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Chemical Profiles of the Medicinal and Edible Native Super Fruit *physalis peruviana* L.

Amir-Mohammad Jame-Bozorgi[1], Parisa Ziarati*[2]

1- Nutrition and Food Sciences Research center, TeM S.C, Islamic Azad University, Tehran, Iran
2 - Halal Research Center of IRI, Food and Drug Administration, Ministry of Health and Medical Education
**Correspondence author: Parisa Ziarati*

A B S T R A C T

Physalis peruviana L. (Goldenberry) belongs to the *Solanaceae* family and produces a spherical fruit used to treat various diseases. However, the chemical composition, nutritional characterization, and Mineral and trace elements of the *P. peruviana* fruits growing in the Urumieh (North West of Iran) have not been studied so far. The research aims to investigate the chemical composition of cultivated *P. peruviana* fruit, providing insights to enhance its use in food applications and facilitate the development of related functional products. Ripe *physalis peruviana* fruits collected in August 2021, and main trace /mineral elements as well as heavy metals were determined by standard international analytical protocols. The results indicated significantly elevated average levels of selenium, magnesium, and potassium: 8.12±0.01, 360.534±0.041, and 328.426±0.121 (μg/g ± SE), respectively. Environmental factors, including soil composition, atmospheric temperature, light quality, and various other conditions, significantly influence the chemical composition and nutritional value of herbal plants and fruits. These factors play a crucial role in shaping their properties and may be the primary reason for variations in the nutritional profile of *P. peruviana* cultivated in different regions. Current research reveals that the average concentrations of arsenic, cobalt, cadmium, and lead in all examined samples are well below the maximum limits defined by national standards and the thresholds outlined by FAO/WHO. This suggests no grounds for concern regarding heavy metal contamination. Boasting a rich profile of magnesium, potassium, and various other trace minerals, the native golden-berry stands out as an exceptional super fruit known for its numerous medicinal benefits. Its remarkable qualities position it as a highly lucrative and valuable food product in the food industry and market.

Keywords: *physalis peruviana*, Goldenberry, Nutritional composition, Mineral elements

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1. Introduction

The aggregation of numerous ethnopharmacological surveys conducted globally reveals that more than 50,000 plant species possess notable nutritional and therapeutic attributes. Approximately 80% of the global population has utilized at least one of these plants at some point in their lives to address health-related issues (Kasali et al., 2022). Iran, with its remarkable diversity of climates and abundant genetic plant resources, stands out as one of the most resource-rich countries, showcasing an impressive array of natural talents (Kumleh et al., 2016). The genus Physalis as a member of the Solanaceae family, with more than 100 species (Zhang & Tong, 2016), owing to its rich content of bioactive compounds and robust antioxidant properties, demonstrates a diverse range of biological activities. These include anti-inflammatory (Castro et al., 2008; Yari et al., 2025), anti-tumor (Hseu et al., 2011; Yari et al., 2025), immune-suppressive, antimicrobial (Yang et al., 2016), anti-leishmanial, anti-diabetic (Hu et al., 2018; Vicas et al., 2020; Zhang et al., 2018), and anti-asthmatic effects, among others (Yang et al., 2022).
The growing demand for natural ingredients across pharmaceutical, cosmetic and food industries has significantly heightened interest in

*Corresponding author: E-Mail Address: ziarati@iau.ac.ir

medicinal plants. As a result, substantial research efforts are currently focused on discovering new drug sources and molecular structures. A key factor influencing the industrial use of medicinal plants is their quality control and standardization. Ensuring the quality of medicinal raw materials forms a fundamental part of this process, as the origin and quality of these materials are crucial for maintaining the integrity of pharmaceutical products. Achieving this often involves domesticating and cultivating wild plant species. To foster domestication, it is essential to grow medicinal plants beyond their native habitats (Hadi et al., 2017).

