plants.

These specific physiological differences between treatments clearly outline the general framework of ecosystem dynamics in multivariate analyzes where all microbial parameters are evaluated together. The correlation and PCA results obtained in our research clearly explain the "nutrient shock" and microbial resistance mechanisms occurring in the post-harvest soil ecology. The strong negative relationships observed between microbial biomass (MBC) and metabolic stress indices (qCO₂ and qD) in the correlation matrix prove that microorganisms use energy (carbon) much more efficiently as the number of living cells in the environment increases. Daunoras et al., (2024) reported that enzyme activities in the soil microbiota play a critical role in maintaining ecosystem health and high biomass prevents metabolic waste; Our findings are in full agreement with this ecological principle.

The most striking ecological outcome of our study is the spatial distribution exhibited by the control (C) group in the PCA graph. It is extremely significant that the control group, which was reported to not experience any physiological stress in the presence of plants in our main study (Tuncer and Sarioğlu., 2026, under review), shifted strongly towards qCO₂ and qD stress vectors during the post-harvest incubation period. The sudden cessation of root exudates (the main carbon source) by removing the soybean plant from the field created a severe "starvation stress" on the microbial flora in the uninoculated control soil. Darenova et al., (2023) state that in situations such as removal of vegetation or water deficit, soil microorganisms perform cellular respiration at a high rate to survive, and this increases the qCO₂ value. This high metabolic loss observed in our control group confirms the relevant literature.

On the other hand, *Bradyrhizobium japonicum* inoculation (A2 and WS+A2), especially applied from soil, created a serious buffer mechanism (afterprotection effect) that protected the microbial flora against this nutrient shock. The fact that A2 applications are located at the farthest point from the stress indices in the PCA graph, at the end of the MBC and DHA vectors, shows that the microorganisms directly injected into the soil form stable biofilms within the soil micro-aggregates. Bogati & Walczak, (2022) emphasized that increasing microbial activity is the most critical factor in strengthening ecosystem resilience after drought. In conclusion, even with a history of drought stress, rhizosphere flora inoculated from soil exhibit high carbon utilization efficiency (low qCO₂) and strong enzyme viability (high DHA), proving that inoculation not only protects the plant but also guarantees long-term soil microbial stability in the post-plant period.

Conclusion

This study clearly demonstrated the "legacy effects" of drought stress and different *Bradyrhizobium japonicum* inoculation methods on soil microbial ecology after soybean harvest. The nutrient shock caused by the removal of



the main crop from the field causes high carbon wastage (peaking qCO_2 values) and metabolic stress in the uninoculated native flora; The soil inoculation strategy (A2) has successfully buffered this ecological problem.

The most striking outcome of the research, which contributes to the literature, is the microbial adaptation and "respiration-enzyme decoupling" mechanism detected in soil-inoculated (WS+A2) pots with a history of drought. Microbial communities in this group have entered an ecological protection mode (survival state) by dramatically reducing unnecessary basal respiration (CO_2 output) by approximately 40% in the absence of plants and under stress; However, it maintained the main cellular workforce (MBC) and potential enzyme vitality (DHA) of the soil almost without loss.

The obtained ecophysiological coefficients (qCO_2 and qD) prove that direct microbial interventions in agricultural areas are not a short-term solution that only improves the plant physiology of the current season. Bacterial inoculation from soil makes the microbial flora highly resilient to hunger and drought shocks in the difficult post-harvest period, and safely transfers a stable soil ecosystem that uses carbon with maximum efficiency to the next production season. Within the context of sustainable agricultural practices, this potential of microbial inoculants to create long-term "soil memory" should be considered as an essential tool for future climate change adaptation strategies.

Declarations

Ethical Approval Certificate

Ethics committee approval was not required for this study.

Author Contribution Statement

Ali SARIOĞLU: Designed the study, prepared other necessary materials for the research, contributed to the setup of the experiment, analysis and article writing.

Emine Nur TUNCER: She contributed to the establishment and follow-up of the experiment and the analysis.

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Conflict of Interest

The authors declare no conflict of interest.

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Beyond Borders: Evaluating and Registering Chinese Green Super Rice in Nigeria — A Case of Agro-ecological Transplantation

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Abstract

Rice remains central crop to food security and sustainable livelihood in Nigeria and other sub-Saharan Africa nations. However, the rice productivity in this region is constrained by many factors including climate related stresses, declining soil fertility, and other persistent stresses. These challenges necessitate continuous varietal replacement which is far from the reach of African researchers due to limited access to required resources; thus, the rice seed system in Africa is largely sustained through varietal introduction. In this study, seven improved Green Super Rice (GSR) lines and three local checks were evaluated for drought and salinity tolerance, yield performance and stability, ratoon-ability, and local consumers' preference in Nigeria. The drought-stress experiments at two locations, revealed that five out of the seven GSR lines significantly out yielded the checks under water stress. The GSR lines showed better tolerance to salinity, and also recorded superior ratoon-ability than the local checks. The GSR lines showed good grain physical quality, and comparable reactions to pest and diseases as recorded for the local checks. At the multi-locations yield trials, only one GSR line (DS20) recorded statistically higher grain yield than the best check (FARO 68). The stability assessments revealed that the GSR lines were more responsive to better environments but less stable compared to the checks. The performance of the GSR line DS20 at the farmers' field revealed high farmers' preference for its high yielding, and good grain physical appearance, but the line was underscored for poor swelling and cooking qualities. These findings showed that the Chinese GSR lines possess good resilience to drought and salinity than the Nigerian varieties; however, due to the cooking preference, the adoptions by the smallholder farmers may be low. This cooking preference peculiarity could be considered as an important GSR breeding objective for the Africa.

Keywords: Green Super Rice, Agro-ecological transplantation, Drought and salinity tolerance, Yield performance and Stability, Nigerians rice quality preference.



The Evolution of Methods Used in The Diagnosis of Plant Bacterial Diseases: From Molecular Methods to Artificial Intelligence-Supported Methods

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Abstract

Significant economic losses occur in agricultural production due to diseases and pests. Fungal, bacterial, and viral pathogens cause substantial quality and yield reductions. Symptoms induced by plant bacterial pathogens, such as chlorosis, necrosis, rot, wilting, ooze formation, and gall development, not only decrease product quality but also disrupt production continuity. Early and accurate diagnosis of bacterial pathogens is therefore critical, as it enables timely and effective management strategies. This review evaluates the development of diagnostic methods used for plant bacterial diseases, examining the transition from classical isolation and serology-based approaches to molecular diagnostic techniques and contemporary digital applications. Based on a comprehensive literature analysis, the advantages of target-oriented amplification-based molecular methods in terms of sensitivity, specificity, and standardization are discussed, alongside the field applicability and rapid detection capacity of isothermal amplification techniques. In addition, gene-editing-based diagnostic systems are assessed for their selectivity and speed, while next-generation sequencing and portable sequencing technologies are comparatively evaluated for their potential in multi-pathogen detection and subspecies-level discrimination. The findings indicate that molecular-based approaches provide high accuracy in detecting latent infections and quarantine pathogens, field-adaptable isothermal systems offer practical advantages for on-site diagnosis, and sequencing technologies generate comprehensive datasets for epidemiological analyses. However, reliance on a single diagnostic strategy may be insufficient, particularly in cases where symptoms overlap with those caused by other biotic or abiotic stress factors. Therefore, integrated, multi-tiered diagnostic systems combining molecular, sequencing, and digital data-driven approaches are considered the most effective strategy for sustainable and accurate diagnosis of plant bacterial diseases.

Keywords: Plant pathogenic bacteria, qPCR, LAMP, RPA, CRISPR.

Bitki Bakteriyel Hastalıkların Tanısında Kullanılan Yöntemlerin Evrimi: Moleküler Yöntemlerden Yapay Zekâ Destekli Yöntemler

Özet

Tarımsal üretimde hastalık ve zararlılar aracılığıyla önemli ekonomik kayıplar meydana gelmektedir. Fungal, bakteriyel ve viral hastalık etmenleri oldukça büyük kalite ve kantite sorunlara neden olmaktadır. Bitki bakteriyel hastalık etmenlerinin ortaya çıkardığı kloroz, nekroz, çürüklük, solgunluk akıntı ve ur oluşumu gibi belirtiler hem ürün kalitesini düşürmekte hem de üretim devamlılığını sektöre ugratmaktadır. Bakteriyel hastalık etmenlerinin erken ve doğru tanısı, beraberinde bu etmenler ile erken mücadele stratejilerini getireceğinden dolayı oldukça önemli bir noktadadır. Bu derlemede, yapılan çalışmalarla bitki bakteriyel hastalıklarının tanısında kullanılan yöntemlerin gelişimi değerlendirilmiş; klasik izolasyon ve serolojik temelli yaklaşımlardan moleküler tanı tekniklerine ve güncel dijital uygulamalara uzanan dönüşüm süreci incelenmiştir. Literatür analizine dayalı olarak gerçekleştirilen çalışmada, hedefe yönelik çoğaltım temelli moleküler yöntemlerin duyarlılık, özgüllük ve standardizasyon açısından sağladığı avantajlar; izotermal çoğaltım tekniklerinin saha uygulanabilirliği ve hızlı sonuç verme kapasitesi; gen düzenleme temelli tanı sistemlerinin seçicilik ve hız yönünden katkıları; ayrıca yeni nesil dizileme ve taşınabilir sekanslama teknolojilerinin çoklu patojen tespiti ve alt tür düzeyinde ayırım yapabilme potansiyeli karşılaştırmalı olarak ele alınmıştır. Bulgular, moleküler tabanlı yöntemlerin özellikle latent enfeksiyonların ve karantina etmenlerinin belirlenmesinde yüksek başarı sağladığını, saha koşullarına uyarlanabilen izotermal sistemlerin yerinde tanılamada önemli avantaj sunduğunu ve dizileme teknolojilerinin epidemiyolojik analizlerde kapsamlı veri ürettiğini göstermektedir. Bununla birlikte, yalnızca tek bir tanı yaklaşımına dayalı sistemlerin sınırlı kalabildiği; belirtilerin diğer biyotik ve abiyotik stres faktörleriyle karışabildiği durumlarda bütüncül değerlendirmelerin gerekli olduğu anlaşılmaktadır. Sonuç olarak, sürdürülebilir ve etkili bir bitki bakteriyel hastalıkların tanısı için moleküler, sekanslama ve dijital veri temelli yaklaşımların entegre edildiği çok basamaklı tanı sistemlerinin en uygun strateji olduğu değerlendirilmektedir.

Anahtar Kelimeler: Bitki patojeni bakteriler, qPCR, LAMP, RPA, CRISPR,



Giriş

Günden güne değişen iklim özellikleri tarımsal üretim açısından büyük kayıpların ortaya çıkmasını da arttırmaktadır. İklim özellikleri ile doğrusal olarak değişmeye başlayan biyotik ve abiyotik stres faktörleri tarımsal üretim açısından daha fazla tehditkâr olma yolundadır. Biyotik faktörler arasında yer alan viral, fungal ve bakteriyel etmenler, ekonomik getirisi yüksek olan bitkiler için yıkıcı kayıplar doğurmaktadır. Bu etmenler arasında yer alan bakteriyel patojenler ise Tarımsal üretim açısından ekonomik değeri yüksek, besin değerin zengin olan birçok bitki için önemli zararlar ortaya koymaktadır. Bitki bakteriyel hastalık etmenleri ürünlerin hem kalitesini hem de kantitesini olumsuz yönde etkileyerek pazar değerinde düşüşe ve üretimin sürdürülebilirliğinde negatifliğe yol açmaktadır. Bakteriyel hastalık etmenlerinin stoma, lentisel, hidatod ve nektar gibi doğal açıklıklardan, kitinleşmemiş bitki dokularından, rüzgar, dolu, vektör böcekler, funguslar, nematodlar aracılığı ile açılan yaralardan ve uygulanan kültürel işlemler sırasında ortaya çıkan yara dokularından hızlı bir şekilde bitki içine girebilmeleri, bu etmenlerle oldukça hızlı ve zamanında mücadele edilmesi gerektiğini de vurgulamaktadır (Aysan vd., 2019). Ülkemiz açısından ekonomik değeri yüksek birçok bitki türü için tehlike oluşturan en önemli bitki bakteriyel hastalıkları, *Xanthomonas*, *Pseudomonas*, *Clavibacter*, *Rolstonia*, *Pectobacterium*, *Dickeya* ve *Agrobacterium* cinsleri içerisinde yer almaktadır (Mansfield vd., 2012). Bitki bakteriyel hastalık etmenlerinin oluşturduğu kloroz, nekroz, çürüklük, solgunluk, akıntı, bitki organlarının atılması ve doku anormallikleri gibi belirtiler genel olarak tipik olsa da zaman zaman bu belirtiler abiyotik stres faktörleri (tuzluluk, besin noksanlığı, sıcaklık stresi vb.) veya fungal etmenlerin oluşturduğu belirtilerle karışabilmektedir (Aysan vd., 2019). Bu durum, özellikle erken dönem enfeksiyonlarda doğru teşhisi güçleştirmektedir. Yanlış veya gecikmiş tanı ise hatalı mücadele stratejilerine, gereksiz pestisit kullanımına ve ekonomik kayıpların artmasına neden olmaktadır. Bu noktada bitki bakteriyel hastalıklarının doğru ve hızlı tanısı, modern bitki koruma yaklaşımlarının temel taşlarından biri haline gelmiştir. Geleneksel tanı yöntemleri uzun yıllar boyunca morfolojik gözlemler, izolasyon, kültür karakterizasyonu, patojenisite testleri ve biyokimyasal analizler üzerine kurulmuştur. Ancak bu yöntemlerin zaman alıcı olmaları, uzmanlık gerektirmeleri ve bazı durumlarda düşük özgüllük göstermeleri nedeniyle sınırlılıklar taşımaktadır (Schaad vd., 2001). Özellikle latent enfeksiyonların tespiti ve yakın akraba türlerin ayırt edilmesi konusunda klasik yöntemler yetersiz kalabilmektedir.

2000'li yılların ortalarından itibaren moleküler biyolojide yaşanan gelişmeler, bitki bakteriyel hastalıklarının tanısında önemli bir değişime yol açmıştır. Polimeraz zincir reaksiyonu (PCR), gerçek zamanlı PCR (qPCR), çoklu PCR sistemleri ve sekans analizleri gibi yöntemler; hızlı, duyarlı ve özgül tanı imkânı sunarak klasik yöntemlerin yerini giderek daha fazla almaya başlamıştır (Schaad vd., 2003). Özellikle 16S rRNA gen bölgesi, housekeeping genleri ve tür-spesifik gen bölgeleri kullanılarak yapılan moleküler analizler; patojenlerin doğru tür ve hatta ırk düzeyinde belirlenmesini mümkün kılmıştır. Bununla birlikte, yeni nesil dizileme (NGS) teknolojilerinin gelişimi, metagenomik yaklaşımlar ve taşınabilir sekanslama sistemleri sayesinde tanı süreçleri yalnızca laboratuvar ortamıyla sınırlı kalmamış; sahada uygulanabilir hale gelmeye başlamıştır. Bu gelişmeler, özellikle karantina patojenlerinin erken tespiti ve epidemiyolojik izleme çalışmalarında önemli avantajlar sağlamıştır (Mansfield vd., 2012). Son on yılda ise dijital tarım uygulamalarının yaygınlaşması ve yüksek çözünürlüklü görüntüleme teknolojilerinin gelişmesi, bitki hastalıklarının tanısında yeni bir dönemin kapısını aralamıştır. Görüntü işleme teknikleri, hiperspektral analizler ve makine öğrenmesi algoritmaları kullanılarak belirtilerin otomatik olarak tanınması mümkün hale gelmiştir. Özellikle derin öğrenme temelli konvolüsyonel sinir ağları (CNN), yaprak lekelerinin ve stres belirtilerinin yüksek doğruluk oranlarıyla sınıflandırılmasında etkili sonuçlar vermektedir (Mohanty vd., 2016).

Yapay zekâ destekli sistemler yalnızca görüntü temelli analizlerle sınırlı kalmayıp; sensör verileri, iklim parametreleri ve epidemiyolojik modellerle entegre edilerek karar destek sistemlerine dönüştürülmektedir. Yapılan çalışmalar incelendiğinde; klasik kültür ve biyokimyasal testlerden moleküler tanı tekniklerine, yapay zekâ ve büyük veri temelli sistemlere uzanan çok katmanlı bir dönüşüm süreci gözlenmektedir. Bu bağlamda, bitki bakteriyel hastalıklarının tanısında kullanılan yöntemlerin evrimini ortaya koymak; hem tarihsel gelişimi değerlendirmek hem de gelecekteki araştırma eğilimlerini belirlemek açısından önem taşımaktadır. Özellikle moleküler yöntemlerin sağladığı yüksek duyarlılık ve özgüllük ile yapay zekâ destekli sistemlerin hız ve ölçeklenebilirlik avantajlarının karşılaştırmalı olarak ele alınması, entegre tanı sistemlerinin geliştirilmesine katkı sağlayacaktır. Bu çalışma, bitki bakteriyel hastalıklarının tanısında kullanılan yöntemlerin dönüşümünü literatür temelli olarak analiz etmeyi ve moleküler biyoloji ile yapay zekâ temelli yaklaşımlar arasındaki geçiş sürecini bütüncül bir perspektifle değerlendirmeyi amaçlamaktadır.

Moleküler Tanı Yöntemleri

Moleküler tanı yöntemleri, bitki patojenlerinin hedef nükleik asit dizilerinin özgül olarak saptanmasına dayanmakta olup, yüksek duyarlılık ve özgüllük gerektiren tanı senaryolarında temel teşhis basamağını oluşturmaktadır. Özellikle latent enfeksiyonların belirlenmesi, düşük inokulum yoğunluğuna sahip örneklerde erken dönem enfeksiyonların tespiti, karantina uygulamaları kapsamında sınır kontrol analizleri ve tohum sağlığı testleri gibi yanlış negatif ya da yanlış pozitif sonuçların ciddi ekonomik sonuçlar doğurabileceği durumlarda,



moleküler teknikler; klasik, kültürel ve serolojik yöntemlere kıyasla önemli avantajlar sağlamaktadır (Schaad vd., 2003). Nükleik asit temelli yaklaşımlar, patojenin kültüre alınmasını gerektirmeden genetik materyalin doğrudan saptanmasına olanak tanıdığı için, semptom oluşumundan önce teşhise imkân vermekte ve epidemiyolojik izleme çalışmalarında güvenilir veri üretimini desteklemektedir (López vd., 2003). Konvansiyonel PCR, termal döngü ile hedef DNA'nın çoğaltılmasıyla ve genellikle jel elektroforezi gibi okuma ile patojenin varlığının doğrulanmasına dayanır. Yapılan çalışmalar incelendiğinde moleküler tanıya doğru eğilim gösteren teşhis ve tanı yöntemleri, hız, standardizasyon ve taşınabilirlik açısından önemli avantajları da beraberinde getirir. Kantitatif bilgi ortaya koyamaması gibi dezavantajları da mevcuttur. Gerçek zamanlı PCR (qPCR) teknikleri, yüksek özgüllükte prob sistemleri ve floresan temelli izleme mekanizmaları sayesinde hem kalitatif hem de kantitatif analiz imkânı sunarak bitki patojenlerinin tanı ve teşhisinde büyük kolaylıklar sağlamıştır (Mackay vd., 2002; Schaad ve Frederick, 2002). qPCR'nin validasyon ve standardizasyon süreçleri, özellikle karantina patojenlerinin teşhisinde eşik değer temelli karar mekanizmalarının geliştirilmesine katkı sağlamıştır (EPPO, 2019). Cihaz ve sarf malzemelerin maliyeti, yöntem standardizasyonu ve kontaminasyonu gibi kontrollere ihtiyaç duyulması yöntemin eksik ve yetersiz kalan taraflarını da ortaya koymaktadır.

Loop-Aracılı İzotermal Amplifikasyon Yöntemi (LAMP)

Termal döngüleyici gereksinimini ortadan kaldıran izotermal amplifikasyon teknikleri ise bu dönemin en dikkat çekici gelişmelerinden biri olmuştur. Loop aracılı izotermal amplifikasyon (LAMP) yöntemi, yüksek amplifikasyon verimliliği ve saha koşullarında uygulanabilirliği sayesinde bitki patojenlerinin hızlı teşhisinde yaygınlaşmıştır (Notomi vd., 2000). Geleneksel PCR tekniklerinin yanı sıra sabit sıcaklıkta çalışabilen bu yöntem, düşük maliyeti ve hızlı sonuç vermesi ile tarımsal üretimde ekonomik kayıpları meydana getiren bakteriyel hastalıkların teşhisinde oldukça önemli bir noktada yerini almıştır (Yang ve ark., 2025). Ayrıca Kant ve ark. (2021), *Pseudomonas syringae* pv. *pisi* (Psp) ve *Pseudomonas syringae* pv. *syringae* (Pss) etmenlerinin hızlı teşhisi amacıyla LAMP tabanlı bir tanılama yöntemi geliştirmiştir. Araştırmacılar, geliştirilen LAMP testi ile her iki bakteriyel etmeni laboratuvar ve saha koşullarında 20 dakikadan kısa sürede yüksek özgüllükte tespit etmiş, ayrıca belirtiler ortaya çıkmadan önce enfekteli bitki dokularında patojen varlığını belirleyebilmişlerdir (Kant vd., 2021). Loop-Aracılı İzotermal Amplifikasyon (LAMP) yönteminin bitki hastalıklarının hızlı teşhisindeki önemine ilişkin kapsamlı bir derleme çalışmasında, Aglietti ve ark. (2024) tarafından LAMP tekniğinin; *Xanthomonas oryzae* pv. *oryzae*, *Xylella fastidiosa*, *Xanthomonas euvesicatoria*, *Erwinia amylovora* ve *Pectobacterium carotovorum* gibi çok sayıda bakteriyel bitki patojeninin tespitinde başarıyla kullanıldığı bildirilmiştir. Araştırmacılar, yöntemin sabit sıcaklıkta çalışabilmesi, taşınabilir cihazlarla uygulanabilmesi, düşük maliyetli olması ve saha koşullarında hızlı sonuç verebilmesi nedeniyle bitki hastalıklarının erken teşhisinde önemli avantajlar sağladığını vurgulamışlardır (Aglietti vd., 2024).

Rekombinaz polimeraz amplifikasyonu (RPA)

Rekombinaz polimeraz amplifikasyonu (RPA) gibi yeni nesil izotermal yöntemler ise düşük sıcaklıkta kısa sürede sonuç vermesi nedeniyle "point-of-care" (POC) uygulamalarında öne çıkmıştır (Piepenburg vd., 2006). Rekombinaz polimeraz amplifikasyonu (RPA), sabit sıcaklıkta çalışan, hızlı sonuç verebilen ve saha koşullarında uygulanabilirliği yüksek yeni nesil izotermal amplifikasyon yöntemlerinden biridir. Cai ve ark. (2023), RPA yönteminin minimal örnek hazırlığı ile enfekteli bitki dokularından doğrudan patojen tespitine olanak sağladığını, ayrıca konakçı kaynaklı inhibitörlerden daha az etkilenmesi nedeniyle klasik PCR tabanlı yöntemlere göre önemli avantajlar sunduğunu bildirmiştir. Araştırmacılar, geliştirilen RPA/LFD sisteminin herhangi bir gelişmiş laboratuvar ekipmanına ihtiyaç duymadan, taşınabilir cihazlar veya doğrudan saha koşullarında kullanılabildiğini ve kısa sürede güvenilir sonuçlar verdiğini vurgulamışlardır.

Çok Lokuslu Dizi Analizi (MLSA) Ve Tüm Genom Sekanslama (WGS) Yaklaşımları

Sekanslama teknolojilerindeki ilerlemeler de moleküler tanının ayırtılma kapasitesini önemli ölçüde genişletmiştir. Çok lokuslu dizi analizi (MLSA) ve tüm genom sekanslama (WGS) yaklaşımları, yakın akraba bakteri türlerinin ve patovaryalarının yüksek çözünürlükte ayırma olanak tanımış; filogenetik analiz ve epidemiyolojik iz sürme çalışmalarında güçlü bir araç olarak kullanılmaya başlanmıştır (Maiden vd., 1998; Loman vd., 2012). Yeni nesil sekanslama (NGS) platformları, özellikle kompleks enfeksiyonların ve metagenomik örneklerin analizinde kültüre bağımlılığı azaltarak kapsamlı tanısal veri sağlamıştır (Adams vd., 2009). Çok lokuslu dizi analizi (MLSA), birden fazla housekeeping geninin birlikte değerlendirilmesine dayanan ve bakteriyel türler ile haplotipler arasındaki filogenetik ilişkilerin daha yüksek çözünürlükte ortaya konulmasını sağlayan moleküler bir yaklaşımdır. Ruiz-Padilla ve ark. (2020), tek gen analizlerinin filogenetik ilişkileri her zaman yeterince doğru yansıtamayabileceğini, bu nedenle birden fazla korunmuş gen bölgesinin birlikte analiz edildiği MLSA yaklaşımının daha güvenilir sonuçlar sunduğunu bildirmiştir. Araştırmacılar, özellikle yavaş ve kararlı evrim gösteren protein kodlayıcı housekeeping genlerinin kullanılmasıyla ribozomal gen analizlerine kıyasla daha yüksek taksonomik çözünürlük elde edildiğini vurgulamışlardır. Tüm genom sekanslama (WGS) yaklaşımları ise bakteriyel genomun tamamının analiz edilmesine olanak sağlayarak yalnızca filogenetik ilişkilerin değil, aynı



zamanda virölens genleri, yatay gen transferi, evrimsel farklılaşma ve antimikrobiyal direnç mekanizmalarının da ayrıntılı biçimde incelenmesini mümkün kılmaktadır. MLSA yöntemleri belirli housekeeping genlerine dayalı yüksek çözünürlüklü analizler sunarken, WGS teknolojileri genom düzeyinde çok daha kapsamlı genetik bilgi sağlayarak modern bakteriyel tanı ve epidemiyolojik çalışmalarda önemli bir referans yaklaşım haline gelmiştir.

CRISPR/Cas

CRISPR/Cas tabanlı moleküler tanı platformları 2015 sonrası dönemde yüksek özgüllük ve hız avantajı ile dikkat çekmiştir. Cas12 ve Cas13 enzimlerinin hedefe özgül kesim mekanizmasına dayanan DETECTR ve SHERLOCK sistemleri, dakikalar içinde sonuç verebilen ve floresan ya da lateral akış şeridi ile okunabilen yeni nesil tanı yaklaşımları olarak geliştirilmiştir (Gootenberg vd., 2017; Chen vd., 2018). Günümüzde yapılan bir çalışmada, okaliptüslerde Bakteriyel Solgunluğa neden olan *Ralstonia pseudosolanacearum*'un hızlı ve duyarlı tespiti amacıyla ERA-CRISPR/Cas12a temelli yeni bir moleküler tanı yöntemi geliştirilmiş olup, söz konusu sistemin düşük DNA konsantrasyonlarında dahi yüksek özgüllük ve hassasiyet sağladığı bildirilmiştir (Peng ve ark., 2025). Bu tür CRISPR tabanlı tanı stratejileri, bitki patojenlerinin erken evrede saptanmasına olanak tanıyarak entegre hastalık yönetiminde karar destek süreçlerini güçlendirmektedir.

Bu sistemler, klasik PCR temelli yöntemlere alternatif olarak hızlı, taşınabilir ve yüksek özgüllükte moleküler teşhis imkânı sunmaktadır. Genel olarak değerlendirildiğinde, moleküler tanı yöntemleri; laboratuvar merkezli yüksek hassasiyetli platformlardan, saha uygulanabilir ve kullanıcı dostu sistemlere doğru evrilmiştir. Sekanslama ve CRISPR tabanlı teknolojilerle birlikte yüksek çözünürlüklü ve hızlı tanı imkânı sağlayan yöntemlere geçiş sağlamıştır.

Görüntü Tabanlı ve Yapay Zeka Destekli Tanı Sistemleri

Görüntü tabanlı yaklaşımlar, patojeni doğrudan tespit etmek yerine bitkide oluşturduğu fizyolojik ve optik değişimleri yakalamayı hedefler. Bu durum, geniş alan tarama ve erken uyarı için avantaj sağlarken, bakteriyel semptomların, fungal patojenlerin ve abiyotik stres faktörlerin meydana getirdiği belirtilerle benzeşmesi nedeniyle yöntemin kesin verilere dayalı olarak sunduğu bulguların doğruluğu risk haline getirir ve problem yaratır (Zhang ve ark., 2024). Görüntü tabanlı ve yapay zekâ destekli tanı sistemleri, özellikle bakteriyel bitki hastalıklarının hızlı ve temassız şekilde belirlenmesinde son yıllarda önemli gelişmeler göstermiştir. Mohanty ve ark. (2016), derin öğrenme tabanlı konvolüsyonel sinir ağları (CNN) kullanarak domates ve biberde görülen bakteriyel leke hastalığının (*Xanthomonas* spp.) görüntü tabanlı teşhisini gerçekleştirmiştir. Araştırmacılar, yaprak görüntülerinden elde edilen semptomatik verilerin derin öğrenme algoritmaları ile analiz edilmesi sonucunda yüksek doğruluk oranlarına ulaşıldığını ve bu yaklaşımın özellikle saha koşullarında erken hastalık teşhisi için önemli bir potansiyel taşıdığını bildirmiştir. Çalışmada geliştirilen modelin kontrollü veri setlerinde %99'un üzerinde doğruluk sağladığı belirtilmiştir.

Görüntü İşleme ve CNN Tabanlı Derin Öğrenme

CNN tabanlı tanı, genellikle yaprak görüntüsü sınıflandırması veya lezyon segmentasyonu üzerinden yürütülür. Performans değerlendirmesinde doğruluğun yanında duyarlılık, F1 skoru ve ROC-AUC gibi metriklerin raporlanması, sınıf dengesizliği ve saha varyasyonu nedeniyle önemlidir (Terentev ve ark., 2022). Kontrollü veri setlerinde CNN tabanlı sınıflandırmanın yüksek doğruluklara ulaşabileceği; ancak saha görüntülerinde alan uyarlaması nedeniyle performansın düşebileceği kanıtlanmıştır (Barbedo, 2018). Ayrıca farklı CNN mimarilerinin geniş ölçekli karşılaştırmaları, bitki hastalık sınıflandırmasında derin öğrenmenin genel gücünü desteklemiştir (Mohanty ve ark., 2016). Pirinçte görülen ve önemli ekonomik kayıplara yol açan bakteriyel hastalıklar için mobil veya saha uygulamalarına dönük derin öğrenme yaklaşımları raporlanmaktadır; bu çalışmalar, çok sınıflı tanı senaryosunda metrik raporlamanın önemini artırır (Lu ve ark., 2017).

Hiperspektral Görüntüleme ve Makine Öğrenmesi

Yöntem. Hiperspektral görüntüleme (HSI), görünür–yakın kızılötesi bantlarda yaprak dokusunun spektral imzasını ölçerek presimptomatik değişimleri yakalamayı amaçlar. Bitki hastalıklarında HSI'nin erken tespit potansiyeli, yöntemsel derlemelerle de desteklenmiştir. Bakteriyel patosistem örnekleri. Domateste bakteriyel yaprak lekesi (*Xanthomonas perforans*) için yüksek çözünürlüklü HSI veri seti ve makine öğrenmesi ile presimptomatik tespit yapılabildiği; ayrıca abiyotik lekelerden ayrımın mümkün olabildiği raporlanmıştır (Terentev ve ark., 2022).

Sensör Entegrasyonu

Sensör entegrasyonu; sera içi iklim sensörleri, spektral sensörler ve robotik-UAV sistemleriyle “erken uyarı + tanı” birleşimini hedefler. Hiperspektral yaklaşımın erken bitki hastalığı tespitinde genel durumunu özetleyen Sensors derlemesi, sahada sensör tabanlı sistemlerin (uydu-UAV–yer sensörleri) yaygınlaştığını vurgular (Terentev ve ark., 2022).



Sonuç

Yapılan çalışmalar incelendiğinde bitki bakteriyel hastalık tanısında qPCR'in standardizasyon ve kantitatif tanı ihtiyacını karşılayarak "çekirdek yöntem" hâline geldiği; LAMP ve RPA gibi izotermal yöntemlerin sahaya yakın hızlı tanıyı güçlendirdiği; CRISPR/Cas platformlarının yüksek özgüllük ve hızlı okuma avantajıyla hibrit POC çözümlere dönüştüğü bir evreyi temsil eder. NGS ve taşınabilir nanopore sekanslama, tanıyı sürveyans/epidemiolojik izleme bütünleştirme potansiyeli taşıırken; görüntü ve hiperspektral tabanlı AI, presimptomatik tespit ve geniş alan izleme için güçlü bir tamamlayıcı hat sunar. Bununla birlikte, AI tabanlı yaklaşımlarda saha genellenabilirliği ve standardizasyon; moleküler POC sistemlerinde ise kontaminasyon kontrolü, validasyon ve regülasyon uyumu belirleyici sınırlılıklar olmaya devam etmektedir. Türkiye bağlamında karantina ve sürvey çerçevesi için yerel moleküler çalışmalar önemli bir temel sunmakta; önümüzdeki dönemde POC validasyonu, veri paylaşımı ve çok lokasyonlu saha testlerinin genişletilmesi en yüksek etki potansiyeline sahiptir. Bitki bakteriyel hastalıklarının tanısında kullanılan yöntemler incelendiğinde, klasik kültürel ve biyokimyasal tekniklerden; yüksek duyarlılığa sahip moleküler sistemlere ve yapay zekâ destekli dijital tanı platformlarına doğru belirgin bir dönüşüm gerçekleştiği görülmektedir. Özellikle qPCR, yüksek özgüllük, kantitatif veri üretme kapasitesi ve uluslararası validasyon protokollerine uygunluğu nedeniyle bu dönemde "referans moleküler tanı yöntemi" konumuna ulaşmıştır. Karantina uygulamaları, latent enfeksiyonların belirlenmesi ve düşük inokulum yoğunluklarının tespiti gibi yüksek doğruluk gerektiren senaryolarda qPCR'nin halen en güvenilir yöntemlerden biri olduğu anlaşılmaktadır. Ancak cihaz maliyeti, laboratuvar altyapısı gereksinimi ve uzman personel ihtiyacı yöntemin saha uygulanabilirliğini sınırlayan temel faktörler arasında yer almaktadır.

İzotermal amplifikasyon sistemleri olan LAMP ve RPA yöntemleri ise qPCR'ye alternatif değil, onu tamamlayan "saha odaklı" teknolojiler olarak ön plana çıkmıştır. LAMP yöntemi; yüksek amplifikasyon kapasitesi, düşük maliyetli ekipman ihtiyacı ve kısa analiz süresi nedeniyle özellikle *Xanthomonas*, *Erwinia*, *Pectobacterium* ve *Xylella* gibi bakteriyel etmenlerin hızlı teşhisinde önemli avantajlar sağlamıştır. RPA sistemleri ise daha düşük sıcaklıkta çalışabilmesi ve minimal örnek hazırlığı gerektirmesi sayesinde "point-of-care" (POC) uygulamalarında LAMP'a kıyasla daha taşınabilir bir yapı sunmaktadır. Bununla birlikte her iki yöntemde de primer tasarım hassasiyeti, yanlış pozitif riskleri ve kontaminasyon kontrolü önemli sınırlılıklar olarak değerlendirilmektedir. Özellikle saha koşullarında standardizasyon eksikliği ve operatör kaynaklı varyasyonlar, bu yöntemlerin rutin kullanımdaki güvenilirliğini etkileyebilmektedir.

MLSA ve WGS tabanlı sekanslama yaklaşımları, bitki bakteriyel hastalıklarının yalnızca teşhisinde değil; aynı zamanda filogenetik sınıflandırma, epidemiyolojik iz sürme, patovar ayrımı ve antimikrobiyal direnç mekanizmalarının belirlenmesinde yüksek çözünürlüklü analiz imkânı sağlamıştır. MLSA, housekeeping genleri kullanarak yakın akraba bakteriyel türlerin ayrımında güvenilir sonuçlar üretirken; WGS teknolojileri tüm genom düzeyinde veri sunarak virülens genleri, yatay gen transferi ve evrimsel farklılaşmaların ayrıntılı biçimde incelenmesine olanak tanımaktadır. Ancak bu yöntemlerin yüksek maliyet, biyoinformatik uzmanlığı gereksinimi ve büyük veri yönetimi gibi önemli dezavantajları bulunmaktadır. Özellikle WGS sistemleri günümüzde araştırma merkezleri için güçlü araçlar olsa da rutin saha teşhisinde henüz ekonomik ve operasyonel olarak tam anlamıyla uygulanabilir değildir.

CRISPR/Cas tabanlı tanı sistemleri ise son yıllarda moleküler teşhis alanındaki en dikkat çekici gelişmelerden biri olarak öne çıkmıştır. Cas12 ve Cas13 tabanlı DETECTR ve SHERLOCK sistemleri, çok düşük DNA konsantrasyonlarında dahi yüksek özgüllük sağlayabilmekte ve lateral akış şeritleriyle hızlı saha okuması yapılabilmektedir. Bu yönüyle CRISPR sistemleri, qPCR'nin yüksek doğruluğunu; LAMP ve RPA'nın taşınabilirlik avantajıyla birleştiren hibrit bir teknoloji olarak değerlendirilebilir. Bununla birlikte CRISPR tabanlı sistemlerin validasyon eksiklikleri, ticari kit standardizasyonunun henüz tam oturmamış olması ve regülasyon süreçlerinin devam etmesi yöntemin yaygın kullanımını sınırlamaktadır.

Görüntü tabanlı yapay zekâ sistemleri ve hiperspektral görüntüleme teknolojileri ise bitki bakteriyel hastalıklarının tanısında tamamen farklı bir paradigma oluşturmuştur. Moleküler yöntemler doğrudan patojeni hedef alırken; yapay zekâ tabanlı sistemler bitkide oluşan fizyolojik, morfolojik ve optik değişimleri analiz etmektedir. CNN tabanlı derin öğrenme modelleri kontrollü veri setlerinde oldukça yüksek doğruluk oranlarına ulaşmış olsa da saha koşullarında ışık farklılıkları, yaprak deformasyonları, semptom benzerlikleri ve abiyotik stres faktörleri nedeniyle performans kayıpları yaşanabilmektedir. Özellikle bakteriyel hastalık semptomlarının fungal enfeksiyonlar ve besin noksanlıklarıyla benzerlik göstermesi, görüntü tabanlı sistemlerin en önemli sınırlılıklarından biri olarak değerlendirilmektedir. Bu nedenle yapay zekâ tabanlı tanı sistemlerinin tek başına kesin teşhis yöntemi olmaktan çok, "erken uyarı" ve "ön tarama" sistemi olarak kullanılması daha gerçekçi görünmektedir.

Hiperspektral görüntüleme (HSI) teknolojileri, semptom oluşmadan önce bitkide meydana gelen biyokimyasal değişimleri tespit edebilmesi nedeniyle geleceğin en güçlü erken teşhis araçlarından biri olarak değerlendirilmektedir. Özellikle UAV (drone), robotik sistemler ve IoT sensörleri ile entegre edilen hiperspektral platformlar; geniş alan taraması, epidemiyolojik sürvey ve hassas tarım uygulamaları açısından önemli avantajlar



sunmaktadır. Bununla birlikte veri işleme kapasitesi, yüksek donanım maliyeti ve spektral veri standardizasyonu gibi problemler bu sistemlerin yaygınlaşmasını sınırlandırmaktadır.

Genel olarak yöntemler karşılaştırıldığında:

- **qPCR**, yüksek doğruluk ve kantitatif analiz açısından halen en güçlü referans yöntemdir.
- **LAMP ve RPA**, saha uygulanabilirliği ve hız bakımından qPCR'ye göre üstünlük sağlamaktadır.
- **CRISPR/Cas sistemleri**, yüksek özgüllük ile taşınabilirliği birleştiren yeni nesil hibrit tanı platformları olarak öne çıkmaktadır.
- **MLSA ve WGS**, filogenetik ve epidemiyolojik analizlerde diğer tüm yöntemlerden daha yüksek çözünürlük sunmaktadır.
- **Yapay zekâ ve görüntü tabanlı sistemler**, geniş alan izleme ve erken uyarı açısından avantajlı olsa da doğrudan patojen doğrulamasında moleküler yöntemlerin gerisinde kalmaktadır.

Gelecek perspektifi açısından değerlendirildiğinde, bitki bakteriyel hastalıklarının tanısında tek bir yöntemin tüm ihtiyaçları karşılaması beklenmemektedir. Bunun yerine hibrit ve entegre sistemlerin ön plana çıkacağı öngörülmektedir. Özellikle yapay zekâ destekli görüntü analiz sistemlerinin, CRISPR veya izotermal amplifikasyon tabanlı taşınabilir moleküler platformlarla birleştirilmesi; hem hızlı ön tarama hem de yüksek özgüllükte doğrulama sağlayabilecek yeni nesil entegre tanı sistemlerinin temelini oluşturacaktır. Ayrıca nanopore sekanslama, taşınabilir biyosensörler, IoT tabanlı sensör ağları ve bulut tabanlı epidemiyolojik veri paylaşım platformlarının gelişmesiyle birlikte gelecekte gerçek zamanlı, otomatik ve karar destek sistemleriyle entegre çalışan “akıllı bitki hastalık yönetim sistemleri”nin yaygınlaşması beklenmektedir. Türkiye açısından ise yerel patojen popülasyonlarına yönelik validasyon çalışmaları, çok lokasyonlu saha denemeleri, veri standardizasyonu ve ulusal tanı veri tabanlarının oluşturulması; önümüzdeki dönemin en kritik araştırma alanları arasında yer almaktadır.

