ID: 941

A Comprehensive Review of Superfoods from Gilan Province, Northern Iran: Phytochemistry, Therapeutic Potential, Environmental Safety, and Future Perspectives

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Abstract

Background: Gilan Province, located in the Caspian Hyrcanian ecoregion, benefits from a humid subtropical climate that fosters exceptional biodiversity. Among its rich flora, several edible species have been traditionally used as functional foods or "superfoods" – nutrient-dense foods with purported health benefits beyond basic nutrition. However, a comprehensive, evidence-based evaluation of Gilan's superfoods, integrating phytochemical profiles, clinical evidence, and safety aspects (especially heavy metal contamination), is lacking.

Objective: This review aims to systematically identify, characterize, and evaluate the scientific evidence for five prominent superfoods of Gilan: green tea (*Camellia sinensis*), wild edible mushrooms (primarily *Agaricus bisporus* and *Pleurotus ostreatus*), raspberry (*Rubus idaeus*), olive (*Olea europaea*), and hazelnut (*Corylus avellana*). We also critically assess the risk of toxic metal accumulation in these foods based on original research from the region.

Methods: A systematic literature search was conducted in PubMed, Scopus, Web of Science, Google Scholar, and local Iranian databases (SID, Magiran) for articles published from 2000 to March 2026. Keywords included "Gilan superfoods", "Camellia sinensis Iran", "wild mushrooms Iran", "Rubus idaeus Gilan", "Olea europaea northern Iran", "Corylus avellana Iran", "heavy metals medicinal plants Iran", "antioxidant activity", and "functional foods". We included all peer-reviewed original articles, reviews, and case studies reporting nutritional, phytochemical, pharmacological, or toxicological data on these five foods, with emphasis on studies conducted in Gilan Province. All 58 references provided by the authors were integrated into the review. Data were extracted on bioactive compounds, traditional uses, in vitro/in vivo effects, clinical trials, and heavy metal concentrations.

Results: Green tea from Lahijan contains epigallocatechin-3-gallate (EGCG) at 80–120 mg/g dry weight, with demonstrated anticancer (IC50 30–50 µg/mL against MCF-7), cardioprotective, and neuroprotective effects. Wild mushrooms from Roodsar and Amlash show high β-glucan content (15–25% dry weight) and antioxidant activity (DPPH IC50 45–80 µg/mL). Raspberry leaf extract exhibits uterine relaxant activity in vitro (EC50 0.8 mg/mL) and anti-inflammatory effects via NF-κB inhibition. Olive oil from Roudbar has oleuropein levels up to 240 mg/kg and reduces LDL oxidation by 35% in human studies. Hazelnuts from Roudbar contain vitamin E (15 mg/100g) and proanthocyanidins that improve endothelial function. However, heavy metal analyses from the authors' previous studies (2018–2026) reveal that some samples of these superfoods contain lead (0.2–4.5 mg/kg), cadmium (0.1–1.2 mg/kg), and arsenic (0.05–0.8 mg/kg) exceeding WHO/FAO permissible limits, especially when cultivated near roadsides or industrial zones.

Conclusion: Gilan Province hosts a valuable portfolio of superfoods with robust scientific evidence for health promotion. Nevertheless, routine monitoring of heavy metals and implementation of good agricultural practices are essential to ensure consumer safety. This review provides a foundational resource for researchers, policymakers, and the food industry aiming to develop safe, high-value functional foods from this unique region.

***Keywords:** Superfoods; Gilan; Camellia sinensis; medicinal mushrooms; Rubus idaeus; Olea europaea; Corylus avellana; heavy metals; phytoremediation; functional foods; Iran.*

1. Introduction

1.1. The concept of superfoods and global interest

The term "superfood" has no legal or scientific definition but is commonly used to describe foods rich in compounds (e.g., antioxidants, polyphenols, omega-3 fatty acids, dietary fiber) that confer health benefits beyond basic nutrition [1,2]. Over the past decade, global demand for superfoods has increased dramatically, driven by rising awareness of diet–disease relationships, particularly for chronic conditions such as cardiovascular disease, diabetes, cancer, and neurodegenerative disorders [3,4]. Examples of internationally recognized superfoods include blueberries, kale, quinoa, goji berries, chia seeds, and matcha tea [5,6].

However, the concept often overlooks locally available, traditional foods that may possess equal or superior nutritional profiles [7]. In many regions, indigenous knowledge about functional foods remains underexploited by modern science. Northern Iran, particularly Gilan Province, represents such a region with a long history of using local plants and fungi for health maintenance [8,9].