Physalis peruviana L. is among plant species possessing evident nutritional, nutraceutical, and commerce al interests. The Physalis fruit typically has a texture resembling that of a firm tomato, while its flavor combines the sweetness and tanginess of a grape (Sánchez-Bravo & Noguera-Artiaga, 2024). Certain species, like the Cape gooseberry and tomatillo, have been selectively cultivated into numerous varieties, offering a diverse range of tastes, from tart, sweet to savory. The characteristics of Physalis fruit and its applications across different sectors, particularly in the food sector, aim to enhance the nutritional content of products and create superior quality and more nutritious items. Moreover, it will enable the development of advantageous food products. P. peruviana L. is a semi-upright, herbaceous shrub or perennial plant characterized by its cluster of branched stems. It is indigenous to the Andean region and extensive researches had primarily focused on its fruit, aiming to identify its chemical composition, nutritional benefits, and pharmacological attributes (Olivares-Tenorio et al., 2016; Puente et al., 2019; Singh et al., 2019). Physalis angulata L. is reported as a new record for the flora of Iran. A taxonomic description along with the illustrations of the species was reported on the basis of some collections from Fars province, Iran (Zeraatkar and Ghahremaninejad, 2020). Given that not many studies have been conducted on Physalis fruit in Iran, and that this fruit has been cultivated in recent years in West Azerbaijan, Tonekabon, and recently in Bushehr (Yari et al., 2025). The characterization of these fruits is scarce in Iran, most studies have concentrated on exploring the pharmacological characteristics and agricultural conditions of the plant. Recently, the Physalis family has garnered increased interest, driven by growing consumer demand for distinctive fruits and vegetables. This shift is largely attributed to a deeper awareness of the health benefits linked to maintaining a diverse diet. The current study sets out to analyze the mineral and trace element composition of this native fruit, alongside its heavy metal content, with a focus on food safety. Additionally, it investigated the fruit's potential applications in the food industry and its role in developing functional food products.

2. Materials and Methods

2.1- Study area and sampling

physalis peruviana L. fruits (golden berries) were collected in August 2021 from local growers in Urumieh in Iran. Specimen was identified by and voucher was deposited in the Herbarium of Faculty of Pharmacy, Pharmaceutical Sciences faculty, Islamic Azad University, Tehran.

Urmia(Urumieh: 37° 32′ 38″ N, 45° 3′ 53″ E) is the largest city in West Azerbaijan Province of Iran. In the Central District of Urmia County, it is capital of the province, the county, and the district. The city is situated near the borders of Iran with Turkey and Iraq.

Intact fruits were carefully selected according to the degree of ripeness measured by fruit color; brilliant orange(figure 1). The whole fresh fruits of P. peruviana samples were sent by plane from Urumieh to the Nutrition and Food sciences Research center, Tehran Medical Sciences University where they were studied; they were preserved at room.

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Figure 1- Aerial parts and fruit of *Physalis peruviana* L.

2.2- Zinc, Manganese, Copper, and Potassium Determination

To ensure accurate results, all stock solutions and working standards were maintained at 4°C and brought to room temperature (25°C) prior to use. For the analysis of Zinc, Manganese, Copper, and Selenium concentrations in *P. peruviana* samples, the powdered seeds were oven-dried for 48 hours at 85°C. After drying, the samples were ground and sieved through a 0.5 mm mesh. The powdered samples underwent acid digestion using concentrated nitric acid (65% Merck), sulfuric acid (96.5% Merck), and perchloric acid (70% Sigma). Analar grade hydrogen peroxide (approximately 30%) was also utilized during the digestion process. Concentrated HNO3, combined with 30% hydrogen peroxide (Merck), facilitated complete mineralization of the samples according to the Environmental Protection Agency (EPA, 2014) Method 3052. For the digestion procedure, two grams of each air-dried *P. peruviana* sample were accurately weighed, and 30.0 mL of the digestion mixture comprising two parts by weight of nitric acid, one part of sulfuric acid, and four parts by weight of perchloric acid was introduced. The mixture was slowly heated in an oven before gradually increasing the temperature. The remaining dry inorganic residues were then dissolved in 30.0 mL of concentrated nitric acid, and this solution was prepared for the analysis of trace and essential mineral elements. Additionally, blanks and sample runs were processed and analyzed in tandem to ensure consistency. All employed chemicals were of analytical grade (AR), adhering to standardized international protocols for material preparation and heavy metal content analysis. The samples were analyzed utilizing a Flame Emission Spectrophotometer Model AA-6200 (Shimadzu, Japan), with parameters set for air-acetylene flame at a temperature of 2800°C, acetylene pressure ranging from 0.9 to 1.0 bar, and air pressure at 4.5–5 bar. The reading time was set between 1 and 10 seconds (up to a maximum of 60 seconds), with a flow time of 3–4 seconds (maximum 10 seconds). At least five standard solutions for each metal were utilized for the determination of potassium content, as per FDA elemental analysis guidelines (ORA Laboratory Manual FDA, 2004). To confirm the reliability of the measurement apparatus, periodic testing of standard solutions was conducted. The accuracy of the procedures was validated using quality control tests for fungal samples and their substrates, which demonstrated a degree of agreement with standard values, showing discrepancies of less than 5%.

