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An extensive analysis of trace element content and antioxidant properties of nuts and dried fruits

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Abstract: This study examined the microelement composition and antioxidant activity of nuts and dried fruits that included soya raisin, golden raisin, malayar raisin, dried apricot, dried prune, walnut, peanut, almond, dried mango, dried melon, apricot with stone, cashew, dried kiwi, dried apple, pumpkin seed, pistachio, hazelnut, and rosehip. Ethanol infusions were assessed using the DPPH and ABTS methods to evaluate their ability to eliminate radicals and determine total phenolic content. Among the tested samples, hazelnuts displayed the lowest antioxidant content alongside high toxicity levels, while cashews exhibited the weakest reactivity. To ascertain the trace element content, the samples underwent processing in microwave ovens, and concentrations of various components were measured using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). The method's accuracy was further validated using a certified sample material (NIST SRM 1515, apple leaves). The concentrations observed in the samples varied as follows: Al: 4.7–172.1 mg/kg, B: 3.3–50 mg/kg, Cu: 5.6–52.6 mg/kg, Fe: 14.1–145.4 mg/kg, Mn: 0.3–51.3 mg/kg, Ni: 1.5–8.7 mg/kg, Sr: 1.75–78.5 mg/kg, and Zn: 5.8–63.9 mg/kg, and the findings were compared with existing literature on similar matrices. Overall, the results underscore the nutritional significance of hazelnuts and dried grapes as natural antioxidant sources, raise concerns about potential health risks associated with potentially toxic metal accumulation, and emphasize the necessity for ongoing analyses to ensure consumer safety. The novelty of this study lies in its analysis of both antioxidants and minerals found in nuts and dried fruits from Kazakhstan, which are significant in everyday diets, festive events, and traditional medicine.

Keywords: ICP-OES; nuts; dried fruits; antioxidant capacity; trace element.

1. Introduction

For centuries, nuts and dried fruits have been valued for their caloric density and health-promoting and preservative properties [1,2]. Recent scientific research validates that these products contain diverse biologically active compounds, particularly polyphenols, flavonoids, carotenoids, and essential fatty acids. These enhance their antioxidant capacity in combating reactive oxygen species (ROS) and free radicals [3]. Natural antioxidants such as ascorbic acid, tocopherols, phenolic acids, and vegetable oils are widely recognized for their potential to lower the risk of cardiovascular disease, diabetes, and certain types of cancer

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[4]. Unlike synthetic antioxidants like BHT and BHA, which are restricted in some countries due to health concerns and regulatory limitations, nuts and dried fruits present a safe and natural alternative [5]. Their high antioxidant activity often surpasses that of synthetic supplements, making them especially relevant in the realm of functional nutrition. Walnuts and hazelnuts are particularly valuable for their rich content of polyphenolic compounds and omega-3 fatty acids, which provide anti-inflammatory, antitumor, and cardiovascular protective benefits [6]. Almonds, in addition to their abundant phenolic composition, are a significant source of vitamin E, known for its capacity to prevent lipid peroxidation. Dried fruits such as apricots, raisins, and prunes are also rich in carotenoids and flavonoids, enhancing their antioxidant properties and supporting optimal metabolic processes [7].

Living organisms are continually subjected to molecular damage from free radicals, which arise from internal processes like cellular metabolism and external factors, such as infections, stress, and pollution. The primary reactive oxygen species (ROS) of concern for humans include the superoxide anion (O_2^-), hydrogen peroxide (H_2O_2), and hydroxyl radical (^-OH) [8]. An excess of these radicals can negatively impact cellular processes. In situations where antimicrobial protection is insufficient, these radicals can exacerbate oxidative stress, leading to complications such as bleeding and severe conditions like atherosclerosis, hypertension, vascular diseases, and cirrhosis [9]. Antioxidants are vital in neutralizing these radicals through various mechanisms involving oxidative systems, such as glutathione peroxidase, catalase, and superoxide dismutase, along with pharmacological compounds like calcium, vitamins C and E, selenium, carotenoids, and flavonoids [10].