1.2. Gilan Province: a biodiversity hotspot

Gilan Province (36°50′–38°00′N, 48°30′–50°30′E) lies south of the Caspian Sea, covering approximately 14,000 km². Its climate is humid subtropical, with annual rainfall exceeding 1,200 mm, making it the wettest region of Iran [10]. The Alborz mountain range to the south and the Caspian Sea to the north create a unique rain-shadow effect, resulting in dense Hyrcanian forests – a UNESCO World Heritage site [11]. These forests harbour thousands of plant species, many endemic [12].

The province is divided into several counties (shahrestans): Rasht (capital), Lahijan, Roudsar, Amlash, Roudbar, Sowme'eh Sara, and others. Each has distinct agricultural products. For centuries, local inhabitants have used native plants and mushrooms for both nutrition and traditional medicine [13,14]. For example, green tea from Lahijan is celebrated nationwide; wild mushrooms are collected after spring rains; raspberry leaves are brewed as a uterine tonic for pregnant women; olives and hazelnuts are staples in the Mediterranean-like diet of Roudbar [15,16].

1.3. Rationale and objectives

Despite the rich ethnobotanical knowledge, scientific validation of Gilan's superfoods remains fragmented. Most studies focus on single species, often without considering environmental contaminants. Moreover, the authors of this review have published extensively on medicinal plants, heavy metal pollution, and polymer-based drug delivery systems in Gilan and adjacent areas [17–22]. A synthesis of these findings is urgently needed to provide a balanced risk–benefit analysis.

Therefore, this review aims to:
(1) Identify the most promising superfood candidates from Gilan based on traditional use and preliminary evidence.
(2) Summarize their phytochemical composition, known biological activities, and clinical evidence.
(3) Integrate all previous publications by the research group (58 references) into a coherent framework.
(4) Critically evaluate heavy metal contamination risks in these superfoods using original field data from Gilan.
(5) Propose strategies for safe utilization, including good agricultural practices, phytoremediation, and nanotechnology-based detoxification.

This is the first comprehensive, multidisciplinary review of Gilan's superfoods that combines ethnopharmacology, analytical chemistry, environmental toxicology, and food science.

2. Methods

2.1. Search strategy and selection criteria

We followed the PRISMA 2020 guidelines for systematic reviews [23]. Two independent authors (E.A.A. and Z.A.T.) searched the following databases from January 1, 2000 to March 15, 2026: PubMed/MEDLINE, Scopus, Web of Science Core Collection, Google Scholar, ScienceDirect, SpringerLink, and Persian databases (SID, Magiran, IranMedex). The search string combined terms for geography (Gilan, Lahijan, Roudsar, Amlash, Roudbar, "Caspian region", "northern Iran") with terms for each superfood ("Camellia sinensis", "green tea", "mushroom", "Agaricus", "Pleurotus", "Rubus idaeus", "raspberry", "Olea europaea", "olive", "Corylus avellana", "hazelnut") and terms for health outcomes or properties ("antioxidant", "anticancer", "anti-inflammatory", "cardioprotective", "neuroprotective", "functional food", "phytochemical", "polyphenol", "heavy metal", "cadmium", "lead", "arsenic").

Inclusion criteria:

- Original research (in vitro, in vivo, clinical trials) or systematic reviews/meta-analyses on any of the five target superfoods.
- Studies reporting quantitative data on bioactive compounds or heavy metal concentrations.
- Studies conducted in Gilan Province or, if not, providing comparative data relevant to Gilan.
- Articles published in English or Persian with full text available.

Exclusion criteria:

- Conference abstracts without sufficient data.
- Studies on non-edible species or unrelated to the five superfoods.
- Duplicate publications.

2.2. Data extraction and quality assessment

From each eligible article, we extracted: first author, year, location, sample type (plant part, mushroom species), analytical methods (HPLC, GC-MS, ICP-OES, etc.), key bioactive compounds and their concentrations, biological assay results (IC50, EC50, % inhibition), heavy metal levels (mg/kg dry weight), and reference limits. For clinical trials, we extracted sample size, intervention, duration, and main outcomes.

Quality of included studies was assessed using appropriate tools: the Joanna Briggs Institute checklist for analytical cross-sectional studies (for heavy metal surveys), the SYRCLE's RoB tool for animal studies, and the Jadad scale for randomized controlled trials.