2-3. Iron Determination

An aliquot was analyzed using an atomic absorption spectrophotometer to determine its iron concentration. Calibration standards were prepared using a stock solution of 10 mg/L, which was made with ferrous ammonium sulfate (Jafari-Moghadam et al., 2015). Between 3 and 60 ml of the stock solution were transferred into 100 ml volumetric flasks, followed by the addition of 2 ml of hydrochloric acid (Merck). The flasks were then carefully brought to volume with distilled water. The iron concentration in the aliquot was measured in micrograms per gram (μg/g) using the atomic absorption spectrophotometer and the entire procedure were performed in triplicate.

2-4. Calcium, Sodium and Magnesium Determination

To analyze calcium, sodium, and magnesium, 5 ml of the aliquot was transferred to a titration flask using a pipette and diluted to a total volume of 100 ml with distilled water. Subsequently, 15 ml of buffer solution, ten drops of Eriochrome Black T indicator, and 2 ml of triethanolamine were added. The mixture was then titrated with Ethylene-Diamine-Tetra-Acetate (EDTA) solution until a color change from red to clear blue was achieved(3500-Ca B. EDTA Titrimetric Method 3500-Ca B. EDTA Titrimetric Method, National Environment Methods Index (NEMI).

2-5. Selenium Determination

For the selenium determination, stock standard solutions with a concentration of 1000 g/mL were prepared. All reagents and standards were of analytical grade, sourced from Merck, Germany. The palladium matrix modifier solution was obtained by diluting Pd $(NO3)_2$ to a concentration of 10 g/L. Furthermore, an iridium AA standard solution at 1000 g/mL was prepared using 20% hydrochloric acid, alongside 0.1% V/V nitric acid derived from trace-grade 65% nitric acid mixed with 0.1% Triton X-100. Doubly distilled water was utilized for all steps in the procedure. The samples were analyzed using the Shimadzu Flame Emission Spectrophotometer (Model AA-6200) following the Analytical Method ATSRD guidelines (Yarahmadi et al., 2024; ATSRD, 2013).

2-6. Cadmium, Lead and Cobalt Determination

Standardized international protocols were followed for the preparation of the material and analysis of heavy metal contents. The flasks were first heated slowly and then vigorously till a white residue was obtained. The residue was dissolved and made up to 10 ml with 0.1 N HNO3 in a volumetric flask. Heavy metals in fruit samples were analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) (PerkinElmer, USA), using six standard solutions for each metal. All necessary precautions were taken to avoid any possible contamination of the sample as per the AOAC guidelines (AOAC, 2000; Ziarati et al., 2023).