Nuts and dried fruits are important sources of essential trace elements and contain various biologically significant compounds. Notable amounts of elements such as copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), and zinc (Zn) can be found in walnuts (Juglans regia), hazelnuts (Corylus avellana), pistachios (Pistacia vera), and dried apricots (Prunus armeniaca) [11]. These trace elements play vital roles in enzymatic functions, redox processes, and the overall maintenance of metabolic homeostasis [12]. On the other hand, there is evidence of elevated levels of toxic metals—such as lead (Pb), cadmium (Cd), and arsenic (As)—in dried fruits. These heightened levels may be linked to agricultural practices, soil quality, and environmental conditions. Analyses of nuts and dried fruits have revealed exceeding permissible limits for cadmium and lead. Moreover, studies suggest that raisins and dried apricots can accumulate significant concentrations of potentially toxic metals when cultivated in unfavorable conditions [13,14]. This dual nature—providing both nutritional benefits and potential risks associated with harmful substances—underscores the necessity for systematically monitoring the elemental composition in nuts and dried fruits.

Potentially toxic metals contribute to oxidative stress in biological systems by generating reactive oxygen species (ROS), which can result in cellular and molecular damage [15]. Similar to plants, which have evolved both enzymatic (such as superoxide dismutase, catalase, and peroxidases) and non-enzymatic (including phenolics, flavonoids, and vitamins) antioxidant defense mechanisms to address metal toxicity, nuts and dried fruits contain bioactive compounds that play a role in countering oxidative stress [16,17]. Studies have demonstrated that exposure to elevated levels of cadmium (Cd) and lead (Pb) in food products is linked to decreased antioxidant capacity and various adverse health effects in humans, including impaired cognitive function and metabolic imbalances [18]. Additionally, research highlights that natural antioxidants, such as polyphenols, flavonoids, and ascorbic acid—found in abundance in walnuts (Juglans regia), hazelnuts (Corylus avellana), and rosehip (Rosa canina)—may be essential in reducing oxidative damage by scavenging free radicals and binding to toxic metals.

This study explores a diverse range of nuts and dried fruits, including soya raisin, golden raisin, malayar raisin, dried apricot, dried prune, walnut, peanut, almond, dried mango, dried melon, apricot with stone, cashew, dried kiwi, dried apple, pumpkin seed, pistachio, hazelnut, and rosehip, which are bought in Kazakhstan. The antioxidant properties were evaluated using DPPH and ABTS assays, along with the measurement of total phenolic content. Furthermore, the levels of trace elements following microwave treatment were determined through ICP-OES analysis. By integrating assessments of antioxidant properties and trace element content, this study aims to enhance our understanding of nuts' and dried fruits' nutritional value and safety, underscoring their importance for nutritional health and food safety monitoring.

2. Experimental

2.1. Sample Collection

The eighteen samples of dried fruits and nuts examined in this study were collected from various local markets in Kazakhstan. Table 1 provides the common and Latin names of these samples, while their images are presented in Figure 1.

Table 1. Latin names of the properties in nuts and dried fruits

Common name	**Latin name**
Soya raisin	*Vitis vinifera L.*
Golden raisin	*Vitis vinifera aurea*
Malayar raisin	*Vitis vinifera var. sultania*
Dried apricot	*Prunus armeniaca*
Dried prune	*Prunus domestica*
Walnut	*Juglans regia*
Peanut	*Arachis hypogaea*
Almond	*Prunus amygdalus*
Dried mango	*Mangifera indica*
Dried melon	*Cucumis melo*
Apricot with stone	*Prunus armeniaca*
Cashew	*Anacardium occidentale*
Dried kiwi	*Actinidia deliciosa*
Dried apple	*Malus pumila*
Pumpkin seed	*Cucurbita pepo*
Pistachio	*Pistacia vera*
Hazelnut	*Corylus avellana*
Rosehip	*Rosa canina L.*