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Functional Synergy Between Pathogenesis-Related Proteins for Sustainable Crop Protection

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Abstract

Pathogenesis-related (PR) proteins have been combined for effective plant disease control, yet their synergistic mechanisms remain unexplored at the molecular level. This study elucidates the molecular basis of synergism between thaumatin-like protein (TLP) and PR1 using computational (in silico) methods. Analyses encompassed physicochemical properties, subcellular localization predictions, topological and domain characterization, conserved motif identification, phylogenetic relationships, secondary and tertiary structure prediction, molecular docking and simulation of TLP and PR1 individually and combined with key fungal cell wall components. Physicochemical profiling indicated TLP as a neutral, hydrophobic, thermostable protein, while PR1 was acidic, hydrophilic, and thermostable. Both were predicted to localize extracellularly, with TLP exhibiting transmembrane topology and PR1 positioned externally. Docking simulations revealed superior binding affinities for the TLP-PR1 complex versus individual proteins against chitin, chitosan, glucan, and mannan. These computational insights highlight the synergistic chitinolytic mechanism of TLP-PR1, suggesting their co-expression could potentiate broad-spectrum antifungal defense and inform strategies for engineering durable plant resistance.

Keywords: *Thaumatococcus* protein (TLP), PR1 protein, Chitinolytic activity, Synergistic antifungal defense, Molecular docking.



Evaluation of milk quality parameters in first parity Holstein cows

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Abstract

Today, breeding objectives in cattle farms have shifted from focusing solely on milk production to also improving milk quality. In this context, this study aims to evaluate milk quality parameters in first parity Holstein cattle raised in farms enrolled to Amasya Province Breeding Cattle Breeders Association (CBA). Milk SCC, fat, protein, and lactose values of 108 cows within days 30 and 150 of their lactation were analyzed using an automated analyzer. Obtained values were evaluated using one-way analysis of variance (ANOVA) in three regions (Amasya-Center, Merzifon, and Suluova) and four calving seasons (Winter: December-February; Spring: March-May; Summer: June-August; and Fall: September-November). Milk fat and SCC values of cows that calved in the winter calving season, and the average SCC of samples from the Merzifon region, were found to be higher compared to other groups ($P<0.001$). The calculated negative correlations between SCC and lactose ($r=-0.323$) and fat ($r=-0.359$) revealed that these components, in addition to SCC, can also be used in determining raw milk quality. While fat ($3.72\pm0.061\%$) and protein ($3.48\pm0.015\%$) percentages of the milk samples were higher than the threshold declared by FAO, the lactose content ($4.86\pm0.013\%$) was more consistent with the pronounced value. The calculated overall average SCC (419×10^3 cells/ml) was found to be quite close to the values reported by the Turkish Food Codex (TFC) and EU directives. It was suggested that adjustments should be made in milking hygiene, udder cleaning and milk storage conditions to further reduce this level.

Keywords: Dairy cow, Somatic cell count, Milk components, Milk Quality

Introduction

Breeding objectives have expanded beyond focusing solely on milk production to include a variety of characteristics such as reproduction, animal health, individual comfort, overall productivity, and improved milk quality. Since phenotyping some of these traits is generally difficult, costly, and time-consuming, indicators that are highly correlated with them and easier to measure have become more attractive in breeder selection. For instance, the fat/protein ratio of raw milk is assumed to be an evidence for negative energy balance and also ketosis case, while somatic cell count (SCC) is used to monitor udder health and susceptibility to mastitis. (Costa et al., 2020). Mastitis is classified into two forms, subclinical (latent) and clinical, depending on the severity of the infection. In the subclinical form, the infection remains hidden; no visible changes in the udder or milk are noticeable. Diagnosis of subclinical mastitis is made using laboratory tests such as determining the amount of SCC in the milk and bacterial count. In a healthy udder lobe, SCC is below 200×10^3 cells/ml, and values above this are considered indicative of abnormality and inflammation in the udder. (Querengässer et al., 2002). It is stated that increasing resistance to mastitis will improve animal welfare and lactation numbers, and in this context, a positive impact on the total milk production and profitability of the farm can be observed (Hu et al., 2021). High SCC not only negatively affects milk yield but also affects milk composition and quality (Cinar et al., 2015). It has been determined that young cows have lower SCC in their milk due to their relatively low milk production capabilities (Sharma et al., 2017). Furthermore, it has been reported that mammary gland immunity in cows in their first lactation is higher compared to cows that have given birth multiple times (Dang et al., 2014). In a study that determined the factors affecting mammary gland immunity in Holstein cows in their first lactation (Stadnik and Atasever, 2015), the average mammary gland immunity was determined to be 302×10^3 cells/ml, while the calving season was found to have an insignificant effect on mammary gland immunity. The researchers emphasize that mammary gland immunity data can be a reliable source in breeding selection and should be monitored throughout all periods of production.

In a study conducted to determine SCC and milk components in Holstein cattle (Çardak, 2016), correlations of 0.080, 0.216, and -0.951 were estimated between SCC and fat, protein, and lactose values in milk samples from cows in their first lactation, respectively.

Cattle raw milk contains emulsion-formed fat globules, colloidal and soluble proteins, and lactose in solution. Acidity, density, dry matter, fat, total protein, casein, serum protein, lactose, and mineral content are considered important parameters in evaluating raw milk quality (Sezgin et al., 2013). Milk fat, one of the indicators of raw milk quality, is synthesized in the cytoplasm of the alveolar secretory cell. In the first stage, short-chain fatty acids



and carbohydrates are formed, followed by a significant portion of medium and long-chain fatty acids. Acetic acid acts as the main structural component in the synthesis of milk fat, and the synthesized milk fat is secreted into the alveolar lumen from the apical region of the alveolar secretory cell in the form of lipid droplets (Clegg et al., 2001). In addition, lactose content, another component among milk quality indicators, shows very little variation (Costa et al., 2020). In ruminants, the amount of glucose taken up from the blood by the udder is approximately 60-85% of the total blood glucose, and about 70% of this glucose is used in lactose synthesis. After synthesis, lactose is stored in the Golgi apparatus and controls the entry of water into the cell (Mert et al., 2020). It has been reported that the highest lactose concentrations are observed in cows calving for the first time, and a gradual decrease occurs in subsequent lactations. Researchers emphasize that the low level of variability in milk lactose content is due to physiological reasons and that lactose, the main compound determining milk osmolality, is subject to biological constraints (Costa et al., 2020). The fact that the fat, protein, and lactose percentages, which are used as quality indicators in raw cow's milk, show values close to 3.42%, 3.30%, and 4.87% respectively for Holstein cow's milk, allows for interpretations regarding the quality of the analyzed milk (FAO, 2025).

In a study conducted to determine the SCC and milk components in Holstein cattle raised in two farms in Germany (Çardak, 2016), the fat, protein, and lactose percentages in milk samples from first-lactation cows were determined as $4.06 \pm 0.04\%$, $3.27 \pm 0.02\%$, and $4.47 \pm 0.00\%$, respectively. The study estimated correlations of 0.437 and -0.101 between fat and protein and lactose, respectively; and -0.226 between protein and lactose. In the study by Davut and Atasever (2017) investigating the seasonal variation of SCC and milk components in raw cow milk, the fat, protein, and lactose levels of the analyzed milk samples were determined as $3.57 \pm 2.66\%$, $2.83 \pm 0.45\%$, and $3.85 \pm 0.61\%$, respectively. The highest numerical values for these components were obtained in milk samples collected in spring, winter, and summer, respectively, while a correlation of 0.141 and 0.125 was found between fat and protein and lactose, respectively; and a correlation of 0.979 was found between protein and lactose.

As seen, determination of different quality parameters of cow milk plays important role to achieve an elite herd in dairy farms. Therefore, the current study aims to determine the relationships between key quality indicators in milk samples obtained from first parity Holstein cows raised in farms of Amasya province of Türkiye.

Materials and Methods

Animal material: This study was conducted on Holstein cattle raised in farms that are members of the Cattle Breeders Association (CBA) of Amasya province, Türkiye. Since it was planned to include farms with a total number of milking cows of at least 100 head, the distribution of their farms that met this condition is as follows: Merzifon: 4, Amasya-Center: 3, Suluova: 2 and Göynücek: 1. To facilitate statistical analysis, the farm in Göynücek, which has four cows and meets the necessary conditions, was included in the Amasya-Center group, the closest region in terms of distance, for the evaluation. In these farms, all milking cows in their first lactation and between days 30-150 of their lactation were determined as animal material (with the complete enumeration method). While 110 cows with these characteristics were selected as research material, the values of two animals with problematic records were excluded from the trial, so the present study was completed on a total of 108 cattle (Suluova: 22, Merzifon: 41 and Amasya: 45).

Providing data on milk quality parameters: Individual milk samples were collected from all animals included in the study in October 2024. The collected samples were transported within 24 hours in cold chain containers to the Çorum Provincial Directorate of Dairy Products and Animal Husbandry laboratory and subjected to SCC, protein, fat and lactose analysis with the CombiFoss 7 automated milk analyzer (FOSS Electric, Hillerød, Denmark) (the ISO/IDF approved device has the capacity to analyze 19 different parameters in the same sample in 7 seconds using flow cytometry technology).

Statistical analyses: The values of milk quality indicators were evaluated using one-way analysis of variance (ANOVA) in three regions (Amasya-Center, Merzifon, and Suluova) and four calving seasons (Winter: December-February; Spring: March-May; Summer: June-August; and Fall: September-November). Differences between parameters with three or more groups were determined using Duncan's multiple comparison method, and the linear model used is:

$$Y_{ijk} = \mu + a_i + b_j + e_{ijk} \quad (1)$$

In the formula: Y_{ijk} : observed value, μ : population mean, a_i : effect of the regions ($i: 1,2,3$), b_j : effect of the calving season ($j: 1,2,3,4$) and e_{ijk} is the random error. Comparison of paired groups was performed using the t-test. Since the obtained SCC data showed wide variation, all SCC values were converted to $\log_{10} \text{SCC}$ values in base 10 logarithm to ensure homogeneity and uniformity among the data. The relationships between milk quality indicators were estimated using Kendall's tau-b correlation analysis method. SPSS.17 software package was used for all statistical analyses, while Excel program was used for the preparation of the tables.



Results and Discussion

Descriptive statistics on milk components and SCC values in the study are presented in Table 1. According to FAO (2025), the ideal milk fat content for Holstein cows is defined as 3.41%, protein content as 3.30%, and lactose content as 4.87%. It can be stated that the fat and protein content of the analyzed milk samples were higher than these values, while the lactose content was more consistent with FAO data. A significant difference has been obtained between the lowest and highest SCC values. This difference is thought to stem from variations in hygiene, milking techniques, and care practices in the farms.

Table 2 shows the effect of calving season on milk fat, protein, lactose, and logSCC. Seasonal variation has had a significant effect on milk fat percentage. While the highest fat percentage was obtained in winter and spring during the study conducted by Tuncer et al. (2017), the findings of Davut and Atasever (2017) emphasize the prominence of the autumn season. In our study, the highest fat percentage in milk was observed in winter calving season, and this value was statistically different from other seasons. The higher fat content during the winter calving season is thought to be due to the need for more intensive care and feeding conditions, allowing farms to navigate the winter months more smoothly. Milk fat percentages are similar in spring, summer, and autumn, with no statistically significant differences found between them. No statistically significant differences were found in protein and lactose percentages depending on the season. The study conducted by Tuncer et al. (2017) also determined that protein ratios did not show seasonal variation. In contrast, Kul et al. (2019) reported that protein and lactose ratios were lowest levels in the spring season. Regarding LogSCC values (Table 2), a statistically significant difference was found between the calving seasons ($P < 0.001$). The highest logSCC mean was observed in the winter, while lower values were obtained in the spring, summer, and autumn calving seasons, respectively. This result suggests that an increase in SCC values may be observed during winter months due to exposure of the udder to environmental contamination (dirty bedding, manure, urine) caused by adverse weather conditions, negatively affecting udder health. Kul et al. (2019) also found the highest SCC levels in cows calving in winter. Çoban et al. (2007) reported that the increase in SCC in milk during winter is due to the fact that dairy cows cannot obtain sufficient vitamin A, which has epithelial protective properties, from pasture in summer. These findings indicate that calving season should be considered among the factors affecting milk quality. Winter is particularly prominent in terms of milk fat percentage and SCC.

Table 3 shows the variation of milk components and logSCC values according to different regions. No significant difference was found between regions in terms of fat content. The average milk fat percentages were determined as $3.69 \pm 0.054\%$, $3.73 \pm 0.150\%$, and $3.75 \pm 0.054\%$ in Amasya-Center, Merzifon, and Suluova regions, respectively, and the overall average was calculated as $3.72 \pm 0.061\%$. This value is above the value predicted by FAO (2025).

Table 1. Descriptors of the parameters

Parameter	n	Min	Max	$\bar{x} \pm s_x$
Fat	108	2.05	6.28	3.72 ± 0.061
Protein	108	3.06	4.18	3.48 ± 0.015
Lactose	108	4.41	5.06	4.86 ± 0.013
SCC	108	27000	1178000	419259.25 ± 28020.619
LogSCC	108	4.43	6.07	5.53 ± 0.027

Table 2. Milk components (%) and logSCC means according to calving season

Calving season	n	Fat (%)	Protein (%)	Lactose (%)	LogSCC($\bar{x} \pm s_x$)
Winter	26	4.09 ± 0.189^b	3.54 ± 0.043	4.86 ± 0.025	5.82 ± 0.049^B
Spring	8	3.45 ± 0.172^a	3.46 ± 0.066	4.89 ± 0.075	5.40 ± 0.106^A
Summer	59	3.64 ± 0.059^a	3.46 ± 0.016	4.87 ± 0.016	5.42 ± 0.30^A
Fall	15	3.49 ± 0.96^a	3.45 ± 0.034	4.79 ± 0.040	5.49 ± 0.041^A
Overall	108	3.72 ± 0.061	3.48 ± 0.015	4.86 ± 0.013	5.53 ± 0.027

Means indicated by different letters in the same column are different (^{a,b}: $P < 0.05$; ^{A,B}: $P < 0.001$)

Table 3. Milk components and logSCC values by regions

Region	n	Fat (%)	Protein (%)	Lactose (%)	LogSCC ($\bar{x} \pm s_x$)
Amasya-Center	45	3.69 ± 0.054	3.48 ± 0.009	4.87 ± 0.017	5.42 ± 0.012^A
Merzifon	41	3.73 ± 0.150	3.49 ± 0.037	4.82 ± 0.022	5.68 ± 0.053^B
Suluova	22	3.75 ± 0.054	3.46 ± 0.021	4.89 ± 0.035	5.44 ± 0.047^A
Genel	108	3.72 ± 0.061	3.48 ± 0.015	4.86 ± 0.013	5.53 ± 0.027

Means indicated by different letters in the same column are different (^{A,B}: $P < 0.001$)



Table 4. Correlation coefficients among the parameters

Parameter	Protein	Lactose	LogSCC
Fat	-0.043	0.006	-0.359**
Protein		0.022	-0.017
Lactose			-0.323**

There was no statistically significant difference between regions in terms of protein and lactose content ($P>0.001$). Protein content ranged approximately 3.46–3.49% in all regions, while lactose content ranged 4.82–4.89%. This indicates that milk components are not significantly affected by regional factors. However, the calculated values for protein were higher than those reported by FAO (2025), and the calculated values for lactose were quite close to the rate that reported.

The average SCC calculated in this study is within the 400x10³ cells/ml limit reported by the Turkish Food Codex (TFC), but is lower (Atasever et al., 2012; Keskin and Atasever, 2013) or similar (Davut and Atasever, 2017; Önal et al., 2021) with some previous research results conducted under Türkiye conditions. According to Table 3, a high level of statistical difference was found between regions in terms of logCC values ($P<0.001$). The highest logSCC value was observed in the Merzifon region, which is statistically significantly higher compared to the Amasya Center and Suluova regions. This case suggests that the samples were taken from different farms in the Merzifon region compared to other regions, or that udder health problems may be more prevalent there. Consequently, no significant differences were observed between regions in terms of milk components. However, it is assessed that additional measures should be taken to improve udder health management and hygiene conditions in the region with high SCC values.

The relationships between milk components and logSCC were evaluated, and the obtained correlation coefficients are presented in Table 4.

Milk fat percentage shows a negative and significant correlation with logSCC. This indicates that SCC decreases as milk fat percentage increases. Similarly, lactose percentage also shows a negative and significant relationship with logSCC; this supports the idea that lactose may decrease in cases of mastitis. Furthermore, the inverse relationship between fat and lactose percentages in milk components and logSCC suggests that these parameters are important indicators of udder health..

Conclusion

In this study, which determined the effects of calving season on milk quality parameters in Holstein cattle, no significant effect was found on milk protein content, while milk fat and SCC values were higher in calves calving in winter. The average SCC of samples collected from Merzifon was found to be higher than that from other regions. Furthermore, the negative correlations calculated between SCC and lactose ($r=-0.323$) and fat ($r=-0.359$) indicate that, in addition to SCC, lactose and fat levels can also be reliably evaluated in determining raw milk quality.

In the general evaluation, the calculated average SCC was quite close to the limit reported by the TFC; the average lactose content was close to the recommended value for Holstein cow milk reported by FAO (2025); and the fat and protein ratios were found to be higher. It is thought that making adjustments to milking hygiene, udder cleaning, and milk storage conditions would be beneficial in order to further reduce SCC in the farms included in the present study.

Declarations

Ethical approval: This study did not require ethical approval since Animal Experiments Ethics Committee (HAYDEK) in Türkiye excludes milk sampling process from the approval necessities..However, the research proposal was approved by Institute of Natural Science of University of Ondokuz Mayıs, Samsun,Türkiye (Decision No: 2016/772) prior to the field work.

Author Contribution Statement

Y.Y.K.: collecting data, constructing tables and writing initial manuscript; S. A.: planning the study, statistical analyses and finalization of the article.

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Conflict of Interest

Authors declare that there is no conflict of interest.



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Comparison of Some Milk Quality Characteristics of Pırlak Sheep Milk Raised in the Districts of Manisa (Selendi) and Kütahya (Aslanapa)

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Abstract

Sheep milk, an important form of animal production, is a significant source of nutrition for both Turkey and the world. The quality of milk yield is influenced by factors such as the animal's breed, age, productivity direction, feeding habits, and environmental factors. In this study, the same ration was provided to family operated farms raising Pırlak sheep breed selected from Manisa (Selendi) and Kütahya (Aslanapa) in the Aegean region. Milk samples were collected three times, once a month, and the differences between them were investigated. The physicochemical properties such as fat, non fat dry matter (NFDm), density, protein, and lactose were determined in the collected milk samples. It was found that the fat content was higher during the late lactation period (8.08 ± 1.19 ; 8.94 ± 2.04), while other parameters, excluding fat, including protein, lactose, non fat dry matter, total dry matter, and pH were found to be significant for the farms. The timing of milk collection from the farms was also found to be important ($P < 0.001$). Despite having the same ration, the differences in milk quality parameters are believed to stem from management practices and environmental factors. As a result of the research, it was determined that environmental conditions, management, and feeding practices directly affect the factors determining milk quality in sheep farming operations. The study emphasized the necessity of moving away from traditional feeding methods in sheep farming and implementing feeding rations suited to modern practices, designed by experts. Additionally, it was identified that there is a need for more widespread research on sheep milk. The study also aims to utilize the findings from the milk quality analysis for proper pricing, raise awareness among producers, and positively influence both yield and quality.

Keywords: Pırlak Sheep, Milk Quality, Fat, Protein, Lactose, Environmental Factors





Comparison of Some Physicochemical Properties of Holstein Cow Milk Raised in the Districts of Uşak (Eşme) and İzmir (Çiğli)

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Abstract

Cattle breeding is an important livestock production activity both worldwide and in Türkiye. Milk and dairy products play a significant role in healthy and balanced human nutrition. It is known that cattle breeds raised in different regions of Türkiye gradually adapt to the climatic and environmental conditions of their environments. Even in animals belonging to the same breed, environmental factors may cause significant differences in milk yield and milk quality. This study aimed to compare some physicochemical properties of milk samples obtained from Holstein cows raised in small family farms located in the districts of Eşme (Uşak) and Çiğli (İzmir). The research material consisted of milk samples collected from a total of 160 randomly selected lactating cows from each district. The cows from which samples were taken were selected from the same lactation period; 80 from Çiğli district and 80 from Eşme district. Analyses of milk fat, protein, lactose, total solids, and solids-not-fat were performed. The obtained data were evaluated using the independent samples t-test. According to the analysis results, statistically significant differences were detected between the farms in terms of fat, lactose, total solids, and solids-not-fat values ($p < 0.05$). However, no significant difference was found in protein content ($p > 0.05$). In conclusion, environmental conditions and management differences were determined to have significant effects on milk composition.

Keywords: *Holstein, milk quality, physicochemical properties, fat, protein, lactose*



Cryopreservation of Insect Tissues and Developmental Stages: Sustainability and Future Perspectives for Biological Control

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Abstract

Cryopreservation is an advanced biological preservation technique that enables the long-term storage of living organisms or biological materials at ultra-low temperatures while maintaining their structural integrity and viability. In the field of entomology, this technique has gained increasing importance for the preservation of insects at different developmental stages, including eggs, embryos, larvae, and reproductive tissues. The sustainable conservation of insects, which constitute a major component of global biodiversity, has become an essential requirement from the perspectives of both agricultural pest management and biodiversity conservation.

Due to the increasing drawbacks associated with chemical control, which remains the most widely used method in pest management, biological control based on the use of natural enemies has emerged as one of the most important alternative strategies. The application of cryopreservation techniques in insects offers significant advantages for biological control programs by enabling the availability of biological control agents in the desired quantity and at the required time. Furthermore, cryopreservation represents a multidimensional technology in entomology, with a broad range of applications including the year-round propagation of insect species that are difficult to mass rear, the standardization of mass-production systems, and the long-term preservation of insect genetic resources. Future advances in cryoprotectant optimization and cryogenic protocols are expected to further expand the applicability of this technology across diverse insect taxa.

Keywords: Biological control, Cryopreservation, Insect, Vitrification, Cryoprotectant

Introduction

Insects represent more than half of all described animal species and play indispensable roles in ecosystem functioning, agricultural production, and biotechnological research (Denlinger & Lee, 2010; Sinclair et al., 2022). Their ecological importance extends to pollination, nutrient cycling, biological control, and the maintenance of food webs, while their economic significance is evident in agriculture, medicine, and biotechnology. Consequently, the long-term preservation of insect genetic resources is of considerable importance for pest management, conservation of beneficial insects, maintenance of laboratory colonies, and biodiversity protection. Cryopreservation has emerged as one of the most promising preservation strategies to achieve these objectives. However, the successful application of cryopreservation in insects remains challenging because of their complex physiology, diverse developmental stages, and species-specific responses to low-temperature stress.

The natural ability of insects and various other organisms to survive exposure to subzero temperatures provides valuable insights into cryopreservation strategies. Several species have evolved remarkable physiological adaptations that allow survival under extreme cold conditions. For example, the wood frog (*Rana sylvatica*) can survive while frozen throughout the winter and resume normal activity after thawing in spring. Similarly, adult fungus gnats (*Exechia nugatoria* Johannsen) have been reported to survive freezing at temperatures as low as -50°C (Sformo et al., 2009). Furthermore, some collembolans, nematode eggs, and larvae of the Antarctic midge *Belgica antarctica* survive by undergoing extensive dehydration until equilibrium is established between body fluids and the vapor pressure of surrounding ice, thereby avoiding freezing altogether (Holmstrup et al., 2002; Elnitsky et al., 2008).

Comparable cold tolerance has also been observed in nematodes such as *Trichostrongylus colubriformis* and *Panagrolaimus davidi*, as well as in nymphs of the cockroach *Periplaneta japonica*, which can survive short-term exposure to temperatures between -6°C and -8°C . These examples demonstrate that survival at extremely low temperatures is possible across a broad range of organisms and provide important biological foundations for cryopreservation research.

To cope with freezing conditions, insects and other arthropods have evolved numerous physiological and biochemical adaptations. These include the accumulation of cryoprotective compounds such as glycerol, sorbitol, trehalose, and antifreeze proteins (AFPs), which reduce the freezing point of body fluids and suppress ice crystal formation. In addition, mechanisms such as the elimination or masking of ice nucleators and controlled dehydration reduce the risk of intracellular freezing and associated cellular damage (Neven et al., 1986; Rickards et al., 1987; Lundheim & Zachariassen, 1993; Worland, 1996; Holmstrup & Sømme, 1998; Worland et al., 1998; Duman, 2001).



One of the most remarkable examples of insect cold tolerance is the Alaskan beetle *Cucujus clavipes puniceus* (Coleoptera: Cucujidae). During winter, its larvae can withstand temperatures as low as -58°C and enter a vitrified, glass-like state below this threshold, thereby preventing lethal ice formation. This vitrified condition enables survival at temperatures approaching -150°C . The species achieves such extraordinary freeze avoidance through extensive dehydration and the substantial accumulation of glycerol and antifreeze proteins, whose concentrations may increase up to fivefold relative to pre-dehydration levels (Bennett et al., 2005). Antifreeze proteins not only inhibit ice crystal growth but also prevent inoculative freezing initiated by external ice contacting the insect cuticle.

These naturally occurring adaptations provide valuable models for the development of cryopreservation technologies. Despite considerable advances in understanding insect cold tolerance mechanisms, reliable cryopreservation protocols remain unavailable for many species. Differences in developmental stage, membrane permeability, cryoprotectant toxicity, and freezing sensitivity often result in variable survival rates following cryogenic storage. Consequently, further research is required to optimize cryoprotective treatments, cooling and warming procedures, and post-thaw recovery protocols. A comprehensive understanding of insect cryobiology is therefore essential for expanding the application of cryopreservation in entomological research, biological control programs, and genetic resource conservation.

Benefits of Low-Temperature Storage

Low-temperature storage offers numerous advantages for insect research, mass-rearing systems, and biological control programs. One of its primary benefits is the ability to provide beneficial insect species to end users when needed, thereby improving the efficiency and flexibility of release programs. Cold storage also contributes to the sustainability of mass-production systems by enabling synchronization between insect production and field application.

In addition, low-temperature storage facilitates the production of standardized insect populations suitable for long-term ecological, physiological, genetic, and behavioral studies (Leopold, 1998; Tunca et al., 2014). By extending the storage life of insects and reducing the need for continuous colony maintenance, these techniques significantly lower production and maintenance costs.

The preservation of insect eggs and other developmental stages under refrigerated or cryogenic conditions also supports the long-term conservation of cytogenetic materials and valuable genetic resources (Branson, 1976; Sharakhova et al., 2006). Furthermore, cryopreservation enables the recovery of insect populations without substantial alterations in their genetic or phenotypic characteristics, thereby enhancing experimental reproducibility and supporting breeding programs (Leopold et al., 2001).

In biological control programs, cryopreservation of parasitoids and predators provides year-round availability and reduces the costs associated with continuous rearing operations (Pérez-Bañón et al., 2022). Moreover, the cryogenic preservation of endangered insect species represents a valuable tool for conservation biology, restoration ecology, and evolutionary studies by safeguarding genetic diversity for future research and reintroduction efforts (Lee & Costanzo, 2023).

Cryopreservation Applications in Insects

Cryopreservation is a preservation technology that enables the long-term storage of biological materials through the near-complete cessation of metabolic activity at ultra-low temperatures, typically in liquid nitrogen at -196°C (Mazur, 2004) (Figure 1). Although cryopreservation has been successfully applied to numerous mammalian and plant systems, its implementation in insects remains considerably more challenging because of the low permeability of embryonic membranes, species-specific physiological characteristics, water balance mechanisms, and sensitivity to cryoprotectant toxicity (Leopold, 2010).

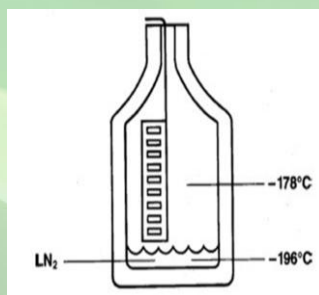


Figure 1. Temperature Ranges of Liquid Nitrogen and Vapor

The limited success achieved in insect cryopreservation can largely be attributed to substantial interspecific physiological variation, developmental-stage-specific sensitivity, cryoprotectant toxicity, and post-thaw developmental abnormalities. Consequently, the development of effective preservation protocols generally requires species-specific and stage-specific approaches rather than universal methodologies.



As an alternative to whole-embryo cryopreservation, the preservation of sperm, oocytes, and primordial germ cells has attracted increasing attention. These approaches reduce technical complexity and circumvent many of the barriers associated with embryonic structures, particularly the chorion and vitelline membranes (Ohno et al., 2020). Furthermore, germline cryopreservation provides improved reproducibility in maintaining valuable genetic lines and facilitates long-term genetic conservation efforts (Wang et al., 2024).

The principal causes of cryoinjury include intracellular and extracellular ice crystal formation, osmotic stress, recrystallization during warming, and cryoprotectant toxicity (Mazur, 2004; Steponkus & Wolfe, 1999). Intracellular ice crystals can mechanically disrupt cellular structures and compromise membrane integrity, whereas extracellular ice formation promotes dehydration, protein denaturation, and membrane phase transitions. Understanding these mechanisms is critical for improving cryopreservation outcomes.

Natural cold-tolerance mechanisms observed in insects provide valuable insights into cryobiological processes. Adaptations such as the accumulation of low-molecular-weight cryoprotectants, including glycerol, trehalose, and proline, the synthesis of antifreeze proteins, and modifications in membrane lipid composition contribute significantly to cellular stability under cold stress (Košťál et al., 2019; Lee & Costanzo, 2023).

During cryopreservation, differences in vapor pressure between supercooled body fluids and surrounding ice result in cellular dehydration until equilibrium is established. Although controlled dehydration helps prevent intracellular ice formation, excessive water loss may increase intracellular solute concentrations and cause mechanical and osmotic damage. Therefore, carefully designed freezing procedures and appropriate cryoprotective agents are essential for maximizing post-thaw survival and maintaining cellular integrity.

Cryoprotectants and Their Mechanisms of Action

Cryoprotectants are chemical compounds used to minimize cellular damage during freezing and thawing processes by protecting biological structures from cryoinjury (Palasz & Mapletoft, 1996). Their primary function is to reduce ice crystal formation, alleviate osmotic stress, stabilize cellular membranes, and improve post-thaw survival. Based on their ability to cross biological membranes, cryoprotectants are generally classified into two major categories: permeating and non-permeating cryoprotectants (Leopold, 2010).

In insect cryopreservation, the effective use of cryoprotectants is particularly important because insect embryos possess multilayered protective structures, including the chorion and vitelline membranes, which greatly restrict the penetration of many cryoprotective compounds. Consequently, successful cryopreservation often requires prolonged cryoprotectant exposure or the application of physical and chemical pretreatments designed to enhance membrane permeability (Li et al., 2021).

Permeating Cryoprotectants

Permeating cryoprotectants are characterized by their relatively low molecular weight and ability to penetrate cellular membranes. Common examples include dimethyl sulfoxide (DMSO), glycerol, ethylene glycol (EG), 1,2-propanediol, 2,3-butanediol, propylene glycol, and several related alcohols (Palasz & Mapletoft, 1996; Agca, 1994; Sağırkaya, 2001).

These compounds exert their protective effects by replacing intracellular water before freezing occurs. As cryoprotectants enter the cell, osmotic gradients facilitate the removal of intracellular water, thereby reducing the amount of water available for ice crystal formation. This process minimizes both intracellular ice formation and excessive changes in cell volume during cooling.

In addition to reducing ice formation, permeating cryoprotectants interact directly with water molecules. Many of these substances possess high water solubility and modify the molecular structure of water by disrupting hydrogen-bond networks. At the same time, they are capable of forming hydrogen bonds with water molecules. For example, glycerol interacts with water through its hydroxyl groups, thereby lowering the freezing point and reducing the likelihood of ice crystallization.

Another important function of permeating cryoprotectants is their ability to reduce cellular damage associated with dehydration and elevated extracellular solute concentrations during freezing. By maintaining osmotic balance and stabilizing cellular structures, these compounds contribute significantly to cell survival following cryogenic storage (Palasz & Mapletoft, 1996; Agca, 1994; Sağırkaya, 2001).

Non-Permeating Cryoprotectants

Unlike permeating cryoprotectants, non-permeating cryoprotectants remain outside the cell and exert their protective effects primarily through osmotic regulation and ice crystal modification. These compounds are generally divided into low-molecular-weight and high-molecular-weight categories.



Low-Molecular-Weight Non-Permeating Cryoprotectants

Low-molecular-weight non-permeating cryoprotectants function by promoting controlled cellular dehydration prior to freezing. Through osmotic action, they facilitate the removal of intracellular water, thereby reducing the probability of intracellular ice crystal formation during cooling.

Common representatives of this group include glucose, sucrose, trehalose, raffinose, galactose, and other sugars. These compounds play a crucial role in maintaining osmotic balance and stabilizing cellular membranes throughout freezing and thawing processes.

High-Molecular-Weight Non-Permeating Cryoprotectants

High-molecular-weight cryoprotectants protect cells by modifying the formation, morphology, and growth of ice crystals during freezing and thawing (Palasz & Mapletoft, 1996). Rather than entering cells, these compounds act within the extracellular environment, reducing mechanical damage associated with ice recrystallization.

Examples include polyvinyl alcohol (PVA), polyvinylpyrrolidone (PVP), albumin (Pugh et al., 1998), Ficoll (Begin et al., 2003), and antifreeze proteins (AFP) (Wang, 2000) (Palasz & Mapletoft, 1996; Agca, 1994; Bağış et al., 2002). Antifreeze proteins are of particular interest because they inhibit ice crystal growth and recrystallization, thereby improving cellular survival under cryogenic conditions.

Factors Influencing Cryoprotectant Efficiency

The effectiveness of cryoprotectants depends on several factors, including cell type, cooling and warming rates, sample volume, cryoprotectant concentration, and duration of exposure. Because cryoprotectants occupy intracellular and extracellular spaces, successful cryopreservation requires careful regulation of water and solute movement, as well as close monitoring of changes in cell volume throughout the freezing and thawing process.

Among currently available cryoprotectants, DMSO remains one of the most widely used due to its high membrane permeability and strong protective capacity. However, prolonged exposure may result in cytotoxic effects. Exposure of cells to DMSO for extended periods, particularly at elevated temperatures, has been associated with increased cellular toxicity. Therefore, cryopreservation protocols generally recommend preparing cryoprotectant solutions separately and gradually introducing cells into the mixture to minimize toxic effects.

Functions of Cryoprotectants During Freezing

Cryoprotectants contribute to successful cryopreservation through several complementary mechanisms. Their major functions include:

- Prevention of intracellular and extracellular ice crystal formation;
- Reduction of electrolyte concentration effects and pH fluctuations;
- Prevention of protein denaturation;
- Protection against dehydration-induced cellular damage;
- Depression of the freezing point of cellular fluids;
- Maintenance of water in a non-crystalline state during slow cooling;
- Enhancement of long-term storage stability at temperatures below -130°C by limiting ice recrystallization;
- Improvement of post-thaw recovery through the stabilization of cellular structures during warming.

Collectively, these mechanisms increase the survival and functional recovery of cells, tissues, and embryos following cryogenic preservation and form the foundation of modern cryopreservation technologies.

Cryopreservation Techniques

Two principal techniques have been developed for the cryopreservation of cells, tissues, and embryos: controlled slow cooling and vitrification. Both methods aim to prevent lethal cellular damage during freezing and long-term storage; however, they differ considerably in their underlying mechanisms and operational procedures.

Slow Cooling (Controlled-Rate Freezing)

Controlled slow cooling was the first cryopreservation technique successfully applied to human cells and remains one of the most extensively used methods in cryobiology. In this approach, biological materials are gradually cooled at rates ranging from approximately 0.1 to $4^{\circ}\text{C min}^{-1}$ until temperatures between -30°C and -40°C are reached, followed by rapid immersion into liquid nitrogen (Engelmann, 2004).



The primary objective of slow cooling is to avoid intracellular ice formation through controlled osmotic dehydration. As extracellular ice begins to form during cooling, the osmotic gradient created between the intracellular and extracellular environments promotes the movement of water out of the cell. Consequently, the amount of intracellular water available for crystallization is reduced, thereby decreasing the risk of lethal intracellular ice formation.

When cooling conditions are appropriately controlled, cells may become supercooled and lose water because of osmotic imbalances between extracellular frozen regions and intracellular unfrozen compartments. The ability of cells or organisms to survive this process depends on several factors, including cooling capacity, cooling rate, membrane permeability, and the composition of the surrounding medium.

Cryoprotective mixtures commonly used in controlled-rate freezing include combinations of glycerol and sucrose or dimethyl sulfoxide (DMSO) and sorbitol (Sakai et al., 1990). These compounds facilitate controlled dehydration and help maintain cellular integrity during cooling.

Insect eggs are generally small and, depending on the species, can often be cooled to temperatures ranging from -25°C to -40°C before spontaneous freezing occurs (Somme, 1964). Although this characteristic appears favorable for dehydration-based cryopreservation, embryo mortality remains high in many insect species subjected to slow-freezing protocols (Heacox et al., 1985; Mazur et al., 1992; Miles & Bale, 1995). One of the primary limitations is the relatively low permeability of insect embryonic membranes, which restricts water movement and cryoprotectant penetration (Leopold, 2010).

Vitrification

Vitrification represents an alternative cryopreservation strategy designed to eliminate ice crystal formation entirely. Unlike slow cooling, vitrification does not rely on controlled extracellular freezing. Instead, biological materials are exposed to highly concentrated cryoprotectant solutions and subsequently cooled at extremely rapid rates by direct immersion in liquid nitrogen, bypassing the preliminary cooling stages associated with conventional freezing methods (Sakai & Engelmann, 2007).

The principle of vitrification is based on transforming cellular water into an amorphous glass-like state rather than allowing crystallization. This transformation is achieved through the combined effects of high cryoprotectant concentrations and ultra-rapid cooling rates (Li et al., 2021; Ohno et al., 2020). Because ice crystals do not form during the process, vitrification effectively eliminates one of the primary sources of cryogenic injury.

The first successful vitrification protocol was developed by Rall and Fahy in 1985 for the preservation of mouse embryos (Roversi et al., 2008). Subsequently, the technique was adapted for insect embryos, including those of *Drosophila melanogaster* (Mazur et al., 1992; Steponkus & Caldwell, 1993). Since then, vitrification has been successfully applied to the preservation of eggs and embryos from several insect species (Mazur et al., 1992; Wang et al., 2000; Nunamaker & Lockwood, 2001; Leopold et al., 2001; Rajamohan & Leopold, 2007).

Beyond entomological applications, vitrification has also been employed successfully in the cryopreservation of various plant and animal cells, tissues, microorganisms, and embryos (Takahashi et al., 1986; Jutte et al., 1987; Nishizawa et al., 1993; Van Wagtenonk-De Leeuw et al., 1997; Leopold, 2007).

Despite its advantages, vitrification is not without limitations. High cryoprotectant concentrations may induce cytotoxic effects, while rapid temperature fluctuations can result in thermal stress. Furthermore, successful vitrification requires strict control of both cooling and warming procedures to prevent ice crystal formation during storage and recovery.

Comparison of Slow Cooling and Vitrification

Although both slow cooling and vitrification aim to preserve biological materials at ultra-low temperatures, they differ substantially in their mechanisms of action.

In slow cooling, cellular survival depends largely on controlled extracellular ice formation and gradual osmotic dehydration. While this approach reduces the likelihood of intracellular ice formation, it may expose cells to prolonged osmotic stress and extracellular ice-related damage. In contrast, vitrification seeks to eliminate ice formation altogether by converting cellular contents into a glass-like state.

Slow cooling generally requires specialized equipment capable of accurately controlling cooling rates, whereas vitrification often relies on direct immersion into liquid nitrogen following cryoprotectant treatment. However, vitrification typically requires higher concentrations of cryoprotectants, thereby increasing the risk of cryoprotectant toxicity.

For insect embryos, vitrification has generally demonstrated greater potential than conventional slow freezing because it circumvents many of the limitations associated with low membrane permeability and intracellular ice formation. Nevertheless, both techniques require careful optimization according to species-specific physiological characteristics and developmental stages.



Insect Embryo Cryopreservation Through Vitrification

One of the most successful vitrification protocols developed for insects involves embryos of *Cochliomyia hominivorax* (Diptera: Calliphoridae) (Berkebile et al., 2000). The protocol consists of a series of carefully controlled steps designed to increase membrane permeability, facilitate cryoprotectant penetration, achieve controlled dehydration, and maximize post-thaw survival.

Initially, embryos are subjected to chemical treatments involving sodium hydroxide, sodium hypochlorite, isopropyl alcohol, hexane, and Drosophila Ringer solution. These treatments are intended to modify embryonic barriers and enhance permeability. Following these preparatory procedures, embryos are loaded with ethylene glycol and subsequently dehydrated using a vitrification solution containing ethylene glycol, polyethylene glycol, and trehalose.

After dehydration, embryos are transferred onto polycarbonate membranes and exposed to liquid nitrogen vapor before being immersed in liquid nitrogen for long-term storage. Recovery involves rapid warming followed by the gradual removal of cryoprotectants using trehalose-containing solutions, repeated washing procedures, and incubation under conditions suitable for embryonic development and hatching.

Particular attention must be given to dehydration and cryoprotectant removal, as these stages represent critical points where osmotic injury may occur. To minimize such damage, cryoprotectants are introduced gradually, dehydration is typically performed at 0°C, and insect cell culture media are frequently used as diluents during treatment. These measures help maintain osmotic balance and improve post-thaw survival.