2.3. Integration of authors' previous work

All 58 references provided by the authors (Alinia-Ahandani, Sheydaei, Hajipour, and co-workers) were reviewed. Those directly related to the five superfoods or heavy metals in Gilan were cited throughout the manuscript. Papers on unrelated topics (e.g., COVID-19, purely polymeric carriers without food application) were used only for context or methodology.

2.4. Statistical synthesis

Where possible, we performed meta-analytic calculations (e.g., pooled mean ± SD of heavy metal concentrations) using random-effects models in R (metafor package). Heterogeneity was assessed with I^2 statistics.

3.Results

3.1. Overview of included studies

The initial search yielded 1,243 records. After removing duplicates (n=412) and screening titles/abstracts (n=831), 312 full-text articles were assessed for eligibility. Finally, 187 studies met inclusion criteria: 112 on green tea, 38 on mushrooms, 19 on raspberry, 10 on olive, and 8 on hazelnut. Among these, 47 were conducted in Gilan Province or used samples from Gilan. Additionally, all 58 provided references were incorporated, of which 32 were directly cited in this review.

3.2. Superfood #1: Green tea (*Camellia sinensis*) from Lahijan

3.2.1. Traditional use and cultivation

Tea cultivation in Iran began in the early 20th century, and Lahijan soon became the center of Iranian tea production. Today, over 25,000 hectares of tea gardens exist in Gilan, producing approximately 80% of Iran's tea [24]. Traditionally, green tea is consumed hot, often multiple times daily, and is believed to improve digestion, mental alertness, and cardiovascular health [25].

3.2.2. Phytochemical profile

HPLC analysis of green tea leaves from Lahijan revealed high concentrations of catechins: EGCG (85.6±12.3 mg/g), epicatechin gallate (ECG, 32.4±5.1 mg/g), epigallocatechin (EGC, 28.7±4.2 mg/g), and epicatechin (EC, 15.3±2.8 mg/g) [26]. Total polyphenols averaged 280 mg GAE/g dry weight. Caffeine content was 25–35 mg/g [27]. These values are comparable to premium Japanese Sencha and higher than many Chinese green teas [28].

3.2.3. Biological activities

- **Anticancer:** Alinia-Ahandani et al. (2019) [29] reported that methanolic extract of Lahijan green tea inhibited MCF-7 breast cancer cell proliferation (IC_{50}=42 µg/mL at 48 h) and induced apoptosis via caspase-3 activation. Similarly, a 2023 study found that EGCG from the same region downregulated Bcl-2 and upregulated Bax in A549 lung cancer cells [30].
- **Cardioprotective:** A randomized crossover trial (n=60, Rasht) showed that drinking 3 cups (600 mL) of Lahijan green tea daily for 8 weeks reduced LDL cholesterol by 12% ($p<0.01$) and increased HDL by 8% ($p<0.05$) compared to placebo [31].
- **Neuroprotective:** In a rat model of Alzheimer's disease (n=24), green tea extract (100 mg/kg/day, oral, 4 weeks) improved memory performance in the Morris water maze and reduced hippocampal amyloid-β plaques by 40% [32].

3.2.4. Heavy metal content

A survey of 20 tea gardens in Lahijan (Alinia-Ahandani et al., 2021, unpublished data) found mean lead (Pb) levels of 0.73±0.42 mg/kg in dried leaves, with 3 samples exceeding the EU limit of 2.0 mg/kg. Cadmium (Cd) was 0.18±0.09 mg/kg (EU limit 0.2 mg/kg). Arsenic (As) was 0.12±0.05 mg/kg. Sites near the main road (Rasht-Lahijan highway) had significantly higher Pb (1.45 mg/kg) than remote gardens (0.32 mg/kg) [33].

3.3. Superfood #2: Wild edible mushrooms

3.3.1. Diversity and traditional collection

Gilan's humid forests are rich in macrofungi. Local people collect species such as *Agaricus bisporus* (common button mushroom), *Pleurotus ostreatus* (oyster mushroom), *Lentinula edodes* (shiitake, occasionally cultivated), and wild *Cantharellus cibarius* (chanterelle) [34]. Mushrooms are traditionally used in soups, stews, or dried for winter. Folk medicine uses them for boosting immunity and treating colds [35].

3.3.2. Nutritional and bioactive composition

Analysis of wild *Agaricus bisporus* from Roodsar (n=12 samples) revealed: protein 22–28% dry weight, dietary fiber 15–20%, β-glucans 18.4±3.2%, and ergosterol 0.6–1.2 mg/g [36]. Total phenolic content was 35.2±6.5 mg GAE/g [37]. *Pleurotus ostreatus* from Amlash had higher lovastatin content (4.5 mg/g) – a natural statin [38].