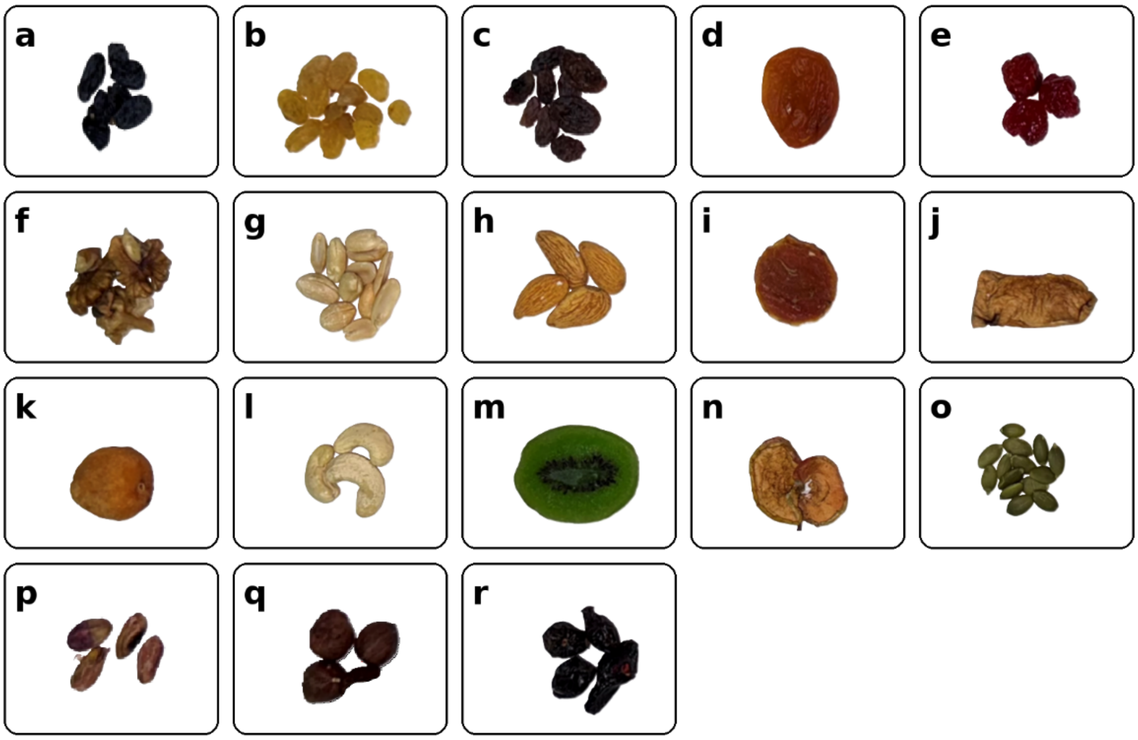

Figure 1. Images of the nuts and dried fruits; (a) Soya raisin, (b) Golden raisin, (c) Malayar raisin, (d) Dried apricot, (e) Dried prune, (f) Walnut, (g) Peanut, (h) Almond, (i) Dried mango, (j) Dried melon, (k) Apricot with stone, (l) Cashew, (m) Dried kiwi, (n) Dried apple, (o) Pumpkin seed, (p) Pistachio, (q) Hazelnut, (r) Rosehip.

2.2. Extraction of the Samples with Ethanol

Each nut and dried fruit sample was individually milled into a fine powder using a sterile, dry blender to prevent any risk of cross-contamination. The powders were then sieved to achieve a uniform particle size and subsequently stored in sealed containers at 4 °C for 72 hours, allowing stabilization of volatile constituents and minimizing enzymatic reactions. For extraction, approximately 5 g of each cooled powder was mixed with 50 mL of ethanol (99.9% v/v) in tightly closed flasks. Ethanol is chosen as an extraction solvent for its effectiveness in extracting both non-polar and moderately polar compounds. The mixtures were shaken at 200 rpm for 24 hours at ambient temperature. Following extraction, samples were filtered using Whatman No. 1 filter paper, and the filtrates were collected into amber vials and preserved at −20 °C until further analysis of their bioactive properties [A].

DPPH activity, ABTS activity, and total phenolic content determination calculations were performed according to the following formula, where A_{Blank} denotes the absorbance of the blank measured at either 15 or 30 minutes, and A_{Sample} corresponds to the absorbance of the sample at the same time intervals corresponds to the absorbance of the sample at the same time intervals. All antioxidant studies were performed in triplicate to ensure the accuracy and reliability of the results.

$$\%Radical\ Scavenging\ Activity = \frac{(A_{Blank} - A_{Sample})}{A_{Blank}} x100$$

2.3. DPPH Activity

The DPPH assay is an alcohol-based method commonly used to determine antioxidant activity [19]. Samples containing antioxidant compounds exert their effect by scavenging DPPH radicals. For the assay, extracts were prepared in various concentrations using alcohol/water mixtures. A DPPH solution was then prepared in methanol at a 0.025 mg/mL concentration and stored in the dark until use. The absorbance of the DPPH solution was adjusted to 0.700–0.900 at 517 nm using a spectrophotometer. In 1 mL spectrophotometer cuvettes, 900 µL of the DPPH solution was mixed with 100 µL of the ethanol extract. The absorbance values were recorded at 15 and 30 minutes (measured at 517 nm) (n=3). Methanol was used as a blank in place of the extract. Ascorbic acid served as the standard, and the antioxidant capacity of the samples was calculated as ascorbic acid equivalents using the calibration curve constructed with the standard.