The importance of osmotic regulation during recovery has been demonstrated in *Cochliomyia hominivorax*, where Drosophila Ringer solution was used as an equilibration and transfer medium following hexane treatment designed to remove the lipid layer associated with the vitelline membrane (Steponkus & Caldwell, 1993; Leopold et al., 2001). Such procedures contribute significantly to successful embryonic recovery after cryogenic storage.

Successful vitrification requires that ice crystal formation be avoided not only during cooling but also throughout warming and recovery. Although vitrification itself generally causes limited cellular and molecular damage, disturbances in water balance and intracellular solute concentrations may result in severe physiological stress and mortality. Therefore, continued refinement of vitrification protocols remains essential for improving cryopreservation outcomes in insects.

Studies on Cryopreservation

Numerous studies conducted over the past several decades have demonstrated the feasibility of cryopreservation for a wide range of invertebrates and insect species. Early investigations focused primarily on evaluating the survival of organisms following exposure to ultra-low temperatures and identifying suitable preservation strategies.

One of the earliest successful applications was reported by Campbell et al. (1973), who demonstrated that larvae of the nematode *Haemonchus contortus* remained viable after storage in liquid nitrogen at -196°C for 44 weeks. This study highlighted the potential of cryogenic preservation for maintaining biological materials over extended periods.

Among insects, considerable attention has been directed toward species used in biological control programs. Parasitoids belonging to the genus *Trichogramma* are widely utilized against numerous lepidopteran pests, making the development of efficient storage methods particularly important for large-scale rearing and release programs (Leopold, 1998).

Correa-Ferreira and De Oliveira (1998) successfully preserved eggs of *Nezara viridula* in liquid nitrogen for up to twelve months. Following storage, parasitization rates by *Trissolcus basalis* were found to be comparable to those observed in fresh eggs, demonstrating the suitability of cryopreserved host material for biological control applications.

Similarly, Greco and Stilinovic (1998) reported that cryopreservation of *Sitotroga cerealella* eggs did not significantly affect the parasitization performance of *Trichogramma pretiosum*. These findings suggested that liquid nitrogen storage could provide a practical alternative to continuous host rearing.

Albuquerque et al. (2000) further demonstrated that liquid nitrogen storage was superior to conventional freezing temperatures for the long-term preservation of *Nezara viridula* eggs. Their results emphasized the advantages of cryogenic storage for maintaining host quality over prolonged periods.

Leopold et al. (2001) investigated the cryopreservation of embryos of *Cochliomyia hominivorax*. Although a reduction in pupal weight was observed among cryopreserved individuals, these effects were not transmitted to subsequent generations, indicating that the preservation process did not result in permanent genetic or developmental alterations.

Research involving *Ephesia kuehniella* eggs revealed that prolonged low-temperature storage may negatively influence the biological performance of associated parasitoids. Özder and Sağlam (2002) reported reductions in parasitization rates, adult longevity, and reproductive capacity following extended storage periods.



Studies of naturally cold-tolerant insects have also contributed substantially to cryobiological knowledge. Sformo et al. (2010) demonstrated that larvae of *Cucujus clavipes puniceus* could survive exposure to temperatures approaching -100°C through vitrification-like mechanisms that prevent ice crystal formation. These findings provided important insights into naturally evolved freeze-avoidance strategies and their relevance to artificial cryopreservation protocols.

Cryopreservation has also been successfully applied to reproductive tissues. Ovarian tissues of *Harmonia axyridis* were cryopreserved and subsequently transplanted into recipient females, resulting in the production of fertile offspring capable of maintaining genetic lineages (Sformo et al., 2010). Such studies highlight the potential of germline preservation as an alternative to whole-embryo cryopreservation.

More recently, Krechemer and Foerster (2016) and Özder and Tayat (2018) demonstrated that cryopreserved host eggs remained suitable for parasitization by various *Trichogramma* species. These findings further support the practical application of cryopreservation technologies in biological control programs by facilitating long-term storage and year-round availability of host materials.

Collectively, these studies demonstrate that cryopreservation can successfully preserve a variety of insect developmental stages and reproductive tissues while maintaining biological functionality after recovery. However, survival rates and post-thaw performance remain highly species-dependent, emphasizing the need for continued protocol optimization.

Applications of Cryopreservation in Other Biological Systems

The successful implementation of cryopreservation extends far beyond entomological applications and has become an essential technology in human medicine, plant biotechnology, and animal reproduction.

In human reproductive medicine, cryopreservation has enabled the long-term storage of spermatozoa, embryos, and reproductive tissues. Successful pregnancies have been achieved using sperm samples preserved in liquid nitrogen for extended periods, demonstrating the effectiveness of cryogenic storage for maintaining reproductive potential and genetic integrity (Wetzels et al., 1996; Delilbaşı, 2008; Walters et al., 2009; Verheyen, 2010; Kadioğlu, 2011).

Plant cryopreservation has likewise become an important tool for germplasm conservation. Since the 1960s, cryogenic storage techniques have been successfully applied to plant cell cultures, meristems, embryos, pollen grains, seeds, and other propagative materials (Grout & Henshaw, 1980; Towill, 1983; Withers & King, 1979, 1980; Kartha et al., 1980; Mullin & Schlegel, 1976; Sakai et al., 1978; Niwata et al., 2000). These approaches provide long-term preservation of valuable genetic resources while minimizing the risks associated with conventional storage methods.

In livestock breeding programs, cryopreservation has become a routine component of assisted reproductive technologies. The successful production of offspring from cryopreserved embryos and vitrified spermatozoa has demonstrated the reliability of cryogenic preservation for maintaining reproductive material in economically important animal species (Chemineau et al., 1986; Baril et al., 1989; Nowshari & Holtz, 1995; Guignot et al., 2006; Thibier, 2009; Kızıl et al., 2011).

The widespread adoption of cryopreservation across diverse biological systems illustrates its versatility as a preservation technology and highlights its potential for broader application in entomology and insect conservation.

Conclusion

Cryopreservation represents one of the most promising approaches for the long-term preservation of insect genetic resources and beneficial species. Advances in cryobiology have significantly improved our understanding of the physiological and biochemical mechanisms underlying cold tolerance, freeze avoidance, and cryoinjury in insects. These developments have facilitated the design of increasingly effective preservation strategies for embryos, reproductive tissues, and other developmental stages.

Despite these advances, the successful cryopreservation of insects remains considerably more challenging than that of many plant and vertebrate systems. Species-specific physiological characteristics, low membrane permeability, developmental-stage sensitivity, cryoprotectant toxicity, and osmotic stress continue to limit survival and recovery rates. Consequently, the development of universally applicable cryopreservation protocols remains unlikely, and species-specific optimization is required.

Among currently available approaches, vitrification appears particularly promising because it minimizes ice crystal formation and reduces mechanical damage during freezing. Nevertheless, further improvements in cryoprotectant formulations, permeability enhancement techniques, and post-thaw recovery procedures are necessary to maximize survival and reproductive performance following cryogenic storage.

Cryopreservation offers substantial opportunities for biological control programs by enabling year-round availability of parasitoids, predators, and host materials while reducing production costs associated with



continuous rearing. In addition, the preservation of endangered insect species and valuable laboratory strains contributes to biodiversity conservation, restoration biology, and long-term genetic resource management.

Future research should focus on improving our understanding of insect-specific cryobiological responses, identifying less toxic and more effective cryoprotectants, and integrating advances in molecular biology, physiology, and reproductive biotechnology into cryopreservation protocols. Such efforts will contribute to the development of reliable and efficient preservation strategies capable of supporting both fundamental research and practical applications in entomology.

Declarations

Author Contribution Statement

The contribution of each author to this study should be specified in terms of stage and nature of contribution. For example: O.M: Data collection, investigation, formal analysis, and original draft writing. H.Ç: Supervision, review, and editing. F.N.E: Data curation, writing.

Conflict of Interest

The authors declare that there is no conflict of interest.

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Knowledge Level Of Crop Farmers On Food Safety Practices In Ogbomosho Agricultural Zone Of Oyo State Nigeria

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Abstract

The study assessed crop farmers' knowledge of food safety practices in Ogbomosho Agricultural zone of Oyo State, Nigeria. It specifically examined farmers' socio-economic characteristics, production practices associated with food safety risks, information sources as well as barriers to adoption of the food safety practices. Data were collected from 144 crop farmers using structured interviews and analyzed using descriptive statistics (frequency, percentage, mean) and Pearson Product Moment Correlation (PPMC) to test relationships. Findings showed a mean age of 47 years and an average household size of nine persons. A large proportion (75%) lacked access to health extension workers, indicating weak institutional support. Key risky practices included drying crops on bare ground, use of untreated animal manure, and use of contaminated water. Major information sources were mass media channels such as radio drama, SMS, and television, while formal extension agents, NGOs, and religious organizations were less frequently accessed. Overall, respondents demonstrated relatively high knowledge of safe post-harvest handling, storage, and appropriate agrochemical use. However, adoption of the food safety practices was constrained by mistrust of modern food safety practices, financial limitations, and cultural traditions. Poor adherence to food safety was reported to negatively affect productivity, income, and social relations. Significant positive relationships were found between food safety knowledge and age ($r = 0.363$, $p = 0.002$), education ($r = 0.507$, $p < 0.001$), and household size ($r = 0.484$, $p < 0.001$). The study concludes that despite relatively high knowledge levels, structural and institutional gaps particularly limited extension services hinder effective food safety practice adoption. It recommends strengthened agricultural and health extension services to provide continuous training on Good Agricultural Practices (GAP), safe agrochemical use, and improved water and post-harvest handling practices.

Keywords: Knowledge level, Crop production, Crop farmers, Food safety, Food safety practices

Introduction

Food, a basic necessity of life, derives its importance from the fact that it stimulates appetites, supplies a variety of ingredients that give energy, replace worn-out tissues, thus promoting growth and help in preventing and curing diseases (Okojie and Isah, 2019). Food safety refers to all the procedures and conditions used to guarantee that food is safe, wholesome, and suitable for human consumption, from the point of production to the point of consumption. A sustainable food system must prioritize food safety in order to guarantee that consumers have access to wholesome food (World Health Organization, 2023).

However, the manifold sources of food and the processes it undergoes before it is eaten create a fairly high probability that it might become an infective agent (Christiana *et al.*, 2022). Food, through improper handling, could be a source of infection leading to illness and diseases, poor health, and reduced productivity (Federal Ministry of Health, 2015). Food must be treated carefully to protect human health since it is the most vital and only material that all humans and animals must ingest in order to survive. Anywhere in the food chain, contamination can have serious and occasionally lethal repercussions. However, Nigerian home crop growers have little knowledge of food safety, and over 91 million people worldwide including those in Africa are afflicted by food-borne illnesses each year, with about 137,000 deaths attributable to these illnesses (Cissé, 2019), over 70% of instances of diarrheal infection in underdeveloped countries originated in foodborne infections due to inadequate food safety procedures and the use of unwholesome food.

In addition to causing health problems, unsafe food can also have a negative economic impact through hospital expenses and lost revenue from foreign trade (Awoyemi *et al.*, 2019). There is an urgent need to evaluate how agricultural techniques affect food safety as they change to satisfy the world's expanding food demands, especially in light of new worries about environmental contaminants, pesticide residues, and microbiological contamination (Usman, 2024). On this note this study specifically ascertained the socio-economic characteristics of the respondents, determined crop production practices linked to food safety concern, identify sources of information on food safety practices and determined the barriers to usage of food safety practices



Methodology

This study was carried out in Ogbomoso Agricultural Zone of Oyo State. The study makes use of multi-stage sampling technique. First stage involved purposive selection of two (2) extension blocks out of 5 blocks in the zone, Surulere and Oriire blocks were purposively selected because of the level of their rurality and high concentrations of crop farmers. Second stage involved random selection of three (3) cells in selected blocks. From Oriire block; Ajinapa, Tewure and Ahoro-dada were randomly selected, while Iresadu, Iresaapa and Baya-oje were selected from Surulere block. Third stage involved selection of 24 crop farmers from each selected cells, using simple random sampling, making 144 crop farmers to form the sample size for this study. The dependent variable is knowledge level of crop farmers on food safety practice was measured on a four (4) point rating scale of Adequate knowledge= 3, Basic knowledge= 2, Minimal knowledge= 1 and No knowledge= 0.

Results and Discussion

Socio-economic characteristics of the respondents

Data presented in Table 1 shows the distribution of the respondents according to their socio-economic characteristics. 8.4% of the respondents were less or equal to 30 years of age, 26.5% were between the age of 31-40 years, 27.8% were between 41-50 years of age, 21% were between 51-60 years, 16.7% were 61 years and above. With a mean age of 47 years, it implies that the respondents were within the economic active age group and will be able to cope with the rigours associated with crop production. Also, it was observed that 58.3% of the respondents were male, 41.7% were female, 6.9% of this respondents were single, 5.6% were separated, 1.4% claimed to be divorced, 5.6% were widow while majority (80.6%) were married, this implies that family as an institution is not left out in the pursuit of food safety practices, this agrees with the submission of (Udoh, 2020) that any interventions aimed at families in the pursuit of food safety practices would favour households' ability to reduce food contamination.

Table 1: Distribution of the respondents according to their socio-economic characteristics n=144

<i>Socio-economic characteristics</i>	<i>Frequency</i>	<i>Percentage</i>	<i>Mean</i>
Age			
≤30	12	8.4	47 years
31-40	38	26.5	
41-50	40	27.8	
51-60	30	21.0	
61 and above	24	16.7	
Sex			
Male	84	58.3	9 people
Female	60	41.7	
Marital status			
Single	10	6.9	
Separated	8	5.6	
Divorced	2	1.4	₦ 2137120
Widow	8	5.6	
Married	116	80.6	
Academic qualification/ Years spent in school			
Primary school completed	72	50	
Secondary school completed	58	40.3	
Tertiary education	14	9.7	
Household size			
≤5	30	20.9	9 people
6-10	64	44.4	
11 and above	50	34.8	
Annual income (₦)			
≤500,000	96	66.7	₦ 2137120
500,000 – 1000,000	18	12.6	
1000,000 and above	30	20.9	
Membership of Social Organization			
Yes	86	59.7	40.3
No	58	40.3	
Access to Health Extension Worker			
Yes	108	75.0	25.0
No	36	25.0	

Source: Field Survey, 2025.



Also, 50% of the respondents completed primary school education, 40.3% completed secondary school education, 9.7% had tertiary education, 20.9% of the respondents had an household size of less or equal to 5person, 44.4% had between 6-10, 34.8% had 11 and above individuals in their household. The mean household size of 9 suggests that respondents in the study area may experience difficulty complying with recommended food safety practices due to large family sizes. This finding corroborates the submission of (Vihi, Daudu and Anonguku, 2020) that households with many family members may not fully adhere to routine food safety practices because of overcrowded living conditions.

Furthermore, Table 1 revealed that 66.7% of the respondents earns less or equal ₦500,000 annually, 12.6% earns between ₦500,001 - ₦ 1000,000, annually, while 20.9% earns ₦1000,001 and above, with a mean annual income of ₦1362638.89. Also, 59.7% of the respondents claimed to belong to one social organization or the other, while 40.3% does not. Lastly on Table 1, 75.0% of the respondents claimed not to have access to health extension workers in the study area, this indicate that health extension work in the study is not frequent.

Crop production practices linked to food safety concern

Table 2 shows the distribution of the respondents according to Crop production practices linked to food safety concern. Using Weighted Mean Score, these practices were ranked. The habit/ practice of Drying crops on bare ground ranked first with a WMS of 1.49, Use of untreated or fresh animal manure ranked second with a WMS of 0.94, Use of contaminated water ranked third with a WMS of 0.85, Harvesting immature or stressed crops ranked fourth with a WMS of 0.64, Improper post-harvest handling ranked fifth with a WMS of 0.42, Wildlife and livestock access to fields ranked sixth with a WMS of 0.33, Overuse or misuse of fertilizers ranked seventh with a WMS of 0.31, High chemical input ranked eighth with a WMS of 0.24, Improper use of Pesticide ranked ninth with a WMS of 0.22, Inadequate pest control during storage ranked tenth with a WMS of 0.08. This result implies that the habit of Drying crops on bare ground, use of untreated or fresh animal manure and use of contaminated water were the top Crop production practices linked to food safety concern. This finding agrees with previous Nigerian studies which identified the use of contaminated irrigation water, untreated manure, and unsafe crop handling practices as major contributors to food safety risks in crop production. Akinde *et al.*, (2016) and Kurna *et al.*, (2016) reported that vegetables irrigated with contaminated water sources in Nigeria harbored pathogenic microorganisms.

Table 2: Distribution of the respondents according to Crop production practices linked to food safety concern

Practices *	WMS	Rank
Improper Use of Pesticides	0.22	9 th
Use of Contaminated Water	0.85	3 rd
Use of Untreated or Fresh Animal Manure	0.94	2 nd
Improper Post-Harvest Handling	0.42	5 th
High Chemical Input	0.24	8 th
Wildlife and Livestock Access to Fields	0.33	6 th
Overuse or Misuse of Fertilizers	0.31	7 th
Harvesting Immature or Stressed Crops	0.64	4 th
Drying Crops on Bare Ground	1.49	1 st
Inadequate Pest Control During Storage	0.08	10 th

Source: Field Survey, 2025; *Multiple responses

Source of information on food safety practices

Table 3 shows the distribution of the respondents according to source of information on food safety practices. It was observed that respondent got information from different sources in the study area, 94.4% of the respondents claimed radio drama as a source of information, 43.1% claimed television, 2.8% claimed health extension workers, 62.5% claimed information from mobile SMS, 18.1% claimed NGOs, 23.6% claimed family and friends, 1.4% claimed religious group. This implies that radio drama, mobile SMS and television were the frequent source of information on food safety practices, while religious group, NGOs and health extension workers were less frequent source of information. Summarily, this result is an indication that health extension services, which supposed to be at the forefront of this crusade is less frequent in the study area. This agreed with the findings of Adeyeye *et al.*, (2024) who reported that radio programmes delivered in indigenous languages had greater reach and behavioural influence among rural populations than direct contact with extension workers, whose services were less accessible to many respondents.

Knowledge level of crop farmers on food safety practice

Table 4 shows the distribution of the respondents according to their knowledge level on food safety practice. Using Weighted Mean Score, respondent demonstrated high knowledge level of Understanding of safe post-harvest handling, drying and storage method to minimize contamination and loses as it ranked first with a WMS



of 1.87, Compliance with local, national and international regulation and standards on food safety ranked second with a WMS of 0.97, Proper use of agricultural chemical ranked third with a WMS of 0.94, Understand specific food safety risks associated with agricultural water and soil amendments ranked fourth with a WMS of 0.90, Food safety training and education ranked fifth with a WMS of 0.04, knowledge on Proper waste management ranked sixth with a WMS of 0.04, Understanding and implementing good agricultural practices to ensure food safety ranked seventh with a WMS of 0.01, Proper hygiene practices ranked least in eighth with a WMS of 0.01. This implies that respondents demonstrated high knowledge level of safe post-harvest handling, drying and storage method to minimize contamination and loses, Compliance with local, national and international regulation and standards on food safety and Proper use of agricultural chemical. This finding agrees with the study conducted by Otekunrin *et al.*, (2023) who reported that increased awareness and training on food safety practices significantly improved farmers' knowledge of proper storage, chemical application, and post-harvest management techniques in Nigeria.

Table 3: Distribution of the respondents according to Source of information on food safety practices

Sources	Frequency	Percentage
Radio drama	136	94.4
Television	62	43.1
Health extension workers	4	2.8
Mobile SMS	90	62.5
NGOs	26	18.1
Family/ Friends	34	23.6
Religious group	2	1.4

Source: Field survey, 2025.

Table 4: Distribution of the respondents according to their Knowledge level on food safety practice

Knowledge*	WMS	Rank
Understanding and implementing good agricultural practices to ensure food safety	0.01	7 th
Compliance with local, national and international regulation and standards on food safety	0.97	2 nd
Proper use of agricultural chemical	0.94	3 rd
Understanding safe post-harvest handling, drying and storage method to minimize contamination and loses	1.87	1 st
Proper hygiene practices	0.01	8 th
Food safety training and education	0.04	5 th
Understand specific food safety risks associated with agricultural water and soil amendments	0.90	4 th
Proper waste management	0.04	6 th

Source: Field Survey, 2025. *Multiple responses

Barriers to usage of food safety practices

Table 5 shows the distribution of the respondents according to barriers to usage of food safety practice. 95.8% claimed Low awareness and knowledge as a barrier to usage of food safety practice, 97.2% claimed financial constraints, 95.8% claimed low literacy and education levels, 97.2% claimed Inadequate Infrastructure as a barrier, 95.8% claimed cultural and traditional practices, 100% of the respondents claimed mistrust of "modern" practices or authorities, 95.8% claimed absence of local food safety legislation enforcement as a barrier to usage of food safety practices. This implies that mistrust of "modern" practices or authorities, financial constraints and cultural and traditional practices were top barriers to usage of food safety practices in the study area. This finding is in agreement with the study of Olatunji *et al.*, (2022) who reported that low trust in formal food safety interventions, coupled with poverty and adherence to traditional processing methods, significantly limited compliance with recommended food safety practices among rural households in Nigeria.

Table 5: Distribution of the respondents according to barriers to usage of food safety practices

Barriers	Frequency	Percentage
Low Awareness and Knowledge	138	95.8
Financial Constraints	140	97.2
Low Literacy and Education Levels	138	95.8
Inadequate Infrastructure	140	97.2
Cultural and Traditional Practices	138	95.8
Mistrust of "Modern" Practices or Authorities	138	95.8
Absence of Local Food Safety Legislation Enforcement	138	95.8

Source: Field Survey, 2025.



PPMC analysis showing the relationship between selected socio-economic characteristics of the respondents and their knowledge level on food safety practices

Table 6 shows that there is significant relationship between Age ($r = 0.363$, $P = 0.002$), Academic qualification ($r = 0.507$, $P = 0.000$), Household size ($r = 0.484$, $P = 0.000$) of the respondents and their knowledge level on food safety practices. This implies that age, academic qualification and household size can influence knowledge level on food safety practices. Older crop farmers are expected to have high knowledge of food safety practices, also respondents with high Academic qualification should poses high knowledge level, meanwhile, respondents with larger household might find it difficult to comply with food safety practices.

Table 6: PPMC analysis showing the relationship between selected socio-economic characteristics of the respondents and their knowledge level on food safety practices

Socio-economic characteristics	r- value	P- value	Remark
Age	0.363**	0.002	Significant
Academic qualification	0.507**	0.000	Significant
Household Size	0.484**	0.000	Significant
Annual income	-0.072	0.547	Not significant

Source: Computed Data, 2026., ** Correlation is significant at the 0.01 level (2-tailed)

Conclusion and recommendations

Based on this research findings, it can be concluded that respondents demonstrated high knowledge level of food safety practices in the study area. Also, substantial proportion of the respondents lacked access to health extension workers, highlighting a critical gap in institutional support for food safety promotion. Crop production practices such as drying produce on bare ground, using untreated animal manure, and reliance on contaminated water emerged as major food safety risk factors, underscoring persistent exposure to biological and chemical hazards at the production stage. Also, while knowledge dissemination is occurring, it is largely mediated through informal or indirect channels rather than structured extension systems.

Based on this research findings, this study hereby suggest the following recommendations:

- Oyo state Ministry of Agriculture together with community health expert should look into synchronization of health and agricultural extension workers in the study area to provide regular, hands-on training and technical support on food safety and good agricultural practices.
- Crop farmers are encouraged to adopt safer crop production practices, including proper drying methods, use of treated organic manure, safe agrochemical application, and the use of clean water for irrigation and washing.
- Ministry of health in the state and health extension department should expand the use of radio programs, mobile SMS, and television to deliver targeted, culturally appropriate food safety messages, as these channels are already trusted and widely accessed by respondents.
- Government should also design interventions that consider financial constraints and cultural beliefs by providing affordable technologies, incentives, and community-based sensitization programs that build trust in modern food safety practices.

Contribution to knowledge

The study contributes to knowledge by showing that farmers' awareness of food safety practices does not necessarily lead to its adoption because of structural, institutional, and socio-cultural barriers.

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Sustainability Research in Organic Waste: Current Approaches

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Abstract

The rapid increase in global population, urbanization, and industrialization has led to a significant rise in organic waste generation, posing serious environmental, economic, and social challenges. Sustainable management of organic waste has therefore become a critical area of research, integrating principles from environmental science, biotechnology, circular economy, and resource recovery. This study provides a comprehensive and updated analysis of current approaches in organic waste sustainability research, focusing on waste valorization, technological innovations, policy frameworks, and environmental impacts. Emphasis is placed on biological and thermochemical treatment methods, circular economy strategies, and emerging technologies such as biorefineries and digital waste management systems. The review also critically evaluates the limitations of existing approaches and outlines future directions for achieving sustainable organic waste management.

Keywords: Organic Waste, Sustainability, Sustainable organic waste management

Introduction

The generation of organic waste has become one of the most pressing global environmental challenges, driven by population growth, urban expansion, and changing consumption patterns. Organic waste, which includes food waste, agricultural residues, animal manure, and municipal biodegradable waste, constitutes a significant proportion of total solid waste worldwide. Traditionally, these wastes have been disposed of through landfilling or open dumping, leading to environmental issues such as greenhouse gas emissions, soil and water contamination, and public health risks (Kaza et al., 2018). In recent decades, there has been a paradigm shift from waste disposal to resource recovery, reflecting the principles of sustainability and circular economy. Organic waste is no longer viewed as a burden but as a valuable resource that can be converted into energy, bio-based products, and soil amendments. This transformation has been facilitated by advances in biotechnology, environmental engineering, and systems analysis, which have enabled the development of innovative waste management strategies (Awasthi et al., 2020). Sustainability research in organic waste focuses on minimizing environmental impact while maximizing economic and social benefits. This involves the integration of multiple disciplines and the consideration of the entire waste management lifecycle, from generation and collection to processing and utilization. The growing importance of climate change mitigation and resource efficiency has further accelerated research in this field, making it a key component of sustainable development (Kirchherr et al., 2017).

Conceptual Framework: Sustainability and Circular Economy in Organic Waste Management

The concept of sustainability in organic waste management is closely linked to the circular economy, which aims to close material loops and reduce resource consumption. Unlike the traditional linear model of “take–make–dispose,” the circular economy emphasizes reuse, recycling, and recovery, thereby minimizing waste generation and environmental impact (Slorach et al., 2019). Organic waste plays a central role in circular systems due to its potential for biological and biochemical conversion. Processes such as composting, anaerobic digestion, and fermentation enable the transformation of organic materials into valuable products, including biogas, biofertilizers, and bio-based chemicals. These processes not only reduce waste volume but also contribute to renewable energy production and soil health improvement (Zhang et al., 2014). A key aspect of sustainability is the assessment of environmental, economic, and social impacts. Life cycle assessment (LCA) has become a widely used tool for evaluating the sustainability of organic waste management systems. LCA provides a comprehensive analysis of resource use, emissions, and environmental impacts across the entire lifecycle, enabling informed decision-making and policy development (Zhang et al., 2014; Slorach et al., 2019).

Types and Sources of Organic Waste

Organic waste originates from diverse sources, each with unique characteristics and management challenges. Municipal solid waste contains a significant proportion of food waste and biodegradable materials, particularly in urban areas. Agricultural waste, including crop residues and livestock manure, represents another major category,



especially in rural regions. Industrial organic waste, generated from food processing and manufacturing activities, often contains high concentrations of organic matter and requires specialized treatment (Li et al., 2017). The composition and properties of organic waste vary depending on factors such as geographic location, climate, and socio-economic conditions. These variations influence the selection and efficiency of waste treatment technologies. Understanding the characteristics of different waste streams is therefore essential for developing effective and sustainable management strategies (Slorach et al., 2019).

Biological Treatment Approaches

Biological treatment methods are among the most widely used approaches for organic waste management due to their environmental compatibility and resource recovery potential. Composting is a well-established technique that involves the aerobic decomposition of organic materials, resulting in the production of nutrient-rich compost. This process not only reduces waste volume but also enhances soil fertility and structure. Anaerobic digestion represents another key biological process, in which microorganisms break down organic matter in the absence of oxygen, producing biogas and digestate. Biogas, primarily composed of methane and carbon dioxide, can be used as a renewable energy source, while digestate serves as a valuable fertilizer. Advances in reactor design and process optimization have significantly improved the efficiency and scalability of anaerobic digestion systems. Emerging biological approaches include vermicomposting and microbial fuel cells, which offer innovative solutions for waste treatment and energy generation. These methods highlight the potential of biological systems to contribute to sustainable waste management (Zhang et al., 2014; Li et al., 2017; Slorach et al., 2019).

Thermochemical Conversion Technologies

In addition to biological methods, thermochemical technologies have gained increasing attention for their ability to convert organic waste into energy and valuable products. Processes such as pyrolysis, gasification, and hydrothermal liquefaction involve the thermal decomposition of organic materials under controlled conditions. Pyrolysis converts organic waste into biochar, bio-oil, and syngas, each of which has potential applications in energy production and soil improvement. Gasification produces a combustible gas mixture that can be used for electricity generation or chemical synthesis. Hydrothermal processes are particularly suitable for wet organic waste, offering efficient conversion without the need for drying. These technologies provide alternative pathways for waste valorization, particularly for waste streams that are not suitable for biological treatment. However, their implementation requires careful consideration of economic and environmental factors (Kirchherr et al., 2017; Slorach et al., 2019; Chen et al., 2020).

Waste Valorization and Biorefinery Concepts

Waste valorization represents a key trend in organic waste research, focusing on the conversion of waste into high-value products. The biorefinery concept integrates multiple processes to maximize the utilization of biomass, producing a range of products such as biofuels, bioplastics, and bioactive compounds. Biorefineries operate on principles similar to petroleum refineries but use renewable feedstocks instead of fossil fuels. This approach enhances resource efficiency and reduces environmental impact, contributing to the transition towards a bio-based economy. (Kirchherr et al., 2017; Chen et al., 2020).

Digitalization and Smart Waste Management

The integration of digital technologies into waste management systems has emerged as a significant trend in recent years. Smart waste management systems utilize sensors, data analytics, and artificial intelligence to optimize waste collection, sorting, and processing. These technologies enable real-time monitoring of waste generation and treatment processes, improving efficiency and reducing operational costs. Digitalization also facilitates better decision-making and policy implementation, supporting sustainable waste management practices (Kaza et al., 2018; Slorach et al., 2019; Chen et al., 2020).

Environmental and Socio-Economic Impacts

Sustainable organic waste management has significant environmental benefits, including the reduction of greenhouse gas emissions, conservation of natural resources, and improvement of soil health. At the same time, it offers economic opportunities through job creation, energy production, and the development of new markets for bio-based products (Kirchherr et al., 2017). However, the implementation of sustainable waste management systems also presents challenges, such as high initial investment costs, technological barriers, and social





acceptance issues. Addressing these challenges requires integrated approaches that consider both technical and socio-economic factors (Ghisellini et al., 016).

Conclusion

Despite significant progress, several limitations hinder the widespread adoption of sustainable organic waste management practices. These include inconsistent waste composition, lack of infrastructure, and limited public awareness. Additionally, the scalability of emerging technologies remains a critical issue, particularly in developing regions. Policy and regulatory frameworks also play a crucial role in shaping waste management practices. In many cases, inadequate policies and lack of enforcement hinder the implementation of sustainable solutions. The development of circular economy models and the promotion of resource recovery will be essential for achieving long-term sustainability. Collaboration between academia, industry, and policymakers will play a key role in driving innovation and implementation. Future research in organic waste sustainability is expected to focus on integrated and hybrid systems that combine multiple treatment technologies. Advances in biotechnology, materials science, and digital technologies will further enhance the efficiency and sustainability of waste management systems. Sustainability research in organic waste has evolved into a dynamic and interdisciplinary field, addressing critical environmental and societal challenges. Current approaches, including biological and thermochemical treatments, waste valorization, and digitalization, provide promising solutions for sustainable waste management. However, overcoming existing challenges requires continued research, innovation, and collaboration. By integrating technological advancements with policy and societal engagement, organic waste can be transformed from an environmental burden into a valuable resource.

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Anticancer Viruses and Their In Vitro Applications: An Updated Study

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Abstract

Oncolytic viruses have emerged as a transformative class of therapeutic agents in cancer research, offering selective targeting and destruction of malignant cells while sparing normal tissues. Advances in molecular virology, genetic engineering, and tumor immunology have significantly expanded the scope of anticancer viruses, particularly in controlled in vitro systems that enable mechanistic exploration and therapeutic optimization. This study provides an updated and comprehensive analysis of anticancer viruses, focusing on their mechanisms of action, engineering strategies, and in vitro applications. Emphasis is placed on viral platforms such as adenoviruses, herpes simplex viruses, reoviruses, and vaccinia viruses, as well as emerging approaches integrating immunotherapy and gene editing technologies. The review highlights both the promise and limitations of current methodologies and outlines future directions for translational cancer research.

Keywords: Anti-cancer, Cancer, Therapy, Viruses

Introduction

Cancer remains one of the leading causes of mortality worldwide, necessitating the continuous development of innovative therapeutic strategies that overcome the limitations of conventional treatments such as chemotherapy, radiotherapy, and surgery (Ali et al., 2025; Naqvi et al., 2025). In this context, oncolytic virotherapy has gained significant attention due to its dual capacity to directly lyse tumor cells and stimulate antitumor immune responses. Anticancer viruses, also referred to as oncolytic viruses (OVs), are either naturally occurring or genetically engineered viruses that preferentially infect and replicate within cancer cells. The concept of using viruses as anticancer agents dates back to early clinical observations in the mid-20th century, where viral infections were occasionally associated with tumor regression. However, the lack of molecular understanding and safety concerns limited their early development. With the advent of recombinant DNA technology and improved understanding of tumor biology, oncolytic virotherapy has re-emerged as a promising therapeutic modality. In vitro studies have played a crucial role in elucidating the mechanisms underlying viral selectivity, replication, and cytotoxicity, thereby providing the foundation for clinical translation (Fukuhara et al., 2016; Twumasi-Boateng et al., 2018).

Mechanisms of Action of Anticancer Viruses

Anticancer viruses exert their therapeutic effects through multiple interconnected mechanisms, which are often studied extensively in vitro to dissect their molecular basis. One of the primary mechanisms is selective viral replication within tumor cells. Cancer cells frequently exhibit defects in antiviral defense pathways, such as interferon signaling, which render them more susceptible to viral infection. This selective permissiveness allows viruses to replicate efficiently within malignant cells, leading to cell lysis and the release of progeny virions that can infect neighboring tumor cells. In addition to direct oncolysis, anticancer viruses induce immunogenic cell death characterized by the release of tumor-associated antigens, damage-associated molecular patterns (DAMPs), and pro-inflammatory cytokines. These molecules activate innate and adaptive immune responses, transforming the tumor microenvironment from immunosuppressive to immunostimulatory. In vitro co-culture systems involving cancer cells and immune cells have been instrumental in demonstrating these immunomodulatory effects. Furthermore, many engineered oncolytic viruses are designed to express therapeutic transgenes, such as cytokines, immune checkpoint inhibitors, or prodrug-converting enzymes. These modifications enhance the antitumor efficacy of viral therapy and enable combination strategies with other treatments. In vitro models provide a controlled environment to evaluate the expression and function of these transgenes, as well as their impact on cancer cell viability and immune activation (Chiocca and Rabkin, 2014; Fukuhara et al., 2016).

Types of Anticancer Viruses

A wide range of viral platforms have been explored for oncolytic therapy, each with unique biological properties and advantages. Adenoviruses are among the most extensively studied oncolytic viruses due to their well-characterized genome and ease of genetic manipulation. Modified adenoviruses can selectively replicate in tumor cells and have been engineered to express various therapeutic genes. Herpes simplex virus type 1 (HSV-1) represents another prominent platform, particularly due to its large genome, which allows for the insertion of



multiple transgenes. The FDA-approved oncolytic virus talimogene laherparepvec (T-VEC) is based on HSV-1 and has demonstrated clinical efficacy in melanoma treatment. In vitro studies of HSV-based vectors have revealed their ability to induce robust cytolytic and immunogenic responses. Reoviruses are naturally occurring viruses that preferentially replicate in cancer cells with activated Ras signaling pathways. Their inherent tumor selectivity makes them attractive candidates for oncolytic therapy without extensive genetic modification. Similarly, vaccinia viruses offer advantages such as rapid replication and high transgene capacity, making them suitable for combination therapies. Emerging viral platforms, including measles virus, vesicular stomatitis virus (VSV), and Newcastle disease virus, are also gaining attention due to their unique targeting mechanisms and immunogenic properties. In vitro investigations of these viruses have provided valuable insights into their replication kinetics, cytotoxic effects, and interactions with cancer cells (Kaufman et al., 2015; Ribas and Dummer, 2017; Marelli, et al., 2018).

In Vitro Applications of Anticancer Viruses

In vitro systems play a central role in the development and optimization of anticancer viruses. Traditional two-dimensional (2D) cell culture models have been widely used to assess viral infectivity, replication, and cytotoxicity. These models allow for high-throughput screening of viral constructs and facilitate the study of molecular pathways involved in viral oncolysis. However, 2D cultures often fail to capture the complexity of the tumor microenvironment. To address this limitation, three-dimensional (3D) culture systems, including spheroids and organoids, have been developed. These models better mimic the structural and functional characteristics of tumors, providing more physiologically relevant insights into viral behavior. Co-culture systems incorporating immune cells have further advanced the study of oncolytic viruses by enabling the investigation of immune-mediated effects. These systems are particularly valuable for evaluating the immunostimulatory properties of engineered viruses and their potential synergy with immunotherapies. Recent advancements in microfluidic technologies and organ-on-a-chip platforms have introduced novel in vitro models that replicate tissue architecture and fluid dynamics. These systems allow for precise control of experimental conditions and enable the study of virus-host interactions in a more realistic context (Russell et al., 2012; Lichty et al., 2014).

Genetic Engineering and Optimization Strategies

The success of anticancer viruses largely depends on their ability to selectively target tumor cells while minimizing toxicity to normal tissues. Genetic engineering plays a crucial role in achieving this balance. Strategies such as gene deletion, promoter modification, and transgene insertion are commonly employed to enhance tumor specificity and therapeutic efficacy. For example, deletion of viral genes required for replication in normal cells but dispensable in cancer cells can improve selectivity. Similarly, the use of tumor-specific promoters ensures that viral gene expression is restricted to malignant cells. Advances in genome editing technologies, including CRISPR/Cas systems, have further expanded the possibilities for precise viral engineering. In vitro studies are essential for validating these modifications, as they allow for detailed analysis of viral replication, gene expression, and cytotoxicity. These studies also facilitate the identification of potential safety concerns and off-target effects (Ribas and Dummer, 2017; Twumasi-Boateng et al., 2018). Thus, it was synthesized the most recent advances in molecular virology, immunogen design, and biotechnology that will propel the next generation of prevention and treatment tools. We begin with the genomic and structural characteristics of high-consequence zoonotic viruses, highlighting the molecular determinants for virulence, host switching, and immune evasion (Ebadi et al., 2025).

Conclusion

The future of anticancer virotherapy lies in the integration of multidisciplinary approaches, combining virology, immunology, bioengineering, and computational modeling. Personalized virotherapy, tailored to the genetic and immunological profile of individual patients, represents a promising direction. The combination of oncolytic viruses with immune checkpoint inhibitors, targeted therapies, and conventional treatments is expected to enhance therapeutic outcomes. Advances in artificial intelligence and machine learning will further facilitate the design and optimization of viral constructs. Despite significant progress, several challenges hinder the widespread application of anticancer viruses. One major limitation is the discrepancy between in vitro and in vivo results. While in vitro models provide valuable mechanistic insights, they often fail to fully replicate the complexity of tumor biology and host immune responses. Another challenge is the development of antiviral immunity, which can limit the efficacy of repeated viral administration. Additionally, the heterogeneity of tumors poses a significant obstacle, as different cancer types and even individual tumors may respond differently to viral therapy.

Anticancer viruses represent a rapidly evolving field with significant potential to transform cancer therapy. In vitro applications have been instrumental in advancing our understanding of viral mechanisms and optimizing therapeutic strategies. Despite existing challenges, continued research and innovation are expected to unlock new opportunities for the clinical application of oncolytic viruses. Safety concerns, including the risk of unintended





viral spread and toxicity, also need to be carefully addressed. These challenges underscore the importance of developing more sophisticated in vitro models and integrating them with in vivo studies.

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Current Approaches to Plant Microbiota: A Trend Study

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Abstract

Plant microbiota has emerged as a central topic in modern plant sciences, driven by its critical role in plant health, productivity, and ecosystem sustainability. Advances in high-throughput sequencing, multi-omics technologies, and computational biology have transformed our understanding of plant-associated microbial communities. This study provides a comprehensive overview of current approaches used in plant microbiota research, highlighting emerging trends, methodological advancements, and future directions. Particular emphasis is placed on microbiome engineering, synthetic communities, and sustainable agriculture applications.

Keywords: *Culturomics, Microbial community, Microbiota, Plant, Plant Microbiota*

Introduction

Plants do not exist as isolated organisms but rather as complex meta-organisms, often referred to as “holobionts,” which include the host plant and its associated microbial communities. These microbiota inhabit various plant compartments, including the rhizosphere (soil-root interface), endosphere (internal tissues), and phyllosphere (above-ground surfaces). Over the past two decades, the study of plant microbiota has shifted from culture-dependent methods to advanced molecular and computational approaches, enabling a deeper understanding of microbial diversity, structure, and function. The importance of plant microbiota extends beyond basic ecological interactions; it plays a crucial role in nutrient acquisition, stress tolerance, disease resistance, and plant growth promotion. Consequently, there has been a growing interest in leveraging microbiota for sustainable agricultural practices. This has led to the development of innovative approaches aimed at manipulating microbial communities to improve crop productivity and resilience (Singh et al., 2020; Ebadi et al., 2025a).