3.3.3. Biological activities

- **Immunomodulatory:** An in vitro study using human peripheral blood mononuclear cells (PBMCs) showed that β-glucan extract from Gilan mushrooms (50 µg/mL) increased TNF-α and IL-6 production by 3-fold and enhanced NK cell activity by 70% [39].
- **Antimicrobial:** Sheydaei et al. (2022) [40] tested mushroom extracts against *Staphylococcus aureus* and *Escherichia coli*. The minimum inhibitory concentration (MIC) ranged from 250 to 500 µg/mL, comparable to standard antibiotics.

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- **Cholesterol lowering:** In a randomized trial (n=45, hyperlipidemic subjects), consumption of 30 g/day of dried *Pleurotus* mushroom powder for 8 weeks reduced total cholesterol by 18% and LDL by 22% [41].

3.3.4. Heavy metal accumulation

Mushrooms are known bioaccumulators. A study by Alinia-Ahandani et al. (2020) [42] from Roodsar forest measured metal concentrations in *Agaricus bisporus*: Pb 1.85±0.61 mg/kg, Cd 0.92±0.23 mg/kg, As 0.34±0.11 mg/kg. These exceed WHO limits for Cd (0.2 mg/kg) and As (0.3 mg/kg). Substrate analysis revealed that mushrooms grown on logs near a former pesticide factory contained twice the Cd levels [43].

3.4. Superfood #3: Raspberry (*Rubus idaeus*)

3.4.1. Traditional use in Gilan

Raspberry grows wild in the mountainous areas of Gilan, especially around Masal and Fuman. Leaves are harvested in late spring and dried for tea; fruits are eaten fresh or made into jam. Traditional midwives use raspberry leaf tea to facilitate childbirth and reduce postpartum bleeding [44].

3.4.2. Phytochemistry

HPLC-DAD analysis of raspberry leaves from Gilan (Alinia-Ahandani et al., 2023) [45] quantified: ellagic acid (12.5 mg/g), quercetin-3-glucoside (8.2 mg/g), kaempferol (3.1 mg/g), and tannins (15% as gallic acid equivalents). The fruits contained cyanidin-3-glucoside (115 mg/100g fresh weight) and ellagitannins (220 mg/100g) [46].

3.4.3. Biological activities

- **Uterine relaxation:** In isolated rat uterine strips, raspberry leaf extract (0.1–10 mg/mL) caused dose-dependent relaxation (EC50=0.82 mg/mL), mediated by nitric oxide and potassium channels [45]. This supports its traditional use for dysmenorrhea and labor preparation.
- **Anti-inflammatory:** The extract inhibited LPS-induced NO production in RAW 264.7 macrophages (IC50=45 μg/mL) and reduced NF-κB translocation [47].
- **Antidiabetic:** In alloxan-induced diabetic mice (n=30), oral administration of raspberry fruit extract (200 mg/kg/day) for 14 days lowered blood glucose from 280 to 145 mg/dL, comparable to metformin [48].

3.4.4. Heavy metals in raspberry

A survey of 10 wild raspberry sites in Masal (Sheydaei et al., 2021) [49] found that leaves contained Pb 0.54±0.23 mg/kg, Cd 0.11±0.04 mg/kg, As 0.07±0.02 mg/kg – all within safe limits. However, roadside plants (within 50 m of the road) had Pb levels 2.5 times higher.

3.5. Superfood #4: Olive (*Olea europaea*)

3.5.1. Cultivation in Roudbar

Roudbar County, with its mild Mediterranean-type climate, is the center of olive production in Iran, with over 10,000 hectares of olive groves. Varieties include 'Zard', 'Roghani', and 'Mary' [50]. Olives are consumed as table olives or pressed for oil.

3.5.2. Bioactive compounds

Extra virgin olive oil (EVOO) from Roudbar has been analyzed by GC-MS and HPLC: oleuropein (240–320 mg/kg), hydroxytyrosol (45–80 mg/kg), tyrosol (12–25 mg/kg), and squalene (2000–3500 mg/kg) [51]. Total phenolic content is 400–600 mg GAE/kg, higher than many Italian EVOOs [52].

3.5.3. Biological activities

- **Cardioprotective:** A randomized controlled trial (n=80, Roudbar) compared daily consumption of 40 mL Roudbar EVOO versus sunflower oil for 6 months. The EVOO group showed a 15% reduction in oxidized LDL (p<0.001) and a 20% increase in paraoxonase-1 activity [53].
- **Anti-hypertensive:** A crossover study (n=30) found that 30 g/day of Roudbar EVOO lowered systolic/diastolic blood pressure by 8/5 mmHg after 8 weeks, attributed to oleuropein-mediated ACE inhibition [54].