2.4. ABTS Activity

The ABTS assay is an alcohol-based method for evaluating antioxidant capacity [20]. To prepare the ABTS solution, 0.0693 g of potassium persulfate ($K_2S_2O_8$) was dissolved in 100 mL of distilled water. Subsequently, 0.0388 g of ABTS was combined with 10 mL of the potassium persulfate solution, and the mixture was incubated overnight in the dark. The resulting solution was then diluted with ethanol to adjust its absorbance to 0.700–0.800 at 739 nm. For the measurement, 850 µL of the prepared solution was transferred into 1 mL disposable spectrophotometer cuvettes, followed by the addition of 150 µL of the ethanol extracts. After 6 minutes, absorbance was recorded at 739 nm to determine the radical scavenging activity (n=3). Trolox was used as the standard, and the radical scavenging capacity was calculated using the following formula:

2.5. Total Phenolic Content Determination

The total phenolic content of the samples was determined using the Folin–Ciocalteu method. For this analysis, a calibration curve was constructed using nine different concentrations of gallic acid standard solutions in the 0.01–1 mg/mL range. The results were calculated from the regression equation of the calibration curve and expressed as milligrams of gallic acid equivalents (mg GAE). In this method, 350 µL of the 20 mg/mL ethanol extract was mixed with 125 µL of deionized water, followed by 125 µL of Folin–Ciocalteu reagent. After 5 minutes, 1 mL of 2% sodium carbonate solution was added, and the mixture was thoroughly vortexed. The reaction mixture was then kept in the dark for 30 minutes, after which the absorbance was measured at 755 nm using a spectrophotometer (n=3).

2.6. Sample Preparation for Microwave Digestion

The eighteen nut and dried fruit samples utilized in this study were dried in an oven at 70 °C, then ground into a fine powder with a porcelain mortar and stored in polyethylene containers. All solvents employed for the sample dissolution studies—including HNO_3(65%) and H_2O_2 (30%) from E. Merck, Darmstadt, Germany—were of suprapure grade.

2.7. ICP-OES Measurement

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is a valuable technique for analyzing the elements found in aqueous solutions, enabling the detection of trace elements at low concentrations. For this study, the Arcos FHE-16 model from Spectro Analytical Instruments (Germany) was employed, and the operating conditions for the device are detailed in Table 2. Calibration solutions were systematically prepared at eight distinct concentrations, ranging from 0.1 to 6 mg/L, through the precise dilution of Merck Multi Element Standard Solution IV, which has a 1000 mg/L concentration. Table 3 also displays the wavelength for each element studied.

Table 2. ICP-OES Device Operating Parameters

Device	**Spectro Arcos FHE-16 ICP-OES**
Observation Height (mm)	12
Replication	3
RF Power (W)	1400
Spray Chamber	Cyclonic
Nebulizer	Modified Lichte model
Nebulizer Flow Rate (L/min)	0.9
Plasma Torch	Quartz, fixed 3.0 mm injector tube
Reading Time per Replication (s)	50
Plasma Gas Flow Rate (L/min)	12
Auxiliary Gas Flow Rate (L/min)	1
Sample Aspiration Rate (mL/min)	2.0
Sample Pump Speed (rpm)	30

Table 3. The wavelength of the measured elements

Element	**Wavelength (nm)**
Al	167.078
B	249.773
Cu	324.754
Fe	259.941
Mn	257.611
Ni	231.604
Sr	407.771
Zn	213.856

2.8 .Microwave Digestion Method

The digestion of nut and dried fruit samples was carried out using the Start D Microwave Digestion System (Milestone, Japan). The microwave dissolution method is quicker and requires less solvent than traditional dry and wet combustion methods, which is why it was utilized in the study. One gram of each powdered sample was weighed and placed into Teflon vessels. To each vessel, 8 mL of a 3:1 (v/v) mixture of HNO_3 and H_2O_2 was added, and the samples were allowed to stand for 10 minutes. The Teflon vessels were then positioned in the device, where the operating conditions specified in Table 4 were applied. Upon completion of the digestion process, the resulting solutions were brought to a final volume of 25 mL using ultrapure water and subsequently analyzed with the ICP-OES device [B].

Table 4. Microwave digestion method operation conditions (without heating)

Operation	Power (W)	Time (min)
1	250	2
2	0	2
3	250	6
4	400	5
5	550	8
6	0	8

3. Results and Discussion

Nuts and dried fruits are widely recognized as sources of energy-dense snacks and as functional foods that provide unique flavors, aromas, and bioactive compounds beneficial to human health. In many cultures, including Kazakhstan, nuts and dried fruits are special in daily diets, festive occasions, and even traditional medicine. Their regular consumption has been associated with reduced risks of chronic non-communicable diseases such as cardiovascular disorders, diabetes, and certain types of cancer. Beyond their nutritional value, nuts and dried fruits also carry significant socio-economic importance, being traded in local markets and exported globally. Therefore, understanding their chemical composition, particularly the balance between beneficial and potentially toxic elements, is of both scientific and public health interest.