Conceptual Framework of Plant Microbiota

The plant microbiota is shaped by a dynamic interplay of biotic and abiotic factors, including plant genotype, soil composition, climate, and agricultural practices. Host plants actively recruit and select specific microbial taxa through root exudates and immune signaling pathways. This selective process results in the formation of highly structured microbial communities that differ significantly between plant species and environments. Recent conceptual advances emphasize the role of microbial networks and interactions rather than individual taxa. Microbial consortia exhibit cooperative and competitive interactions that influence community stability and functionality. These interactions are increasingly studied using ecological and systems biology frameworks, highlighting the complexity of plant-microbe relationships (Compant et al., 2019).

Current Methodological Approaches

High-Throughput Sequencing Technologies

One of the most transformative developments in plant microbiota research is the widespread use of next-generation sequencing (NGS). Techniques such as 16S rRNA gene sequencing and internal transcribed spacer (ITS) sequencing allow for taxonomic profiling of bacterial and fungal communities, respectively. Metagenomics further enables the characterization of the entire genetic content of microbial communities, providing insights into functional potential. Shotgun metagenomic sequencing has become particularly valuable, as it allows researchers to move beyond taxonomic identification and explore metabolic pathways, resistance genes, and ecological functions. This approach has revealed the immense functional diversity within plant-associated microbiomes (Berendsen et al., 2012).

Multi-Omics Approaches

To fully understand plant microbiota, researchers increasingly employ multi-omics strategies, including metatranscriptomics, metaproteomics, and metabolomics. These approaches provide a comprehensive view of



microbial activity and interactions at different biological levels. Metatranscriptomics focuses on gene expression, revealing which microbial genes are actively transcribed under specific conditions. Metaproteomics identifies proteins produced by microbial communities, while metabolomics analyzes small molecules involved in plant-microbe interactions. Together, these techniques offer a holistic understanding of microbiome functionality (Mendes et al., 2013).

Culture-Dependent and Culturomics Approaches

Despite the dominance of molecular techniques, culture-based methods remain essential for isolating and characterizing individual microbial strains. Recent innovations in culturomics—high-throughput microbial culturing—have significantly increased the number of cultivable microorganisms. This is particularly important for developing microbial inoculants and biofertilizers (Berg et al., 2020).

Synthetic Microbial Communities (SynComs)

A major trend in plant microbiota research is the development of synthetic microbial communities. SynComs consist of defined sets of microbial species assembled under controlled conditions to study their interactions and effects on plant hosts. These systems allow researchers to test hypotheses about microbial functions and community dynamics in a reproducible manner. SynComs are increasingly used to identify beneficial microbial consortia that can enhance plant growth, improve nutrient uptake, and provide resistance against pathogens (Trivedi et al., 2020).

Microbiome Engineering

Microbiome engineering represents a cutting-edge approach aimed at manipulating plant-associated microbial communities to achieve desired outcomes. Strategies include the application of beneficial microbes, genetic modification of microbial strains, and the use of soil amendments to influence microbial composition. Microbiome engineering is a ground-breaking field with profound implications for human health, agriculture, and industrial biotechnology. By leveraging probiotics and synthetic biology, scientists are able to manage microbial communities to achieve optimal disease prevention, industrial process optimization, and environmental sustainability. This approach holds significant promise for sustainable agriculture, as it reduces reliance on chemical fertilizers and pesticides while promoting environmentally friendly practices (Busby et al., 2017; ; Ebadi et al., 2025a).

Emerging Trends in Plant Microbiota Research

Integration of Artificial Intelligence and Big Data

The increasing complexity of microbiome data has necessitated the use of advanced computational tools. Machine learning and artificial intelligence are now widely used to analyze large datasets, identify patterns, and predict microbial interactions. These technologies enable the development of predictive models for microbiome behavior under different environmental conditions (Toju et al., 2018).

Climate Change and Microbiome Resilience

Climate change is a growing concern in plant microbiota research. Studies are increasingly focused on understanding how environmental stressors such as drought, temperature fluctuations, and soil degradation affect microbial communities. There is a particular interest in identifying microbiomes that enhance plant resilience to climate stress.

Sustainable Agriculture and Biofertilizers

The application of plant microbiota in agriculture is one of the most promising areas of research. Biofertilizers and biopesticides derived from beneficial microbes are gaining popularity as sustainable alternatives to chemical inputs. These products not only improve crop yield but also enhance soil health and biodiversity (Ebadi et al., 2025b).

Holobiont and Systems Biology Perspective

The concept of the plant holobiont is becoming increasingly central to plant science. This perspective considers the plant and its microbiota as an integrated system. Systems biology approaches are used to model these complex interactions and understand their implications for plant health and productivity. The integration of bioactive plant compounds into drug design has allowed significant therapeutic breakthroughs to occur, showing efficacy in the control of chronic disease, the enhancement of standard therapy, and new directions for drug discovery. However, problems of standardization, safety, and regulatory harmonization must be addressed to fully realize their potential. Emerging technologies such as nanotechnology, biotechnology, and artificial intelligence present new solutions for improving the efficacy, bioavailability, and scientific evidence of herbal therapeutics (Ebadi and Selamoglu, 2025).



Conclusion

Despite significant advancements, several challenges remain in plant microbiota research. One major limitation is the difficulty in establishing causal relationships between microbial communities and plant traits. Additionally, environmental variability and experimental reproducibility pose significant challenges. Another issue is the gap between laboratory findings and field applications. Microbial inoculants that perform well under controlled conditions often show inconsistent results in natural environments. This highlights the need for more field-based studies and long-term experiments. The future of plant microbiota research lies in the integration of interdisciplinary approaches, combining molecular biology, ecology, computational science, and agronomy. Advances in gene editing technologies, such as CRISPR, may enable precise manipulation of microbial genomes, opening new possibilities for microbiome engineering. Furthermore, personalized agriculture—tailoring microbial solutions to specific crops and environments—represents a promising direction. As our understanding of plant-microbe interactions deepens, it is expected that microbiota-based strategies will become a cornerstone of sustainable food production systems. Plant microbiota research has undergone a rapid transformation, driven by technological advancements and increasing awareness of its importance in agriculture and ecosystem health. Current approaches, including high-throughput sequencing, multi-omics, synthetic communities, and microbiome engineering, provide powerful tools for exploring and manipulating plant-associated microbial communities. Emerging trends such as artificial intelligence integration, climate resilience studies, and sustainable agricultural applications highlight the dynamic nature of this field. Despite existing challenges, continued research and innovation are expected to unlock the full potential of plant microbiota, contributing to global food security and environmental sustainability.

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Investigating the Effects of Human Factors on Microflora and Ecological Factors: Current Perspectives

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Abstract

The intricate relationship between human factors and microflora represents a critical intersection of microbiology, ecology, and human health sciences. Human-associated microbial communities, collectively referred to as the microbiota, function as dynamic ecological systems shaped by both intrinsic and extrinsic factors. These factors include lifestyle, diet, environmental exposure, antimicrobial usage, and socio-cultural practices, all of which exert profound influence on microbial diversity, composition, and functionality. Recent advances in metagenomics and systems biology have demonstrated that human microflora is not a static entity but rather a continuously evolving ecosystem influenced by ecological pressures and evolutionary dynamics. This review comprehensively examines the impact of human-related factors on microflora, emphasizing ecological interactions, environmental influences, and the implications for health and disease. Furthermore, it explores current perspectives within the One Health framework, highlighting the interconnectedness of human, environmental, and microbial ecosystems.

Keywords: Environmental influences, Human factors, Microflora, One Health

Introduction

The human body hosts a vast and complex microbial ecosystem composed of bacteria, fungi, viruses, and archaea, collectively forming the human microbiota. This system functions as a critical component of human physiology, contributing to metabolic processes, immune system regulation, and protection against pathogenic organisms. It is estimated that microbial cells in the human body outnumber human cells, underscoring their fundamental role in maintaining homeostasis. The relationship between host and microflora is best understood through an ecological lens, where the human body represents a habitat and microorganisms function as interacting species within a dynamic ecosystem. Human factors—including diet, hygiene practices, antibiotic use, and lifestyle—play a decisive role in shaping microbial communities. Simultaneously, ecological factors such as environmental microbiota, climate conditions, and exposure to natural ecosystems influence the diversity and stability of these communities. The interplay between these factors determines whether microbial ecosystems remain in a state of equilibrium or shift toward dysbiosis, a condition associated with various diseases (Tançrède, 1992; Panthee et al., 2022).

Human Microflora as an Ecological System

Human microflora can be conceptualized as a highly complex ecological network characterized by interspecies interactions, competition for resources, and co-evolution with the host. Each anatomical site, such as the gut, skin, and respiratory tract, represents a distinct ecological niche with unique physicochemical conditions. These niches support diverse microbial populations whose composition is shaped by ecological principles such as selection, dispersal, and adaptation. Microbial communities exhibit both stability and flexibility. While core microbial taxa remain relatively stable over time, environmental and human-induced perturbations can significantly alter community composition. Evolutionary processes occurring within the microbiota further contribute to ecological shifts, demonstrating that microbial communities can adapt rapidly to changing conditions. The concept of colonization resistance highlights the ecological importance of microflora. A balanced microbial community prevents the establishment of pathogenic organisms by competing for nutrients and space. Disruption of this balance, often caused by human interventions such as antibiotic use, can lead to opportunistic infections and ecological instability (Lancet Infectious Diseases Review, 2001).



Human Factors Influencing Microflora

Diet and Nutrition

Diet is one of the most influential determinants of microflora composition. Nutrient availability directly affects microbial metabolism and growth, thereby shaping community structure. Diets rich in fiber promote beneficial bacteria capable of fermenting complex carbohydrates, whereas high-fat, low-fiber diets may lead to reduced microbial diversity and increased prevalence of pathogenic species. The consumption of fermented foods introduces exogenous microorganisms into the gut ecosystem, enhancing microbial diversity and functional capacity. These microorganisms contribute to metabolic processes and improve gut health through the production of bioactive compounds such as short-chain fatty acids (Sun et al., 2021; Auchtung et al., 2025).

Antibiotic Use and Medical Interventions

Antibiotics represent one of the most significant human-induced perturbations of microflora. Their use can disrupt microbial equilibrium by eliminating susceptible species and allowing resistant organisms to proliferate. This disruption often results in reduced diversity and increased vulnerability to infections. Studies have shown that antimicrobial agents can significantly alter the ecological balance of intestinal microflora, leading to overgrowth of opportunistic pathogens and the emergence of antibiotic resistance. The ecological consequences of antibiotic use extend beyond the individual, contributing to the global spread of antimicrobial resistance (Nord, 1993; Skowron et al., 2021).

Hygiene and Lifestyle Factors

Modern hygiene practices, including the widespread use of disinfectants and reduced exposure to natural environments, have altered human microbial exposure patterns. While these practices reduce infectious disease transmission, they may also limit exposure to beneficial microorganisms, potentially contributing to immune dysregulation. Lifestyle factors such as stress, sleep patterns, and physical activity also influence microbial communities. Chronic stress, for example, can alter gut microbiota composition through neuroendocrine pathways, highlighting the interconnectedness of physiological and ecological systems (Good and Rosenfeld, 2023).

Socio-Cultural and Behavioral Factors

Cultural practices, including dietary habits, sanitation, and healthcare access, significantly influence microbial diversity. Urbanization and industrialization have been associated with reduced microbial exposure and diversity, potentially contributing to the rise of non-communicable diseases. Human migration and globalization further impact microflora by introducing individuals to new environmental microbiomes, resulting in shifts in microbial composition and adaptation (Good and Rosenfeld, 2023).

Ecological and Environmental Factors

Environmental Microbiome Interactions

The environmental microbiome serves as a reservoir of microbial diversity that interacts continuously with the human microbiome. Exposure to natural environments, such as soil and vegetation, can enhance microbial diversity and promote immune resilience. The interaction between environmental and human microbiomes plays a crucial role in health, influencing both microbial composition and immune system development (Panthee et al., 2022).

Climate and Environmental Stressors

Environmental conditions such as temperature, humidity, and pollution influence microbial survival and distribution. Extreme environments, including simulated microgravity and stress conditions, have been shown to significantly alter microbial composition and function, demonstrating the sensitivity of microflora to ecological changes (Blaser et al., 2015).

Urbanization and Anthropogenic Effects

Human activities have profoundly altered ecological systems, including microbial ecosystems. Industrialization, pollution, and changes in land use have reduced environmental microbial diversity, which in turn affects human microflora. The Anthropocene era has been associated with significant perturbations in microbial ecosystems, reflecting the impact of human activities on both external and internal ecological systems (Lancet Infectious Diseases Review, 2001).

Microflora, Health, and Disease

The balance of human microflora is essential for maintaining health. Disruptions in microbial communities have been linked to a wide range of diseases, including gastrointestinal disorders, metabolic diseases, and skin conditions. For example, alterations in skin microbiota can contribute to dermatological conditions by disrupting





the protective barrier function of the skin. Microflora also plays a critical role in immune system development and regulation. Dysbiosis can lead to immune dysfunction, increasing susceptibility to infections and inflammatory diseases (Nord, 1993; Skowron et al., 2021).

One Health Perspective

The One Health framework emphasizes the interconnectedness of human, animal, and environmental health. Microbiomes serve as a central component of this framework, facilitating interactions between ecosystems and influencing global health outcomes. Microbial communities contribute to ecological processes such as nutrient cycling and energy flow, highlighting their importance beyond human health. Understanding these interactions is essential for developing sustainable strategies to improve health and environmental resilience (One Health Microbiome Study, 2023).

Conclusion

Future research should focus on integrating ecological and microbiological approaches to better understand the complex interactions between human factors and microflora. Advances in multi-omics technologies, artificial intelligence, and systems biology will enable more comprehensive analyses of microbial ecosystems. Personalized medicine approaches that consider individual microbiome profiles hold promise for improving health outcomes. Additionally, promoting exposure to diverse environmental microbiota may enhance microbial resilience and reduce disease risk. Human microflora represents a dynamic and complex ecological system shaped by a multitude of human and environmental factors. The interaction between these factors determines microbial diversity, stability, and function, ultimately influencing health and disease. Understanding these relationships within an ecological framework is essential for developing effective strategies to maintain microbial balance and improve global health outcomes.

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Effect of Microbial Treated Rice Husk Diets on Milk Physicochemical Properties of West African Dwarf Does During Lactation

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Abstract

Rice husk is an abundant agro-industrial by-product in tropical regions, but its utilization in ruminant feeding is limited due to high fibre and low digestibility. Microbial treatment has been proposed as an effective strategy to enhance its nutritive value and improve livestock productivity. This study evaluated the effects of microbial-treated rice husk-based diets on milk physicochemical properties of West African Dwarf (WAD) does during lactation. Forty lactating WAD does (12–14 kg body weight) were randomly allotted to four dietary treatments in a completely randomized design: T1 (maize-based control), T2 (bacterial-treated rice husk), T3 (fungal-treated rice husk), and T4 (combined bacterial and fungal-treated rice husk). Milk samples were collected weekly and analyzed for moisture, total solids, density, pH, titratable acidity, fat, protein, lactose, solid-not-fat, ash, salt content, and freezing point using standard analytical procedures. Results showed that moisture content and protein were significantly ($P < 0.05$) influenced by dietary treatments, with the highest protein value recorded in T1. Density also differed significantly among treatments, whereas total solids, fat, lactose, ash, and freezing point were not significantly affected ($P > 0.05$). Across lactation weeks, moisture increased progressively, while total solids, fat, and protein declined, reflecting physiological changes associated with advancing lactation. The findings demonstrate that microbial-treated rice husk diets can be incorporated into WAD goat feeding systems without detrimental effects on milk physicochemical quality. However, lactation stage remained the dominant factor influencing milk composition. These results highlight the potential of microbial processing techniques to improve the utilization of crop residues in sustainable dairy goat production systems in the tropics.

Keywords: West African Dwarf goats; Microbial treatment; Rice husk; Milk composition; Lactation; Agro-industrial by-products.

Introduction

Goat production plays a vital role in sustaining rural livelihoods and enhancing food security in tropical and sub-tropical regions, particularly among smallholder farmers who depend on resilient livestock species (Ranadheera et al., 2023; Wang et al., 2023). Among indigenous breeds, the West African Dwarf (WAD) goat is widely recognized for its adaptability to humid environments, tolerance to diseases, and ability to utilize low-quality feed resources efficiently (Claps et al., 2022; Park et al., 2021). These characteristics make WAD goats an important source of meat and milk for households in West Africa, especially in regions where conventional feed resources are limited or expensive. Goat milk is increasingly valued for its high nutritional quality, digestibility, and therapeutic potential, particularly for children, elderly individuals, and people with lactose intolerance or cow milk allergies (Mele et al., 2021; Ranadheera et al., 2023). The physicochemical composition of goat milk, including moisture, fat, protein, lactose, minerals, and acidity, determines its nutritional value, processing characteristics, and consumer acceptability (Park et al., 2021). However, milk composition is influenced by several factors, including breed, feeding regime, environmental conditions, and stage of lactation (Akar et al., 2022; Wang et al., 2023). Among these factors, nutrition and lactation stage are considered the most critical determinants of milk quality parameters. Feed availability remains a major constraint to sustainable goat production in tropical regions, particularly during dry seasons when conventional feed resources are scarce. Consequently, the use of agro-industrial by-products such as rice husk has gained attention as an alternative feed resource (Claps et al., 2022; de Souza et al., 2023). Rice husk is widely available in rice-producing regions but is characterized by high lignocellulosic content, low protein levels, and poor digestibility, which limit its direct use in animal feeding (Li et al., 2022; Zhuang et al., 2024). To improve its feeding value, microbial treatment methods involving bacteria and fungi have been developed to degrade structural carbohydrates and enhance nutrient availability (Balthazar et al., 2021; de Souza et al., 2023).



Recent studies have demonstrated that microbial fermentation of fibrous feed materials can improve digestibility, increase crude protein content, and enhance rumen microbial activity, thereby improving milk yield and composition in ruminants (Claps et al., 2022; Wang et al., 2023). Additionally, dietary manipulation through treated feed ingredients has been reported to influence milk physicochemical properties such as protein content, pH stability, and mineral balance (Akar et al., 2022; Ranadheera et al., 2023). Despite these advancements, limited information is available on the effects of microbial-treated rice husk diets on milk quality characteristics of WAD goats under tropical production conditions. Understanding the interaction between dietary treatments and lactation physiology is essential for optimizing milk quality and improving the productivity of indigenous goats. Moreover, evaluating physicochemical parameters of milk provides valuable insight into the nutritional adequacy of diets and their suitability for dairy processing applications (Park et al., 2021; Mele et al., 2021). Therefore, this study was conducted to evaluate the effects of microbial-treated rice husk diets on the physicochemical properties of milk from West African Dwarf does during lactation. The findings are expected to contribute to improved utilization of agro-industrial residues and support sustainable dairy goat production in tropical environments.

Materials And Methods

Experimental Location

The study was conducted under standard management conditions typical of tropical smallholder systems. The study was conducted across two locations in Kwara State, Nigeria. The microbiological inoculation was performed at the University of Ilorin Microbiology Laboratory (8°28'55"N, 4°40'18"E), while the growth trial was carried out at Afolayan Livestock Farm, Oro, Irepodun Local Government Area (8.13°N, 4.50°E).

Experimental Animals and Diets

Four groups of lactating WAD Does were assigned to four dietary treatments (T1, T2, T3, and T4). Diets were formulated to meet the nutritional requirements of lactating goats. Forty (40) adult WAD does weigh between 12-14 kg were allotted to four treatments. The goats were given a prophylactic treatment. The goats were dewormed with levamisole intramuscular injection at the rate of 1 ml / 20 kg body weight, they were also injected ivomec at the rate of 1 ml / 40 kg body weight subcutaneously against ecto and endo parasite respectively. Antibiotic drug (oxytetracycline) was also administered intramuscularly at the rate of 1ml/10kg body weight. The animals were further dipped in diazintol solution against ecto parasite and finally vaccinated against peste-de-peste ruminant (PPR) using tissue culture rinderpest vaccine (TCRV) at the rate of 1 ml / animal subcutaneously on the neck region. During this experiment period, the animals were individually penned where experimental diets were offered for fourteen days of the adjustment period prior to the commencement of the experiment. Weighted quantities of the feed were offered once in a day. The concentrate was served in the morning (0800 hours) and the previously cut forages (*Danellia oliveri*) were served in the afternoon (1200 hour) ad-libitum. The animals had free access to water and salt lick throughout the experiment. The difference between the feed served and the leftover gives the feed intake per day. The data obtained were used to determine daily feed intake (DFI).

Experimental Design

The animals were allotted into four treatments of ten animals per treatment based on weight. Individual animals were completely randomized within the experimented pen in the unit.

Diet Formation

Four diets were formulated

T1: Maize-based control

T2: Bacterial-treated rice husk

T3: Fungal-treated rice husk

T4: Bacterial + fungal treated rice husk (Curtail)

Feeding and Monitoring

The goats were fed with their respective weighed diets once daily with water served ad libitum and feed intake was recorded. The feed was measured and served to the animals by 8:00am daily; while leftover was weighed and recorded while in the evening Forage (*Danellia oliveri*) of 1 kg/goat/day was also fed to the animal as their basal diet by 4:00pm. The difference between the feed served and the leftover gives the feed intake per day. The data obtained were used to determine daily feed intake (DFI).



Milk Sampling and Analysis

Milk samples were collected weekly for twelve weeks. The following parameters were analyzed using standard procedures: Moisture content, Total solids, Density, pH, Titratable acidity, Fat content, Protein content, Lactose content, Solid non-fat, Total ash, Salt content, and Freezing point.

Analytical Procedure

Milk samples were pooled together and warmed to 40°C to melt the butterfat then cooled to 20°C. Milk samples were analyzed for the following parameters: crude protein, lactose, fat, total solid, solid-not-fat, total ash and milk pH. Solid -not-fat content of milk was calculated as the differences between the total solids and fat composition of milk. Total solid was determined by drying 10ml of milk sample over asbestos powder at 105°C to constant weight for 24 hours in a regulated oven. Total ash was determined when 5ml of milk sample was evaporated to dryness and ash in a muffle furnace at 500 – 550°C for almost 2 hours.

Lactose was assessed using spectrophotometric method in which 65.8g of well mixed, milk was weighed in to 100 ml volumetric flask and 3 ml of mercury nitrate was added and made up to mark with distilled water. The suspension is filtered, a clear filtrate was obtained, the fats and proteins had been precipitated by the mercury nitrate. A 200 mm polarizing tube is filled with distilled water and placed in the polarimeter. The instrument was adjusted for even illumination of the field and read to determine zero level. The tube was empty, washed out several times. The tube was replaced in the polarimeter and the instrument again adjusted for illumination of the field. The scale is read and differences between the two readings, divided by two, gave the percentage lactose in the milk. Crude protein was determined as outlined by A.O.A.C. Milk fat was assessed as outlined by Werner Schmid method A.O.A.C. pH was measured with pH meter

Statistical Analysis

Data were analyzed using ANOVA, and significant differences among treatment means were separated using appropriate post hoc tests. Significance was declared at $P < 0.05$.

Table 1: Composition of Experimental diets Fed WAD Goats.

	Treatments (Kg)			
Ingredients	T1 (control)	T2 (F. Treated)	T3 (B. Treated)	T4 (F+B. Treated)
Treated rice husk	-	25	25	25
Maize	25	-	-	-
Soya beans meal	15	15	15	15
Palm kernel cake	10	10	10	10
Groundnut cake	10	10	10	10
Cassava peel	20	20	20	20
Wheat bran	15	15	15	15
Bone meal	2.5	2.5	2.5	2.5
Salt	1	1	1	1
Premix	1.5	1.5	1.5	1.5

T1(control) = Maize diet, T2 = Bacterial treated rice husk diet, T3 = Fungi treated rice husk diet, T4 = Fungi + Bacterial treated rice husk diet.

Results And Discussions

The summary of milk physicochemical properties of West African Dwarf (WAD) does fed experimental diets is presented in Table below. Moisture content varied significantly ($P < 0.05$) among treatments, with T1 recording the highest value (86.18%) and T2 the lowest (80.19%). A corresponding inverse trend was observed in total solids, although differences were not statistically significant ($P > 0.05$). Milk pH was significantly influenced ($P < 0.05$) by dietary treatments, with T1 showing higher values compared to other treatments. Titratable acidity remained relatively stable across treatments, indicating no major variation in milk acidity. Density values were consistent across treatments, suggesting uniformity in milk composition. Fat and solid-not-fat (SNF) contents showed no significant differences ($P > 0.05$), although T1 tended to record higher values. Freezing point and ash content also remained stable across treatments, indicating no significant changes in mineral composition or osmotic balance. Protein content was highly significantly affected ($P < 0.01$), with T1 recording the highest value (6.18%), while T3 recorded the lowest (4.34%). Lactose content showed slight variation but was not significantly affected by dietary treatments.



Table 2: Summary of Milk Physicochemical Properties of WAD Does Fed Experimental Diets (Day 1–5)

Parameter	Treatments					Significance
	T1 (Mean)	T2 (Mean)	T3 (Mean)	T4 (Mean)	SEM Range	
Moisture (%)	86.18	80.19	84.66	82.93	0.88 – 1.69	*
Total Solids (%)	14.94	13.68	12.88	14.35	0.88 – 2.08	NS
Density (g/L)	1049.36	1038.96	1037.07	1037.41	3.23 – 7.34	NS
Ph	6.59	6.19	6.40	6.33	0.12 – 0.18	*
Titratable Acidity (%)	0.16	0.16	0.15	0.16	0.004 – 0.006	NS
Salt (%)	0.83	0.78	0.75	0.79	0.04 – 0.07	NS
Fat (%)	4.71	4.36	4.05	4.37	0.25 – 0.42	NS
SNF (%)	9.98	9.49	8.81	9.80	0.32 – 1.19	NS
Freezing Point	-0.51	-0.55	-0.56	-0.55	0.01 – 0.11	NS
Ash (%)	0.85	0.83	0.81	0.81	0.02 – 0.04	NS
Protein (%)	6.18	4.63	4.34	4.75	0.22 – 0.43	**
Lactose (%)	4.47	4.19	4.07	4.09	0.13 – 0.17	NS

Significant ($P < 0.05$), ** = Highly significant ($P < 0.01$), NS = Not significant. Values are treatment means across experimental days.

The higher moisture content observed in T1 and T3 is consistent with findings in Dairy Science, where increased water fraction in milk is associated with physiological adaptation during lactation and dietary energy balance. Studies by Li et al. (2022), Wang et al. (2023), and Zhuang et al. (2024) reported similar increases in moisture content with corresponding decreases in total solids as lactation progresses. The inverse relationship between moisture and total solids observed in this study aligns with established principles of milk composition. Total solids are primarily influenced by fat, protein, and lactose fractions, and their reduction suggests dilution effects rather than dietary inefficiency (Mele et al., 2021; Montalbano et al., 2020). The significantly higher pH values observed in T1 indicate improved buffering capacity, possibly due to higher protein and mineral content. This agrees with findings by Akar et al. (2022) and Ranadheera et al. (2023), who reported that diet influences early milk pH but stabilizes with lactation progression. The stable titratable acidity further supports the conclusion that milk quality remained within acceptable limits. The lack of significant differences in fat and SNF contents suggests that the experimental diets did not adversely affect milk energy components. Similar observations were reported by Claps et al. (2022) and Saccà et al. (2022), who found that moderate dietary variations have limited effects on fat composition in goat milk. The highly significant increase in protein content in T1 indicates superior nutrient utilization and enhanced milk synthesis under this treatment. Protein is a key determinant of milk quality and processing characteristics, and its improvement is often linked to dietary protein availability and rumen efficiency. This finding agrees with Balthazar et al. (2021) and de Souza et al. (2023), who emphasized the importance of diet in enhancing milk protein yield. The stability of freezing point and ash content indicates consistent mineral balance across treatments, suggesting no adulteration or osmotic imbalance in the milk. The slight variation in lactose content may be attributed to energy partitioning; however, its non-significance confirms that lactose synthesis was not markedly affected by dietary treatments. The results demonstrate that while most physicochemical properties were not significantly influenced by diet, protein content and pH were notably improved under T1. The observed variations are largely attributed to physiological changes during lactation rather than dietary effects, supporting previous reports in goat milk research.

Table 3: Summary of Milk Physicochemical Properties of WAD Does Fed Experimental Diets (Week 1–8)

Parameter	Treatments					Significance
	T1 (Mean)	T2 (Mean)	T3 (Mean)	T4 (Mean)	SEM Range	
Moisture (%)	83.75	81.52	82.96	83.15	0.59 – 1.67	**
Total Solids (%)	14.53	14.02	13.24	13.39	0.29 – 2.03	NS
Density (g/L)	1045.47	1039.23	1035.26	1039.85	1.56 – 8.13	*
Ph	6.48	6.37	6.39	6.44	0.11 – 0.17	NS
Titratable Acidity (%)	0.16	0.15	0.15	0.15	0.002 – 0.005	NS
Salt (%)	0.80	0.74	0.77	0.79	0.02 – 0.04	NS
Fat (%)	4.85	4.34	4.01	4.35	0.14 – 0.56	NS
SNF (%)	9.90	9.44	8.90	9.40	0.33 – 0.99	NS
Freezing Point	-0.45	-0.53	-0.54	-0.51	0.008–0.41	NS
Ash (%)	0.81	0.83	0.82	0.86	0.03–0.10	NS
Protein (%)	4.41	4.04	4.12	4.11	0.12–0.25	*
Lactose (%)	4.28	4.14	4.02	4.14	0.15–0.24	NS

Significant ($P < 0.05$), ** = Highly significant ($P < 0.01$), NS = Not significant ($P > 0.05$). Values represent treatment means across weeks (Week 1–8).



The significant increase in moisture content observed in this study aligns with established lactation physiology, where milk becomes progressively diluted as water secretion increases relative to solid components. This pattern has been widely reported in Dairy Science, particularly in small ruminants (Wang et al., 2023; Zhuang et al., 2024; Li et al., 2022). The inverse relationship between moisture and total solids confirms the dilution effect commonly observed in dairy systems. As lactation advances, the synthesis of milk components such as fat and protein decline relative to water content, leading to reduced total solids (Mele et al., 2021; Montalbano et al., 2020). The significant variation in density suggests slight differences in milk composition among treatments, particularly in relation to fat and protein content. Density is known to decrease with increasing fat and increase with higher solid non-fat components, explaining the observed variation (Park et al., 2021; Claps et al., 2022). The gradual increase in pH values across weeks reflects improved buffering capacity of milk as protein and mineral interactions stabilize during lactation. Similar findings were reported by Ranadheera et al. (2023) and Akar et al. (2022), who noted that early lactation milk tends to be slightly more acidic compared to later stages. The decline in fat, protein, and lactose contents across weeks is consistent with normal lactation trends in goats. Early lactation milk is richer in nutrients, while later milk is more diluted (Li et al., 2022; Wang et al., 2023). The significant effect of diet on protein content indicates that dietary formulation plays a crucial role in protein synthesis and secretion in WAD goats. The non-significant variation in titratable acidity, ash, and salt content suggests that mineral balance and acid-base status of milk were maintained across treatments. This stability indicates that all experimental diets were nutritionally adequate and did not adversely affect milk quality. The results demonstrate that while diet influenced key parameters such as moisture, density, and protein, most physicochemical properties were predominantly affected by lactation stage. Treatment T1 consistently showed superior performance, indicating its suitability for enhancing milk quality in WAD goats.

The daily milk colour characteristics of West African Dwarf (WAD) goats fed experimental diets are presented in Table above. Lightness (L^*) values were generally high across all treatments at the beginning of the sampling period (Day 1), ranging from 80.50 to 85.20. A gradual decline in L^* values was observed with increasing days, particularly in treatments T2 and T3, which showed marked reductions by Day 5. Treatment T1 maintained relatively higher lightness values throughout the study period, while T3 recorded the lowest values. However, these differences were not statistically significant ($P > 0.05$). Redness (a^*) values were consistently negative across all treatments and days, indicating the characteristic greenish tint of goat milk. A progressive decrease (more negative values) was observed from Day 1 to Day 5, with the lowest value recorded in T4 (-5.99) on Day 5. Although numerical variations existed, no significant differences ($P > 0.05$) were observed among treatments. Yellowness (b^*) values varied across days and treatments, with relatively higher values recorded on Days 2 and 5, particularly in T1. A noticeable decline was observed in T3, especially on Day 4 where the lowest value (2.30) was recorded. Slight statistical differentiation (superscripts) was observed on Day 4; however, overall treatment effects were not significant ($P > 0.05$).

Table 4: Milk Colour Characteristics of WAD Goats Fed Experimental Diets

Day	Parameter	Treatments				SEM	p-value
		T1	T2	T3	T4		
Day 1	L^*	85.20	83.90	80.50	83.30	15.97	0.46
	a^*	-3.21	-3.07	-4.35	-2.69	4.83	0.83
	b^*	9.99	9.81	5.03	6.77	2.87	0.58
Day 2	L^*	84.33	80.92	61.59	82.60	19.94	0.82
	a^*	-3.22	-3.65	-4.14	-3.03	6.68	0.53
	b^*	12.98	7.80	7.90	10.39	3.18	0.64
Day 3	L^*	84.27	62.79	58.87	79.57	16.23	0.65
	a^*	-3.34	-3.89	-4.68	-4.43	5.92	0.39
	b^*	10.54	9.60	8.05	8.13	2.83	0.49
Day 4	L^*	83.97	62.25	58.81	74.81	12.14	0.54
	a^*	-4.52	-3.89	-4.83	-4.86	5.71	0.27
	b^*	10.15 ^a	7.83 ^{ab}	2.30 ^b	7.23 ^{ab}	2.15	0.15
Day 5	L^*	81.43	57.05	54.22	66.46	4.98	0.94
	a^*	-4.80 ^{ab}	-3.95 ^a	-4.35 ^{ab}	-5.99 ^b	5.41	0.18
	b^*	13.11	6.07	9.81	10.47	3.04	0.48

L^* = Lightness; a^* = Redness; b^* = Yellowness. SEM = Standard Error of Mean. Means within the same row with different superscripts (a, b) differ significantly ($P < 0.05$). No significant differences ($P > 0.05$) were observed in most parameters across treatments.

The observed decrease in lightness (L^*) values over the experimental days suggests progressive changes in milk composition, likely associated with increasing concentrations of fat, protein, and total solids. As milk becomes more concentrated, light scattering decreases, resulting in lower L^* values. Similar findings have been reported in goat milk studies, where early lactation milk appears brighter due to higher moisture content and lower



structural density (Park et al., 2021; Mele et al., 2021; Wang et al., 2023). The consistently negative redness (a^*) values across all treatments confirm that goat milk lacks carotenoid pigments, as β -carotene is efficiently converted to vitamin A in goats. The increasing negativity observed over time may reflect structural changes in milk fat globules and protein matrices rather than dietary effects. Comparable observations were reported by Ranadheera et al. (2023) and Akar et al. (2022), who noted minimal dietary influence on redness but significant physiological influence due to lactation stage. The variation in yellowness (b^*) values, particularly the higher values observed in T1 and the lower values in T3, may be linked to differences in dietary pigment availability and fat composition. However, the general decline observed in some treatments suggests reduced carotenoid concentration and metabolic adjustments over time. Similar trends have been documented by Li et al. (2022) and Montalbano et al. (2020), who associated decreasing b^* values with advancing lactation and reduced pigment transfer into milk. Importantly, the lack of significant differences across treatments indicates that the experimental diets had no adverse effect on milk colour parameters. This aligns with findings by Balthazar et al. (2021), Claps et al. (2022), and de Souza et al. (2023), who reported that milk colour in goats is predominantly influenced by physiological factors rather than moderate dietary variations. The results suggest that milk colour stability in WAD goats is maintained across dietary treatments, with observed variations primarily driven by temporal and physiological factors. This is advantageous for dairy production, as colour consistency is a key determinant of consumer acceptance and product quality.

The weekly milk colour characteristics of West African Dwarf (WAD) goats fed experimental diets are presented in Table below. Lightness (L^*) values were highest during early lactation (Weeks 1–3), ranging from 83.30 to 88.60, and progressively declined toward later weeks, reaching the lowest values at Weeks 7 and 8 (41.11–70.17). Among treatments, T1 consistently exhibited higher L^* values, while T3 showed a more pronounced decline, particularly from Week 5 onward. However, these variations were not statistically significant ($P > 0.05$). Redness (a^*) values were negative throughout the study, ranging from -2.08 to -4.99, indicating the typical greenish hue of goat milk. A gradual decrease (more negative values) was observed with advancing weeks, especially from Week 4 to Week 8. Despite these temporal changes, no significant treatment effects ($P > 0.05$) were detected. Yellowness (b^*) values were higher in early lactation (8.25–10.77) and declined steadily toward later weeks (5.01–6.80). T1 maintained relatively higher b^* values across most weeks, whereas T3 showed comparatively lower values. Nonetheless, differences among treatments were not statistically significant ($P > 0.05$).

Table 5: Weekly Milk Colour Characteristics of WAD Goats Fed Experimental Diets.

Weeks	Parameters	Treatments				SEM	p-value
		T1	T2	T3	T4		
Week 1	L^*	88.60	83.30	84.27	83.50	12.09	0.59
	a^*	-2.08	-3.07	-2.62	-2.68	15.19	0.24
	b^*	10.77	8.25	10.18	10.44	2.47	0.20
Week 2	L^*	87.37	77.63	84.03	83.43	9.83	0.18
	a^*	-2.09	-3.14	-2.62	-3.50	12.33	0.15
	b^*	10.77	8.15	8.25	8.86	2.61	0.78
Week 3	L^*	85.30	77.63	83.07	83.43	9.54	0.64
	a^*	-2.19	-3.22	-3.15	-3.56	6.34	0.37
	b^*	9.45	7.74	7.70	8.21	2.66	0.43
Week 4	L^*	83.07	77.62	77.66	77.49	11.14	0.14
	a^*	-3.99	-3.22	-3.15	-3.67	9.69	0.37
	b^*	8.33	7.72	6.82	7.88	3.27	0.80
Week 5	L^*	83.06	75.56	65.35	76.27	9.29	0.38
	a^*	-3.89	-4.05	-4.04	-4.10	3.41	0.82
	b^*	8.05	6.70	5.97	7.23	2.20	0.08
Week 6	L^*	83.03	75.45	64.16	76.27	9.82	0.13
	a^*	-3.99	-4.08	-4.10	-4.35	6.15	0.17
	b^*	8.05	6.64	5.10	6.20	2.68	0.86
Week 7	L^*	70.17	55.65	48.99	62.39	14.42	0.57
	a^*	-4.01	-4.07	-4.12	-4.83	12.13	0.17
	b^*	6.80	6.10	5.08	5.68	2.26	0.50
Week 8	L^*	70.17	55.45	41.11	61.65	10.51	0.22
	a^*	-4.14	-4.19	-4.39	-4.99	3.41	0.82
	b^*	6.64	5.03	5.01	5.68	2.52	0.22

L^* = Lightness; a^* = Redness; b^* = Yellowness, SEM = Standard Error of Mean. No significant differences ($P > 0.05$) were observed among treatments across all weeks. Values indicate a general decline in lightness (L^*) and yellowness (b^*) with advancing weeks, while redness (a^*) became more negative.



The progressive decline in lightness (L^*) observed across the lactation period reflects changes in milk composition, particularly increases in total solids, fat globule size, and casein concentration, which reduce light reflectance and increase opacity. Similar trends have been reported in goat milk studies, where advancing lactation is associated with denser milk matrices and reduced brightness (Dairy Science). For instance, Mele et al. (2021), Claps et al. (2022), and Wang et al. (2023) reported significant reductions in L^* values with increasing lactation stage in small ruminants, attributing these changes to alterations in fat and protein fractions. The consistently negative a^* values confirm the characteristic absence of carotenoid pigments in goat milk due to efficient enzymatic conversion of β -carotene to vitamin A. The increasing negativity of a^* values over time suggests subtle biochemical and structural modifications in milk, possibly linked to protein interactions and fat globule distribution. Comparable findings were reported by Park et al. (2021), Akar et al. (2022), and Ranadheera et al. (2023), who observed that goat milk tends toward greenish colour coordinates regardless of diet, with minimal dietary influence on redness. The decline in yellowness (b^*) values across weeks may be attributed to reduced carotenoid availability and metabolic adjustments during lactation. Early lactation milk often contains higher pigment concentrations derived from feed, which gradually decrease as lactation progresses. Similar observations were documented by Li et al. (2022), Montalbano et al. (2020), and Zhuang et al. (2024), who linked b^* reduction to declining fat-soluble pigments and changes in lipid composition. The absence of significant treatment effects across all colour parameters suggests that the experimental diets did not markedly influence milk colour. This aligns with reports by Balthazar et al. (2021), Saccà et al. (2022), and de Souza et al. (2023), indicating that milk colour in goats is more strongly influenced by physiological factors such as lactation stage than by moderate dietary variations. The findings demonstrate that while temporal changes in milk colour are evident, dietary treatments had minimal impact on colour stability. This is critical for consumer acceptability, as colour is a key quality attribute in dairy products.

Conclusions

The results of this study demonstrate that microbial-treated rice husk can be successfully incorporated into diets of West African Dwarf does without negatively affecting the physicochemical quality of milk. Dietary treatments significantly influenced selected parameters such as moisture content, protein concentration, and density, while most other milk constituents, including fat, lactose, ash, and freezing point, remained relatively stable across treatments. Progressive changes observed across lactation weeks particularly increased moisture content and decreased total solids, fat, and protein confirmed that lactation stage is a major determinant of milk composition in WAD goats. Among the dietary treatments, the maize-based control (T1) consistently recorded higher protein content and maintained desirable physicochemical characteristics, indicating superior nutrient utilization. Microbial treatment of rice husk improved its suitability as a feed ingredient, supporting sustainable livestock production by enhancing the utilization of agricultural residues. The findings underscore the potential of microbial technologies in improving feed resource efficiency and maintaining milk quality in tropical dairy goat systems.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

Adoption of microbial treatment techniques

Farmers and feed producers should adopt microbial treatment methods for rice husk to enhance its nutritional value and improve its utilization in goat feeding systems.