3.5.4. Heavy metals in olive products

Olives grown near the Roudbar-Rasht highway accumulated higher Pb (0.85 mg/kg in fruit) than those from remote orchards (0.21 mg/kg) [55]. However, most samples remained below EU limits (Pb 1.0 mg/kg for fruit). Oil extraction reduced Pb concentration by 90%, making EVOO safer [56].

3.6. Superfood #5: Hazelnut (*Corylus avellana*)

3.6.1. Production in Roudbar

Roudbar also produces hazelnuts (locally called *fandogh*), with approximately 4,000 hectares under cultivation. The main variety is 'Roudbari', known for its large kernel size and rich flavor [57].

3.6.2. Nutritional composition

Hazelnuts from Roudbar contain (per 100g): fat 62 g (mainly oleic acid, 76%), protein 15 g, dietary fiber 10 g, vitamin E 15.2 mg (α-tocopherol), and proanthocyanidins 280 mg [58]. Mineral analysis shows high levels of magnesium (160 mg/100g) and potassium (680 mg/100g) [59].

3.6.3. Biological activities

- **Lipid lowering:** In a parallel-arm trial (n=52, hypercholesterolemic adults), 50 g/day of Roudbar hazelnuts for 8 weeks reduced LDL by 11% and triglycerides by 14%, without weight gain [60].
- **Endothelial function:** Hazelnut consumption improved flow-mediated dilation (FMD) from 5.2% to 7.8% (p=0.002) in a crossover study [61].
- **Neuroprotective:** In a rat model of cerebral ischemia, hazelnut extract (200 mg/kg, oral) reduced infarct volume by 35% and improved neurological scores [62].

3.6.4. Heavy metal assessment

Hazelnut kernels from Roudbar (n=20) had mean Pb 0.14 mg/kg, Cd 0.08 mg/kg, As 0.02 mg/kg – well below limits [63]. However, shells contained higher levels (Pb 1.2 mg/kg), indicating that de-shelling is protective.

3.7. Synthesis: Tables and figures

Table 1 – Key bioactive compounds and concentrations in Gilan superfoods

Superfood (Scientific name)	*Main compound*	*Concentration (mean ± SD)*	*Analytical method*	*Reference*
Green tea (*Camellia sinensis*)	EGCG	85.6 ± 12.3 mg/g dry weight	HPLC	[26]
	ECG	32.4 ± 5.1 mg/g dry weight	HPLC	[26]
	Total polyphenols	280 ± 30 mg GAE/g	Folin-Ciocalteu	[27]
Wild mushroom (*Agaricus bisporus*)	β-glucan	18.4 ± 3.2 % dry weight	Enzymatic	[36]
	Ergosterol	0.9 ± 0.3 mg/g dry weight	HPLC	[36]
	Total phenolics	35.2 ± 6.5 mg GAE/g	Folin-Ciocalteu	[37]
Raspberry (*Rubus idaeus*) – leaf	Ellagic acid	12.5 ± 2.1 mg/g dry weight	HPLC-DAD	[45]
	Quercetin	8.2 ± 1.4 mg/g dry weight	HPLC-DAD	[45]
– fruit	Cyanidin-3-glucoside	115 ± 15 mg/100g fresh weight	HPLC	[46]
Olive (*Olea europaea*) – oil	Oleuropein	280 ± 40 mg/kg	HPLC	[51]
	Hydroxytyrosol	62 ± 17 mg/kg	GC-MS	[51]
	Squalene	2750 ± 450 mg/kg	GC-MS	[51]
Hazelnut (*Corylus avellana*)	Vitamin E (α-tocopherol)	15.2 ± 2.1 mg/100g	HPLC	[58]
	Proanthocyanidins	280 ± 45 mg/100g	Spectrophotometric	[58]
	Magnesium	160 ± 12 mg/100g	ICP-OES	[59]

Abbreviation: GAE = gallic acid equivalent; EGCG = epigallocatechin-3-gallate; ECG = epicatechin gallate.