2-7. Arsenic Determination

All glassware and plastic containers utilized in the study underwent thorough cleaning using liquid soap, followed by rinsing with water. Subsequently, they were soaked in 10% v/v nitric acid for 24 hours, rinsed meticulously with distilled water, and dried to eliminate the possibility of contamination. Calibration curves and reference solutions were prepared using standard solutions containing 1000 mg/L arsenic (ICP Standard, Merck, Darmstadt, Germany). All solutions were prepared with distilled-deionized water. The residual acidity of the digested samples was determined via acid-base titration using sodium hydroxide solution, which had been standardized with potassium hydrogen phthalate. For hydride generation, hydrochloric acid solution (2 mol/L, HCl; Merck: 37%) and sodium borohydride (NaBH4 tablets, purity >97%) at 1.5% in 0.2% NaOH (Sigma Aldrich, Extra Pure) were used. Concentrated acids, including HNO3, HCl, and H3PO4 (Merck, analytical grade), were diluted with ultrapure water to prepare analysis solutions. Additionally, reference material from the National Institute of Standards and Technology (NIST RM 8704) was employed for select tests. Fruit samples were digested following the USEPA method to detect metals using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (EPA, 2014; Gazulla et al., 2022; Ziarati et al., 2023). The digestion process involved a two-step heating protocol: first reaching 140 °C with a hold time of 5 minutes, followed by heating to 180 °C for 10 minutes. A ventilation step lasting 40 minutes ensured cooling of the samples to room temperature (20–25 °C). The procedure was monitored closely throughout (Amaral et al., 2016; Prasad et al., 2020). The extracts were analyzed using an inductively coupled plasma optical emission spectrometer (ICP-OES), model Optima DV 7000 (Perkin Elmer instruments, Shelton, USA), equipped with hydride generation. The instrument's dual-viewing functionality enabled an extensive working range with optimally low detection limits and maximal concentration capacity within a single system. Operational conditions are detailed in Table 1.

Table 1- Operational conditions of ICP-OES.

Parameter	
Auxiliary gas flow rate (L min^{-1})	0.2
Plasma gas flow rate (L min^{-1})	15
Injector tube diameter (mm)	2.0
View	Axial
Interface	Shear gas
Applied power (kW)	1.3
Nebulization gas flow rate (L min^{-1})	0.6

2-8. Statistical techniques

All the analyses were assessed in triplicate, and the statistical evaluation of the data conducted using a one-way analysis of variance (ANOVA) (IBM Corporation, Armonk, NY, USA). The values mentioned for chemical composition in current investigation are approach of five values. Every pattern records became implying by 5 subsamples.

3. Results and discussion

The findings presented in Table 2 highlight the remarkable potential of *P. peruviana* as a natural food additive. This plant stands out for its impressive nutritional profile and its long-standing use in traditional medicine, making it a promising candidate as a nutraceutical and functional food. Its abundant health benefits further support its classification as a super food. Beyond these attributes, *P. peruviana* has significant value as a functional food ingredient, opening possibilities for developing innovative, value-added products. Its versatility aligns well with contemporary health-focused goals, promoting its applications across the medicinal, nutraceutical, and food industries.

Table 2- Some Nutritional properties of *P. peruviana* fruits from Urumieh Region in Iran

Mineral & Trace Elements	DW±SE(μg/g)
Fe	16.753 ± 0.024
Zn	11.376 ±0.024
Mg	360.534 ±0.041
Mn	3.615 ±0.031
K	328.426 ±0.121
Cu	11.366±0.042
Na	15.018 ±0.003
Se	0.0082±0.001
Li	0.1127±0.004

DW=Dry Weight
SE=Standard Error

It has been observed that high content of Magnesium: 360.534 ±0.041(μg/g DW±SE) in the studied samples can be characterized by the highest bioavailability of Mg in fruits. The claim **"a source of vitamins and/or minerals"** and any other claim with the same meaning for the consumer, may only be attributed to a product that contains at least a significant amount of the micronutrients, as defined in the Annex to Directive 90/496/EEC or according to Article 7 of Regulation (EC) No. 1925/2006 of the European Parliament and of the Council of 20 December 2006 on "the addition of vitamins and minerals and of certain other substances to foods"; this value for magnesium is 300 mg (Fiorentini et al., 2021; European Parliament and Council of the European Union. 2006). Magnesium is a vital nutrient involved in numerous physiological processes. A consistently low intake of magnesium, along with a general deficiency of this essential mineral, can disrupt biochemical pathways, heightening the risk of various illnesses, particularly chronic degenerative conditions. Accurately assessing magnesium status is crucial, yet it remains challenging. While the measurement of serum magnesium levels is the most widely employed and easily accessible method, these values do not reliably reflect total body magnesium content or its distribution across specific tissues. This review aims to provide a comprehensive perspective on magnesium by integrating recent findings. It begins with a biochemical analysis, underlining the risks associated with inadequate magnesium intake—often tied to its limited presence in the modern Western diet. It also discusses strategies to achieve recommended dietary reference levels and emphasizes the need for precise detection of magnesium levels in different areas of the body to mitigate the societal impact of diseases linked to magnesium deficiency (Fiorentini et al., 2021). Magnesium supplements have demonstrated a modest effect in lowering blood pressure among individuals with hypertension, with systolic readings decreasing by roughly 3-4 points and diastolic by 2-3 points. Notably, higher magnesium intake through dietary sources has been linked to even greater reductions in blood pressure. The DASH diet, well-known for its success in managing hypertension, offers an abundant source of magnesium alongside other vital nutrients. However, because foods contain a complex mix of vitamins and minerals, pinpointing the precise role of magnesium remains a challenge (Schuchardt & Hahn, 2017; Ismail et al., 2018).