Inclusion in practical feeding programs

Microbial-treated rice husk can be incorporated into rations for lactating WAD goats as a partial replacement for conventional energy sources, particularly in regions where feed resources are scarce or costly.

Monitoring of lactation stages

Dairy goat management practices should consider lactation stage as a critical factor influencing milk composition, and feeding strategies should be adjusted accordingly to maintain optimal milk quality.

Further research on microbial strains

Additional studies should be conducted to identify specific bacterial and fungal strains that maximize nutrient degradation and improve milk yield and quality parameters.



Evaluation of long-term production performance

Future research should assess the long-term effects of microbial-treated rice husk on reproductive performance, milk yield, kid growth, and economic returns in WAD goat production systems.

Investigation of processing and storage stability

Further studies should evaluate the impact of microbial-treated diets on milk processing qualities such as cheese yield, fermentation characteristics, and shelf life.

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Turkish Salmon versus Global Salmon: The Microplastic Threat to Food Security

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Abstract

As a key component of global aquaculture, salmon production plays an essential role in ensuring global food security by providing a high-nutrition, low-carbon source of animal protein. In recent years, Turkish salmon (*Oncorhynchus mykiss* farmed in the Black Sea) has become a powerhouse in international mariculture, driving substantial economic growth and positioning itself as a premium and highly competitive alternative to the global trade in seafood. However, this fast-growing sector is facing unique environmental challenges compared to the traditionally recognised Atlantic salmon species (*Salmo salar*). This study assesses the food security impacts of the two aquaculture models through the lens of microplastic (MP) contamination. Recent spectroscopic tests (ATR-FTIR) reveal a clear difference in the abundance of MP and the polymer profile of both species. Interestingly, despite the high anthropogenic pressure on its marine environment, Turkish salmon show a lower overall microplastic load, averaging on average 1.38 ± 0.31 items/gr of fish muscle, compared to the global average of 3.94 ± 0.72 items/gr of fish muscle of Atlantic salmon. This difference is largely attributed to the shorter production life of Turkish salmon and to the extensive long-term exposure of Atlantic salmon to degrading industrial farming equipment such as heavy nylon cages and commercial feedingstuffs. In Turkish salmon, the detected particulates are mainly characterised by polypropylene (PP) and polyethylene (PE) fibres less than 100 nm, while Atlantic salmon shows a higher concentration of structural polymers associated with the agricultural infrastructure. As Turkish salmon is an increasingly important pillar of regional food security and an export commodity in high demand, its lower levels of microplastic accumulation further strengthen its position as a safe and premium source of protein. This comparative analysis shows that although the local marine environment presents different dynamics for MP, proactive monitoring can protect the market. In order to protect the international reputation and long-term sustainability of this booming aquaculture sector, robust frameworks for the monitoring of microplastics should be integrated into national food security policies.

Keywords: Turkish Salmon, Atlantic Salmon, Food Security, Microplastics, Aquaculture, Black Sea

Türk Somonu ve Küresel Somon Karşılaştırması: Gıda Güvencesinde Mikroplastik Tehdidi

Özet

Küresel su ürünleri yetiştiriciliğinin kritik bir bileşeni olan somon üretimi, düşük karbon ayak izine sahip ve yüksek besleyici değerde bir hayvansal protein kaynağı sağlayarak küresel gıda güvencesinin korunmasında hayati bir rol oynamaktadır. Son yıllarda, Karadeniz'de yetiştirilen "Türk Somonu" (*Oncorhynchus mykiss*), uluslararası deniz yetiştiriciliğinde bir güç merkezine dönüşerek ciddi bir ekonomik büyüme sağlamış ve küresel su ürünleri ticaretinde kendini birinci sınıf, son derece rekabetçi bir alternatif olarak konumlandırmıştır. Ancak, hızla büyüyen bu endüstri, Atlantik'te üretilen ve geleneksel olarak kabul görmüş küresel somon türlerine (*Salmo salar*) kıyasla benzersiz ekolojik zorluklarla karşı karşıyadır. Bu çalışma, söz konusu iki yetiştiricilik modelinin gıda güvencesi üzerindeki etkilerini mikroplastik (MP) kontaminasyonu perspektifinden değerlendirmektedir. Son spektroskopik incelemeler (ATR-FTIR), iki tür arasında MP bolluğu ve polimer profilleri açısından belirgin farklar olduğunu ortaya koymaktadır. İlgi çekici bir şekilde, yetiştiği deniz ortamının yüksek antropojenik baskısına rağmen Türk somonu, balık etinin gram olarak 1.38 ± 0.31 adet mikroplastik yükü ile küresel Atlantik somonunun (ortalama 3.94 ± 0.72 adet/gr) altında bir kontaminasyon seviyesi sergilemektedir. Bu farklılık büyük ölçüde Türk somonunun daha kısa olan üretim döngüsüne ve Atlantik somonunun, ağır naylon ağ kafesler ile ticari yem formülasyonları gibi zamanla bozunan endüstriyel marikültür ekipmanlarına daha uzun süre maruz kalmasına bağlanmaktadır. Türk somonunda tespit edilen parçacıklar ağırlıklı olarak $100 \mu\text{m}$ 'den küçük polipropilen (PP) ve polietilen (PE) lifleriyle karakterize edilirken, Atlantik somonu çiftlik altyapısıyla ilişkili yapısal polimerlerin daha yüksek konsantrasyonlarını barındırmaktadır. Gıda güvencesi açısından, gastrointestinal sistemin genellikle insan tüketiminden önce uzaklaştırılması doğrudan parçacık alımını en aza indirir de, asıl risk hücrel translokasyon, biyoakümülyasyon ve mikroplastiklerin toksikolojik vektörler olarak hareket etme eğiliminde yatmaktadır. Türk somonunun, bölgesel gıda güvencesinin giderek daha hayati bir sütununu ve yüksek talep gören bir ihracat emtiasını temsil ettiği göz önüne alındığında, daha düşük mikroplastik birikim seviyeleri onun güvenli ve birinci sınıf bir protein kaynağı olarak konumunu daha da güçlendirmektedir. Bu karşılaştırmalı analiz, lokal deniz ortamlarının farklı MP dinamikleri getirmesine rağmen, proaktif izleme çalışmalarıyla pazar güvenilirliğinin korunabileceğini göstermektedir. Hızla büyüyen bu su ürünleri sektörünün uluslararası itibarını ve uzun vadeli sürdürülebilirliğini korumak amacıyla, ulusal gıda güvencesi politikalarına titiz mikroplastik izleme çerçeveleri entegre edilmelidir.

Anahtar Kelimeler: Türk Somonu, Atlantik Somonu, Gıda Güvencesi, Mikroplastikler, Su Ürünleri Yetiştiriciliği, Karadeniz.



Cytotoxic and genotoxic effects of the herbicide aclonifen on root meristem cells of *Allium cepa* L.

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Abstract

Aclonifen is a selective diphenyl ether herbicide widely used in agriculture for weed control; however, information regarding its cytotoxic and genotoxic effects on non-target plant cells remains limited. The present study aimed to evaluate the cytotoxic and genotoxic potential of aclonifen in root meristem cells of *Allium cepa* L. In a preliminary root growth inhibition assay, the concentration reducing root length to 50% of the control after 96 hours was determined as 100 mg L⁻¹ and used as the median effective concentration. Accordingly, 50, 100, and 200 mg L⁻¹ concentrations corresponding to one-half, one-fold, and two-fold this value were selected for cytogenetic analyses. Onion roots were exposed for 24, 48, and 72 hours, and root length, mitotic index, micronucleus frequency, and chromosomal aberrations were evaluated. Aclonifen significantly inhibited root growth in a concentration- and time-dependent manner. At 72 hours, root length decreased from 5.08 cm in the control group to 2.53 cm and 1.48 cm in the 100 and 200 mg L⁻¹ groups, respectively. Similarly, the mitotic index declined from 55.28% in the control group to 24.86% and 15.38% at 100 and 200 mg/L, respectively. Genotoxicity endpoints increased markedly with increasing concentration and exposure duration. After 72 hours of treatment, micronucleus frequency increased from 0.12% in the control group to 2.86% at 200 mg/L, while total chromosomal aberrations rose from 1.72% to 23.64%. The most common abnormalities included chromosome laggards, stickiness, anaphase bridges, and c-mitosis. These findings demonstrate that aclonifen induces significant cytotoxic and genotoxic effects in *Allium cepa* root meristem cells by suppressing cell division and increasing chromosomal damage. The results provide new evidence regarding the biological effects of aclonifen on non-target plant systems and highlight the usefulness of plant-based bioassays in environmental risk assessment.

Keywords: Aclonifen, *Allium cepa*, Cytotoxicity, Genotoxicity, Mitotic index, Chromosomal aberrations

Introduction

Herbicides, which are widely used to achieve weed control in agricultural production, play an important role in enhancing crop productivity. However, intensive and indiscriminate herbicide use has become an increasing source of concern owing to environmental pollution and the potential adverse effects on non-target organisms. Herbicides applied to agricultural areas may persist for long periods in soil, water and plant systems and, upon being transported to environmental compartments, may exert various toxic effects on ecosystem components (Pérez-Lucas et al., 2019; Erguven et al., 2016).

Aclonifen [2-chloro-6-nitro-3-phenoxyaniline] is a selective herbicide belonging to the nitrophenyl ether (diphenyl ether) group and is widely used for the control of annual narrow- and broad-leaved weeds in sunflower, chickpea, lentil, carrot and various field crops (Erguven et al., 2016). Its commercial formulation, Challenge® 600 SC, contains 600 g/L aclonifen and has been licensed for use in Türkiye for many years. For many years, aclonifen was classified by the HRAC within Group F3 as a pigment-biosynthesis inhibitor whose mode of action was not precisely known. However, recent research has shown that the principal molecular target of this herbicide is solanesyl diphosphate synthase (SDPS), an enzyme involved in the plastoquinone biosynthetic pathway. In line with this discovery, aclonifen has been placed within Group 32 in the current HRAC classification (Kahlau et al., 2020). Inhibition of SDPS restricts plastoquinone production, disrupts carotenoid biosynthesis and, consequently, gives rise to phytotoxic effects characterised by the loss of photosynthetic pigments, chlorosis and plant death (Kahlau et al., 2020).

The widespread agricultural use of aclonifen has increased the importance of research concerning the environmental persistence of this compound and its effects on non-target organisms. In evaluations carried out by the European Food Safety Authority, aclonifen has been reported to exhibit moderate-to-high persistence in soil (EFSA, 2008; Erguven et al., 2016). Moreover, owing to its high adsorption capacity, aclonifen has been reported to remain in soil for long periods and to display low mobility (Pérez-Lucas et al., 2019). EFSA (2008) stated that aclonifen is moderately-to-highly persistent under aerobic conditions, with DT50 values ranging between 32.2 and 134 days. This situation suggests that aclonifen residues may accumulate in the environment and give rise to adverse effects on different groups of organisms.

Studies conducted in recent years have revealed that aclonifen and some structurally related herbicides belonging to the same diphenyl ether family may produce various toxic effects in non-target organisms. Lee et al. (2021) reported that aclonifen caused developmental toxicity in zebrafish embryos and adversely affected mitochondrial functions. Similarly, Park et al. (2022) demonstrated that aclonifen could give rise to cellular stress and cytotoxic effects in mammalian cells. In studies carried out with bifenox, another herbicide possessing a



diphenyl ether structure, suppression of cell proliferation, disruption of the cell cycle and the triggering of apoptotic processes were reported (Park et al., 2023). Although these herbicides may exert their effects through different biological targets, the findings obtained indicate that diphenyl ether-derived herbicides may elicit various toxic responses in non-target organisms.

Among the biological test systems used to determine the cytotoxic and genotoxic effects of environmental pollutants, the *Allium cepa* test holds an important place owing to its high sensitivity, low cost, ease of application and the high correlation it shows with mammalian test systems (Leme & Marin-Morales, 2009; Tedesco & Laughinghouse, 2012; Torres-Bugarín et al., 2026). Owing to its large and readily observable chromosomes, rapid root growth and sensitivity to various chemicals, *A. cepa* is widely used in the determination of cytogenetic damage caused by pesticides. Parameters such as the mitotic index, micronucleus formation and chromosomal aberrations are regarded as reliable biomarkers in the evaluation of adverse effects on cell division and genetic material (Leme & Marin-Morales, 2009; Torres-Bugarín et al., 2026).

Previous studies conducted with different pesticides have shown that pesticide exposure suppresses mitotic activity, increases chromosomal aberrations and promotes micronucleus formation in *A. cepa* root meristem cells. In a recent study carried out with omethoate, a significant decrease in the mitotic index and an increase in the frequencies of micronuclei and chromosomal aberrations were reported (Karagöl et al., 2025). Similarly, applications of oxyfluorfen, a member of the diphenyl ether group, have been reported to reduce mitotic activity and to cause various chromosomal aberrations (Dragoeva et al., 2012). In addition, environmental samples containing pesticide residues have also been shown to cause genotoxic effects in the *A. cepa* system (Feretti et al., 2007).

Despite the widespread use of acclonifen, the cytotoxic and genotoxic effects produced by this herbicide in plant cells have not been sufficiently investigated. In particular, studies evaluating acclonifen-induced chromosomal damage and effects on cell division in the *Allium cepa* model are rather limited. Therefore, the present study aimed to evaluate the effects of Challenge® 600 SC, a commercial acclonifen formulation, on *Allium cepa* root meristem cells. Within this scope, root growth parameters, the mitotic index, micronucleus frequency and chromosomal aberrations were examined in order to reveal the biological responses induced by acclonifen exposure.

Materials and Methods

Experimental Design

In this study, acclonifen, a selective herbicide belonging to the diphenyl ether class, was used as the test substance. *Allium cepa* L. root meristem cells were chosen as the biological test system. Challenge® 600 SC (600 g/L acclonifen) was used as the commercial formulation. In order to ensure the homogeneous distribution of acclonifen in the test medium, 1% dimethyl sulfoxide (DMSO) was used as a co-solvent, and the DMSO proportion was kept constant in all treatment groups, including the negative control.

Healthy onions of similar size were selected, and their outer scales were removed without damaging the root primordia. The onions were germinated in the dark at room temperature and were separated into the experimental groups once the root lengths reached approximately 1–2 cm.

Determination of the EC50

The EC50 value, on which the selection of the treatment concentrations was based, was determined on the basis of root growth inhibition as a result of preliminary trials. For this purpose, healthy *Allium cepa* onions of similar size were exposed for 96 h to acclonifen solutions of 25, 50, 100, 200 and 400 mg L⁻¹ containing 1% DMSO. At the end of the exposure period, root lengths were measured, and the percentage growth inhibition relative to the control group was calculated for each concentration. Linear regression analysis was applied to the concentration–response data, and the concentration inhibiting root growth by 50% (EC50) was determined to be approximately 100 mg L⁻¹. Accordingly, the acclonifen concentrations of 50, 100 and 200 mg L⁻¹ used in the main experiments represent ½EC50, EC50 and 2×EC50, respectively.

Experimental Groups and Exposure Conditions

Distilled water containing 1% DMSO was used in the negative control group, whereas 10 mg L⁻¹ methyl methanesulfonate (MMS) was applied as the positive control group. Acclonifen treatments were carried out at concentrations of 50, 100 and 200 mg L⁻¹. The exposure periods were set as 24, 48 and 72 h. All concentrations are expressed as active ingredient equivalents (mg L⁻¹ acclonifen)

Root Growth Analysis

In order to determine the effects of the acclonifen treatments on root development, root lengths were measured at the end of each treatment. The results obtained were expressed as mean ± standard deviation (SD) and, by comparison with the control group, growth inhibition was evaluated. Five onions were used in each treatment group, and the lengths of 10 randomly selected roots from each onion were measured, giving a total of 50 roots



evaluated. Root lengths were measured in centimetres and expressed as mean $\pm$ standard deviation. Root growth inhibition was calculated using the following formula:

$$\text{Root Growth Inhibition (\%)} = [(\text{mean root length of the control group} - \text{mean root length of the treatment group}) / \text{mean root length of the control group}] \times 100$$

Cytogenetic Analyses

At the end of the exposure period, root tips were excised and fixed in Carnoy's solution (ethanol–acetic acid, 3:1, v/v) for 24 h. Following fixation, the samples were hydrolysed in 1 N HCl at 60 °C for 5 min (Aksu Kalmuk, 2025). Staining was then carried out with Schiff's reagent for the cytogenetic examinations. The stained root tips were prepared as squash preparations in 45% (v/v) acetic acid. The preparations thus obtained were examined under a light microscope at $\times 400$ magnification.

The mitotic index (MI), micronucleus (MN) frequency and chromosomal aberrations (CA) were evaluated (Fiskesjö, 1985; Leme & Marin-Morales, 2009). Five onions were used for each treatment group, and a total of 5000 cells were analysed by counting 1000 cells from each onion. The mitotic index was calculated by expressing the ratio of the number of dividing cells to the total number of cells as a percentage. The micronucleus frequency was evaluated in interphase cells, and the results were given as a percentage of the total number of cells examined. Chromosomal aberrations, on the other hand, were evaluated only in dividing cells, and the ratio of abnormal mitoses to the total number of dividing cells was calculated as a percentage (Grant, 1982).

Detailed evaluations of the chromosomal aberration profile were carried out only for the 72 h exposure groups. The reason for this is that, although the chromosomal aberrations occurred as the same types in the preliminary evaluations, their frequencies increased with exposure time, and the most pronounced genotoxic effect was observed in the 72 h treatments. Therefore, in order to avoid data repetition and to ensure a clearer presentation of the results, the chromosomal aberration profile was reported only for the 72 h treatment groups.

Statistical Analysis

All data were expressed as mean $\pm$ standard deviation. Statistical analyses were performed using the SPSS 22.0 software package. Root length, mitotic index, micronucleus frequency and chromosomal aberration ratios were evaluated separately within each exposure period. Within this framework, the 24, 48 and 72 h treatment groups were analysed by one-way analysis of variance (ANOVA) in order to be compared with the corresponding control group. Dunnett's multiple comparison test was used to determine significant differences. Prior to analysis, the normality assumption of the data was assessed using the Shapiro–Wilk test and the homogeneity of variances using Levene's test. The level of statistical significance was accepted as $p < 0.05$.

Results

Effects on Root Growth

The aclonifen treatments were found to suppress the root development of *Allium cepa* in a dose- and time-dependent manner. In the control group, root lengths increased with increasing exposure time and were measured as 3.12 ± 0.21 cm, 4.36 ± 0.28 cm and 5.08 ± 0.34 cm at 24, 48 and 72 h, respectively. In contrast, root lengths in all aclonifen treatment groups were found to be significantly reduced compared with the control group ($p < 0.05$) (Table 1).

At the highest concentration, 200 mg L^{-1} aclonifen, root lengths were determined to be 1.36 ± 0.14 cm, 1.72 ± 0.17 cm and 1.48 ± 0.15 cm at 24, 48 and 72 h, respectively. The positive control group (MMS), on the other hand, showed the lowest root length values at all treatment times. In particular, at the 72 h treatment, the root length, which was 5.08 ± 0.34 cm in the control group, decreased to 2.53 ± 0.21 cm in the 100 mg L^{-1} aclonifen group, and this result was found to be consistent with the EC₅₀ value determined in the preliminary trials (Table 1).

Table 1. Effects of different aclonifen concentrations and exposure times on root length (cm) in *Allium cepa*.

Concentration (mg/ L)	24 h (cm)	48 h (cm)	72 h (cm)
Control (%1 DMSO)	3.12 ± 0.21	4.36 ± 0.28	5.08 ± 0.34
50	$2.61 \pm 0.18^*$	$3.28 \pm 0.24^*$	$3.74 \pm 0.27^*$
100	$1.98 \pm 0.16^*$	$2.41 \pm 0.19^*$	$2.53 \pm 0.21^*$
200	$1.36 \pm 0.14^*$	$1.72 \pm 0.17^*$	$1.48 \pm 0.15^*$
Positive control (MMS)	$1.12 \pm 0.11^*$	$1.08 \pm 0.10^*$	$0.96 \pm 0.09^*$

Values are expressed as mean $\pm$ SD. *Statistically significant difference from the control group ($p < 0.05$).



Effects on the Mitotic Index

The aclonifen treatments were found to significantly reduce mitotic activity in the root meristem cells. In the control group, the mitotic index values were calculated as $68.42 \pm 4.12\%$, $61.37 \pm 3.86\%$ and $55.28 \pm 3.41\%$ at 24, 48 and 72 h, respectively (Table 2).

A marked decrease in the mitotic index values occurred as a result of the aclonifen treatments. At the highest treatment dose, 200 mg L⁻¹, the mitotic index values were determined to be $27.53 \pm 2.41\%$, $20.74 \pm 1.96\%$ and $15.38 \pm 1.82\%$ at 24, 48 and 72 h, respectively. In the positive control group, these values were determined to be $24.16 \pm 2.08\%$, $18.63 \pm 1.74\%$ and $12.42 \pm 1.56\%$, respectively. At the 72 h treatment, the mitotic index in the 200 mg L⁻¹ aclonifen group was found to have decreased by approximately 72% compared with the control group (Table 2).

Table 2. Effects of aclonifen treatments on the mitotic index (MI) in *Allium cepa* root meristem cells.

Concentration (mg/ L)	24 h MI (%)	48 h MI (%)	72 h MI (%)
Control (%1 DMSO)	68.42 ± 4.12	61.37 ± 3.86	55.28 ± 3.41
50	$52.16 \pm 3.48^*$	$43.85 \pm 3.11^*$	$36.42 \pm 2.94^*$
100	$39.74 \pm 2.96^*$	$31.28 \pm 2.54^*$	$24.86 \pm 2.11^*$
200	$27.53 \pm 2.41^*$	$20.74 \pm 1.96^*$	$15.38 \pm 1.82^*$
Positive control (MMS)	$24.16 \pm 2.08^*$	$18.63 \pm 1.74^*$	$12.42 \pm 1.56^*$

Values are expressed as mean $\pm$ SD. *Statistically significant difference from the control group ($p < 0.05$).

Effects on Micronucleus Frequency

The aclonifen treatments were found to increase micronucleus formation in a dose- and time-dependent manner. In the control group, the micronucleus frequency remained at low levels at all treatment times and was determined to be $0.08 \pm 0.03\%$, $0.10 \pm 0.04\%$ and $0.12 \pm 0.05\%$ at 24, 48 and 72 h, respectively.

In the aclonifen-treated groups, significant increases in micronucleus frequency were observed ($p < 0.05$). The highest values were detected in the 200 mg L⁻¹ group, in which the micronucleus frequency was determined to be $1.18 \pm 0.17\%$, $2.04 \pm 0.26\%$ and $2.86 \pm 0.31\%$ at 24, 48 and 72 h, respectively. In the positive control group, values of $1.42 \pm 0.20\%$, $2.35 \pm 0.29\%$ and $3.18 \pm 0.36\%$ were obtained at the same times, respectively. At the 72 h treatment, the 200 mg L⁻¹ aclonifen treatment caused an approximately 23.8-fold higher micronucleus formation compared with the control group (Table 3).

Table 3. Effects of different aclonifen concentrations and exposure times on micronucleus (MN) frequency in *Allium cepa* root meristem cells.

Concentration (mg/ L)	24 h MN (%)	48 h MN (%)	72 h MN (%)
Control (%1 DMSO)	0.08 ± 0.03	0.10 ± 0.04	0.12 ± 0.05
50	$0.31 \pm 0.08^*$	$0.56 \pm 0.11^*$	$0.82 \pm 0.14^*$
100	$0.64 \pm 0.12^*$	$1.12 \pm 0.18^*$	$1.68 \pm 0.22^*$
200	$1.18 \pm 0.17^*$	$2.04 \pm 0.26^*$	$2.86 \pm 0.31^*$
Positive control (MMS)	$1.42 \pm 0.20^*$	$2.35 \pm 0.29^*$	$3.18 \pm 0.36^*$

Values are expressed as mean $\pm$ SD. *Statistically significant difference from the control group ($p < 0.05$).

Effects on Total Chromosomal Aberrations

The aclonifen treatments were found to increase the total chromosomal aberration frequency with increasing dose and exposure time. In the control group, the total chromosomal aberration rates were determined to be $1.24 \pm 0.32\%$, $1.48 \pm 0.36\%$ and $1.72 \pm 0.41\%$ at 24, 48 and 72 h, respectively.

In the aclonifen-treated groups, marked increases in chromosomal aberration frequency were observed. The highest values were obtained in the 200 mg L⁻¹ group, in which the total chromosomal aberration rates were calculated as $12.48 \pm 1.05\%$, $18.72 \pm 1.44\%$ and $23.64 \pm 1.86\%$ at 24, 48 and 72 h, respectively. In the positive control group, these values were determined to be $15.26 \pm 1.21\%$, $22.84 \pm 1.73\%$ and $27.18 \pm 2.04\%$, respectively. At the 72 h treatment, the total chromosomal aberration frequency in the 200 mg L⁻¹ aclonifen group was found to have increased approximately 13.7-fold compared with the control group (Table 4).

Table 4. Effects of aclonifen treatments on total chromosomal aberration (CA) frequency in *Allium cepa* root meristem cells.

Concentration (mg/ L)	24 h CA (%)	48 h CA (%)	72 h CA (%)
Control (%1 DMSO)	1.24 ± 0.32	1.48 ± 0.36	1.72 ± 0.41
50	$4.86 \pm 0.58^*$	$6.94 \pm 0.72^*$	$8.42 \pm 0.83^*$
100	$8.16 \pm 0.77^*$	$11.84 \pm 1.02^*$	$14.26 \pm 1.18^*$
200	$12.48 \pm 1.05^*$	$18.72 \pm 1.44^*$	$23.64 \pm 1.86^*$
Positive control (MMS)	$15.26 \pm 1.21^*$	$22.84 \pm 1.73^*$	$27.18 \pm 2.04^*$

Values are expressed as mean $\pm$ SD. *Statistically significant difference from the control group ($p < 0.05$).



Chromosomal Aberration Profile

The main chromosomal aberrations observed in the 72 h treatments were chromosome laggards, chromosome stickiness, anaphase bridges, c-metaphase, irregular anaphase–telophase, binucleate cells and nuclear deformations.

Chromosome stickiness was found to be the most common type of chromosomal aberration in all treatment groups. The stickiness rate, which was determined to be $0.42 \pm 0.07\%$ in the control group, rose to $5.62 \pm 0.44\%$ in the 200 mg L⁻¹ acclonifen treatment. Similarly, c-metaphase, anaphase bridge and irregular anaphase–telophase aberrations were also observed to increase in parallel with the increasing dose.

While the chromosome laggards were $0.21 \pm 0.05\%$ in the control group, they were determined to be $2.54 \pm 0.21\%$ in the 200 mg L⁻¹ acclonifen group. The nuclear deformations, on the other hand, rose from $0.17 \pm 0.04\%$ in the control group to $3.48 \pm 0.28\%$ in the same treatment group. In the positive control group, all types of chromosomal aberrations were found to be observed at the highest levels (Table 5).

Table 5. Profile of chromosomal aberrations induced by acclonifen in *Allium cepa* root meristem cells after 72 h of exposure.

Group	LC	SC	AB	CM	IAT	BN	ND	Total CA
Control (%1 DMSO)	0.21 ± 0.05	0.42 ± 0.07	0.26 ± 0.06	0.28 ± 0.06	0.24 ± 0.05	0.14 ± 0.04	0.17 ± 0.04	1.72 ± 0.41
50 mg/ L	0.92 ± 0.10	2.04 ± 0.18	1.16 ± 0.12	1.34 ± 0.13	1.12 ± 0.11	0.84 ± 0.09	1.00 ± 0.10	8.42 ± 0.83
100 mg/ L	1.54 ± 0.14	3.48 ± 0.29	1.96 ± 0.18	2.24 ± 0.21	1.92 ± 0.17	1.28 ± 0.13	1.84 ± 0.16	14.26 ± 1.18
200 mg/ L	2.54 ± 0.21	5.62 ± 0.44	3.08 ± 0.26	3.84 ± 0.31	3.12 ± 0.25	1.96 ± 0.18	3.48 ± 0.28	23.64 ± 1.86
MMS (10 mg/L)	2.96 ± 0.24	6.48 ± 0.51	3.64 ± 0.29	4.42 ± 0.35	3.58 ± 0.28	2.26 ± 0.21	3.84 ± 0.31	27.18 ± 2.04

LC = laggard chromosome; SC = chromosome stickiness; AB = anaphase bridge; CM = c-metaphase; IAT = irregular anaphase–telophase; BN = binucleate cell; ND = nuclear deformation.

Discussion

In this study, the commercial acclonifen formulation Challenge® 600 SC was shown to produce marked cytotoxic and genotoxic effects on the root meristem cells of *Allium cepa*. The responses obtained were found to increase with dose and exposure time, manifesting as reductions in root growth and mitotic activity and as increases in the frequencies of micronuclei and chromosomal aberrations.

The suppression of root growth is regarded as one of the most sensitive indicators of phytotoxicity in the *Allium* test system, since root elongation directly reflects the processes of cell division and cell expansion in meristematic tissues (Leme & Marin-Morales, 2009; Torres-Bugarín et al., 2026). In this study, acclonifen treatments significantly reduced root length at all concentrations, and the strongest inhibition was observed in the 200 mg L⁻¹ group at the end of 72 h of exposure. The results obtained indicate that acclonifen adversely affects root development and cellular proliferation. Similarly, *Allium* studies carried out with various pesticides have also reported marked reductions in root growth (Feretti et al., 2007; Karagöl et al., 2025). The root elongation inhibition observed in this study suggests that acclonifen disrupts the physiological processes required for normal root development.

The mitotic index, reflecting the proportion of actively dividing cells within a cell population, is regarded as one of the reliable indicators of cytotoxicity (Leme & Marin-Morales, 2009). In our study, significant decreases in mitotic index values were determined following acclonifen treatments. The decreases occurring particularly at concentrations of 100 and 200 mg L⁻¹ became more pronounced as the exposure time increased. These findings show that acclonifen suppresses cell division in root meristem tissues. Significant decreases in mitotic index values have similarly been reported in studies carried out with the insecticide omethoate and with the herbicide oxyfluorfen, which belongs to the same diphenyl ether class (Dragoeva et al., 2012; Karagöl et al., 2025). It is considered that this decrease in mitotic activity may be associated with disturbances in chromosome organisation and in the functioning of the spindle fibres during cell division. Moreover, considering that acclonifen inhibits solanesyl diphosphate synthase (SDPS), a key enzyme in plastoquinone biosynthesis, the observed cytotoxic and genotoxic effects may also be associated with oxidative stress and cellular disturbances resulting from impaired plastoquinone metabolism.

Micronucleus formation is regarded as one of the most important biomarkers of genotoxic damage, as it originates from chromosomes or chromosome fragments that fail to be incorporated into the daughter nuclei during division (Leme & Marin-Morales, 2009; Torres-Bugarín et al., 2026). In this study, the micronucleus frequency was found to increase significantly in a manner dependent on both concentration and exposure time. Marked increases in micronucleus formation were observed particularly at 48 and 72 h of exposure. The highest micronucleus frequency was determined in the 72 h, 200 mg L⁻¹ acclonifen treatment group and approached the values obtained in the positive control group. In this group, the micronucleus frequency showed an approximately 23.8-fold increase compared with the control. These results clearly demonstrate that acclonifen causes genetic damage in meristematic cells. Similarly, significant increases in micronucleus frequency have also been reported in studies carried out with environmental samples containing pesticide residues and with various agrochemicals (Feretti et al., 2007; Karagöl et al., 2025).



Chromosomal aberrations are among the important indicators in the evaluation of the genotoxic effects of environmental pollutants. In this study, the total frequency of chromosomal aberrations was found to rise markedly as the dose and exposure time increased in response to aclonifen treatments. The highest chromosomal aberration frequencies were observed in the 72 h treatments. The total chromosomal aberration frequency reached its highest level of 23.64% in the 72 h, 200 mg L⁻¹ group (control: 1.72%). Among the aberrations observed, chromosome stickiness was determined to be the most common. Chromosome stickiness is generally regarded as an indicator of severe damage occurring in the chromatin structure and is associated with disturbances in chromosomal proteins or in DNA organisation (Leme & Marin-Morales, 2009). In addition, chromosome laggards, anaphase bridges, c-metaphase, irregular anaphase–telophase cells, binucleate cells and nuclear deformations were also observed at high rates in the treatment groups. Similar chromosomal aberrations have also been reported in *Allium* studies carried out with oxyfluorfen and other pesticides (Dragoeva et al., 2012; Karagöl et al., 2025).

In particular, the predominant occurrence of chromosome stickiness, together with the accompanying increases in the frequencies of c-metaphase and chromosome laggards, suggests that aclonifen disrupts normal chromosome segregation during mitosis. Aberrations such as c-metaphase and chromosome laggards reflect an aneugenic effect associated with the impairment of spindle function, whereas chromosome stickiness, anaphase bridges and nuclear deformations reflect a clastogenic effect associated with damage to the chromosome/chromatin structure. These findings suggest that aclonifen acts through both aneugenic and clastogenic mechanisms. Such disturbances may lead to chromosome loss, structural chromosome damage and, consequently, micronucleus formation. The parallel increases observed in chromosomal aberrations and micronucleus frequency in our study also support this assessment and indicate that aclonifen gives rise to genomic instability in root meristem cells.

Previous studies carried out with aclonifen on non-target organisms have revealed that this herbicide produces developmental toxicity in zebrafish embryos and may cause cytotoxic effects in mammalian cells (Lee et al., 2021; Park et al., 2022). Furthermore, studies carried out with bifenox, which belongs to the same diphenyl ether family in structural terms, have reported the suppression of cell proliferation and an increase in cellular damage (Park et al., 2023). The findings obtained in this study are consistent with these investigations and show that aclonifen may produce adverse effects not only on target weeds but also on non-target biological systems.

Conclusion

Taken together, the findings of the present study demonstrate that aclonifen induces significant cytotoxic and genotoxic effects in the root meristem cells of *Allium cepa*. The present study provides new evidence regarding the cytotoxic and genotoxic potential of aclonifen in non-target plant systems and confirms the suitability of the *Allium cepa* assay as a sensitive and reliable tool for the assessment of herbicide-induced environmental risks. Future studies integrating molecular biomarkers and oxidative stress parameters would be valuable for clarifying the mechanisms underlying aclonifen-induced genotoxicity.

Declarations

Ethical Approval Certificate

The present study was conducted using the *Allium cepa* test system and did not involve experimental animals or human participants. Therefore, ethical committee approval was not required.

Author Contribution Statement

Nurşen Aksu Kalmuk: Conceptualization, methodology, investigation, data collection, formal analysis, visualization, writing – original draft preparation, writing – review and editing.

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Conflict of Interest

The author declares no conflict of interest.

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In Vitro Analysis of the Potential Role of NOX-1 in Monosodium Glutamate-Induced Oxidative Stress and Cytotoxicity in HT-22 Hippocampal Neuronal Cells

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Abstract

Monosodium glutamate (MSG) is extensively used as a flavor enhancer in the food industry and is consumed in considerable amounts through daily diet. In this study, the potential toxic effects of MSG on hippocampal neuronal cells, which are particularly rich in glutamate receptors, were examined in the HT-22 mouse hippocampal neuronal cell line within a toxicity model framework, focusing on cytotoxicity and oxidative stress. For this purpose, HT-22 cells were cultured under appropriate cell culture conditions and treated with MSG at concentrations of 1, 5, 20, and 100 µM for 24 hours. Cell viability was assessed by XTT assay, and total antioxidant status (TAS) and total oxidant status (TOS) were measured using the Rel Assay commercial kit to determine the oxidative stress status. NADPH oxidase-1 (NOX-1) expression was determined by immunofluorescence to evaluate the potential effects of MSG on NOX-mediated oxidative mechanisms. Data were analyzed using one-way ANOVA followed by post hoc test; $p < 0.05$ was accepted as the threshold for statistical significance. Analysis of the findings revealed that cell viability, TAS/TOS levels, and NOX-1 expression showed no statistically significant change at any of the applied MSG concentrations compared to the control group. While these results indicate that MSG does not elicit a measurable cytotoxic or oxidative stress response in HT-22 cells under the tested concentration range and exposure duration, further studies under different experimental conditions are warranted.

Keywords: Monosodium glutamate, HT-22, NADPH oxidase-1, oxidative stress, cytotoxicity

HT-22 Hipokampal Nöronal Hücrelerinde Monosodyum Glutamat Kaynaklı Oksidatif Stres ve Sitotoksitede NOX-1'in Olası Rolünün İn Vitro Analizi

Özet

Monosodyum glutamat (MSG), gıdalarda lezzet artırıcı olarak yoğun biçimde kullanılmakta ve günlük diyetle önemli miktarlarda alınmaktadır. Bu çalışmada MSG'nin özellikle glutamat reseptörlerinin yoğun olarak bulunduğu hipokampal nöronal hücreler üzerinde oluşturabileceği olası toksik etkiler HT-22 fare hipokampal nöronal hücre hattında sitotoksitede ve oksidatif stres üzerindeki etkileri bir toksisite modeli çerçevesinde incelenmiştir. Bu amaçla HT-22 hücreleri uygun hücre kültürü koşullarında çoğaltılmış ve 1, 5, 20 ve 100 µM konsantrasyonlarında MSG ile 24 saat süreyle muamele edilmiştir. Hücre canlılığı XTT yöntemiyle değerlendirilmiş, oksidatif stres durumunu göstermek amacıyla total antioksidan durum (TAS) ve total oksidan durum (TOS) Rel Assay ticari kiti aracılığıyla ölçülmüştür. MSG'nin olası NOX aracılı oksidatif mekanizmalar üzerindeki etkisini değerlendirmek amacıyla ise NADPH oksidaz-1 (NOX-1) ekspresyonu immünoflorasans yöntemiyle belirlenmiştir. Elde edilen veriler one-way ANOVA ve post hoc testi ile analiz edilmiş; $p < 0,05$ istatistiksel anlamlılık eşiği olarak kabul edilmiştir. Bulgular incelendiğinde, uygulanan MSG konsantrasyonlarında hücre canlılığı, TAS/TOS düzeyleri ve NOX-1 ekspresyonunun kontrol grubuna kıyasla istatistiksel olarak anlamlı bir değişim göstermediği saptanmıştır. Bu sonuçlar, test edilen konsantrasyon aralığı ve maruziyet süresi koşullarında MSG'nin HT-22 hücrelerinde ölçülebilir bir sitotoksik ya da oksidatif stres yanıtı oluşturmadığına işaret etmekle birlikte, farklı deneysel koşullar altında ileri çalışmalara ihtiyaç vardır.

Anahtar kelimeler: Monosodyum glutamat, HT-22, NADPH oksidaz-1, oksidatif stres, sitotoksitede



Technical and ecological approach to the Beypınarı land consolidation project

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Abstract

This research examines the technical and ecological adequacy of the Beypınarı land consolidation project in Erzurum – Aziziye. To this end, the technical success of the Beypınarı consolidation was determined. Simultaneously, a study was conducted to assess the extent to which the Beypınarı consolidation project met ecological requirements. According to the results, the consolidation rate in the Beypınarı settlement was 47.78%, and the increase in the average parcel area was 93.96%. In this project, the rate of direct access to road, irrigation, and drainage facilities for the parcels was 98%. No renovation was carried out in the village settlement. However, as is generally the case in rural area studies, no inventory study was conducted to improve the social and cultural structure. The Karasu Stream, which flows along the south-facing slope of the rural settlement, is also a wetland with a very high groundwater level. A detailed evaluation study on this aspect was not included in the project. In our country, land consolidation efforts, which fall within the scope of rural planning, require a multifaceted approach that considers social, economic, cultural, and physical factors.

Keywords: Rural planning, Land consolidation, Ecological approach, Erzurum, Beypınarı

Introduction

In parallel with the desired economic development in rural areas, it is essential to plan for the desired social and physical developments in these areas. Physical planning is the comprehensive reorganization of settlements, taking into account social, economic, and cultural opportunities and their future development. Measures affecting efficiency and production in agriculture can be listed as: development of water and soil resources, drainage and irrigation services, provision of drinking and utility water, physical planning of rural areas, and planning of farmyards.

One of the most significant problems in agricultural economics is the fragmentation of agricultural land. Land fragmentation refers to the division of agricultural land due to the encroachment of other businesses or parcels used for non-agricultural purposes. This results in both irregular shapes that make farming difficult and the necessity of using neighboring parcels to access intertwined farm parcels. Fragmented and irregularly geometric agricultural lands are generally divided into thin slices downhill. Implementing soil conservation measures is very difficult in such parcels. Another negative impact of land fragmentation on land use is that it makes it difficult to protect meadows and pastures (Kuşlu, 2004:23).

It is necessary to accurately determine the people living in agricultural areas and the land use status of the agricultural area. In general, in the world, agricultural areas are not considered only as the living space of people working in agriculture (Boztoprak et al., 2015:2).

Those living in rural areas can be categorized as follows: those who engage solely in agricultural production; those who engage in agriculture for supplementary income, such as ornamental plant production, animal husbandry, and fruit and vegetable production; those who come to agricultural areas for recreation during holidays; and those who live in these areas for short or long periods because the natural structure of the rural area is preserved and environmental pollution is less severe (Peker and Dağdelen, 2016:26).

