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

Beyhan Yeter[1*] and Hasan Eleroğlu[2]

[1]Department of Animal Science, Agriculture Faculty, Kahramanmaraş Sütçü İmam University, 46050 Kahramanmaraş, Türkiye
[2]Department of Plant and Animal Production, Sivas Technical Sciences Vocational School, Sivas Cumhuriyet University, 58140 Sivas Türkiye
**Corresponding author's e-mail: byeter@gmail.com*

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. F_1 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:

Part Yield (%) = (Part Weight / Cold Carcass Weight) × 100 (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:
  - $\Delta E^* = \sqrt{(\Delta L^2 + \Delta a^2 + \Delta b^{*2})}$ (2)
  - $C^* = \sqrt{(a^2 + b^2)}$ (3)
  - $h^\circ = \tan^{-1}(b^*/a^*)$ (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 (Eleroğlu 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).

$$WHC=E/T \quad (5)$$

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

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

AA: Anadolu – T × Anadolu – T; CC: Commercial Broiler × Commercial Broiler; AC: Anadolu – T male × Commercial Broiler female; CA: Commercial Broiler male × 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 × 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) ± SEM	Back (%) ± SEM	Abdominal fat (gr) ± SEM	Abdominal fat (%) ± SEM
AA	Male	325.83+10.76	15.1+0.29	61.67+4.05	2.87+0.19
	Female	249.17+9.08	14.5+0.17	50+5.5	2.87+0.26
	Total	***287.5^{c}+10.55***	14.8+0.18	55.83+3.56	***2.87^{a}+0.16***
CC	Male	416.67+12.87	15.4+0.34	50+4.26	1.85+0.15
	Female	320.83+11.31	15.09+0.32	57.5+4.46	2.71+0.2
	Total	***368.75^{a}+13.04***	15.25+0.23	53.75+3.12	***2.28^{c}+0.15***
AC	Male	358.33+9.99	14.62+0.26	60.83+5.43	2.52+0.25
	Female	318.33+12.6	15.46+0.36	55.83+4.99	2.67+0.2
	Total	***338.33^{b}+8.9***	15.04+0.23	58.33+3.64	***2.6^{ab}+0.16***
CA	Male	354.17+14.64	14.93+0.29	55+2.89	2.32+0.1
	Female	292.5+12.56	15.3+0.38	51.67+5.05	2.66+0.22
	Total	***323.33^{b}+11.42***	15.11+0.24	53.33+2.87	***2.49^{ab}+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 × S		0.122	0.089	0.231	0.166

AA: Anadolu – T × Anadolu – T; CC: Commercial Broiler × Commercial Broiler; AC: Anadolu – T male × Commercial Broiler female; CA: Commercial Broiler male × 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 × Anadolu-T) consistently exhibited the highest WHC values (0.14 ± 0.01), whereas CC (Commercial Broiler × 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 × 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 × 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 ± 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***		***0.000***
Sex (S)				0.191		0.210
Carcass region (CR)				0.052		***0.045***
G × S				0.820		0.663
G × CR				0.474		***0.033***
S × CR				0.449		0.110
G × S × CR				0.431		0.468

AA: Anadolu – T × Anadolu – T; CC: Commercial Broiler × Commercial Broiler; AC: Anadolu – T male × Commercial Broiler female; CA: Commercial Broiler male × 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 × 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 × carcass region, sex × 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; Sarıca 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 & Sarıca, 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 × sex interactions for H° indicate that the effect of sex on hue angle varies depending on genotype. Additionally, a significant sex × 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 × S				0.779	0.035	0.040
G × CR				0.247	0.057	0.332
S × CR				0.156	0.664	0.325
G × S × 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
	Total		144	74.76+1.69	13.82+0.22	47.84+0.55
CC	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
	Total		144	66+3.6	13.88+0.33	49.43+0.64
AC	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
	Total		144	74.55+2.32	13.43+0.23	51.7+3.54
CA	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

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 InterestThe authors declare no conflict of interest.AcknowledgmentsIn 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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