3.1. Antioxidant Capacity Studies

The antioxidant capacities of the dried fruit and nut samples are depicted in Figure 2 as original and extended. The statistical analyses for these tests were performed using GraphPad Prism 8 with one-way ANOVA ($p < 0.05$). Among the tested samples, raisins, dried apples, and dried apricots exhibited the highest antioxidant activities, as measured by the DPPH and ABTS assays. In the total phenolic content (TPC) assay, dried apples were found to have the highest phenolic content compared to the other samples. For the DPPH assay, significant differences ($p < 0.05$) were found between walnut vs soy raisin, golden raisin, malayar raisin, dried apricot, dried prune, pistachio, almond, dried melon, apricot kernel, cashew nut, dried apple, pumpkin seed, Antep pistachio, hazelnut, and rosehip. For the ABTS assay, significant differences ($p < 0.05$) were observed among multiple pairs, including: soy raisin vs dried prune, walnut, dried melon, dried apple, pumpkin seed, Antep pistachio, rosehip; golden raisin vs dried prune, walnut, dried melon, dried apple, Antep pistachio, rosehip; malayar raisin vs dried prune, walnut, dried melon, dried apple, pumpkin seed, Antep pistachio, rosehip; dried apricot vs dried prune, walnut, dried melon, dried apple, pumpkin seed, Antep pistachio, rosehip; dried prune vs walnut, pistachio, almond, apricot kernel, cashew nut, dried apple, Antep pistachio, hazelnut, rosehip, dried kiwi; walnut vs pistachio, almond, dried melon, apricot kernel, cashew nut, dried apple, pumpkin seed, Antep pistachio, hazelnut, rosehip; pistachio vs dried melon, dried apple, pumpkin seed, Antep pistachio, rosehip; almond vs dried melon, dried apple, Antep pistachio, rosehip; dried melon vs apricot kernel, cashew nut, dried apple, Antep pistachio, hazelnut, rosehip, dried kiwi; apricot kernel vs dried apple, Antep pistachio, rosehip; cashew nut vs dried apple, Antep pistachio, rosehip; dried apple vs pumpkin seed, Antep pistachio, hazelnut, rosehip, dried kiwi; pumpkin seed vs Antep pistachio, hazelnut; Antep pistachio vs hazelnut, dried kiwi; hazelnut vs rosehip; and rosehip vs dried kiwi. For the TPC assay, significant differences ($p < 0.05$) were also found between walnut vs soy raisin, golden raisin, malayar raisin, dried apricot, dried prune, pistachio, almond, dried melon, apricot kernel, cashew nut, dried apple, pumpkin seed, Antep pistachio, hazelnut, and rosehip. Raisins (dried grapes) demonstrated strong antioxidant activity due to their rich flavonoid content, phenolic acids, and tannins, significantly enhancing their radical scavenging potential. Dried apples, known for their high chlorogenic acid, catechin, and quercetin levels, showcased the highest total phenolic content. These compounds are crucial in inhibiting lipid peroxidation and protecting DNA from oxidative stress, potentially reducing the risk of chronic diseases. Dried apricots also displayed considerable antioxidant capacity, performing notably better than dried melon, peanuts, hazelnuts, and dried kiwi. This antioxidant activity is likely linked to the presence of compounds such as rutin, caffeic acid, and carotenoids like β-carotene. Nut samples, including walnuts, almonds, and pistachios, exhibited moderate antioxidant activity due to their phenolic compounds and unsaturated fatty acids. Conversely, cashews and peanuts showed lower levels of antioxidant activity, consistent with their reduced polyphenol concentrations.