The significance of retaining right magnesium intake and overall body magnesium content in maintaining human health stays underappreciated among medical specialists and laymen.

This evaluation aimed to reveal the importance of hypomagnesemia as a modifiable risk factor for developing ailment processes. We searched the PubMed database and Google Scholar for the usage of the keywords 'magnesium', 'diabetes', 'cardiovascular ailment', 'respiratory disorder','immune gadget','inflammation','autoimmune disease','neurology','psychiatry','cognitive function','cancer',and'vascular calcification'. In multiple contexts of the hunt phrases, all critiques, animal experiments, and human observational information indicated that magnesium deficiency can result in or contribute to growing many sickness states. The conclusions of numerous in-intensity critiques guide our working hypothesis that magnesium and its supplementation are regularly undervalued and underutilized. Although a great deal research has shown the importance of right magnesium deliver and tissue degrees, simple and inexpensive magnesium supplementation has not yet been sufficiently recognized or promoted (Pethő et al., 2024). Research shows that magnesium supplements can help lower blood pressure in individuals with hypertension, reducing systolic pressure by 3-4 points and diastolic pressure by 2-3 points. Additionally, increasing your intake of magnesium-rich foods may provide even greater reductions in blood pressure. Following the DASH diet, which emphasizes magnesium along with other essential nutrients, is a smart way to foster heart health. Since foods naturally contain a mix of vitamins and minerals, isolating magnesium's specific effects can be tricky. A comprehensive review by DiNicolantonio et al., in 2018 of clinical studies indicated that higher magnesium levels are associated with a reduced risk of heart disease. This suggests that incorporating magnesium into the diet may be beneficial for cardiovascular health (DiNicolantonio et al., 2018; Kothari et al.,2024).

Magnesium and Stroke Prevention: Another review focused on stroke risk by Wang and his team in 2024 , revealed that individuals who consume higher amounts of magnesium through their diet tend to have a lower risk of experiencing strokes, particularly those caused by clots. It's worth noting that other dietary nutrients might also contribute to these findings (Wang *et al.* , 2023).

***Magnesium and Diabetes Management*:** Individuals with diets rich in magnesium tend to have a lower prevalence of Type 2 diabetes. However, since foods provide a variety of nutrients, it's challenging to pinpoint magnesium's individual effects. Nevertheless, there are no downsides to including magnesium-rich foods in a balanced diet. The American Diabetes Association has stated that current evidence does not support magnesium supplementation for blood sugar control in diabetic patients (Kuppusamy et al., 2022; Barbagallo & Dominguez , 2015 ; Veronese et al., 2021).

***Magnesium and Asthma Relief*:** Magnesium might help alleviate asthmatic spasms due to its muscle-relaxing properties. However, this benefit is primarily associated with intravenous magnesium rather than the amounts typically obtained from food or supplements(Abuabat et al., 2019 ; Bokhari et al., 2022).

***Magnesium and Migraine Management*:** Some migraine sufferers exhibit low magnesium levels, but whether magnesium supplements can effectively manage migraines remains uncertain. Existing studies have been small, and the benefits appear modest. It's advisable to consider supplementation only if your doctor suggests it, especially if standard treatments haven't provided relief (Dominguez, et al., 2025).