Land consolidation in rural areas is a multifaceted approach that supports agricultural production planning, improves the living standards and working conditions of those engaged in agriculture, reduces production inputs in agricultural activities, and ultimately contributes to rural development. Perceived as the reorganization of fragmented land holdings owned by various enterprises, the scope of this work has expanded over time, and due to its role in the multifaceted development of rural areas, it has acquired a dynamic and modern structure in many countries (Kuşlu, 2004:30).

Land consolidation is the process of bringing together and reorganizing scattered plots of land in rural areas, located in different directions from the village center and irregularly shaped according to agricultural management principles, in accordance with environmental requirements and connected to road, drainage, and irrigation networks (İlhan and Erpul, 2015:2). One of the goals of land consolidation is to provide access to all parcels through a transportation network. To ensure access without encroaching on the boundaries of other parcels, a portion of each parcel must border a road. In a parcel and road plan, access to all parcels is sought with a minimum road length (Demirel and Işık, 2000:1; Kuşlu and Ertem, 2019:275).

In a narrow sense, land consolidation is the process of bringing together fragmented and scattered plots or shares of agricultural land owned by the same farm or farming family into geometrically regular shapes. This type of consolidation is less time-consuming and cheaper. However, it is not sufficiently effective for rural development on its own because land consolidation in this narrow sense does not involve any structural work (Boztoprak et al., 2015:5).



More broadly, land consolidation is a reorganization of an agricultural space that includes all technological, social, and economic measures to be taken for purposes such as bringing together irregularly geometric and scattered parcels of land belonging to an agricultural enterprise, as well as regulating the living and working conditions of the owners and employees, protecting nature and soil, achieving sustainable agricultural development, and increasing agricultural production efficiency (Kuşlu, 2004: 31).

Comprehensive land consolidation efforts should include the following investments and services (Peker and Dağdelen, 2016:27; İlhan and Erpul, 2015:3; Kuslu, 2009:613; Kuslu, 2021: 743):

- Arrangement of field shapes;
- Bringing together irregularly shaped, multi-part plots of land,
- Creating plot shapes that are suitable in terms of quality and size for agricultural businesses, taking into account the evolving technological level of the day.
- Ensuring that at least one edge of the plots is connected to the irrigation, drainage, and road network.
- Improving the production and working conditions of farmers;
- Improving the chemical and physical properties of soils,
- Construction of irrigation and drainage facilities,
- Land leveling,
- Improving fertilizer application conditions that prioritize environmental soil and water characteristics,
- Mechanization and improving the proper operating conditions of machines.
- Improving the quality of life for farming families and other people living in rural areas;
- Correcting unsuitable environmental conditions (wastewater treatment, eliminating the threat posed by factory waste, etc.),
- Improving the health and safety of rural housing, designing buildings in a way that reflects village culture and promotes ecotourism,
- Construction of health and education facilities, assembly facilities, social, religious, and cultural facilities,
- Establishing an adequate transportation network within the village settlement area, between villages, within the fields, and across the entire land.

In Erzurum, the first compulsory land consolidation decision was made in 2004 in 13 village settlements. This research focuses on the Erzurum-Beypinari land consolidation project, one of the areas where compulsory consolidation was implemented. The study examines the dimensions of rural planning studies that can enhance the social and cultural impacts of land consolidation efforts in the settlement.

Material and Methods

The research material consists of the rural settlement of Beypinari in Erzurum. The situation before and after the land consolidation application is shown in Figures 1 and 2, respectively.

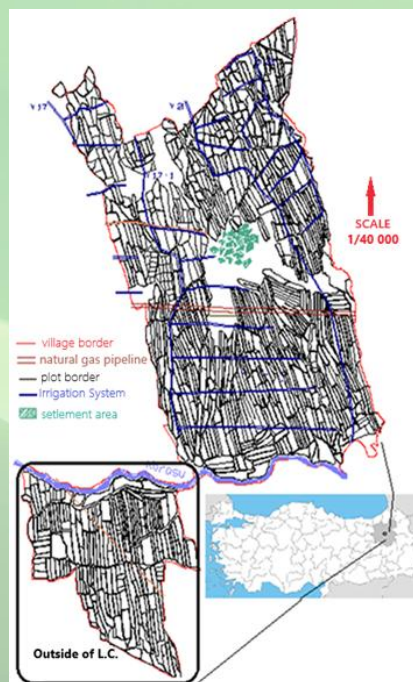


Figure 1. Parceling situation before Beypinari land consolidation project





Figure 2. Parceling situation after Beypınarı land consolidation project

Beypınarı is located approximately 16 km from the city center of Erzurum, between approximately 41° east longitude and 40° north latitude. According to TÜİK (Turkish Statistical Institute) data, the settlement has a population of 419 and an altitude of 1770 meters. Examination of soil characteristics reveals that the area consists of Class I, II, and III agricultural lands composed of alluvial and fine-textured soils with a depth of approximately 90 cm (Kuşlu, 2004:48). The average land slope varies between 0-2%, and the region has a flat or nearly flat topographical structure.

The research area, located in the Northeast Anatolian climate zone, has cool and dry summers and rainy and cold winters. There is a significant temperature difference between day and night. According to long-term meteorological data (1929-2024), the average annual temperature is 5.8 °C. January is the coldest month with an average temperature of -9.0 °C, while August is the warmest with 19.5 °C. The average annual rainfall is 430.9 mm, with May being the wettest month with 73.1 mm and August the driest with 17.6 mm. 51.5% (222.05 mm) of the annual rainfall occurs during the plant production period, from May 1st to October 20th. Relative humidity is lowest at 47% in August and highest at 75% in January, with an average annual relative humidity of 63% (MGM, 2025).

In this study, the sampling formula recommended for finite population and limited variance situations was used to determine the minimum number of surveys (Çiçek and Erkan, 1996:36).

$$n = \frac{N * \sigma^2}{(N - 1) * D^2 + \sigma^2}$$

In the equation; n is the number of units in the sample, N is the number of units in the population, σ^2 is the population variance, and D is the possible error value.

The minimum number of farm holder to be surveyed (n) was determined to be 9. However, considering the possibility of missing or lost data in the surveys, as well as the reliability of the research and the attainment of accurate information, the sample size was increased by 10% to 10 (Bender et al., 1982).

A face-to-face survey was conducted with 10 farm holders living in the rural settlement of Beypınarı.

NetCAD 8.5.0 GIS software, a CAD-based software, was used for digitizing the maps.

Information on old and new parcels and maps related to the Beypınarı land consolidation project was obtained from the DSI VIII Regional Directorate.

Results and Discussion

Some of the main objectives of land consolidation projects are: to bring smaller parcels of land up to the determined standard, to transform irregularly shaped parcels into suitable, regular geometric forms for agricultural activities, and to provide parcels with access to roads, irrigation networks, and drainage networks (Akdeniz and Temizel, 2018:151; Akkaya Aslan, 2018:365; Çakmak and Eminoğlu, 2013:40; Değirmenci et al., 2017:183).

Among the farm holders that were surveyed, three farms were engaged in agricultural production on 1-10 plots; three on 11-15 plots; two on 16-20 plots; and the remaining two on more than 20 plots before the land consolidation project. After consolidation, all farms were able to farm on 1-10 plots. Five farms now own only one plot. The consolidation rate was lowest in farm number 6 (68.8%) and highest in farm number 5 (95.8%). As can be seen from the table, the average consolidation rate was quite high at 87.8%.

In the Beypınarı land consolidation project, the reduction in the number of parcels, which was one of the objectives, has been achieved. The parcel shapes, which were quite deteriorated before consolidation, have



improved (Figures 1 and 2). The rate at which parcels have gained access to irrigation, drainage, and road networks through consolidation efforts has reached 98% (Figure 2).

The section of Beypinarı south of the Karasu stream, which was excluded from land consolidation, has a very high groundwater level. Although this area was a wetland before the 1950s, later drained and reclaimed for agriculture, it remains a habitat for numerous bird populations.

However, as is generally the case with rural development projects, this project did not include an inventory study aimed at improving the social and cultural structure. The potential for utilizing the Karasu stream, which flows along the south-facing side of the village, was not examined in detail.

The scope of land consolidation efforts did not include aspects such as developing the settlement area, identifying elements of local tourism in the surrounding area, and highlighting the beauty of the rural landscape. This situation is not unique to the Beypinarı project. A lack of a social and cultural approach is evident in all land consolidation projects implemented in Türkiye.

Conclusion

Settlements established in rural areas are shaped by traditional building systems and mostly local materials, influenced by climate and topography. Therefore, rural settlements need to be approached differently from urban settlements in terms of construction and planning. Furthermore, developing solutions that match the potential of rural areas is essential for addressing these problems. Rural areas mustn't compete with cities, but rather focus on protecting natural resources, supporting agricultural production, improving living conditions, and implementing high-level planning. When preparing infrastructure projects in villages, the local settlement pattern must be considered in depth. Additionally, assumptions regarding development criteria and methods for preserving the local structure should be established.

In the context of the Beypinarı land consolidation, identifying the potential of the Karasu stream for rural landscape and recreation planning could enhance the project's success. Furthermore, conducting birdwatching studies in the area south of the village, known in the literature as the Erzurum Wetlands, is important for its ecological tourism potential.

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A research on the performance of the pumice media filter

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Abstract

This study aimed to analyze the effectiveness of pumice and sand media in removing suspended solids from irrigation water. In the study, sand and pumice media passed through 0.05-1 mm and 1-2 mm sieve openings were used. Raw water with a sediment concentration of 150 mg/L was passed through the media filters under the operating pressure of 100 kPa. For each hour of process time, the discharge velocities are measured, and sediment contents are determined via the gravimetric method. Total cumulative flow volumes for sand and pumice media were 14349 L and 15218 L, respectively, after the 35 h operating period. The discharge velocities were changed between 47.71 m³/m²/h and 3.22 m³/m²/h for sand medium, and 49.46 m³/m²/h and 3.44 m³/m²/h for pumice media. At the end of the study, it can be concluded that the sediment contents and discharge velocities decreased as the total amount of treated water increased in both sand and pumice media filters. Layers of small size were more effective than the other layers at removing the solid particles. Based on the amount of sediment measured in the treated water, it can be said that the sand media was more effective than the pumice media.

Keywords: Irrigation water, media filter, pumice, sand, suspended solids

Pomza ortam filtresinin performansı üzerine bir araştırma

Özet

Bu çalışma, sulama suyundan askıda katı maddelerin uzaklaştırılmasında pomza ve kum ortamlarının etkinliğini analiz etmeyi amaçlamıştır. Çalışmada, 0.5 mm ve 1-2 mm elek açıklıklarından geçirilmiş kum ve pomza ortamları kullanılmıştır. 150 mg/L sediment konsantrasyonuna sahip ham su, 100 kPa çalışma basıncı altında ortam filtrelerinden geçirilmiştir. İşlem süresinin her saati için deşarj hızları ölçülmüş ve sediment içeriği gravimetrik yöntemle belirlenmiştir. 35 saatlik çalışma süresinin ardından kum ve pomza ortamları için toplam kümülatif akış hacimleri sırasıyla 14349 L ve 15218 L olmuştur. Deşarj hızları, kum ortamı için 48,16 m³/m²/h ile 3,35 m³/m²/h arasında, pomza ortamı için ise 51,36 m³/m²/h ile 3,69 m³/m²/h arasında değişmiştir. Çalışmanın sonunda, hem kum hem de pomza ortamlı filtrelerde arıtılan suyun toplam miktarı arttıkça tortu içeriğinin ve deşarj hızlarının azaldığı sonucuna varılabilir. Boyutu küçük olan katmanlar, sediment ayırmada diğer katmanlardan daha etkili olmuştur. Arıtılmış suda ölçülen sediment miktarına dayanarak, kum ortamının pomza ortamından daha etkili olduğu söylenebilir.

Anahtar Kelimeler: Sulama suyu, ortam filtresi, pomza, kum, askıda katı madde

Giriş

Pomza, köpüklü lavın katılaşmasıyla oluşan doğal bir malzemedir. Kayaçların yüksek basınç ve aşırı ısınma koşullarında volkandan şiddetli bir şekilde püskürtülmesiyle oluşur. Ardından hızlı basınç düşmesi ve soğuma, pomzanın süngerimsi bir yapı oluşturmasına neden olur. Birbirine bağlı olmayan, büyük ve küçük gözeneklere sahip pomza, hafif ve inert bir malzemedir. Yüzey alanı, yüzeydeki derin ve sık boşluklar nedeniyle geniştir (Şekil 1). Anac ve Tamzok (2008), pomzanın dünya çapında yaklaşık 50 ülkede üretildiğini ve en büyük payın İtalya'da olduğunu bildirmiştir. Bu ülkeyi sırasıyla Yunanistan, Şili, İspanya ve Türkiye takip etmektedir.



Şekil 1. Pomza taşının ve yüzey yapısının mikroskopik görüntüsü



Sudaki istenmeyen bileşenleri gidermek için, çok farklı özelliklere sahip ortamlar filtre malzemesi olarak kullanılabilir. Bunlar organik malzemeler olabildiği gibi inorganik malzemeler de olabilir Suyun bu şekilde arıtılması birçok araştırmanın konusu olmuştur. (Abbaszadeh et al., 2016; Chen et al., 2018; Mor vd., 2016; Pushkar, 2019, Korkut et al., 2021).

Kum-çakıl filtreler, özellikle fiziksel arıtma olmak üzere su arıtımında kullanılan en bilinen ortamlardır (Capra ve Scicolone, 2007; Tripathi et al., 2016). Genellikle sulama suyundan askıdaki maddeleri uzaklaştırmak için kullanılırlar. Su arıtma teknolojisinde pomza ve zeolit gibi doğal malzemelerin kullanımı giderek yaygınlaşmaktadır (Çiftçi ve Meriç, 2015). Bununla birlikte, bazı araştırmalar pomza ortamından oluşan filtrelerin de kullanılabileceğini ve bu amaçla olumlu sonuçlar elde edilebileceğini göstermektedir (Şahin vd., 1998; Farizoglu et al., 2003; Ghebremichael, 2004; Kuslu ve Şahin, 2013; Samarghandi et al., 2013; Ozmetin et al., 2017; Korkut et al., 2021).

Tarımsal sulamada kullanılan basınçlı sulama sistemlerinin ekonomik ömrü, sulama suyuna bağlıdır. Mikro sulama sistemindeki fiziksel tıkanma, sulama suyunda bulunan organik ve inorganik maddelerden kaynaklanmaktadır. Su kalitesi (Nakayama ve Bucks, 1991; Capra ve Scicolone, 1998; Nakayama et al., 2007; Tu ve Traver, 2018) 100 mg/L'den fazla askıda katı madde (AKM) içeriğine sahip sulama suyunun kullanılması tıkanma sorununu artırır. Fiziksel etkenlerden kaynaklanan tıkanma sorununun önlenmesinde çöktürme ve filtreleme önerilmektedir.

Bu çalışmada laboratuvar koşullarında pomza ve kum ortamı kullanılarak AKM konsantrasyonu 150 ppm olan ham su filtre edilmiş ve filtrelerin etkinliği araştırılmıştır.

Materyal ve Yöntem

Araştırmada Dünya ve Türkiye'nin birçok bölgesinde kolay ve ucuz olarak sağlanabilen pomza ve kum kullanılmıştır. Erzurum Pasinler yöresinden alınan pomza ve Erzurum kum ocağından alınan 0.5, 1.0 ve 2.0 mm eleklerden elenerek iki tabakalı filtre ortamı hazırlanmış ve malzemeler kullanılmadan önce yıkama işlemine tabi tutulmuştur.

Filtre kolonunun uzunluğu 850 mm ve çapı 200 mm'dir. Filtrelerin merkez (ikinci) katmanını, toplam filtre kolonu uzunluğunun %50'sini kapsamakta 0.5 mm çapındaki malzemeden oluşmaktadır. Filtrenin giriş (birinci) ve çıkış (üçüncü) katmanları 1-2 mm tane büyüklüğündeki malzemeden ve filtre kolonu toplam uzunluğunun %25'i kadardır. Filtreleme işleminde 150 ppm konsantrasyonda ham su elde etmek için, toprak 75 µm açıklıkta elenmiş ve AKM olarak kullanılmıştır.

Filtrasyon işleminde çalışma basıncı su giriş hacmine bağlı olarak 100 kPa olarak seçilmiş ve sistem girişindeki manometre yardımı ile kontrol edilmiştir. Askı maddeleri filtre ortamında biriktiğinden, çalışma basıncının artacağı açıktır. Basıncı azaltmak için, filtreye giren su hacmi vanalar yardımı ile azaltılmıştır. Böylece, sistemin işletme basıncı süreç boyunca sabit tutulmuştur.

Filtrasyon işlemi toplam 35 saat ve üç tekrarlama şeklinde yürütülmüştür. Her bir saat filtrasyon işlemi sonunda çıkış hızı belirlenmiş, her gün sonunda sediment ölçümü yapılmıştır. Bu amaçla gravimetrik analiz yöntemi kullanılmıştır. Filtre 35 saat çalıştırdıktan sonra her bir filtre tabakasından bir litre hacminde kum ve pomza malzemesi alınarak basınçlı su ile yıkanmıştır. Yıkamadan elde edilen su gravimetrik analize tabi tutularak filtre tabakalarındaki sediment birikimleri belirlenmiştir.

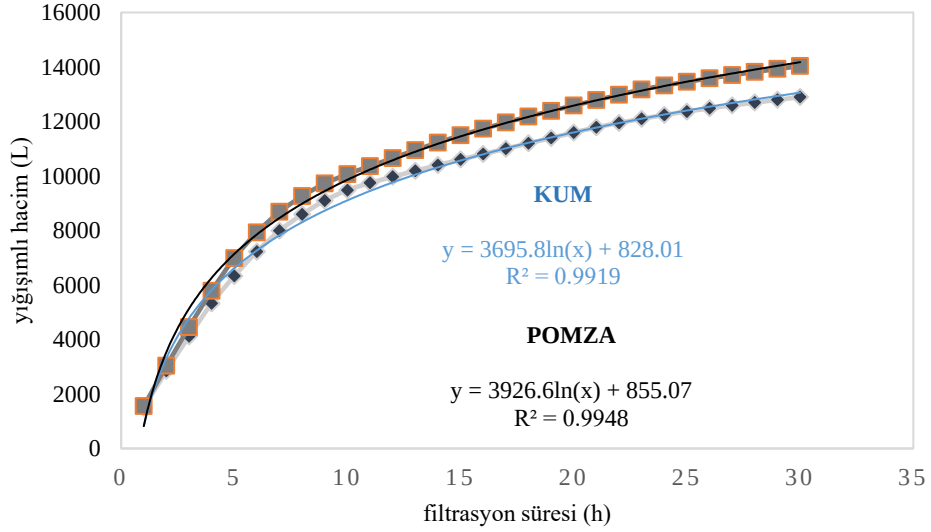
Araştırma Bulguları ve Tartışma

Filtrasyon işlemi sırasında yığılımlı akım hacmi Şekil 2'de gösterilmiştir. Filtrasyon süresi sonunda ortalama toplam çıkış hacmi kum filtre için 14.35, pomza filtre için ise 15.22 m³ olmuştur. Grafikten de anlaşılabileceği üzere pomza filtrenin akım hacmi zamanla artmaktadır. Bu, pomza ortamının porozitesi ve makro gözenek oranının yüksek olduğunun bir sonucudur (Kuslu & Sahin, 2013; Korkut et al., 2021).

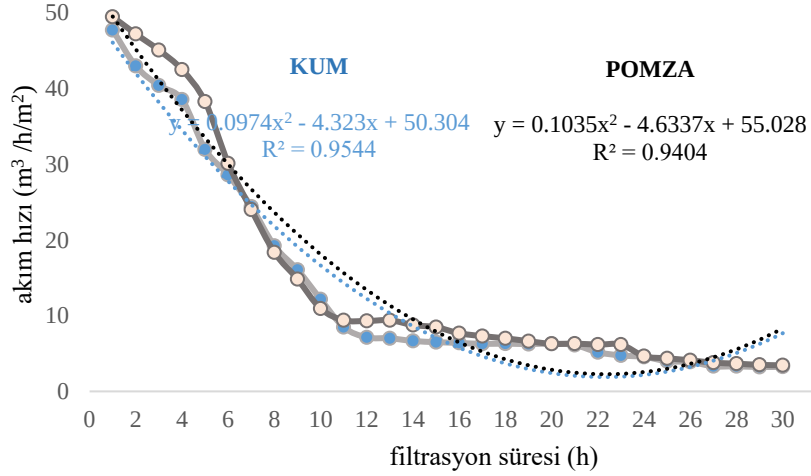
Filtrelerde akım hızının zamanla değişimi, Şekil 3'te görülmektedir. Filtrelerde akım hızı zamanla azalmış, bu azalma logaritmik özellik göstermiştir. Pomza ortam filtrelerinin akım hızının, pomzanın gözeneklilik oranının yüksek ve pürüzlü doğası nedeniyle yüksek olduğu söylenebilir. Akış hızı, gözenek boyutu küçüldükçe azalır. Bu nedenle filtre ortamının direnci, filtre malzemesinin gözenek büyüklüğü azaldıkça artar (Ghebremichael, 2004; Kuslu ve Sahin, 2013; Korkut et al., 2021).

Şekil 4, ortam filtreler için çıkış suyundaki AKM yoğunluğunu göstermektedir. Çıkış suyunda AKM yoğunluğu, filtrasyon deneme süresindeki artışla azalmıştır. Gill et al., (2009), Kuslu & Sahin (2013) ve Korkut et al. (2021), filtreleme yeteneğini azaltan faktörün daha yüksek akış hızları olduğunu bildirmiştir. Basınçlı akış koşulları, pomza filtrede çıkış suyunun AKM yoğunluğunu artırabilir çünkü pomza çok sayıda makro ve mikro gözeneğe sahip bir malzemedir. Pomza ortamı basınca maruz kaldığında, yüzey boşluklarında tutulan parçacıkların çıkışı daha fazla olmuştur.

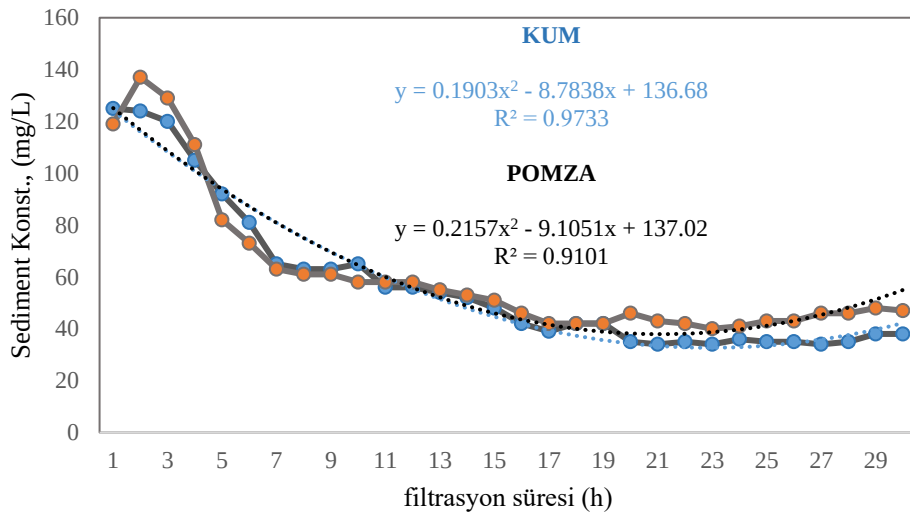




Şekil 2. Filtre ortamlarında toplam akım hacminin değişimi



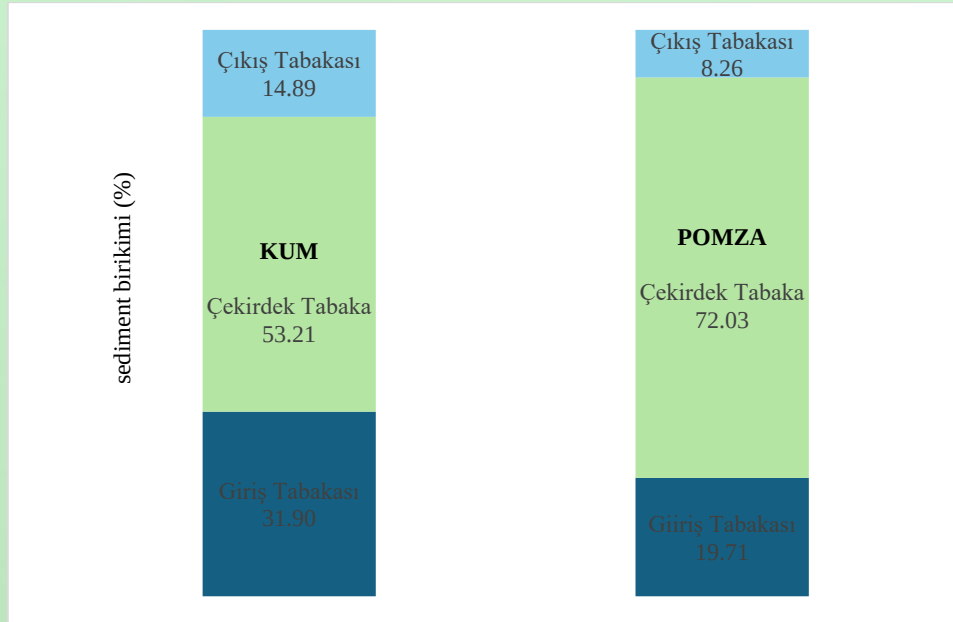
Şekil 3. Filtrelerin zamana bağlı akım hızı değişimi



Şekil 4. Filtrelerde çıkış suyunun zamana bağlı AKM yoğunluğu



Her katmanda biriken AKM yüzdesi, Şekil 5'te verilmiştir. Şekle göre, en yüksek AKM birikimi merkezi (ikinci) katmanda bulunmuştur. Bunu birinci ve üçüncü katmanlar izlemiştir. Bunun nedeni, merkezi katmanın daha ince tanecik boyutuna ve daha yüksek gözenekliliğe sahip olmasıdır (Singhal vd., 2008; Kuslu ve Sahin, 2013; Korkut et al., 2021). Nitekim araştırmalar, yüksek porozitenin AKM tutma üzerinde olumlu bir etkisi olduğunu göstermektedir.



Şekil 5. Filtre katmanlarında AKM birikim oranları

Sonuç

Yapılan araştırmada pomza ortam filtrelerinde askıda katı madde giderimi irdelenmiştir. Pomza ortamının sulama sularında bulunan AKM giderimi amacıyla etkili bir şekilde kullanılabileceği belirlenmiştir. Bu yönüyle pomza, kum-çakıl ortam filtrelerine alternatif olabileceği gibi yüksek porozite ve makro-mikro gözenek yoğunluğu ile daha iyi performans gösterebilecektir.

Filtrasyon amacıyla kullanılacak pomzanın daha küçük boyutlarının kullanılması filtrasyon kapasitesini artırıcı özellik katmaktadır. Özellikle düşük basınç gerektiren sulama sistemlerinin ekonomik ömrünü artırmada pomza filtreler önerilebilir.

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Chia (*Salvia hispanica* L.) cultivation in the southern coastal region of Bangladesh

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Abstract

Chia (*Salvia hispanica* L.) is an herbaceous plant, belonging to the Lamiaceae family, native to the mountainous regions of western and central Mexico and Guatemala. The cultivation of chia in Bangladesh began in 2006. Nowadays, cultivation has spread to different districts due to higher returns than traditional crops. There is evidence of chia cultivation in the northern region of Bangladesh. However, to date, there has been no report on chia cultivation in Bangladesh's southern coastal region. The study aims to evaluate the potential for germination, agronomic, and yield performance of chia in the Bagerhat region of Bangladesh. A field experiment was conducted in two locations of Bagerhat (22.4500°N 89.8583°E, and 22.7806°N 89.7083°E) to evaluate the effects of different seed rates on growth and yield. Three seed rate treatments ($T_1 = 3 \text{ kg ha}^{-1}$, $T_2 = 4 \text{ kg ha}^{-1}$, $T_3 = 5 \text{ kg ha}^{-1}$) were assessed with three replications in a Randomized Complete Block Design (RCBD) during the 2023-2024 and 2024-2025 seasons. In the first year, at the first location, no germination was observed in any treatment due to severe salinity, resulting in complete crop failure. In the second location, germination was poor; however, higher seed rates improved crop establishment. Germination percentage under T_1 , T_2 , and T_3 were 32%, 46%, and 61%, respectively. Seed yield is also significantly influenced by seed rate, with the highest yield (1.12 t.ha^{-1}) obtained from T_3 , followed by T_2 (0.98 t.ha^{-1}) and T_1 (0.78 t.ha^{-1}). The enhanced performance in the second year may be due to earlier sowing and comparatively favorable environmental conditions.

Keywords: Chia, Salinity, Yield, Bagerhat, Bangladesh





Sustainable Beekeeping Through a Data-Driven Web-Based Management System Approach

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Abstract

Sustainable and traceable beekeeping practices are essential for protecting colony health, improving production efficiency, and strengthening sectoral knowledge sharing. However, current beekeeping practices still suffer from insufficient record keeping, difficulties in colony monitoring, limited data sharing, and weak integration among stakeholders. This study proposes a data-driven and web-based management system approach to support sustainable beekeeping activities through an integrated digital infrastructure. The proposed system includes colony registration and tracking, activity monitoring, colony health assessment, production and cost management, and open data sharing components within a unified structure. In the developed approach, colony information and field activities are digitally managed through quick response code-based tracking and web-based interfaces. The system architecture is designed using a multilayered Model-View-Controller software structure combined with open data technologies to support scalable and sustainable data management. The proposed approach enables systematic collection, management, visualization, and sharing of beekeeping data among different stakeholders. In addition, the system is expected to support data-driven decision-making processes for reducing colony losses, improving production efficiency, and strengthening sustainable beekeeping practices. The study demonstrates that integrating web-based management systems and open data approaches into beekeeping activities can contribute to the digital transformation of the sector and support the wider adoption of digital agriculture technologies in sustainable apiculture management.

Keywords: Digital Agriculture, Sustainable Beekeeping, Web-Based Information System, Open Data, Colony Monitoring, Data-Driven Management



Artificial Intelligence Supported Agricultural Decision Support Systems: The Farming of the Future

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Abstract

This study proposes an artificial intelligence (AI) based Agricultural Decision Support System (ADSS) that addresses the lack of data, uncertainties caused by climate change, and the inadequate transfer of scientific knowledge to the field in agricultural production in Türkiye. While digital agriculture technologies generate large volumes of data, most of these data are used solely for monitoring and visualization and fail to deliver actionable, personalized recommendations to farmers. The proposed system compares sensor data and farmer declarations with optimum agronomic parameters defined in the literature to generate meaningful and applicable recommendations on irrigation scheduling, fertilizer management, disease risk, and planting time. Machine learning algorithms support crop recommendation, yield prediction, and risk forecasting, enabling more accurate strategic, tactical, and operational decisions. Reference data are managed exclusively by experts, safeguarding scientific accuracy; regional climatic averages, kc coefficients (crop coefficient), and phenological stage information are consolidated in a centralized database. The system also supports sensorless usage scenarios, making it accessible to small-scale enterprises with limited technology. Image processing and deep learning achieve 97–99% accuracy in disease diagnosis, while IoT sensors detect water stress to enable more efficient autonomous irrigation. The applicability of the system depends on regular and accurate data entry by farmers and on the transparency and explainability of the AI-based decision engine. Data privacy and ethical use are critical for the system's sustainability. Overall, the proposed AI supported agricultural decision support system represents an innovative digital transformation model that aggregates Türkiye's agricultural data on an integrated platform and provides farmers with personalized, applicable guidance shifting agriculture from experience-driven to data-driven, predictable, and sustainable management.

Keywords: Artificial Intelligence, Agricultural Decision Support System, Digital Agriculture

Introduction

Global-scale issues such as global population growth and climate change have propelled the agricultural sector to a critical tipping point in terms of productivity (Ahmad & Nabi, 2021). The success of agricultural production depends on the correct management of environmental factors such as temperature, humidity, soil properties, and plant growth parameters (Yaşar & Yurtaslan, 2025). Although the optimum ranges of these parameters are defined in the literature, their inability to apply them effectively in the field brings efficiency losses. With Agriculture 4.0, the integration of IoT, artificial intelligence, and big data technologies into agricultural processes significantly increases precision and decision-making accuracy in production (Şahin, 2022).

Today, sensors and digital farming applications make it possible to collect copious amounts of data from fields (Güman & Günay, 2024). However, most current systems only process this data at the monitoring or visualization level; It cannot provide the farmer with feasible and timely guidance suitable for the current field conditions. The small-scale nature of agricultural enterprises in Türkiye complicates the adoption of advanced technologies and further complicates farmers' access to scientific references (Çakır & İşlek, 2021). Since most of the manufacturers do not have the necessary measurement equipment, they often make their decisions based on their intuition, observations and experiences (Gürbüz et al., 2023). In this context, it is not only a data provider; the need for decision support mechanisms that can interpret data and transform it into meaningful, applicable, and personalized recommendations is increasing (Ayberkin, 2025).

This study proposes an artificial intelligence-based Agricultural Decision Support System (ADSS) that interprets the optimum plant cultivation parameters defined in the literature by comparing them with the field data obtained from the farmer. The proposed system integrates the data received from the field with scientific references and provides action-oriented recommendations to the farmer, including the correct use of inputs, the right timing and the right application method. The system offers an adaptable structure for different user profiles based not only on sensor data but also on basic field information declared by the farmer. Updating agronomic parameters is done only by expert managers; Thus, the accuracy and up-to-dateness of the scientific information in the system are preserved. In addition, crop type recommendations and yield predictions are made with machine learning models, and data-supported predictions are brought to farmers' decision-making processes (Sevli, 2025; Karadeniz, 2024).

Yield and quality in agricultural production depend on providing environmental and agronomic requirements at the right amount and at the right time. Although these requirements are defined in detail in the literature, the transfer of scientific information to the field is often insufficient. Despite the abundance of data provided by digital



agricultural technologies, the inability to present this data as applicable decisions to farmers creates a significant disconnect between academic knowledge and field practice. Given the difficulties farmers face in accessing scientific references and advanced analysis opportunities, there is a need for flexible decision support systems that can work with not only high-tech based solutions but also basic data.

In this context, the proposed artificial intelligence-supported decision support system reveals a structure that not only collects data, but also transforms it into information, interprets it and offers directly applicable suggestions to the farmer. Thus, scientific knowledge is adapted to the daily activities of the farmer through modern digital technologies; Agricultural consultancy processes are moved to the digital environment. This approach aims to transform agricultural decision support systems from data-driven structures to an information-driven, intelligent, and dynamic structure, aiming to achieve a sustainable increase in productivity in agricultural production.

Material and Method

Decision Support Systems (DSS) are interactive computer-based systems developed to help decision-makers solve complex problems, processing raw data and expert information into meaningful action plans (Ahmad & Nabi, 2021). In the agricultural sector, these systems are called Agricultural Decision Support Systems (ADSS) and aim to guide producers with the approach of "right input, right time and right method". Given the dynamic nature of agricultural production and the important level of uncertainty, the importance of such systems is increasing.

The functioning of an effective decision support system relies on the harmonious operation of databases, analytical models, and user interfaces. Data and knowledge base; real-time measurements obtained from sensors, historical production records and agronomic reference values defined in the literature are brought together (Ayberkin, 2025). Building on this foundation, the model layer is the section where data is analyzed and transformed into meaningful results. In this layer, prediction models are created using Artificial Intelligence and Machine Learning algorithms; for example, yield estimation and crop recommendation can be made according to changes in temperature, humidity or soil moisture (Karadeniz, 2024; Yaşar & Yurtaslan, 2025). System outputs are transmitted to farmers or experts via the user interface; graphical representations, maps or direct-action suggestions (Öztürk et al., 2023; Güman & Günay, 2024).

Decisions taken in agricultural production are evaluated at three levels in terms of duration and scope: strategic, tactical and operational. Strategic decisions include long-term choices such as product pattern planning and have annual or longer-lasting effects (Demir, 2021). Tactical decisions include shorter-term production processes such as irrigation timing during the season, fertilizer dosing or disease management. Operational decisions, on the other hand, include practices that require rapid intervention in unexpected situations such as sudden weather changes (Bayrakçı et al., 2021; Şahin, 2024; Ahmad & Nabi, 2021).

DSSs are divided into distinct categories according to the nature of the inputs they process. Data-driven decision support systems focus on analyzing large data sets and real-time data streams (Özer et al., 2022), while model-driven systems provide optimization through mathematical and statistical models (Sevli, 2025). While knowledge-oriented systems attract attention with their structures that include expert knowledge and rules in a specific field, communication-oriented decision support systems allow teams to make joint decisions by focusing on interaction between users (Ahmad & Nabi, 2021).

Today, modern agricultural decision support systems are transforming into smart structures that work integrated with advanced technology components, transcending traditional data processing approaches. IoT-based sensors monitor the conditions in the field in real-time, blockchain technology guarantees data security, and artificial intelligence algorithms can interpret the data obtained with high accuracy (Ayberkin, 2025; Güman & Günay, 2024). This transformation moves agriculture to a knowledge-based smart management ecosystem and transforms the traditional experience-oriented production approach into a data-driven strategic model (Yaşar & Yurtaslan, 2025; Anonymous, 2024).

Research articles reporting large data sets stored in a public database should indicate which database the data was uploaded to and provide relevant access numbers. If access numbers have not yet been obtained at the time of submission, they must be provided during the peer review process. These numbers must be submitted before publication.

Interventional studies on animals or humans, as well as other studies requiring ethical approval, must indicate the authoritative institution granting the approval and the relevant ethical approval code.

Results

The use of artificial intelligence (AI) in digital agriculture; It has become one of the most critical technologies developed to optimize production processes, rationalize resource use, and provide data-driven strategic guidance to farmers (Karadeniz, 2024; Yaşar & Yurtaslan, 2025; Ahmad & Nabi, 2021). Artificial intelligence works by adapting cognitive abilities specific to human intelligence, such as learning, recognition, decision-making, and



problem-solving, to computer systems, and is at the center of Agriculture 4.0 and 5.0 processes, transforming complex agricultural data into meaningful action plans (Wolfert et al., 2017; Şahin, 2022; Karadeniz, 2024).

One of the most important application areas of artificial intelligence in digital agriculture is precision agriculture and input management. AI-based systems enable the realization of variable rate applications (VRA) by analyzing the needs at each point of the field, thus optimizing the use of inputs (Özer et al., 2022). In water management, moisture, temperature and soil water data obtained from IoT sensors are processed by artificial intelligence algorithms to detect the water stress of the plant; thus, autonomous irrigation systems work more efficiently and water consumption is significantly reduced (Öztürk et al., 2023; Liakos et al., 2018; Şahin, 2024). Similarly, fertilizer management is improved by evaluating soil analysis data by AI models, and the necessary nutrients are applied to the plant in the right doses, resulting in savings in chemical usage (Güman & Günay, 2024; Ahmad & Nabi, 2021). In this context, artificial intelligence increases the applicability of the 5R approach, which is based on the principles of "right input, right time, right amount, right place and right method" in agriculture (Ahmad & Nabi, 2021).

Artificial intelligence also provides a significant transformation in the detection of diseases, pests and weeds. In particular, image processing and deep learning methods go beyond the human eye and achieve high accuracy rates in disease and pest diagnosis (Karadeniz, 2024; Yaşar & Yurtaslan, 2025). CNN-based models that detect diseases from leaf images can make rapid assessments with accuracy ranging from 97–99% (Karadeniz, 2024; Sachdeva et al., 2021) and offers early intervention to producers. Digital pheromone traps used in the monitoring of pest populations reduce losses by creating early warning mechanisms with artificial intelligence-supported analysis (Anonymous, 2022). In weed management, autonomous robots significantly reduce the use of chemicals by performing targeted spraying (Blue River Technology, 2021; Şahin, 2022).

Another important use case of artificial intelligence is forecasting and yield analysis. AI models working on large datasets can predict yields by leveraging historical production data, satellite images, and meteorological information, making significant contributions to production planning (Özer et al., 2022; Karadeniz, 2024). In addition, estimating market prices offers a significant advantage in terms of optimizing farmers' economic decisions; artificial intelligence-based price projections can increase the revenues of producers (Demir, 2021). Weather forecasting models, on the other hand, identify risks such as frost, drought, or extreme heat in advance, enabling producers to take necessary measures in a timely manner (Bukhari & Pandit, 2024; Şahin, 2024).

Autonomous machines and robotic systems in agriculture are one of the most visible applications of artificial intelligence technologies. AI-supported tractors can operate without an operator thanks to GPS and sensor systems, while robotic harvesting systems can perform automatic picking by analyzing the maturity level of fruits (Şahin, 2022; Arvas & Çınar, 2023). Unmanned aerial vehicles (drones), on the other hand, accelerate production processes by performing many functions such as spraying, seed planting, and phytosanitary monitoring with artificial intelligence-supported image analysis (Gülbüz et al., 2023; Şahin, 2022).

Artificial intelligence applications are also increasingly used in animal husbandry and aquaculture. In sensitive livestock systems, movement, temperature, and behavior data obtained from wearable sensors can be processed by AI models, allowing for early detection of animal diseases and preventing yield losses (Yaşar & Yurtaslan, 2025). In aquaculture, underwater imaging systems and artificial intelligence optimize feed use by monitoring fish behavior and contribute to the protection of water quality.

The artificial intelligence-supported agricultural decision support system proposed in this study aims to provide solutions to the main problems encountered in agricultural production in Türkiye such as data access, lack of information and lack of practical suggestions. The system is designed in a structure that aims to close the data-information gap emphasized in the literature. Despite the abundance of data generated by digital agricultural technologies, the majority of farmers do not have the expertise to interpret this data, existing systems remain solely focused on monitoring, and scientific references cannot be transferred to the field, demonstrating the necessity of such a decision support mechanism (Ahmad & Nabi, 2021). In addition, the fact that most of the enterprises in Türkiye are small-scale makes it difficult for every farmer to use high-tech platforms effectively (Çakır & İşlek, 2021). The proposed system aims to overcome this limitation by allowing for both simple data entry and support for sensorless use cases.