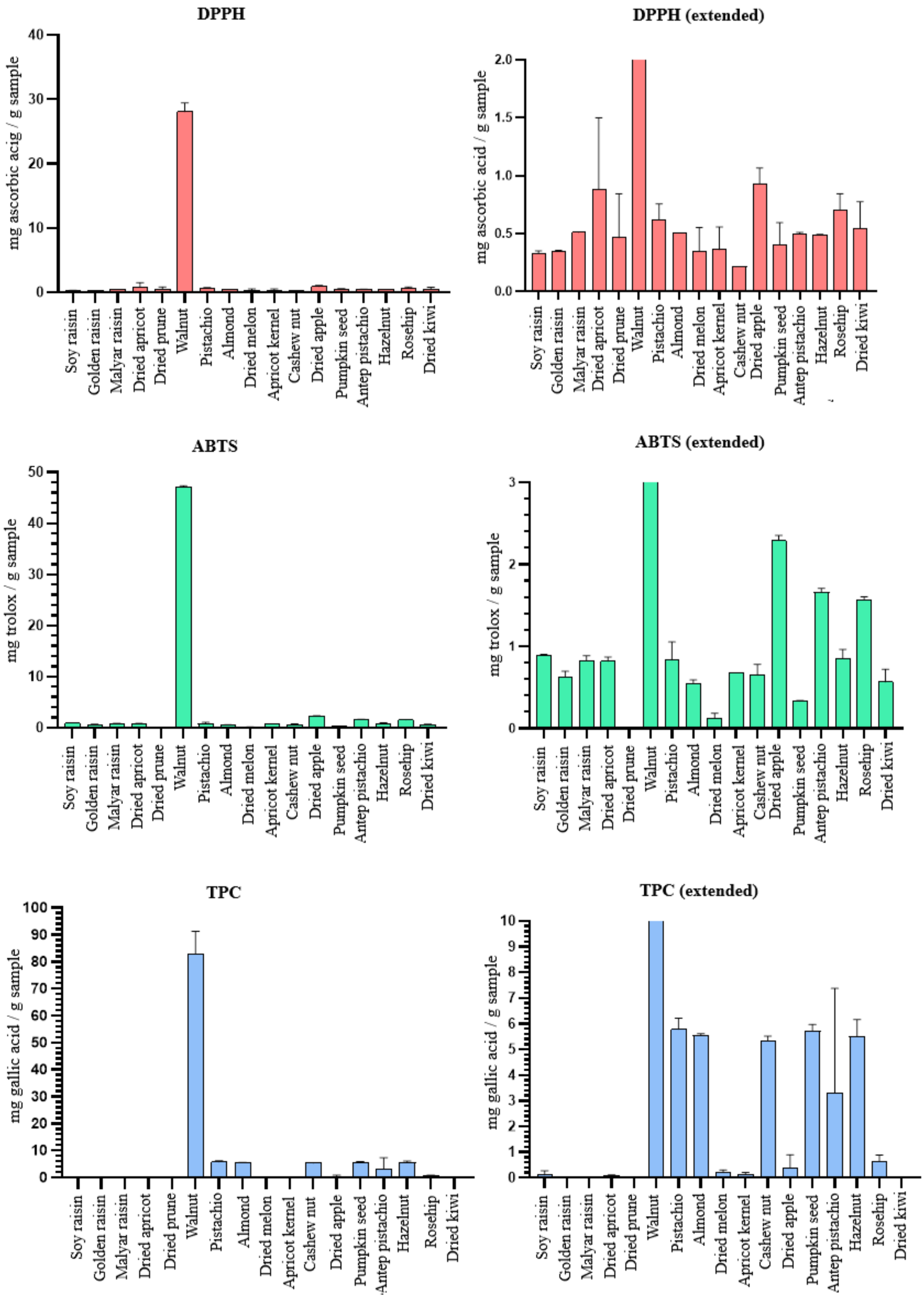

Figure 1. Antioxidant activity results of the analyzed properties in nuts and dried fruits, both original and extended forms.

In summary, the results from the DPPH, ABTS, and TPC assays were consistent, reinforcing the reliability of the findings. This study provides one of the first systematic comparisons of antioxidant activity across a diverse range of dried fruits and nuts within a single experimental framework. The robust antioxidant performance of raisins, dried apples, and dried apricots highlights their significance as valuable dietary sources of natural antioxidants.

The bioactive compounds present in the tested nuts and dried fruits enhance intracellular defense mechanisms and offer significant protection against chronic diseases. The consistently high levels of antioxidants in raisins and dried apples underscore their potential as effective natural antioxidants. Therefore, regularly incorporating these dried fruits into our diet is vital for maintaining health and preventing disorders associated with oxidative stress.

The results indicate that walnuts possess significantly higher antioxidant activity than other nut and dried fruit samples. In contrast, dried prunes demonstrated the lowest levels of antioxidant activity among the examined samples. In a prominent study, Kamiloğlu et al. examined the antioxidant properties of dried fruits—such as figs, apricots, and raisins—as well as various nut derivatives, including almonds, walnuts, and hazelnuts, at different stages of digestion. The findings indicated that walnuts exhibited the highest values for DPPH, ABTS, and total phenolic content (TPC), whereas almonds showed the lowest values. These results align with those of the current study [C].