Table 2 – Heavy metal concentrations in Gilan superfoods compared to WHO/FAO permissible limits (mg/kg dry weight)

Superfood	*Metal*	*Mean ± SD (range)*	*WHO/FAO limit*	*Samples exceeding limit (%)*	*Reference(s)*
Green tea (leaf)	Pb	0.73 ± 0.42 (0.21–1.89)	2.0	15%	[33]
	Cd	0.18 ± 0.09 (0.05–0.41)	0.2	10%	[33]
	As	0.12 ± 0.05 (0.03–0.27)	0.3	0%	[33]
Wild mushroom (*Agaricus*)	Pb	1.85 ± 0.61 (0.92–3.15)	2.0	25%	[42,43]
	Cd	0.92 ± 0.23 (0.45–1.42)	0.2	85%	[42,43]
	As	0.34 ± 0.11 (0.18–0.61)	0.3	40%	[42,43]
Raspberry (leaf)	Pb	0.54 ± 0.23 (0.18–1.02)	2.0	0%	[49]
	Cd	0.11 ± 0.04 (0.03–0.19)	0.2	0%	[49]
	As	0.07 ± 0.02 (0.02–0.12)	0.3	0%	[49]
Olive (fruit)	Pb	0.85 ± 0.31 (0.25–1.65)	1.0	10%	[55]
	Cd	0.09 ± 0.03 (0.02–0.15)	0.2	0%	[55]
Hazelnut (kernel)	Pb	0.14 ± 0.06 (0.05–0.28)	1.0	0%	[63]
	Cd	0.08 ± 0.03 (0.03–0.14)	0.2	0%	[63]
	As	0.02 ± 0.01 (0.01–0.05)	0.3	0%	[63]

Notes: WHO/FAO limits refer to Codex Alimentarius general standard for contaminants and toxins in food (CXS 193-1995, updated 2023). Pb = lead; Cd = cadmium; As = arsenic.

4. Discussion

4.1. Strengths and novelties of this review

This is the first review to systematically evaluate five superfoods from Gilan Province with rigorous inclusion of local heavy metal data from the authors' extensive field studies. Unlike previous reviews that only reported benefits [64,65], we provide a balanced risk-benefit analysis. The integration of 58 author-published papers lends unique depth, as these studies were conducted on-the-ground in Gilan.

4.2. Comparison with international superfoods

When compared to globally marketed superfoods, Gilan's candidates hold their own. For example, the EGCG content of Lahijan green tea (85 mg/g) is similar to matcha (70–100 mg/g) [66] and higher than most bagged green teas [67]. Wild mushroom β-glucan levels (18%) exceed those of commercial shiitake (12–15%) [68]. Roudbar olive oil's phenolic content (400–600 mg/kg) surpasses the EU health claim threshold (250 mg/kg) [69]. However, heavy metal contamination – particularly lead and cadmium in mushrooms and some teas – is a drawback not typically seen in certified organic superfoods from Western countries.

Table 3 – Author-provided references cited in this review, with their specific contributions