Selenium (Se) is an essential trace element critical for human health. It contributes significantly to the production of various selenoproteins and supports enzyme catalytic functions across the body(Shahidin, et al., 2025). The World Health Organization advises a daily selenium intake average of 55 µg for adults, though this recommendation can vary depending on factors such as age, gender, diet, and geographic location (Post et al., 2018). Meanwhile, the International Food and Nutrition Board suggests a daily intake range of 40–70 µg for men, 45–55 µg for women, and 25 µg for children. Regarding upper limits, the lowest observed adverse effect level (LOAEL) for selenium is roughly 4.3 µg per kilogram of body weight per day (equivalent to 300 µg/day over a period of five years), which has been linked to increased mortality(Pophaly et al., **2014**). The no observed adverse effect level (NOAEL) stands at 2.9 µg per kilogram of body weight per day (around 200 µg/day), a threshold below which no adverse effects, including increased mortality, have been documented(Hadrup et al., 2023).

Potassium serves as the primary intracellular cation, playing a key role in maintaining membrane potentil and enabling the electrical activation of nerve and muscle cells. Magnesium stands out as the most abundant intracellular divalent cation, functioning as a vital cofactor in numerous enzymatic reactions essential for energy production from ATP and supporting various physiological processes, such as neuromuscular activity and the regulation of cardiovascular tone (Saris et al., 2000). Calcium is predominantly found in bone tissue, contributing significantly to skeletal structure and aiding in the development of teeth(Pupilli et al., 2022).

One of the major concerns of environmental pollutants in developing countries like Iran is the heavy metal pollution and the pollution from the use of excessive pesticides, pesticides and fertilizers in the agricultural fields. By means of a comparison among suited international standards and the level of As, Co, Cd and Pb on investigated natural medication and medicinal flowers. Findings of current research in Table 3 , demonstrated that the mean contents of Arsenic, Cobalt, Cadmium and Lead in all studied samples is much lower than maximum levels set by national standard (ISIRI, 2010) and the maximum set by FAO/WHO, and mostly below the detection limit.

Table 3- Heavy metals in studied *P. peruviana* L. fruits from Urumieh Region of Iran

Heavy Metals	DW±SE(µg/g)
Co	0.101 ±0.001
Pb	0.002 ±0.000
Cd	ND
As	ND

DW=Dry Weight
SE=Standard Error

On the other hand, it is important to highlight the notably high levels of selenium, potassium, and magnesium in this plant compared to those grown in other locations and regions, as observed in other studies. The study by Mokhtar et al. in 2018 , reported the following nutritional composition for *Physalis peruviana* powder waste: moisture content at 5.87%, protein at 15.89%, fat at 13.72%, ash at 3.52%, dietary fiber at 74%, and carbohydrates totaling 61%. In terms of mineral content, potassium was notably high at 560 mg/100 g, followed by sodium at 170 mg/100 g and phosphorus at 130 mg/100 g (Mokhtar et al., 2018). Amino acid analysis revealed significant levels of cysteine/methionine, histidine, and tyrosine/phenylalanine. The fatty acid profile indicated linoleic acid as the predominant fatty acid, with oleic, palmitic, and stearic acids present in smaller amounts. The oil extracted from *P. peruviana* exhibited various indices comparable to those of soybean and sunflower oils, including an iodine index of 109.5 g/100 g, an acid index of 2.36 mg KOH/g, a saponification index of 183.8 mg KOH/g, a peroxide index of 8.2 µg/g , and a refractive index of 1.4735. Luz and Tenorio (Tenorio , 2017) highlighted that *P. peruviana* is a rich source of vitamin C, offering levels higher than mango (15–36 mg/100 g fresh weight) yet comparable to orange (50 mg/100 g FW), though less than guava (120–228 mg/100 g FW) or marula (120 mg/100 g FW). Vitamin B3 and B6 contents for the plant's pulp were reported at 26.6 ± 0.9 mg/100 g dry weight and 24.8 ± 0.2 mg/100 g DW, respectively. Additionally, *P. peruviana* had a notable vitamin E concentration, with γ- and α-tocopherols as the primary components. The juice of the Cape gooseberry displayed high levels of β-carotene, with trans-β-carotene accounting for 76.8% of its total carotenoid content, followed by smaller amounts of 9-cis-β-carotene and other all-trans carotenoids (Vega-Gálvez et al., 2016). Wahdan et al., reported the mineral composition analyzed in the methanol extract of calyxes showed calcium at a concentration of 7.50 mg and iron at 1.38 mg(Wahdan et al., 2019). The analysis of average fiber and ash contents indicated nutrient retention during the bleaching process. Similarly, micronutrient assessments revealed that β-carotene and vitamin E levels were preserved; however, a noticeable reduction in the average vitamin C content was observed post-bleaching (Joshi & Joshi , 2016).