3.2. Element Analysis

The microwave-assisted digestion technique was employed due to its superior speed and efficiency compared to conventional wet and dry digestion methods. The concentrations of trace elements identified in the dried fruit and nut samples are presented in Table 5.

The concentration ranges observed across all samples were as follows: Aluminum (Al): 4.7–172.1 mg/kg, boron (B): 3.3–50 mg/kg, copper (Cu): 5.6–52.6 mg/kg, iron (Fe): 14.1–145.4 mg/kg, manganese (Mn): 0.3–51.3 mg/kg, nickel (Ni): 1.5–6.8 mg/kg, strontium (Sr): 1.75–78.5 mg/kg and zinc (Zn): 5.8–63.9 mg/kg. Iron (Fe) was typically the most prevalent among the trace elements analyzed, with concentrations reaching 145.4 mg/kg. In contrast, nickel (Ni) consistently showed the lowest concentrations, not exceeding 6.8 mg/kg. This trend highlights the nutritional significance of iron-rich samples, such as pumpkin seeds and cashews, while confirming that nickel occurs only in trace amounts across all nuts and dried fruits examined.

The aluminum content in the analyzed samples varied from 4.7 to 172.1 mg/kg. The highest concentration was found in dried apples, measuring 172.1 mg/kg, which was considerably greater than that in all other samples. This elevated concentration may be connected to apples' capacity to accumulate aluminum through their interactions with pectin and organic acids. Similarly, higher levels were detected in Malayar raisins (59.4 mg/kg) and dried apricots (31.6 mg/kg). Conversely, the lowest aluminum concentrations were found in dried kiwis (4.7 mg/kg). These findings suggest that fruits such as apples and grapes tend to accumulate more aluminum, while nuts and tropical fruits show significantly lower levels [21].

Boron concentrations varied from 3.3 mg/kg to 50 mg/kg. The highest levels were observed in Malayar raisins, which contained 50 mg/kg, and soya raisins, with 44 mg/kg. Notably high boron levels were found in almonds at 48.4 mg/kg and dried apricots at 37.6 mg/kg. In contrast, the lowest concentrations were recorded in dried kiwis and dried prunes, with values of 3.3 mg/kg and 4.8 mg/kg, respectively. These findings suggest that boron tends to accumulate more in certain grape varieties and nuts, particularly almonds, making these foods significant dietary sources of this essential element [22].

Copper is an essential trace element vital for enzymatic activity, iron transport, and neurological functions; however, excessive intake can lead to adverse effects. In this study, the highest concentration of copper was found in rosehip (52.6 mg/kg), followed by malayar raisins and pumpkin seed, while dried mangos had the lowest concentration at 5.6 mg/kg. The elevated copper levels in rosehips and grapes indicate that these fruits could significantly enhance daily copper intake. Existing literature reports copper levels in dried fruits ranging from 2 to 20 mg/kg, which aligns with most of our findings, although rosehips exhibited particularly high values [23].

Table 5. Trace element contents (mg/kg) in dried fruit and nut samples after microwave-assisted digestion method (x ± s) n=3