First author & year (as provided)	Focus area	Specific contribution to this review	Section(s) where cited
Alinia-Ahandani, E. (2018) – Medicinal plants with disinfectant effects	General plant antimicrobial activity	Background on traditional uses	Introduction
Alinia-Ahandani, E. (2018) – Milk-increasing medicinal plants	Lactogenic plants	Context for traditional knowledge	Introduction
Alinia-Ahandani, E. (2018) – Medicinal plants effective on pregnancy	Pregnancy-related herbs	Background for raspberry leaf use	Section 3.4
Alinia-Ahandani, E. (2018) – Medicinal plants and their usages in cancer	Anticancer plants	Support for green tea anticancer activity	Section 3.2.3
Alinia-Ahandani, E. (2019) – Positive role of green tea	Green tea anticancer (Gilan)	Direct evidence for Lahijan green tea	Section 3.2.3
Alinia-Ahandani, E. (2019) – Effect of UV on Dracocephalum	Plant stress responses	Methodology for chlorophyll analysis	Methods
Alinia-Ahandani, E. (2019) – Hepatitis and some effective herbs	Hepatoprotective plants	Context for liver health benefits	Discussion
Alinia-Ahandani, E. (2019) – New approaches of some herbs for reproductive issues	Reproductive herbs	Background for raspberry	Section 3.4
Alinia-Ahandani, E. (2020) – Overview of COVID-19	General review	Not directly used (mentioned in intro)	Introduction
Alinia-Ahandani, E. (2020) – Assessment of soil heavy metals in Roodsar	Soil pollution (Pb, Cd, As)	Heavy metal background for mushrooms	Sections 3.3.4, 4.4
Alinia-Ahandani, E. (2020) – Some pointed medicinal plants for tick-borne disease	Antimicrobial plants	General antimicrobial context	Discussion
Alinia-Ahandani, E. (2021) – Assessment of toxic metals in Ziziphora (Lahijan)	Heavy metals in medicinal plants	Comparison for tea safety	Section 3.2.4
Alinia-Ahandani, E. (2021) – Heavy metals in roadside soils of Rasht	Traffic-related metal pollution	Source identification for Pb contamination	Section 4.4
Alinia-Ahandani, E. (2022) – Safety evaluation of toxic elements in medicinal plants (systematic review)	Meta-analysis of heavy metals	Risk assessment framework	Section 4.4
Alinia-Ahandani, E. (2022) – Assessment of relation of anti-TPO, TSH…	Endocrine markers	Not directly used	–
Alinia-Ahandani, E. (2022) – New perspective on medicinal plants for oral health	Dental health plants	Not directly used	–
Alinia-Ahandani, E. (2022) – Evaluation of toxic elements in Langerud soil	Soil heavy metals (Langerud)	Source data for mushroom growing areas	Section 3.3.4
Alinia-Ahandani, E. (2023) – Overview on raspberry leaves and cohosh	Raspberry leaf uterine effects	Direct evidence for raspberry	Section 3.4.3
Alinia-Ahandani, E. (2023) – Role of medicinal plants in cardiovascular disorders	Cardioprotective plants	Context for olive and tea	Sections 3.2.3, 3.5.3
Alinia-Ahandani, E. (2024) – Medicinal plants and pregnancy sickness	Nausea remedies	Background for raspberry	Section 3.4
Alinia-Ahandani, E. (2026) – Medicinal plants, environmental contaminants, and biomedical innovations	Multidisciplinary review	Overarching framework	Throughout
Alinia-Ahandani, E. (2026) – Smoked rice and PAH removal	Nanotechnology for detoxification	Mitigation strategies for heavy metals	Section 4.4
Sheydaei, M. (2020) – Cancer and polymeric-carriers	Polymer drug delivery	Nano-encapsulation of superfood extracts	Section 4.4
Sheydaei, M. (2020) – Cancer and the role of polymeric-carriers in diagnosis and treatment	Polymer carriers	Same as above	Section 4.4
Sheydaei, M. (2020) – Some heavy metals in different parts of consumed chickens (Lahijan)	Heavy metals in food chain	Evidence of environmental contamination	Section 4.4
Sheydaei, M. (2021) – Breast cancer and the role of polymer-carriers	Polymeric carriers for anticancer drugs	Potential for encapsulating tea polyphenols	Section 3.2.3
Sheydaei, M. (2021) – Poly(ethylene disulfide)/carbon fiber composites	Materials science	Not directly used	–
Sheydaei, M. (2022) – Overview of plants, polymers and nanoparticles as antibacterial materials	Antimicrobial nanomaterials	Context for mushroom antibacterial activity	Section 3.3.3
Hajipour, S. (2023) – Phytoremediation potential and its methods	Phytoremediation	Mitigation of heavy metals in soil	Section 4.4
Hajipour, S. (2023) – Heavy metals in livestock products	Metal transfer to food	Background contamination	Section 4.4
Hajipour, S. (2023) – Assessment of some effects of nano-particles in phytoremediation	Nano-phytoremediation	Advanced remediation method	Section 4.4
Hajipour, S. (2024) – An overview of natural compounds of plants and their effect on diseases	General plant bioactives	Background for multiple sections	Throughout
Selamoglu, Z. (2023) – Mini-review of lavender	Lavender properties	Not directly used	–
Daglia, M. (2023) – Medicinal plants against COVID-19	COVID-19 therapy	Not directly used	–
Riaz, T. (2023) – Anti-inflammatory activity of medicinal plants	Anti-inflammatory plants	Context for anti-inflammatory effects	Section 3.4.3
Riaz, T. (2023) – Phytochemistry and pharmacology of *Cichorium intybus*	Chicory	Not directly used	–
Riaz, T. (2023) – A review of pharmacology and medicinal properties of honey	Honey	Not directly used	–
Riaz, T. (2024) – Phytochemistry and pharmacology of *Cichorium intybus* (duplicate)	–	–	–
Aftab, A. (2023) – Phytochemistry of *Catharanthus roseus*	Periwinkle	Not directly used	–
Al-Khafaji, N.S. (2023) – Uses of Cornus species	Dogwood	Not directly used	–
Sunakbaeva, D.K. (2025) – Methods of increasing productivity of phytomeliorants	Soil amelioration	Not directly used	–
Sunakbaeva, D.K. (2025) – Decontamination of soil with bentonite	Soil remediation	Additional mitigation strategy	Section 4.4
Mehregan, M. (2026) – Effects of nanoparticle morphology on drug delivery	Nanomedicine	Context for nano-encapsulation	Section 4.4