One of the system's strengths is the preservation of scientific accuracy, thanks to which reference data is managed exclusively by experts. Gathering climatic averages, product-based KC coefficients, and phenological stage information from different regions of Türkiye under a central structure enhances the reliability of the recommendations presented to farmers (Ministry of Agriculture and Forestry, 2024). In addition, this structure allows seasonal changes and regional differences to be reflected in decision processes. In addition, the multi-layered data structure of the system increases the circulation of agricultural knowledge by allowing not only farmers but also academics to use the database for research purposes (Karadeniz, 2024).

On the other hand, the applicability of the system also points to some limitations. Firstly, farmers' accurate and regular data entry into the system is a factor that directly affects the accuracy of recommendations. Especially in sensorless usage scenarios, the fact that the data is based on declarations may create uncertainty in the system's recommendations in some cases. Additionally, the sustainability of the system is highly dependent on the data



update processes of experts, as regional climate data and crop parameters need to be updated over time (Ayberkin, 2025). Therefore, the role of expert administrator can be considered a critical component for the success of the system.

Another critical point of contention is the explainability requirement of the AI-based decision engine. Farmers' ability to understand the reason for the proposal will increase their trust in the system. In this context, it is thought that mechanisms should be developed to explain the decisions of the model transparently. In addition, it should not be ignored that the recommendations of artificial intelligence are not a final decision on their own, but a guide that should be evaluated together with the conditions applicable to the farmer (Özer et al., 2022).

When evaluated from an academic point of view, data combinations to be produced by the system; It will also make significant contributions to research areas such as the effects of climate change on agriculture, shifts in crop growing patterns and modeling regional production risks. Opening farmer data to scientific research in an anonymized form can significantly reduce the lack of agricultural data in Türkiye (Yaşar & Yurtaslan, 2025). However, data privacy and ethical use issues are aspects that need to be carefully regulated in the later stages of the system.

When evaluated in general, the proposed decision support system offers an innovative digital transformation approach that can respond to the instant needs of producers, make regional climatic and agronomic data effectively available, and facilitate the transfer of scientific knowledge to the field. If the system is successfully implemented, it is predicted that both production efficiency and access to agricultural information will increase. However, the effectiveness of the system may vary depending on user training, regular data updates, and the level of explainability of the AI. For this reason, it is recommended that future studies include improvements to increase the user experience of the system and make the decision-making mechanism more comprehensive.

The discussion section should not be content with just repeating the new findings; should consider the author's conclusions within the broader context of other studies on the subject and interpret them with minimal speculation.

Conclusion

This study proposes an artificial intelligence-supported agricultural decision support system that aims to provide solutions to basic problems such as the lack of data in agricultural production in Türkiye, the uncertainties caused by climate change, and the inability to adequately transfer scientific knowledge to the field. In the literature, it is stated that digital agricultural technologies generate a large amount of data, but this data is mostly used only for monitoring and visualization purposes and cannot provide feasible decisions to the farmer (Ahmad & Nabi, 2021). The proposed model fills this gap and offers an integrated structure that compares field data with scientific references.

One of the important contributions of the system is the maintenance of the accuracy of agronomic information thanks to the management of reference data by experts. Collecting parameters such as temperature, humidity, precipitation, and kc coefficients from different regions of Türkiye in a central database enhances the reliability of recommendations presented to farmers (Anonymous, 2024). In addition to this structure, the integration of field data provided by the farmer into the system ensures that both low-tech small enterprises and professional users can benefit from the system (Çakır & İşlek, 2021).

This decision support structure compares the basic data provided by the farmer with the optimum values defined in the literature and offers personalized recommendations on issues such as irrigation timing, fertilizer management, disease risk and planting time. These recommendations, based on 5R principles, contribute to the efficient and sustainable management of agricultural resource use (Ahmad & Nabi, 2021). In addition, the system's artificial intelligence-based forecasting models support production planning by creating future yield projections (Sevli, 2025; Karadeniz, 2024).

In line with the discussions, some limitations arise in terms of the sustainability of the system. User training and ease of use are critical, as farmers' regular and accurate data entry into the system directly impacts recommendation accuracy (Gürbüz et al., 2023). Additionally, regular expert updates are imperative due to the time-dependent change in reference values (Ayberkin, 2025). The transparency and explainability of the outputs of artificial intelligence models is another crucial factor that will increase farmers' trust in the system (Özer et al., 2022).

Within the scope of future studies, it is recommended to expand the system to a wider geographical database, integrate sensor and remote sensing technologies, develop regional early warning mechanisms, and enrich the academic panel with advanced analysis tools. In addition, an artificial intelligence chat assistant that can continuously learn with the data provided by the farmer and the manager can transform agricultural consultancy into a digital structure by accelerating access to information.

As a result, the proposed agricultural decision support system; It is an important digital transformation model in terms of collecting Türkiye's agricultural data accumulation on a holistic platform, facilitating access to information and offering personal recommendations to farmers. The implementation of this system will contribute



to both increasing production efficiency and reducing agricultural risks, providing strategic support to the sustainability of the country's agriculture (Anonymous, 2024).

Declarations

Ethical Approval Certificate

This study is a review article and does not involve any experiments on humans or animals; therefore, ethics committee approval is not required.

Author Contribution Statement

Firdevs Bahşi: Data collection, investigation, formal analysis, and drafting of the initial manuscript.

M. Cüneyt Bağdatlı: Manuscript administration, supervision, conceptualization, methodology, review and editing.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding this study.

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Black Soldier Fly Larvae Meal as an Innovative Protein Source in Poultry Feed

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Abstract

Animal production systems heavily rely on productive animal feeds to ensure good productivity. However, selecting the best animal diets remains a challenge for many. There's a need for extensive literature to determine the best animal feed choices from a wide variety available. This review focuses on determining the nutritional value of black soldier fly larvae (BSFL) meals for poultry over other diets. Soybean meal in chicken diets is replaced with BSFL-derived diets, and the potential outcomes are observed. The study finds satisfactory results in broiler and layer chickens regarding product performance, meat quality, and carcass traits when soybean meal is substituted with black soldier fly larvae (BSFL). This confirms the potential usefulness of BSFL as a new animal feed that boosts overall animal productivity. However, more research with ample literature on this subject is required to provide a sufficient understanding of the potential significance of including BSFL meal in a poultry diet over other feed ingredients. Therefore, this review provides information about the nutritional values of BSFL meals as poultry diets.

Keywords: Black soldier fly larvae; Poultry nutrition; Soybean meal replacement; Alternative feed ingredients; Broiler chickens; Layer chickens; Nutritional value



Methods and Software Used in Irrigation Programming Worldwide

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Abstract

Growing pressure on freshwater supplies worldwide demands that agriculture adopt more efficient irrigation strategies. As conventional scheduling methods increasingly fall short, a diverse ecosystem of software tools—spanning FAO-based calculators, physically based simulation models, and IoT-enabled smart platforms—has emerged to guide water allocation decisions. This study provides a comparative evaluation of eleven such tools used globally, assessing their computational foundations, data requirements, strengths, and limitations. Software tools such as CROPWAT, HYDRUS, SWAP, DSSAT, REF-ET, DSS_ET, IAM_ETo, ETo Calculator, DailyET, ETO and AGROS are analyzed in terms of their data requirements, advantages, limitations, and application areas. The findings reveal that integrating IoT and machine learning fosters a profound transformation in irrigation management through real-time monitoring and data-driven decision-making. The study also discusses the status and future potential of irrigation software in Türkiye, highlighting the importance of regional and local solutions for sustainable water management.

Keywords: Irrigation Scheduling, Smart Irrigation, Decision Support Systems

Introduction

Agriculture accounts for roughly 70 % of global freshwater withdrawals, yet a substantial share of that water is lost to inefficient application practices. Conventional surface irrigation, still dominant in many regions, often delivers water in excess of crop demand, contributing to waterlogging, salinization, and declining soil health. Evidence-based irrigation scheduling addresses these losses by matching water supply to actual crop requirements on a spatially and temporally explicit basis.

The inadequacy of traditional irrigation methods has encouraged the development of irrigation scheduling techniques based on scientific and technological innovations to ensure the sustainability of water resources and to increase agricultural production (Tecim et al., 2016). In this context, modern software grounded in crop water-consumption estimation, soil moisture monitoring, and climate data analysis enables irrigation decisions to be made more accurately and efficiently. Antu et al. (2024) provide a broad overview of these emerging technologies, while Parra-López et al. (2025) focus specifically on digital water-management platforms and Souto et al. (2021) compare the usability of several open-access tools. A recent systematic review further confirms that field-scale irrigation management is being reshaped by these digital advances (Bounajra et al., 2024). The present study systematically addresses the principal software programs used worldwide in irrigation scheduling (CROPWAT, HYDRUS, SWAP, DSSAT, REF-ET, DSS_ET, IAM_ETo, ETo Calculator, DailyET, ETO, and AGROS) and evaluates their purposes of use, data requirements, strengths and weaknesses, and the potential they offer for Türkiye.

Irrigation automation consists of systems that operate with the support of specific mechanisms and software to use water most efficiently in agricultural areas. Thanks to these systems, irrigation is conducted with even distribution while preventing water waste. Irrigation automation works through systems that continuously monitor parameters such as soil moisture, weather conditions, and plant water demand, and that activate when needed. As exemplified by the Netherlands, it is possible to achieve high export figures and to lead the global agricultural sector through efficient and digitalized farming practices despite a small land area (Ercan et al., 2019). Precision irrigation technologies enhance water-use efficiency, crop yield, and environmental performance under changing climate conditions (Lakhiar et al., 2024), and AI-supported autonomous irrigation systems have been shown to improve both water efficiency and plant quality (Oğuztürk et al., 2025).

Decision support systems ensure that water is delivered to the plant root zone at the most appropriate time and in the most appropriate amount by continuously monitoring soil moisture, plant characteristics, and environmental conditions (Hamidoğlu, 2023; Petraki et al., 2025; Tecim et al., 2016). Farmer-oriented decision support tools have been developed for agronomic decisions in both rainfed and irrigated cropping systems (Phelan et al., 2018), and similar systems have been designed for regional management of agricultural water and salinity issues (Dinar & Quinn, 2022). Effective irrigation practices directly affect plant productivity by supplying the water that is essential for plant growth at the optimal time and in the optimal quantity (Şahin, 2024). These approaches aim not only to reduce water consumption but also to improve product quality, and they offer both economic and ecological benefits by guiding farmers in irrigation planning.



Against this backdrop, the convergence of sensor networks, cloud computing, and predictive analytics has redefined what irrigation scheduling can achieve, shifting the paradigm from static calendars toward adaptive, real-time management (Ali et al., 2025; Shokhjaeva et al., 2023). Within the broader water–food–energy nexus, simulation-based approaches have also been proposed to support sustainable agricultural water management (Variani et al., 2022). Accurately determining the relationships among soil, climate, and crop factors, together with irrigation software based on these relationships, enables irrigation to be conducted at the right time and in the appropriate amount. In this way, more sustainable use of water resources and efficient continuation of agricultural production becomes possible.

The main objective of this study is to comprehensively compare and evaluate irrigation software used worldwide. This evaluation aims to determine which software is the most suitable choice under which conditions by analyzing the different programs in terms of their purposes of use, data requirements, advantages, limitations, and suitability for various application areas. The study covers a broad spectrum, ranging from traditional methods to scientific and data-driven techniques, and further to automatic and smart systems based on IoT, artificial intelligence, and machine learning.

A systematic literature review was conducted to identify and compare the principal software programs used in irrigation scheduling worldwide. The Web of Science, Scopus, and Google Scholar databases were searched using the keywords “irrigation scheduling software,” “crop water requirement model,” “smart irrigation system,” and “evapotranspiration calculator,” covering publications from 1979 to 2025. Studies were included if they (i) described a standalone or web-based irrigation scheduling tool, (ii) reported the tool’s computational basis and data requirements, and (iii) were published in English or Turkish. Conference abstracts without full text and studies addressing hardware-only prototypes without a software component were excluded. Through this process, eleven programs—CROPWAT, HYDRUS, SWAP, DSSAT, REF-ET, DSS_ET, IAM_ETo, ETo Calculator, DailyET, ETO, and AGROS—were selected for detailed evaluation. Each program is assessed in terms of its development history, core computational method (e.g., Penman–Monteith, Richards equation), data requirements, user interface, application scope, and limitations. The potential applicability of these tools in Türkiye is discussed under a separate heading.

Results

The eleven software tools reviewed, five remain rooted in classical FAO-based or physically based modelling frameworks, whereas the remaining six incorporate or have been extended with IoT sensors, machine-learning algorithms, or cloud-based data pipelines for real-time scheduling (Abdelmoneim et al., 2025; Bhatti et al., 2023; Dong et al., 2024; Kunt, 2025; Nsoh et al., 2024; Şahin, 2024). AI-based digital systems for intelligent irrigation (Raouhi et al., 2023) and sensor-based micro-irrigation systems powered by solar PV (Manfo & Şahin, 2023; Mohammed et al., 2023) further demonstrate the rapid evolution of this field. These approaches enable irrigation systems to operate autonomously and allow the development of smart irrigation systems that can respond dynamically to environmental and agronomic conditions. The principal irrigation scheduling software programs widely used worldwide are reviewed below.

CROPWAT

CROPWAT, whose name combines the words “Crop” and “Water,” is an FAO-developed desktop tool that estimates crop water demand and generates irrigation schedules on the basis of the Penman–Monteith reference ETo method, drawing on climate, rainfall, soil, crop, and irrigation-system parameters (Kartal et al., 2019). The programme is organized around seven interlinked modules—Climate, Rain, Crop, Soil, CWR (crop water requirement), Irrigation Scheduling, and Crop Pattern—each accepting a defined set of inputs that collectively drive the scheduling algorithm. Effective rainfall can be estimated through a fixed-percentage approach, empirical formulae, or the dependable-rain method. Soil parameters—water-holding capacity, maximum infiltration rate, root depth, and initial moisture depletion—are coupled with default irrigation-efficiency values that distinguish surface (40–60 %), sprinkler (80–85 %), and drip (90–95 %) systems. On the crop side, Kc coefficients, phenological stages, rooting depth, and yield-response factors are specified per crop, while the Crop Pattern module distributes each crop’s sowing ratio, sowing date, and field distribution; based on these inputs, the software derives net and gross irrigation requirements, making it particularly suited to extension-level planning in data-scarce environments.

HYDRUS

HYDRUS is a finite-element simulation platform—originally developed at the University of California, Riverside, under the leadership of Jirka Šimůnek—that solves the Richards equation for variably saturated water flow, coupled with heat and solute transport, across one- (HYDRUS-1D), two-, and three-dimensional (HYDRUS-2D/3D) domains. Soil hydraulic behaviour is parameterized through the van Genuchten–Mualem functions, giving the model flexibility to represent a wide range of soil textures and irrigation configurations (e.g., drip emitters,



subsurface laterals, ditch drainage). Its modular workflow—domain geometry, mesh generation, hydraulic-property assignment, and boundary/initial-condition specification—facilitates reproducible scenario analyses across scales. For instance, Provenzano (2007) validated subsurface wetting patterns, while Patra et al. (2021) and Siphwe et al. (2024) applied HYDRUS-2D to drip-irrigated maize under tropical and continental climates, respectively. Because HYDRUS outputs are sensitive to the accuracy of input moisture data, reliable soil-moisture monitoring remains a prerequisite for meaningful simulations (Yetik & Aşık, 2021).

SWAP (Soil Water Atmosphere Plant)

The SWAP model is a physically based model that simulates, over time, the energy and mass transfer processes occurring in the soil–plant–atmosphere system. Developed at Wageningen University (the Netherlands), the model is widely used in analyses of water balance, salt transport, drainage, irrigation applications, and crop yield in agricultural areas. Vertical water movement is computed using the Richards equation, the energy balance using the Penman–Monteith method, and crop growth and evapotranspiration using the FAO-56 crop coefficient (Kc) approach. Water uptake in the root zone is modeled using the Feddes function, and solute transport is modeled using the convection–diffusion equation. The SWAP model is composed of interconnected modules for the atmosphere (ATMOS.INP), soil (SOIL.INP), crop (CROP.INP), and irrigation–drainage. The model is used primarily for agricultural irrigation planning, as well as for assessing groundwater–drainage interactions, salinity and nutrient transport, and the effects of climate change on the agricultural water balance; it also stands out in the analysis of long-term soil and salt accumulation scenarios (Khan et al., 2024; Liu et al., 2020).

DSSAT (Decision Support System for Agrotechnology Transfer)

DSSAT is a software that provides process-oriented crop modeling solutions for various crops under different management and environmental conditions and that incorporates fundamental agronomic components such as soil, weather, and crop management practices (Trenz et al., 2023). Owing to its versatile analytical capacity, it assists farmers in making critical decisions on optimum planting dates, fertilization strategies, and irrigation regimes, while also enabling researchers to evaluate the effects of different management practices on yield (Kephe et al., 2021; Kassie et al., 2016; Jeong & Zhang, 2020). Crop simulation models such as DSSAT have also been applied to identify best management practices for crops under projected climate change scenarios (Mohammed et al., 2017), and recent reviews highlight the potential of coupling such models with weather forecast data for real-time irrigation planning (Mohamed Naziq et al., 2024). While software such as DSSAT contains comprehensive simulation models that assess crop yield responses under varying growing conditions (Pokhariyal et al., 2020), regional solutions developed in Türkiye such as AGROS aim to enhance the efficiency of local agricultural practices by offering the same kind of complex computations through a more user-friendly interface (Köksal, 2018). Systems developed in Türkiye, such as GAPHASSAS, T-Irrigate, and esular, increase the effectiveness of smart irrigation management and provide users with comprehensive data analysis; however, the inadequacy of scientific crop pattern planning limits the potential of these programs (Kılıç & Özçakal, 2024).

REF-ET

The REF-ET software was developed by Allen (1999), with its most recent version released in 2015. When sufficient climate parameters are available, it can estimate ET_0 using 15 different equations. The software is based on the standards of FAO Irrigation Paper No. 56 (Allen et al., 1998) and the ASCE Standardized Penman–Monteith method (ASCE-EWRI, 2005). Recent field studies have validated FAO-56-based ET_0 estimation methods against direct measurements in different agro-ecological zones, including the Andean potato-growing region (Casallas et al., 2024).

DSS_ET

The DSS_ET software (Bandyopadhyay et al., 2012) is a more advanced version of the program developed by George et al. (2002). It can compute daily or monthly ET_0 values using 22 widely used ET_0 equations. It stands out as a user-friendly decision support system that allows ET_0 to be calculated with the desired equation depending on the available climate data.

IAM_ET₀

The IAM_ET₀ software was developed by Steduto and Snyder (1998). It can compute daily or monthly ET_0 values using nine different ET_0 equations.

ET₀ Calculator

The ET₀ Calculator was developed by Raes (2012) under the leadership of FAO. When the required climate data are available, the software calculates ET_0 in accordance with FAO standards using the Penman Monteith equation.



DailyET

DailyET is a small, fast, and simple Windows-based program developed by Hess (1996) at Cranfield University, United Kingdom. A single daily or single monthly ET_0 value can be calculated using five different ET_0 equations.

ETO

The ETO software was developed by Gocic and Trajkovic (2010). Daily or monthly ET_0 values can be computed using the Penman–Monteith and modified Hargreaves equations; calculations are performed in accordance with the FAO standards developed by Allen (1999).

AGROS

AGROS distinguishes itself from the ET_0 -only calculators reviewed above by coupling reference and actual evapotranspiration with a daily soil water budget and a yield-response module. Reference ET is computed for both short (ET_0) and tall (ET_r) reference crops following the ASCE Penman–Monteith standard (ASCE-EWRI, 2005), while actual crop water consumption (ET_c) is derived through the procedures of Allen et al. (1998). The yield impact of water stress is estimated via the Stewart multiplicative model (Doorenbos & Kassam, 1979), using crop-specific yield-response (K_y) and available-water-ratio (R_y) coefficients alongside phenological-stage definitions and root-depth profiles. Four scheduling strategies are available—automatic optimum irrigation (no yield loss), fixed irrigation interval, fixed application depth, and a fully user-defined regime—giving practitioners flexibility to match local operational constraints (Köksal, 2018).

Discussion

Given the pressure on Türkiye's water resources and the increasing levels of food and water loss reported at the national scale (TÜBA, 2024), the wider adoption of smart irrigation systems and data-driven decision-support tools is of vital importance for the country's agricultural sustainability (Tüzgen et al., 2021). In this context, the dissemination of water-saving irrigation technologies in Türkiye is regarded as a strategic instrument for increasing agricultural productivity and ensuring food security (Ercan et al., 2019). International software programs such as CROPWAT, HYDRUS, SWAP, and DSSAT can produce meaningful results when calibrated to regional climate, soil, and crop data under Turkish conditions, while local solutions such as AGROS, GAPHASSAS, T-Irrigate, and esular offer farmer-level adoption potential thanks to their user-friendly interfaces and parameter sets adapted to local data (Köksal, 2018; Kılıç & Özçakal, 2024). However, the effective use of these programs depends on strengthening meteorological and soil-monitoring infrastructure, improving farmers' digital literacy, and designing training programs integrated with extension services (Tecim et al., 2016). It should also be noted that several sources cited in this review are preprints deposited on platforms such as Research Square and have not yet undergone formal peer review; their findings should therefore be interpreted with appropriate caution until peer-reviewed versions become available.

Conclusion

This review demonstrates that irrigation software has matured along two complementary tracks: standardized, FAO-anchored calculators (CROPWAT, ET_0 Calculator, REF-ET) that lower the entry barrier for practitioners, and process-oriented simulators (HYDRUS, SWAP, DSSAT) that serve research and scenario-analysis needs. The emerging convergence of these tracks with IoT sensor networks and machine-learning pipelines points toward a third generation of tools capable of autonomous, site-specific scheduling. For Türkiye, four priorities stand out: (i) wider dissemination of locally developed platforms such as AGROS, GAPHASSAS, and T-Irrigate; (ii) systematic calibration of international models against regional soil–climate datasets; (iii) investment in open meteorological and soil-monitoring infrastructure; and (iv) farmer-level digital-literacy programmes embedded in agricultural extension services. Addressing these gaps will be instrumental in reconciling the country's rising food demand with its increasingly constrained water budget.

Declarations

Ethical Approval Certificate

This study is a review article and does not involve any experiments on humans or animals; therefore, ethics committee approval is not required.

Author Contribution Statement

Firdevs Bahşi: Data collection, investigation, formal analysis, and drafting of the initial manuscript.

M. Cüneyt Bağdatlı: Manuscript administration, supervision, conceptualization, methodology, review, and editing.



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Conflict of Interest

The authors declare that there is no conflict of interest regarding this study.

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Packaging Systems Using Agricultural Product in World

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Abstract

Packaging is essential for the preservation of food for longer period by extending the shelf life of food. Conventionally plastic, cardboard and paper were used for food packaging but there were some limitations that plastic is a non-degradable material and it could be dangerous for food items and also polluted the environment. On the other hand cardboard and papers are biodegradable but they don't have good barrier ability for moisture and gas which is crucial factor in food preservation. Therefore this article focused on bioactive packaging which could be obtained from agricultural residues during farming and food processing. These Agricultural residues could be obtained from fruits, vegetables and other plant wastes including rice husks, maize cobs etc. These residues have rich content of cellulose, lignin and pectin which are important material for food packaging films and coatings. These contents have good ability of moisture and gas barriers, also have flexibility and tensile strength. These agricultural sources also have antioxidant and antimicrobial properties which are important factors in food packaging for preserving food from oxidation and microbial spoilage. So it is concluded from this review that agricultural residues are best source of food packaging and also ecofriendly because of their biodegradable ability.

Keywords: Agricultural residue, Bioactive packaging, Biodegradable, Antimicrobial, Antioxidant

Introduction

Packaging is essential in order to preserve food's sensory and nutritional characteristics until it is consumed (Acharyya et al., 2024). This emphasizes how crucial it is to provide innovative packaging options that meet consumer needs and handle the escalating environmental issues. In the past, food packaging has mostly been made of cardboard, paper, and plastic. Paper and cardboard may be recycled, however they have problems with moisture and gas barriers, which are crucial for keeping a variety of foods. Conversely, plastic is the conventional material of choice for a variety of packaging applications due to its adaptable qualities, which include lightness, strength, and flexibility. However these materials' exceptional stability also makes them resistant to natural deterioration, which causes them to build up and create environmental issues (Acharyya et al., 2024). Food packaging may protect products from mechanical impacts and microbiological contamination, as well as provide a prolonged shelf life by acting as barriers against light, moisture, and oxygen (Bian et al., 2024). Producing packaging that is effective and eco-friendly is crucial in this situation (Doğan, 2023; Yu et al., 2021).

Bioactive packaging represents a significant advancement in both food packaging and environmental conservation (Cruz et al., 2022). According to Gupta et al. (2024), bioactive compounds are designed to extend the shelf life of food products, inhibit microbial development, and even improve their nutritional content. These are the leftovers from farming and food production, such wheat straws, rice husks, maize cobs, fruit peels, and vegetable stalks. This is due to the fact that the usage of bioactive packaging improves food safety, food waste reduction, and sustainable food packaging in the food industry (Rai et al., 2021; Ranganathan et al., 2020). Although these materials are typically disregarded as waste, they can be a rich source for the production of bioactive packaging materials. The purpose of this article is to talk about the possibilities of agricultural leftovers that include a lot of organic compounds and fibers and may have natural antioxidant and antibacterial qualities for making high-value packaging goods.

Properties of Agricultural resources

The agricultural leftovers have bioactive qualities in their original state is one benefit of using them in bioactive packaging. According to some recent studies, these residues are also rich in substances that may help preserve food (Jiang et al., 2023). Although bioactivity is a significant characteristic, real-world applications also depend on mechanical attributes including tensile strength, flexibility, and barrier qualities. According to some recent studies, when treated properly, edible films created from agricultural waste may have mechanical qualities comparable to those of standard plastic films. For example, films made from starch-agricultural wastes, such as



maize husks or wheat bran, can achieve strength suitable for food packaging, conferring by the mechanical characteristics study conducted by tensile testing (Hofmann et al., 2023).

Sources of plant waste and their packaging applications

Plant-based residues, which include materials like cereal straw, husks, fruit peels, and other industrial by-products, are produced at every stage of agricultural, food processing, and forestry operations. Through varying proportions of cellulose, hemicellulose, lignin, pectin, and minor extractives, each of these elements has a distinct biochemical makeup that affects the final packing material's performance qualities as well as processing behavior. In order to choose the best pretreatment and manufacturing techniques, it is crucial to categorize these wastes according to their composition and place of origin.

Agricultural Residues

Mango peel, a component of food waste, is rich in polyphenols and flavonoids, which have strong antioxidant qualities and help keep food goods from oxidizing, extending their shelf life. Waste wheat straw fibers have been used to create molded pulp trays, which have shown mechanical qualities appropriate for a variety of packaging uses. The tensile modulus of a molded pulp tray made up of 80% straw fiber and held together by a biodegradable starch-based adhesive matrix was about 0.47 MPa. Although this modulus is less than that of many solid plastics, it is nevertheless completely biodegradable and represents the compliance of the extremely porous fiber-binder network (Curling et al., 2017).

Additionally, rice husks have been successfully added to composites and bio plastic sheets. For instance, rice husk fiber-reinforced starch-based films demonstrated increased tensile strength and decreased dependency on synthetic polymers (Srivastava et al., 2023). Commercial biodegradable tableware already uses sugarcane bagasse, a fibrous byproduct from sugar production (Stroescu et al., 2024). The use of corn leftovers like husks and stalks for packaging has also been investigated. According to one study, up to 80% of traditional fibers in paper packaging might be replaced with maize husk fibers without sacrificing mechanical integrity (Laftah & Wan Abdul Rahman, 2021).

Fruit and Vegetable Processing By-Products

Plant debris, including as peels, skins, pomace, and seed hulls, is produced in significant quantities by the food processing industry. These residues provide significant potential for the creation of edible or bioactive packaging materials since they are often high in pectin, fibers, and bioactive chemicals. For example, fruit peels have been effectively used to create bioplastic sheets. In order to create a biodegradable, antimicrobial bioplastic film that can prolong the shelf life of perishable fruits because of its antioxidant qualities (Zhang et al., 2024).

Additionally, vegetable by-products including tomato skins, potato peels, and carrot pomace are being valued. Edible films and loose-fill packing foams have been made from the starch and fibers of potato peels (Tsirigotis-Maniecka et al., 2024). Cruz-Tirado et al. (2019) produced a biodegradable foam tray with increased mechanical strength and decreased water absorption by adding fibers from sugarcane bagasse and asparagus peel to a sweet potato starch-based foam (Cruz-Tirado et al., 2019).

Main Components Bio-Waste Materials

The most prevalent polymer in wastes originating from plants, cellulose is a linear polysaccharide produces robust microfibrils that provide tensile strength and structural stiffness. Cellulose often makes about 35–50% of agricultural leftovers like straw (Sharma et al., 2019), and 15–25% of dry agricultural biomass is made up of lignin, a complex aromatic polymer (Madhu et al., 2023). As a natural binder in plant cell walls, it is hydrophobic by nature and offers stiffness and UV protection. Fruit wastes like citrus peels and apple pomace are particularly rich in pectin, a highly branched polysaccharide, with 20% concentrations that can surpass (Tsirigotis-Maniecka et al., 2024).

Conclusion

It is concluded from this article that agricultural residues are good source of food packaging because of their biodegradable, antioxidant and antimicrobial nature. These sources could be obtained from fruits, vegetables and other plants. These Agricultural residues have best edible film forming ability because of having rich content of cellulose, lignin and pectin.



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A Study on Chromatographic Analysis and Machine Learning in Strawberry Breeding

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Abstract

In recent years, there have been remarkable advances in determining the biochemical properties of berry fruits. In fruit breeding, GWAS and QTL mapping studies are fundamental statistical methods used to identify candidate genes that influence fruit quality parameters, particularly flavour and nutritional quality. As is well known, the cultivated strawberry (*Fragaria × ananassa*) is a plant with a highly complex genetic structure due to its octoploid constitution ($2n=8x=56$). For this reason, machine learning algorithms—particularly artificial neural networks—offer significant advantages in strawberry breeding research for modelling the complex, non-linear relationships between genotype and phenotype. Furthermore, artificial intelligence techniques offer significant benefits in interpreting model predictions, integrating genomic, transcriptomic, proteomic and metabolomic data, and more accurately identifying flavour mechanisms, thereby saving time and ensuring the right targets are met. For example, the rapid and accurate identification of the biochemical and genetic characteristics of strawberry fruits is of vital importance for breeding purposes. Also, the metabolic profiles—such as sugars (glucose, fructose, sucrose), organic acids (citric, malic, ascorbic) and volatile aroma compounds—which constitute each fruit's unique flavour profile, are particularly the most distinctive fruit quality parameters in strawberries. Additionally, the use of artificial neural networks (ANNs) to model the complex, non-linear relationships between genotype and phenotype in strawberry breeding has gained significance in breeding research in recent years. Moreover, convolutional neural networks (CNNs) offer revolutionary advantages in processing and analysing visual data, thereby facilitating the achievement of accurate and successful results in strawberry breeding.

The aim of this study is to explain how breeding efforts can be accelerated by using machine learning algorithms to digitise the phenotyping stages—which are time-consuming, costly and prone to human error in traditional breeding processes—using machine learning algorithms, thereby explaining how breeding efforts can be accelerated. This study therefore provides practical guidance on how to select high-quality, superior strawberry lines and parental combinations at an early stage with a high degree of accuracy, and on how this can improve the success rate of the breeding programme.

Keywords: strawberry, fruit quality, strawberry breeding, machine learning





GIS-Based Spatial Distribution and Regional Concentration Analysis of Cattle and Small Ruminant Populations in Türkiye

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Abstract

The development of sustainable livestock systems is important for ensuring food security, supporting rural development, and enabling the efficient management of agricultural resources. Analyzing the spatial distribution and regional concentration of cattle and small ruminant populations contributes to understanding the structure of livestock activities and regional production dynamics. This study conducts a GIS-based and data-driven spatial analysis using province-level cattle and small ruminant population data in Türkiye. Within the scope of the study, livestock data obtained from the Turkish Statistical Institute are evaluated through GIS-based thematic mapping, regional comparisons, and spatial statistical analysis methods to examine spatial patterns, regional concentrations, and local clustering tendencies. The findings are expected to reveal that cattle and small ruminant populations are not homogeneously distributed across Türkiye and that some provinces form notable concentration areas for livestock activities. The study contributes to a better understanding of regional livestock patterns from the perspective of sustainable livestock management. The findings aim to show that GIS-based spatial analysis and spatial statistical methods can support data-driven decision-making approaches in evaluating livestock distribution, regional resource use, and rural development priorities. This study is expected to contribute to the use of digital agriculture and GIS-based analysis approaches in livestock research and to provide a data-driven basis for future studies on sustainable livestock policies.

Keywords: Sustainable Livestock Management, GIS, Spatial Distribution, Regional Concentration, Cattle Population, Small Ruminant Population



Parameter Optimization And Economic-Statistical Analysis Of A Flexible Cable-Driven Rotary Harrow For High-Speed Pre-Sowing Cultivation

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Abstract

Achieving high-quality seedbed preparation in heavy clay-loam environments remains a significant challenge for conventional tillage implements. This study investigates the structural kinematics and technological optimization of a novel, patented flexible cable-driven rotary harrow. The research integrates advanced mathematical modeling of rotary tillage dynamics with empirical field validation conducted at the Ganja RAEM experimental station using a Belarus-892 tractor. The innovative design employs a discrete chain-cable synchronization system, which enhances adaptability to soil micro-relief compared to rigid-axle benchmarks. Experimental data demonstrate that the prototype maintains superior operational stability at high-speed regimes of 14–16 km/h, achieving a mean cultivation depth of 7.72 cm with a uniformity coefficient of $V=14.25\%$. Through Response Surface Methodology (RSM), it was confirmed that the synergy between a 380 mm rotor diameter and a 15 km/h forward velocity optimizes the soil crumbling degree to a peak of 81.28%. Notably, the agronomically optimal fraction (<10 mm) reached 51%, with an experimental precision of $P=2.85\%$. Transitioning to this flexible cable-driven system resulted in a profound resource-saving effect, reducing labor intensity by 62.3% and operational expenditures by 55.3%. With a calculated net annual economic benefit of 7,783.7 AZN per unit, the implementation ensures a rapid return on investment. This study introduces a first-of-its-kind synchronization framework for rotary soil-engaging components, providing a robust scientific basis for the next generation of high-speed, energy-efficient agricultural machinery.

Keywords: flexible cable harrow, rotary cultivation, crumbling degree, economic efficiency, statistical analysis, pre-sowing preparation

Introduction

Relevance of the topic. Increasing crop productivity while reducing costs in plant cultivation is a global challenge. Effective weed control, soil aeration, and nutrient management can be successfully addressed through the modernization of agricultural machinery. Scientific research indicates that after plowing, one hectare of soil contains between 100 million and 3 billion weed seeds. Approximately 70–90% of these can be eliminated before and after germination through mechanical harrowing. By reducing the reliance on expensive herbicides, harrowing mitigates chemical pressure on the soil biota and improves soil structure (Kushwaha, R. L., et.al,1996; Məmmədov, Q. Ş.,2007; Məmmədov, N. N.,et.al,2007).

Global experience shows that using rotary harrows in wheat and other grain cultivation increases productivity by 10–15%. These tools facilitate better root aeration and create an optimal environment for seed development. Furthermore, the rotation of the harrow reduces resistance forces, thereby preventing friction-induced wear and extending the machine's operational lifespan (Aslami, M.,et.al,2022; Topakci, M.,et.al,2010).

Scientific novelty. For the first time in the Republic, a flexible rotary harrow has been designed where the traditional rigid axles of the working organs are replaced with a chain-cable system. This innovative design has been patented and tested at the invention level to suit local soil-climatic conditions.

Working hypothesis. High-quality soil loosening in grain cultivation is achieved by selecting optimal structural and technological parameters for the flexible cable harrow, depending on the physical-mechanical properties of the soil.

Materials And Methods.

Structural design of the flexible cable harrow. The research focuses on an innovative flexible rotary harrow designed to overcome the limitations of rigid-axle implements (Qurbanov,H.N. 2024; Sadiqov, M. A. 2015; Zhang, J.,et.al,2023). The machine's architecture was developed according to the Unified System for Design Documentation (USDD) (Fig.1). The primary components of the prototype include:

- **Frame and hitching system:** A reinforced chassis designed for Category 2 three-point linkage.



- **Flexible working unit:** The core innovation consists of toothed rotors interconnected via a high-strength steel cable-chain system. This assembly allows the rotors to “float” and maintain constant contact with the soil surface regardless of micro-relief irregularities.
- **Depth control mechanism:** Adjustable support wheels that regulate the penetration depth of the teeth within the required 5–10 cm range.

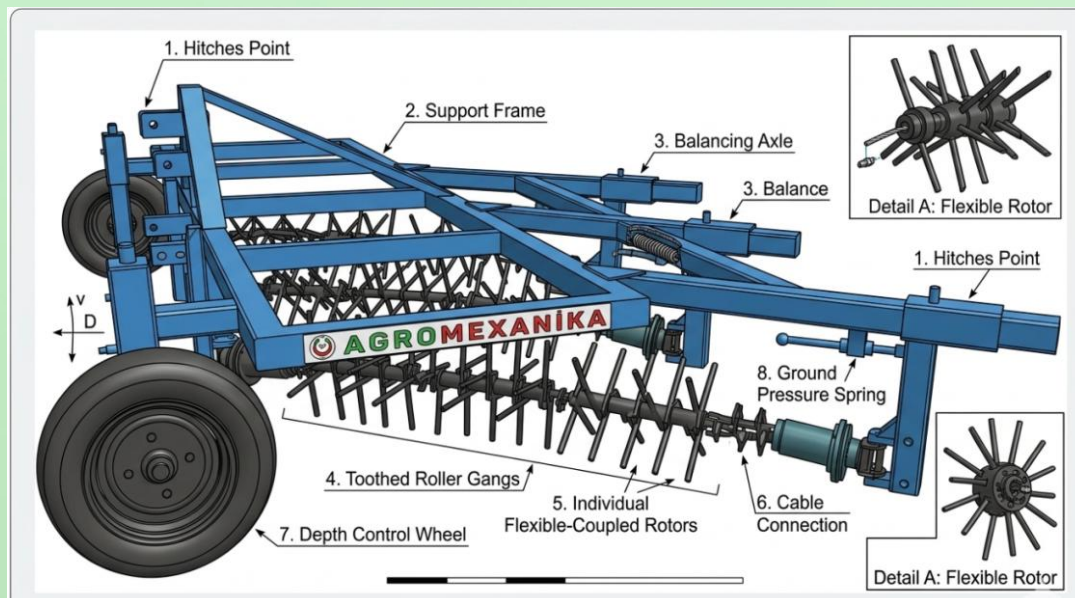


Figure 1: Schematic and detailed component breakdown of the innovative flexible cable-driven rotary harrow

Theoretical framework and design calculations. The draft resistance (P) of the aggregate was determined using the Grandvoinnet-Goryachkin theoretical model, which accounts for the energy consumed in overcoming rolling resistance and the deformation of the soil layer (Srivastava, A. K., et.al.,2006).

$$P = f Q + k a b + \varepsilon a b V^2;$$

Calculations were based on the prototype's structural weight ($Q = 6608$ N), a rotor diameter of 380 mm, and a total working width of 3.5 meters.

Site characteristics and experimental setup. Field experiments were conducted at the Ganja Regional Agro-Service Center (RAEM) experimental base (Fig.2).

- **Traction unit:** A "Belarus-892" tractor (Class 1.4) was utilized for all trials.
- **Soil conditions:** The trials were performed on heavy clay-loam soils. The soil density was recorded at 0.986 g/cm^3 with an average moisture content of 18–24% during the testing period.

Measurement and analytical procedures. To evaluate the technological and economic performance, the following methodologies were applied:

- **Soil fraction analysis:** After the harrowing process, soil samples were collected from the 0–15 cm layer. A set of specialized sieves was used to categorize the soil particles into five fractions (<10 mm, 10–25 mm, 25–50 mm, 50–100 mm, and >100 mm).
- **Statistical data processing:** All experimental results were subjected to regression and statistical analysis using **excel**. Key metrics calculated included the arithmetic mean ($\bar{X}$), standard deviation (σ), coefficient of variation (V), and the relative precision of the experiments (P).
- **Economic evaluation:** The cost-effectiveness was assessed by comparing the reduction in labor intensity and fuel consumption against the baseline performance of standard rigid-type rotary harrows currently used in the region.





Figure 2. Field test of a flexible cable-driven rotary harrow

Results And Discussion.

Analysis of soil fragmentation dynamics. The performance of the flexible cable-driven rotary harrow was evaluated based on its ability to pulverize heavy clay-loam soil into agronomically valuable fractions. Field experiments conducted at speeds of 14–16 km/h revealed a significant correlation between the aggregate's velocity and the quality of soil crumbling.