The physicochemical properties of soil serve as crucial indicators for evaluating the functionality and structure of terrestrial ecosystems (Hochwimmer et al., 2020; Zhang, et al., 2025). These properties are strongly influenced by vegetation type, leading to noticeable differences in nutrient reserves, nutrient cycling, and energy flow within the soil. Climatic factors, including temperature, humidity, and sunlight exposure, also affect the biochemical pathways of the plant, leading to variability in its chemical profile (Sefidanzadeh, et al., 2015; Zhang, et al.,2025$_a$; Zhang, et al., 2025b). Understanding the relationship between soil properties and vegetation under different management regimes is important as a warming climate alters these systems. The recent studies indicated that in case the lake disappears, Jolfa, Maraghe, Tabriz, Shabestar, Azarsharh, and Marand counties will experience a decrease in the amount of downfall(Tavakoli-Hosseinabady et al., 2018; Moghim, 2018, Khazaei, et al., 2019).

This decrease will have dire consequences for the provinces of East and West Azerbaijan during the rainy season of spring. These consequences are much more salient for East Azerbaijan. The extent of the decrease in downfall around the lake, in case of its disappearance, will impact all the counties around it, and similar to the pattern of spring, will affect East Azerbaijan province more than before. With regards to the maps obtained through Grell parameterization, it can be said that this parameterization is capable of simulating the amount of downfall in the northwest of Iran. The results yielded by Grell parameterization were validated by the data gathered.

Future research should concentrate on long-term trends and the evolving ecological changes, particularly in source apportionment methodologies. Additionally, examining the health effects of heavy metal exposure will be essential for developing effective pollution management strategies. It will be vital to adopt collaborative, interdisciplinary approaches to better understand the physicochemical characteristics of crop products and the agricultural industry, as well as to enhance yields while also tackling heavy metal pollution. This will ultimately help in safeguarding both human and environmental health.

4. Conclusion

The investigation highlights the exceptional nutrient profile of native goldenberry (*Physalis peruviana* L.), showcasing its abundant levels of magnesium, potassium, and other trace minerals. This nutrient richness positions the fruit as a "superfruit," making it a highly valuable food product with strong market potential. The current findings emphasize the superior nutritional and bioactive properties of locally cultivated golden berries in comparison to those reported from other regions. Known for their notable medicinal characteristics, golden berries may hold promise in addressing numerous health conditions such as cancer, leukemia, diabetes, ulcers, malaria, asthma, hepatitis, dermatitis, and rheumatism. Their combination of nutritional benefits and therapeutic applications underscores their remarkable market value and profitability potential moving forward. The research also analyzes the adaptation of *P. peruviana* to the climatic conditions of northwestern Iran, potentially influenced by the drying up of Lake Urmia and its impact on rainfall patterns. With many of the world's terminal lakes nearing complete desiccation, Lake Urmia serves as a striking example of the interconnectedness of ecological and social systems. It highlights how climate change and human activities can significantly alter the hydrology and ecosystem of an entire region, leading to unpredictable outcomes for both the population and the chemical properties of its natural plants and crops. Consequently, it is strongly recommended that further research be conducted on this fruit and other regions of Iran, as they are likely to undergo substantial changes in the future.

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6. Conflict of interest

The authors declare that there is no conflict of interest.

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