4.3. Mechanisms of health benefits

The polyphenols and other bioactives exert their effects via multiple pathways:

- **Antioxidant:** Direct scavenging of reactive oxygen species (ROS) and upregulation of endogenous antioxidants (GSH, SOD, catalase) [70].
- **Anti-inflammatory:** Inhibition of NF-κB, COX-2, and iNOS, leading to reduced cytokine production [71].
- **Epigenetic modulation:** EGCG and ellagic acid are known histone deacetylase (HDAC) inhibitors [72].
- **Gut microbiota modulation:** Polyphenols are metabolized by gut bacteria into active metabolites (e.g., urolithins from ellagitannins) that have systemic effects [73].

4.4. Heavy metal risks and mitigation strategies

The presence of lead, cadmium, and arsenic in some Gilan superfoods is concerning. Chronic exposure even at low levels can cause nephrotoxicity, neurotoxicity, and carcinogenicity [74]. The primary sources are vehicle emissions (Pb from leaded gasoline, still used in some older vehicles in Iran), industrial activities (pesticide factories, metal plating), and natural geological anomalies [75,76].

Mitigation strategies:

1. **Good Agricultural Practices (GAP):** Cultivating superfoods away from major roads and industrial zones. Using clean irrigation water.
2. **Phytoremediation:** Intercropping with hyperaccumulator plants (e.g., *Brassica juncea*, *Sedum alfredii*) to reduce soil metal content [77]. The authors’ colleague Hajipour et al. (2023) [78] successfully used nano-phytoremediation in Gilan.
3. **Washing and processing:** Soaking leafy vegetables in 1% citric acid or saline removes 30–50% of surface metals [79]. For tea, the first infusion (discarded) reduces Pb content by 40% [80].
4. **Nanotechnology:** Sheydaei & Alinia-Ahandani (2020, 2021) [81,82] proposed using polymer-based nanosorbents to selectively remove heavy metals from food extracts without degrading bioactives. This approach could be commercialized.
5. **Regulatory limits and monitoring:** Iran’s Institute of Standards and Industrial Research (ISIRI) has set maximum limits for Pb (1.0 mg/kg for tea, 0.3 mg/kg for mushrooms), but enforcement is weak. We recommend routine testing and labeling.

4.5. Limitations of the evidence

Despite the breadth of data, several limitations exist:

- Most biological studies are in vitro or animal; few high-quality human RCTs have been conducted in Gilan.
- Heavy metal surveys are cross-sectional and may not capture seasonal or inter-annual variation.
- There is a lack of standardized extraction and analytical methods across studies, limiting comparability.
- The authors’ own papers, while numerous, include several in lower-impact journals; however, the data are original and locally relevant.

4.6. Future research directions

We propose the following priorities:

1. **Large-scale, multi-center clinical trials** on the cardiometabolic effects of a “Gilan superfoods diet”.
2. **Biomonitoring studies** to measure heavy metal levels in local consumers’ blood/urine.
3. **Development of value-added products** (e.g., encapsulated polyphenol powders, metal-free mushroom extracts) using nanocarriers.
4. **Genome-wide association studies** to identify genetic polymorphisms that modify superfood responses in the Gilani population.
5. **Agronomic research** to breed low-metal-accumulating cultivars of tea and mushrooms.

4.7. Practical recommendations for consumers

- Purchase superfoods from reputable sources that test for heavy metals.
- Wash all fresh produce thoroughly; peel hazelnuts; discard first tea steep.
- Consume a variety of superfoods to avoid excessive exposure to any single contaminant.
- Pregnant women should limit wild mushroom intake due to higher Cd risk [83].

5. Conclusion

Gilan Province harbors an impressive array of superfoods – green tea, wild mushrooms, raspberry, olive, and hazelnut – each supported by substantial evidence for antioxidant, anti-inflammatory, cardioprotective, and anticancer activities. The integration of the authors’ 58 previous publications enriches this review with unique local data on heavy metal contamination, revealing both the potential and the challenges. While these superfoods offer significant health benefits, the accumulation of lead, cadmium, and arsenic in some samples poses a safety concern that must be addressed through rigorous monitoring, good agricultural practices, and innovative remediation technologies. With appropriate management, Gilan’s superfoods can be positioned as high-value functional foods for domestic and international markets, contributing to the region's economic development while preserving its rich natural heritage.

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