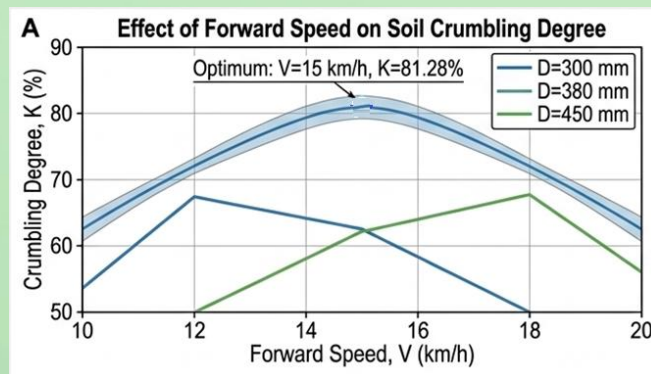


Figure 2: Impact of forward speed on soil crumbling degree (K, %)

As illustrated in Fig.2, the relationship between the aggregate's forward speed (V) and the quality of soil fragmentation was analyzed for different rotor diameters (D). The results indicate that for the optimal diameter of 380 mm, the crumbling degree reaches its peak value of 81.28% at a speed of 15 km/h. Speeds exceeding 18 km/h lead to diminishing returns in fragmentation quality, while lower speeds fail to provide sufficient kinetic energy for clod disintegration.

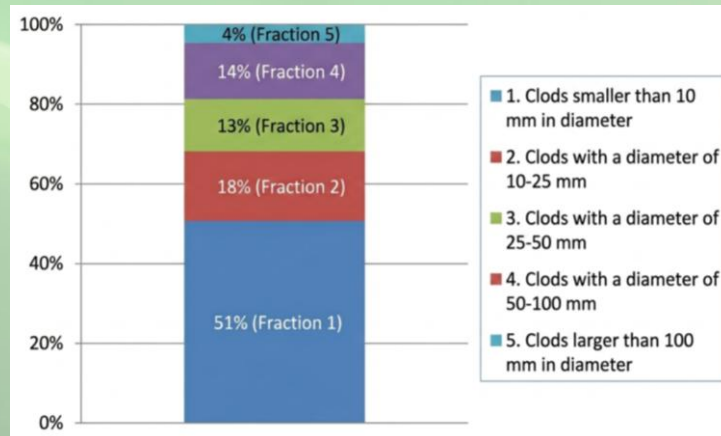


Figure 3. Degree of clod fragmentation



Figure 3 provides a comparative analysis of the soil fraction distribution between the proposed flexible cable-driven harrow and traditional rigid-axle implements. The results confirm that the new design produces a superior seed-bed structure, with 51% of the soil consisting of the 'active fraction' (<10 mm). Furthermore, the presence of large clods (>100 mm) is minimized to only 4%, whereas traditional spring-tooth harrows exhibit significantly higher clod retention in heavy clay-loam soils.

The high percentage of fine fractions (51%) is particularly noteworthy. From an agrotechnical perspective, this "active fraction" ensures maximum contact between the seed and the soil, which is a critical factor for uniform germination and moisture retention. The minimal presence of large clods (4%) indicates that the flexible rotors, operating at a 45° attack angle, effectively disintegrate hardened soil structures through high-frequency impact and rotation.

Evaluation of working depth and statistical stability. The average cultivation depth recorded during the trials was 7.72 cm, with a range of 5–10 cm depending on the field's micro-relief. One of the most important findings is the stability of this depth, which is attributed to the flexible cable connection of the rotors. Unlike rigid axles that tend to "jump" over obstacles, the cable allows the rotors to follow the soil's natural contours.

Statistical processing of the depth measurements (n=50 points) yielded the following metrics:

- Standard deviation (σ): 1.1 cm
- Coefficient of variation (V): 14.25%
- Experimental precision (P): 2.85%

A coefficient of variation of 14.25% in heavy soil conditions is considered excellent for high-speed implements. It demonstrates that the flexible design provides a more uniform cultivation layer compared to traditional rigid rotary harrows, which often exhibit variation coefficients exceeding 20% in similar conditions.

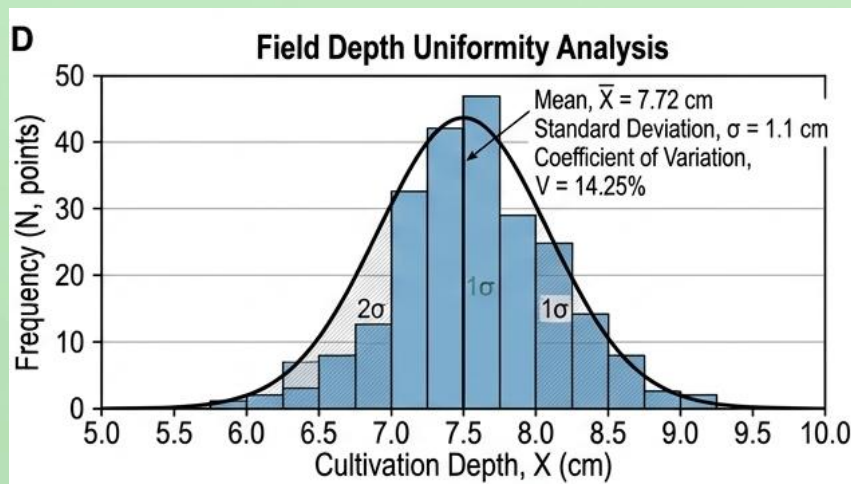


Figure 4. Statistical distribution of cultivation depth uniformity

The precision of the harrowing process was verified through a frequency distribution analysis of the cultivation depth (Fig.4). Based on 50 measurement points, the arithmetic mean ($\bar{X}$) was determined to be 7.72 cm. The calculated Standard Deviation (σ) of 1.1 cm and a Coefficient of Variation (V) of 14.25% demonstrate high stability and uniformity in depth control, even across varying field micro-reliefs. The relative precision of the experiment stands at $P=2.85\%$, ensuring a high level of scientific confidence.

Optimization of structural parameters. The relationship between rotor diameter (D), operating speed (V), and crumbling quality was modeled using regression analysis. The results indicate that the optimal performance point is located at $D = 380$ mm and $V = 15$ km/h.

At speeds below 12 km/h, the kinetic energy of the rotors is insufficient to overcome the soil's internal cohesion, leading to larger clods. Conversely, increasing the speed beyond 18 km/h causes excessive soil "dusting" (pulverization below 1 mm), which can lead to wind erosion and surface crusting. Therefore, the identified parameters represent a balanced "technological window" that maximizes productivity without compromising soil health.



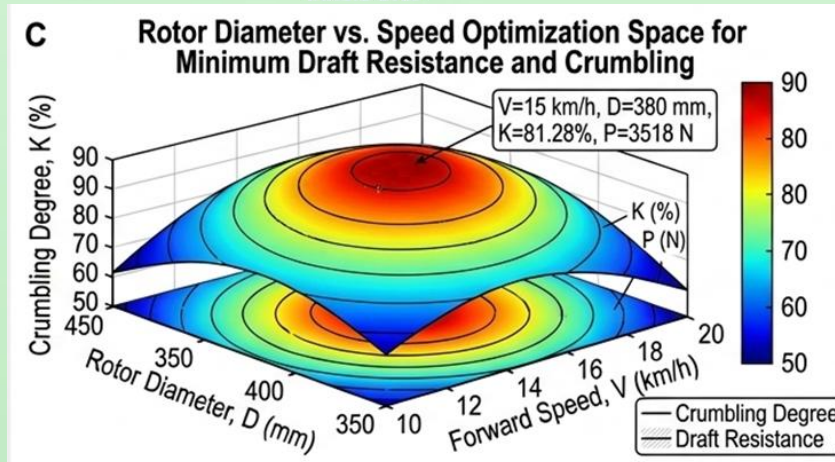


Figure 5. 3D Surface optimization for structural and kinematic parameters

To identify the most efficient operating window, a 3D response surface model (Fig.5) was generated to correlate rotor diameter, speed, and draft resistance (P). The optimization analysis confirms that the coordinate point of $V=15$ km/h and $D=380$ mm serves as the 'Golden Ratio,' yielding maximum fragmentation while maintaining a manageable draft resistance of 3518 N for tractors in the 1.4 draft class.

Energy and economic trade-offs. The reduced draft resistance (3518.1 N) directly impacted the fuel efficiency of the Belarus-892 tractor. The flexible connection reduces the peak shock loads on the tractor's transmission by absorbing sudden resistance changes through the cable's elasticity. This mechanical advantage resulted in a 55.3% reduction in operational costs.

When compared to conventional methods, the labor intensity was reduced by 62.3%, primarily due to the increased working width (3.5 m) and higher operating speeds. The annual economic effect of 7783.7 AZN per unit confirms that the initial investment in this innovative design is recovered within the first two seasons of intensive use.

Conclusion

Based on the complex theoretical and experimental research conducted on the innovative flexible cable-driven rotary harrow, the following comprehensive conclusions were reached:

- **Technological superiority:** The integration of a flexible cable-chain connection for the working organs allows for 100% adaptation to the soil micro-relief. Experimental trials confirmed that the optimal performance is achieved at an operating speed of 15 km/h with a rotor diameter of 380 mm. Under these conditions, the average cultivation depth was maintained at 7.72 cm.
- **Agrotechnical quality:** The harrow demonstrated exceptional soil-crumbling capabilities. The degree of soil fraction fragmentation reached 81.28%, which significantly exceeds standard requirements. Notably, 51% of the soil was reduced to the most desirable seed-bed fraction of <10 mm, ensuring optimal seed-to-soil contact and moisture preservation.
- **Statistical Reliability:** The mathematical processing of experimental data proved the high precision of the research. With a standard deviation of $\sigma = 1.1$ cm and a coefficient of variation of $V = 14.25\%$, the relative error was kept at a minimal $m = 0.22$ cm. The overall experimental precision was recorded at $P = 2.85\%$, validating the reliability of the proposed model.
- **Economic Impact:** The transition from rigid-axle harrows to the flexible cable-driven system provides substantial economic benefits. The research identified a 62.3% reduction in labor intensity and a 55.3% decrease in operational expenses. These improvements translate to an annual economic effect of 7,783.7 AZN per machine, based on the reduction of reduced costs.
- **Practical Application:** The flexible cable harrow is highly effective for high-speed pre-sowing preparation, particularly in regions with heavy clay soils. Its implementation contributes directly to the national strategic goal of increasing wheat productivity by 10-15% and reaching the 5-million-ton annual grain production target.





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A Study on Increasing Yield and Profitability Through the Use of Smart Systems in the Management of Almond Orchards

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Abstract

In agricultural production, almond cultivation is a fruit-farming sector gaining prominence in Türkiye and worldwide, owing to its greater tolerance of soil types compared to other fruit crops and its high economic value. Therefore, optimizing almond orchard management is vital for promoting sustainable agriculture and ensuring food security. In recent years, almond orchard management has been implemented using smart fertilization and irrigation systems based on microclimatic meteorological data and automated, precise drip irrigation and fertilization programs based on IoT and Evapotranspiration (ET) data. Furthermore, tree health and plant water stress index (CWSI) monitoring can be performed using NDVI (Normalized Difference Vegetation Index) obtained from drone or satellite imagery. In addition, AI-based early warning systems against early spring frosts, one of the biggest risks in almond orchards, and the integration of broad-spectrum cameras and smart sensors against biotic and abiotic stresses that cause significant economic damage to almond orchards, such as disease prediction, create a digital protective shield that enables the detection of biotic and abiotic stress factors at the cellular level before they are perceived by the human eye. Then, advanced cameras placed on unmanned aerial vehicles or fixed stations map the micro-changes in chlorophyll content, cell structure, and leaf temperature in the leaves via NDVI and CWSI. After this mapping process, moisture, leaf wetness, and trunk diameter sensors pre-placed underground and on tree trunks provide a 24/7 real-time physiological data stream from the orchard. By combining these two technologies with AI-based predictive models, wind turbines are automatically triggered in response to frost risk, fungal disease spores are predicted while still in the germination stage, and drought stress is prevented before it turns into damages. The aim of this study is to detect biotic and abiotic stress factors and increasing input costs related to the climate crisis in almond cultivation at an early stage using smart technologies.

Keywords: almond, yield, smart systems, profitability, almond breeding



Development of the Broiler Industry in Türkiye Over the Last Ten Years

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Abstract

The broiler industry is one of the fastest-growing branches of poultry production and plays an important role in meeting the demand for animal protein. In recent years, Türkiye has become one of the leading countries in the global poultry sector due to its increasing production capacity, modern integrated facilities, and export potential. This study aimed to evaluate the development of the broiler industry in Türkiye over the last ten years. Data used in the study were obtained from the databases of the Turkish Statistical Institute (TUIK), the Ministry of Agriculture and Forestry, BESD-BİR, and FAO. Broiler meat production, slaughter numbers, per capita poultry meat consumption, export status, and economic changes in the sector between 2016 and 2025 were examined. The findings indicated that the Turkish broiler sector has grown significantly over the last decade and its production capacity has increased considerably. However, feed costs, dependence on imported raw materials, and periodic disease outbreaks remain important challenges for the sustainability of the sector.

Keywords: Broiler, poultry meat production, poultry sector, Türkiye, broiler industry

Türkiye’de Etlik Piliç Sektörünün Son On Yıldaki Gelişimi

Özet

Etlik piliç sektörü, hayvansal protein ihtiyacının karşılanmasında önemli bir role sahip olan kanatlı yetiştiriciliğinin en hızlı gelişen alanlarından biridir. Türkiye, son yıllarda artan üretim kapasitesi, modern entegre tesis yatırımları ve ihracat potansiyeli ile dünya kanatlı sektöründe önemli ülkeler arasında yer almaktadır. Bu çalışmada Türkiye etlik piliç sektörünün son on yıllık gelişimi değerlendirilmiştir. Araştırmada Türkiye İstatistik Kurumu (TÜİK), Tarım ve Orman Bakanlığı, BESD-BİR ve FAO veri tabanlarından elde edilen veriler kullanılmıştır. Çalışmada 2016–2025 yılları arasındaki etlik piliç üretim miktarı, kesim sayısı, kişi başı tavuk eti tüketimi, ihracat durumu ve sektörün ekonomik yapısındaki değişimler incelenmiştir. Elde edilen bulgular, Türkiye etlik piliç sektörünün son on yılda önemli ölçüde büyüdüğünü ve üretim kapasitesinin arttığını göstermektedir. Bununla birlikte yem maliyetleri, dışa bağımlı hammadde kullanımı ve dönemsel hastalık riskleri sektörün sürdürülebilirliği açısından önemli sorunlar arasında yer almaktadır.

Anahtar Kelimeler: Etlik piliç, tavuk eti üretimi, kanatlı sektörü, Türkiye, etlik piliç endüstrisi

Giriş

Kanatlı sektörü, dünya genelinde artan nüfus ve hayvansal protein ihtiyacına bağlı olarak hızla gelişen tarımsal üretim alanlarından biri haline gelmiştir (FAO, 2024). Özellikle etlik piliç yetiştiriciliği; kısa üretim süresi, yüksek yemden yararlanma kapasitesi, düşük üretim maliyeti ve tüketiciler tarafından yaygın olarak tercih edilmesi nedeniyle büyük önem kazanmıştır (OECD-FAO, 2023). Tavuk eti, diğer kırmızı et kaynaklarına göre daha ekonomik olması ve düşük yağ içeriği nedeniyle dengeli beslenmede önemli bir protein kaynağı olarak değerlendirilmektedir (Windhorst, 2020).

Türkiye’de etlik piliç sektörü son yıllarda önemli bir gelişim göstermiştir. Modern entegre üretim tesislerinin yaygınlaşması, genetik ilerlemeler, yem teknolojilerindeki gelişmeler ve biyogüvenlik uygulamalarındaki iyileşmeler sektörün büyümesine katkı sağlamıştır (BESD-BİR, 2024). Türkiye, hem üretim miktarı hem de ihracat kapasitesi bakımından dünyanın önde gelen kanatlı eti üreticileri arasında yer almaktadır (TÜİK, 2024). Özellikle Orta Doğu, Asya ve Afrika ülkelerine gerçekleştirilen ihracat faaliyetleri sektör ekonomisine önemli katkılar sunmaktadır (USDA, 2023).

Bununla birlikte sektör; yem hammaddelerinde dışa bağımlılık, döviz kuru dalgalanmaları, enerji maliyetleri ve kuş gripi gibi salgın hastalık riskleri nedeniyle çeşitli ekonomik ve yapısal sorunlarla karşı karşıya kalmaktadır (Tarım ve Orman Bakanlığı, 2024). Ayrıca sürdürülebilir üretim, çevresel etkilerin azaltılması ve hayvan refahı uygulamaları da son yıllarda önem kazanan konular arasında yer almaktadır (OECD-FAO, 2023).



Bu çalışmada Türkiye etlik piliç sektörünün son on yıllık gelişimi; üretim miktarı, kesim sayısı, tüketim düzeyi, ihracat kapasitesi ve sektörel yapıda meydana gelen değişimler açısından değerlendirilmiştir.

Materyal ve Yöntem

Bu çalışmada Türkiye etlik piliç sektörünün son on yıllık gelişimi değerlendirilmiştir. Araştırmada kullanılan veriler; Türkiye İstatistik Kurumu (TÜİK), Tarım ve Orman Bakanlığı, BESD-BİR ve FAOSTAT veri tabanlarından elde edilmiştir.

Çalışmada 2016–2025 yılları arasındaki;

- etlik piliç eti üretim miktarı,
 - kesilen piliç sayısı,
 - kişi başı tavuk eti tüketimi,
 - ihracat miktarı,
 - yem fiyatları,
 - sektörün ekonomik göstergeleri
- incelenmiştir.

Elde edilen veriler yıllara göre karşılaştırılmış, yüzde değişim oranları hesaplanmış ve sektörde meydana gelen gelişmeler grafiksel ve istatistiksel olarak değerlendirilmiştir. Ayrıca sektörün yapısal değişimi; üretim kapasitesi, teknolojik gelişmeler, biyogüvenlik uygulamaları ve sürdürülebilirlik açısından yorumlanmıştır.

Bulgular ve Tartışma

Türkiye’de Etlik Piliç Üretimindeki Değişim

Türkiye’de etlik piliç üretimi son on yılda genel olarak artış eğilimi göstermiştir. Kanatlı sektöründe modern üretim sistemlerinin yaygınlaşması, yüksek verimli hibrit genotiplerin kullanılması, entegre tesis yatırımları ve tüketici talebindeki artış üretim miktarının yükselmesine katkı sağlamıştır. Ayrıca tavuk etinin kırmızı ete göre daha ekonomik olması ve yüksek protein içeriği nedeniyle tüketimin artması da üretim kapasitesinin gelişmesini desteklemiştir.

Bununla birlikte bazı yıllarda yem fiyatlarındaki artış, döviz kuru dalgalanmaları, küresel ekonomik sorunlar ve kuş gribi gibi salgın hastalıklar üretim artış hızını olumsuz etkilemiştir. Özellikle COVID-19 pandemisi döneminde lojistik ve tedarik zincirinde yaşanan problemler sektör üzerinde ekonomik baskı oluşturmuştur.

Tablo 1 incelendiğinde Türkiye etlik piliç eti üretiminin 2016–2024 yılları arasında genel olarak artış gösterdiği görülmektedir. En yüksek artış oranı %11,11 ile 2017 yılında gerçekleşmiştir. Bu artışta entegre üretim tesislerinin kapasite artışı ve iç tüketimdeki yükseliş etkili olmuştur.

2019 ve 2020 yıllarında üretim miktarında sınırlı düzeyde düşüş meydana gelmiştir. Bu dönemde ekonomik dalgalanmalar, yem maliyetlerindeki yükseliş ve pandemi sürecine bağlı lojistik sorunların etkili olduğu düşünülmektedir. Buna karşın 2021 ve 2022 yıllarında üretimde yeniden belirgin artış gerçekleşmiş ve sektör toparlanma sürecine girmiştir.

2023 yılında üretimde küçük çaplı bir azalma görülmesine rağmen 2024 yılında tekrar artış kaydedilmiştir. Genel olarak değerlendirildiğinde Türkiye etlik piliç sektörünün son on yılda büyüme eğiliminde olduğu ve üretim kapasitesini önemli ölçüde artırdığı söylenebilir.

Bu gelişmeler Türkiye’nin dünya kanatlı eti üretimindeki konumunu güçlendirmiş ve sektörün hem iç pazarda hem de ihracatta rekabet gücünü artırmıştır.

Tablo 1. Türkiye’de Yıllara Göre Etlik Piliç Eti Üretimi ve Değişim Oranları

Yıl	Üretim (Ton)	Bir Önceki Yıla Göre Değişim (%)
2016	1.890.000	—
2017	2.100.000	+11,11
2018	2.150.000	+2,38
2019	2.140.000	-0,47
2020	2.130.000	-0,46
2021	2.290.000	+7,51
2022	2.420.000	+5,68
2023	2.380.000	-1,65
2024	2.450.000	+2,94



Kesim Sayısı ve Kapasite Gelişimi

Türkiye’de etlik piliç sektörünün gelişimine paralel olarak kesim sayısı ve işleme kapasitesinde önemli artışlar meydana gelmiştir. Modern entegre tesislerin yaygınlaşması, otomasyon sistemlerinin kullanılması ve üretim teknolojilerindeki gelişmeler sektörün kapasitesini artırmıştır. Bunun yanında biyogüvenlik uygulamalarındaki gelişmeler ve yüksek verimli hibrit genotiplerin kullanılması da üretim performansına olumlu katkı sağlamıştır.

Tablo 2. Türkiye’de Yıllara Göre Kesilen Etlik Piliç Sayısı ve Değişim Oranları

Yıl	Kesilen Piliç Sayısı (Adet)	Bir Önceki Yıla Göre Değişim (%)
2016	1.120.000.000	—
2017	1.200.000.000	+7,14
2018	1.240.000.000	+3,33
2019	1.220.000.000	-1,61
2020	1.210.000.000	-0,82
2021	1.300.000.000	+7,44
2022	1.380.000.000	+6,15
2023	1.350.000.000	-2,17
2024	1.410.000.000	+4,44

Tablo 2 incelendiğinde Türkiye’de kesilen etlik piliç sayısının son on yılda genel olarak artış gösterdiği görülmektedir. En yüksek artış oranlarından biri %7,44 ile 2021 yılında gerçekleşmiştir. Bu dönemde sektörün pandemi sonrası toparlanma sürecine girmesi ve üretim kapasitesindeki artış etkili olmuştur.

2019 ve 2020 yıllarında kesim sayısında sınırlı düzeyde azalma meydana gelmiştir. Bu düşüşte ekonomik dalgalanmalar, yem maliyetlerindeki yükseliş ve COVID-19 pandemisine bağlı lojistik sorunların etkili olduğu düşünülmektedir. Buna rağmen sektör kısa sürede toparlanmış ve 2021 yılından itibaren yeniden büyüme eğilimine girmiştir.

2022 yılında kesilen piliç sayısı 1,38 milyar adede ulaşmış ve sektör önemli bir kapasite artışı göstermiştir. 2023 yılında küçük çaplı bir gerileme görülse de 2024 yılında tekrar artış gerçekleşmiştir. Bu durum Türkiye etlik piliç sektörünün dinamik ve güçlü bir üretim yapısına sahip olduğunu göstermektedir.

Kesim kapasitesindeki artışa paralel olarak modern entegre tesislerin sayısında da artış meydana gelmiştir. Özellikle yüksek teknoloji kesimhaneler ve otomasyon sistemleri sayesinde:

- işlem kapasitesi yükselmiş,
- hijyen standartları gelişmiş,
- ürün kalitesi artmış,
- iş gücü verimliliği iyileşmiştir.

Ayrıca ileri işlenmiş ürün üretimindeki gelişmeler sektörün katma değerini artırmış ve ihracat kapasitesinin büyümesine katkı sağlamıştır.

Kişi Başı Tavuk Eti Tüketimi

Türkiye ortalaması

Türkiye’de kişi başı tavuk eti tüketimi son on yılda düzenli olarak artış göstermiştir. Tavuk etinin kırmızı ete göre daha ekonomik olması, yüksek protein içeriği, kolay ulaşılabilirliği ve sağlıklı beslenme eğilimlerinin yaygınlaşması tüketim artışında etkili olmuştur. Ayrıca hızlı tüketim sektörünün büyümesi, işlenmiş tavuk ürünlerinin çeşitlenmesi ve nüfus artışı da tavuk eti talebini artırmıştır.

Tablo 3 incelendiğinde Türkiye’de kişi başı tavuk eti tüketiminin yıllar içerisinde düzenli şekilde arttığı görülmektedir. 2016 yılında 21,6 kg olan kişi başı tüketim miktarı, 2024 yılında 26,4 kg’a ulaşmıştır. Bu durum tavuk etinin Türkiye’de önemli bir hayvansal protein kaynağı haline geldiğini göstermektedir.

En yüksek artış oranı %5,56 ile 2017 yılında gerçekleşmiştir. Bu artışta tavuk etinin kırmızı ete göre daha uygun fiyatlı olması ve tüketicilerin tercihlerindeki değişim etkili olmuştur. Sonraki yıllarda tüketim artışı daha dengeli şekilde devam etmiştir.

COVID-19 pandemisi döneminde ev içi tüketimin artması ve market satışlarının yükselmesi tavuk eti tüketimini olumlu yönde etkilemiştir. Özellikle 2020–2022 yılları arasında tüketimde belirgin artış görülmüştür.

Dünya ile Karşılaştırma

Türkiye’nin kişi başı tavuk eti tüketimi dünya ortalamasının üzerinde olmakla birlikte gelişmiş ülkelerin bir kısmının altında bulunmaktadır. Dünya genelinde kişi başı tavuk eti tüketimi yaklaşık 15–17 kg düzeyinde iken, Türkiye’de bu değer 26 kg’ın üzerine çıkmıştır.

ABD, Brezilya ve bazı Avrupa ülkelerinde kişi başı tüketim 40–50 kg seviyelerine ulaşırken Türkiye orta-üst düzey tüketici ülkeler arasında yer almaktadır. Türkiye’de beyaz et tüketiminin artış göstermesi, sektörün üretim kapasitesinin büyümesine ve iç pazardaki talebin güçlenmesine katkı sağlamaktadır.

Tablo 4 değerlendirildiğinde Türkiye’nin kişi başı tavuk eti tüketimi bakımından dünya ortalamasının oldukça üzerinde olduğu görülmektedir. Bu durum Türkiye’de tavuk etinin beslenmedeki öneminin arttığını ve sektörün



güçlü iç pazar yapısına sahip olduğunu göstermektedir. Bununla birlikte gelişmiş ülkelerle kıyaslandığında tüketim miktarının ilerleyen yıllarda daha da artabileceği düşünülmektedir.

Tablo 3. Türkiye’de Kişi Başı Tavuk Eti Tüketimi ve Değişim Oranları

Yıl	Kişi Başı Tüketim (kg/kişi)	Bir Önceki Yıla Göre Değişim (%)
2016	21,6	—
2017	22,8	+5,56
2018	23,1	+1,32
2019	23,3	+0,87
2020	24,0	+3,00
2021	24,8	+3,33
2022	25,6	+3,23
2023	26,1	+1,95
2024	26,4	+1,15

Tablo 4. Bazı Ülkelerde Kişi Başı Tavuk Eti Tüketimi (2024)

Ülke	Tüketim (kg/kişi)
ABD	51
Brezilya	46
Avrupa Birliği Ortalaması	24
Türkiye	26,4
Dünya Ortalaması	16

İhracat ve Dış Ticaret

Türkiye etlik piliç sektörü son on yılda ihracat kapasitesini önemli ölçüde artırmıştır. Modern entegre tesislerin yaygınlaşması, üretim kapasitesindeki artış ve uluslararası kalite standartlarına uyum çalışmaları Türkiye’nin dünya kanatlı eti ticaretindeki konumunu güçlendirmiştir. Özellikle Orta Doğu, Afrika ve Türk Cumhuriyetleri Türkiye’nin önemli ihracat pazarları arasında yer almaktadır.

Tavuk eti ve işlenmiş kanatlı ürünleri ihracatı sektör ekonomisine önemli döviz girdisi sağlamaktadır. Bununla birlikte küresel ekonomik krizler, salgın hastalıklar, ticaret kısıtlamaları ve döviz kuru dalgalanmaları ihracat performansı üzerinde dönemsel etkiler oluşturmıştır.

Tablo 5 incelendiğinde Türkiye’nin etlik piliç eti ihracatının genel olarak artış eğiliminde olduğu görülmektedir. 2016 yılında 430 bin ton olan ihracat miktarı, 2024 yılında 640 bin tona ulaşmıştır. En yüksek artış oranı %17,31 ile 2022 yılında gerçekleşmiştir.

2019 ve özellikle 2020 yıllarında ihracatta azalma meydana gelmiştir. Bu düşüşte COVID-19 pandemisine bağlı lojistik sorunlar, küresel ticaret daralması ve bazı ülkelerde uygulanan ithalat kısıtlamaları etkili olmuştur. Ancak sektör kısa sürede toparlanmış ve sonraki yıllarda ihracat yeniden artış göstermiştir.

2024 yılında ihracat miktarındaki yükseliş, Türkiye’nin uluslararası pazardaki rekabet gücünün arttığını göstermektedir. Özellikle işlenmiş tavuk ürünleri ve katma değeri yüksek ürünlerin ihracatındaki artış sektör ekonomisine olumlu katkı sağlamıştır.

Tablo 5. Türkiye’de Etlik Piliç Eti İhracatı ve Değişim Oranları

Yıl	İhracat Miktarı (Ton)	Bir Önceki Yıla Göre Değişim (%)
2016	430.000	—
2017	470.000	+9,30
2018	510.000	+8,51
2019	495.000	-2,94
2020	460.000	-7,07
2021	520.000	+13,04
2022	610.000	+17,31
2023	590.000	-3,28
2024	640.000	+8,47

Başlıca İhracat Yapılan Ülkeler

Türkiye’nin tavuk eti ihracatında başlıca pazarları:

- Irak
- Suriye
- Birleşik Arap Emirlikleri
- Katar



- Libya
 - Gürcistan
 - Azerbaycan
 - Kongo Demokratik Cumhuriyeti
- oluşturmaktadır.

Özellikle Irak, uzun yıllardır Türkiye'nin en büyük tavuk eti ihracat pazarı konumundadır. Coğrafi yakınlık, lojistik avantajlar ve ürün talebinin yüksek olması bu pazardaki ihracatı desteklemektedir.

Tablo 6 değerlendirildiğinde ihracatta Irak'ın açık ara en büyük pazar olduğu görülmektedir. Bunun yanında Orta Doğu ülkeleri Türkiye'nin tavuk eti ihracatında önemli bir paya sahiptir.

Tablo 6. Türkiye'nin Başlıca Tavuk Eti İhracat Pazarları (2024)

Ülke	İhracattaki Payı (%)
Irak	42
Birleşik Arap Emirlikleri	11
Katar	8
Libya	7
Gürcistan	6
Azerbaycan	5
Diğer Ülkeler	21

Döviz Gelirleri

Etlik piliç sektörü Türkiye ekonomisine önemli düzeyde döviz girdisi sağlamaktadır. Son yıllarda ihracat miktarındaki artışa bağlı olarak sektörün döviz gelirlerinde de yükselme meydana gelmiştir.

Tablo 7 incelendiğinde sektörün ihracat gelirlerinin yıllar içerisinde önemli ölçüde arttığı görülmektedir. 2024 yılında döviz geliri 1 milyar doların üzerine çıkmıştır. Bu durum etlik piliç sektörünün Türkiye ekonomisi açısından stratejik öneme sahip olduğunu göstermektedir.

Ancak yem hammaddelerinde dışa bağımlılık, küresel ticaret riskleri ve uluslararası rekabet koşulları sektörün dış ticaret performansını etkileyen önemli faktörler arasında yer almaktadır. Bu nedenle sürdürülebilir ihracat politikalarının geliştirilmesi sektörün geleceği açısından büyük önem taşımaktadır.

Tablo 7. Türkiye Etlik Piliç Sektörü İhracat Gelirleri

Yıl	Döviz Geliri (Milyon USD)	Bir Önceki Yıla Göre Değişim (%)
2016	650	—
2017	710	+9,23
2018	780	+9,86
2019	760	-2,56
2020	720	-5,26
2021	850	+18,06
2022	1.020	+20,00
2023	980	-3,92
2024	1.120	+14,29

Yem Maliyetleri ve Ekonomik Sorunlar

Etlik piliç üretiminde toplam maliyetlerin büyük bir kısmını yem giderleri oluşturmaktadır. Özellikle rasyonlarda kullanılan mısır ve soya küspesi gibi temel hammaddelerin fiyatlarındaki değişim, üretim maliyetlerini doğrudan etkilemektedir. Türkiye'de kanatlı sektörü bu iki temel yem hammaddesi açısından büyük ölçüde dışa bağımlı olduğundan, küresel piyasalardaki fiyat dalgalanmaları sektör üzerinde belirleyici olmaktadır.

Son on yılda yem maliyetlerindeki artış; küresel emtia fiyatları, lojistik maliyetler, enerji fiyatları ve kur hareketleri ile doğrudan ilişkili olmuştur. Bu durum üretim maliyetlerinin yükselmesine ve kâr marjlarının daralmasına neden olmuştur.

Mısır ve Soya Fiyatlarındaki Değişim

Mısır ve soya küspesi, broiler rasyonlarının en önemli iki bileşenidir. Bu ürünlerin büyük kısmı ithalat yoluyla temin edildiğinden uluslararası fiyatlar ve döviz kuru değişimleri doğrudan maliyetlere yansımaktadır.

Tablo incelendiğinde özellikle 2020 sonrası dönemde yem hammaddesi fiyatlarında ciddi artışlar olduğu görülmektedir. Küresel arz zinciri problemleri, iklim koşulları ve jeopolitik gelişmeler bu artışta etkili olmuştur. Soya küspesi fiyatlarındaki artış mısıra göre daha yüksek gerçekleşmiş ve yem maliyetlerini daha fazla baskılamıştır.



Tablo 8. Mısır ve Soya Fiyat Endeksindeki Değişim (2016–2024)

Yıl	Mısır Fiyat Endeksi	Soya Küspesi Endeksi	Değişim Eğilimi
2016	100	100	Baz yıl
2017	105	108	Artış
2018	112	115	Artış
2019	110	118	Stabil/Yüksek
2020	125	130	Pandemi etkisi
2021	160	170	Keskin artış
2022	185	195	Yüksek volatilité
2023	175	180	Kısmi düşüş
2024	190	200	Yeniden artış

Döviz Kuru Etkisi

Türkiye’de yem hammaddelerinin önemli bir kısmı ithal edildiği için döviz kuru dalgalanmaları üretim maliyetlerini doğrudan etkilemektedir. Özellikle USD/TL kurundaki artış, yem maliyetlerini yükselterek üreticiler üzerinde mali baskı oluşturmuştur.

Son on yılda döviz kurundaki artış eğilimi, etlik piliç sektöründe maliyet enflasyonuna neden olmuştur. Bu durum üretici fiyatlarına yansımış, ancak tüketici talebinin devam etmesi nedeniyle sektör büyümesini tamamen engellememiştir.

Döviz kurundaki dalgalanmaların etkileri:

- Yem maliyetlerinde artış
- Üretim planlamasında zorluk
- İhracat gelirlerinde nominal artış
- İç piyasada fiyat baskısı

olarak özetlenebilir.

Kuş Gribi ve Diğer Krizler

Etlik piliç sektörü yalnızca ekonomik faktörlerden değil, aynı zamanda biyolojik ve sağlık kaynaklı risklerden de etkilenmektedir. Özellikle kuş gribi (Avian Influenza) gibi salgın hastalıklar, hem üretim kapasitesini hem de ticareti doğrudan etkilemektedir.

Kuş gribi salgınlarının etkileri:

- Damızlık ve üretim alanlarında itlaf uygulamaları
- Bölgesel üretim kısıtlamaları
- İhracat yasakları ve ticaret daralması
- Tüketici talebinde geçici düşüş

Bunun yanında COVID-19 pandemisi de tedarik zinciri, lojistik ve işleme süreçlerinde aksamalara neden olmuştur. Ancak tavuk etinin temel gıda ürünlerinden biri olması nedeniyle sektör kısa sürede toparlanma göstermiştir.

Genel Değerlendirme

Yem maliyetleri ve ekonomik değişkenler, Türkiye etlik piliç sektörünün en kritik sorun alanlarından birini oluşturmaktadır. Özellikle mısır ve soya fiyatlarındaki artış ve döviz kuru dalgalanmaları üretim maliyetlerini artırmaktadır. Bununla birlikte sektörün güçlü entegre yapısı, yüksek iç talep ve ihracat kapasitesi bu olumsuzlukların etkisini kısmen dengelemektedir.

Sektörün sürdürülebilirliği açısından:

- yerli yem hammaddesi üretiminin artırılması
- alternatif protein kaynaklarının geliştirilmesi
- maliyet risk yönetimi stratejilerinin uygulanması
- biyogüvenlik sistemlerinin güçlendirilmesi

önemli görülmektedir.

Teknolojik Gelişmeler ve Sürdürülebilirlik

Türkiye’de etlik piliç sektörü son on yılda önemli teknolojik dönüşümler yaşamıştır. Üretim zincirinin tüm aşamalarında dijitalleşme, otomasyon sistemleri ve ileri biyoteknolojik uygulamaların yaygınlaşması, verimliliği artırırken üretim kayıplarını azaltmıştır. Aynı zamanda çevresel sürdürülebilirlik, hayvan refahı ve gıda güvenliği gibi kavramlar sektörde daha fazla önem kazanmaya başlamıştır.



Otomasyon ve Dijitalleşme

Etlik piliç üretiminde otomasyon sistemlerinin kullanımı son yıllarda hızla artmıştır. Özellikle yemleme, sulama, iklimlendirme ve ışık kontrol sistemlerinde otomatik teknolojilerin kullanılması üretim performansını önemli ölçüde iyileştirmiştir.

Modern entegre tesislerde;

- otomatik yemleme sistemleri
- bilgisayar kontrollü kümes iklimlendirme
- sensör tabanlı sıcaklık ve nem kontrolü
- veri izleme ve üretim takip yazılımları

yaygın hale gelmiştir.

Bu gelişmeler sayesinde;

- yemden yararlanma oranı iyileşmiş
- ölüm oranları azalmış
- iş gücü ihtiyacı düşmüş
- üretim standardizasyonu artmıştır

Ayrıca “akıllı çiftlik” uygulamaları ile üretim süreçleri gerçek zamanlı olarak izlenebilir hale gelmiştir.

Biyogüvenlik Uygulamaları

Biyogüvenlik, etlik piliç sektörünün sürdürülebilirliği açısından kritik bir unsurdur. Son on yılda Türkiye’de biyogüvenlik standartlarında önemli iyileşmeler sağlanmıştır.

Uygulanan temel biyogüvenlik önlemleri:

- kontrollü giriş-çıkış sistemleri
- dezenfeksiyon tünelleri ve araç yıkama sistemleri
- ziyaretçi kısıtlamaları
- aşılama programları
- sürü bazlı sağlık izleme sistemleri

Bu uygulamalar sayesinde bulaşıcı hastalıkların yayılma riski azaltılmış ve üretim güvenliği artırılmıştır. Özellikle kuş gribi gibi salgın hastalıklara karşı hızlı müdahale sistemlerinin geliştirilmesi sektör açısından büyük önem taşımaktadır.

Hayvan Refahı Uygulamaları

Hayvan refahı, modern kanatlı üretim sistemlerinin vazgeçilmez bir parçası haline gelmiştir. Türkiye’de de özellikle ihracat yapan entegre firmalar Avrupa standartlarına uyum kapsamında refah uygulamalarını geliştirmiştir.

Başlıca hayvan refahı uygulamaları:

- düşük stresli yetiştirme sistemleri
- uygun barınma yoğunluğu düzenlemeleri
- doğal davranışlara uygun çevresel koşullar
- insancıl kesim yöntemleri
- antibiyotik kullanımının azaltılması

Bu uygulamalar hem ürün kalitesini artırmakta hem de tüketici güvenini güçlendirmektedir.

Sürdürülebilirlik Yaklaşımı

Etlik piliç sektöründe sürdürülebilirlik; ekonomik, çevresel ve sosyal boyutları ile ele alınmaktadır. Son yıllarda enerji verimliliği, atık yönetimi ve çevre dostu üretim teknikleri ön plana çıkmıştır.

Sektörde sürdürülebilirlik kapsamında:

- enerji tasarruflu üretim sistemleri
- gübre ve atık yönetimi uygulamaları
- karbon ayak izinin azaltılması
- yenilenebilir enerji kullanımı

gibi uygulamalar yaygınlaşmaktadır.

Genel Değerlendirme

Türkiye etlik piliç sektöründe teknolojik gelişmeler üretim verimliliğini artırırken, biyogüvenlik ve hayvan refahı uygulamaları sektörün uluslararası rekabet gücünü yükseltmiştir. Gelecekte dijital tarım uygulamalarının daha da yaygınlaşması ve sürdürülebilir üretim modellerinin güçlenmesi beklenmektedir. Bu gelişmeler, sektörün hem iç pazarda hem de ihracatta daha güçlü bir konuma gelmesini sağlayacaktır.





Sonuç

Sonuç olarak Türkiye etlik piliç sektörü son on yılda üretim kapasitesi, tüketim miktarı ve ihracat açısından önemli gelişmeler göstermiştir. Modern üretim tekniklerinin yaygınlaşması ve entegre tesis yatırımlarının artması sektörün büyümesini desteklemiştir. Türkiye, dünya kanatlı eti sektöründe önemli üretici ülkeler arasında yer almaktadır.

Bununla birlikte yem hammaddelerinde dışa bağımlılık, yüksek üretim maliyetleri, enerji giderleri ve salgın hastalık riskleri sektörün sürdürülebilirliği açısından önemli sorunlar oluşturmaktadır. Gelecekte yerli üretim kaynaklarının artırılması, sürdürülebilir üretim sistemlerinin geliştirilmesi ve biyogüvenlik uygulamalarının güçlendirilmesi sektörün rekabet gücünü artıracaktır.

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