Sample	Al (mg/kg)	B (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Sr (mg/kg)	Zn (mg/kg)
Soya raisin	26.3 ± 0.7	44 ± 0.5	18.5 ± 0.3	33.3 ± 0.5	8.2 ± 0.1	1.75 ± 0.05	1.75 ± 0.05	14.6 ± 0.2
Golden raisin	32.4 ± 1.9	28.7 ± 0.1	8.3 ± 0.1	45.4 ± 0.6	4.6 ± 0.1	1.9± 0	15.4 ± 0.1	8.1 ± 0.2
Malayar raisin	59.4 ± 6.7	50 ± 0.5	22.4 ± 0.4	57.6 ± 0.4	8.3 ± 0.1	1.8 ± 0.03	30.2 ± 1.2	16.9 ± 0.2
Dried apricot	31.6 ± 1.3	37.6 ± 0.5	5.7 ±0.1	36.8 ±1	5.3 ± 0.8	2.6 ± 0.08	33.6 ± 1.5	12.3 ± 0.7
Dried prune	8.9 ± 3.9	4.8 ± 0.2	9 ± 0.1	14.4 ± 0.1	0.3 ± 0	1.7 ± 0	4.2 ± 0.03	5.8 ± 0.03
Walnut	13.7 ± 0.3	13.7 ± 0.1	19.6 ± 0.4	47.5 ± 0.6	44 ± 0.2	4.95 ± 0.1	3.85 ± 0.1	36.8 ± 1.1
Peanut	12.8 ± 1.6	24 ± 0.3	9.1 ± 0.3	22.6 ± 0.2	13.3 ± 0.1	1.5 ± 0.05	4.7 ± 0.1	36 ± 1
Almond	11.1 ± 0.2	48.4 ± 0.4	16.5 ± 0.5	46.8 ± 1.3	38.8 ± 0.8	4.4 ± 0.1	38.6 ±0.8	43.5 ± 2.3
Dried mango	8.3 ± 0.7	15.4 ±0.08	5.6 ± 0.2	14.1 ± 0.4	16.9 ± 0.3	5.2 ± 0.2	3.2 ± 0.1	18.1 ± 1.4
Dried melon	19.8 ± 0.8	28.9 ± 0.1	27.3 ± 0.1	41.6 ± 0.1	4.7 ± 0	3.4 ± 0	36.7 ± 0.1	32 ± 0.1
Apricot with stone	24.3 ± 0.5	31.1 ± 0.3	6.4 ± 0.2	38.9 ± 0.9	3.6 ± 0.1	1.8 ± 0.03	8.3 ± 0.03	8.9 ± 0.5
Cashew	8.5 ± 0.3	10.1 ± 0.1	6.5 ± 0.1	74.8 ± 1.1	26.1 ± 0.4	6.8 ± 0.2	3.7 ± 0.03	24.1 ± 0.8
Dried kiwi	4.7 ± 0.3	3.3 ± 0.1	13.3 ± 0.3	17.3 ± 0.9	0.6 ± 0.03	2.4 ± 0.05	2.7 ± 0.1	7.8 ± 0.5
Dried apple	172.1 ± 4.2	28.6 ± 0.2	18.2 ± 0.6	111.2 ±2.7	4.3 ± 0.1	1.8 ± 0	7.2 ± 0.1	11.3 ± 0.8
Pumpkin seed	22.8 ± 0.8	13.5 ± 0.1	20.3 ± 0.1	145.4 ±1.4	45.8 ± 0.5	2.9 ± 0.05	2.8 ± 0.05	63.9± 0.3
Pistachio	14.5 ± 0.9	17.3 ± 0.3	14.2 ± 0.2	36.4 ± 0.6	7.3 ± 0.1	3.9 ± 0.1	37.1 ± 0.6	31 ± 0.9
Hazelnut	10.5 ± 0.3	15.9 ± 0.2	19.5 ± 0.3	67.9 ± 0.9	47.3 ± 0.5	4.6 ± 0.08	4.7 ± 0.1	20.5 ± 0.6
Rosehip	25.8 ± 2	16.7 ± 0.3	52.6 ± 1.3	34.9 ± 0.7	51.3 ± 0.9	2.1 ± 0.3	78.5 ± 3.8	30.3 ± 1.4

Iron is crucial for forming hemoglobin, cellular respiration, and energy metabolism. Among the samples analyzed, pumpkin seeds demonstrated the highest iron content at 145.4 mg/kg, followed closely by cashews. In contrast, dried mangos exhibited the lowest concentration at 14.1 mg/kg. The elevated iron content in pumpkin seeds underscores their potential role in addressing iron-deficiency anemia. Earlier studies have reported iron levels in dried fruits ranging from 48.8 to 231 mg/kg; our results align with this range, with pumpkin seeds and cashews displaying particularly high concentrations [24].

Manganese is essential in bone metabolism and enzyme function; however, excessive accumulation can lead to neurotoxicity. In this study, manganese concentrations varied from 0.3 mg/kg in dried prunes to 51.3 mg/kg in rosehips. Notably, hazelnuts and walnuts also demonstrated relatively high levels of manganese, reinforcing their reputation as manganese-rich foods. The differences in manganese content are likely attributable to both the plant species and the mineral composition of the soil in which they are cultivated [25].

Nickel was identified as the least abundant trace element in the samples, with concentrations varying from 1.5 mg/kg in peanuts to 6.8 mg/kg in cashews. Although nickel is not an essential nutrient, it is commonly found in trace amounts in plant-based foods. High levels of nickel exposure have been associated with allergic reactions and potential carcinogenic effects. Fortunately, the nickel levels detected in our samples fall within the safe dietary ranges established for nuts and dried fruits [26].

The strontium content across the studied samples varied from 1.75 to 78.5 mg/kg. The highest concentration, 78.5 mg/kg, was found in rosehips, confirming its recognized capacity to accumulate this element. Significant strontium levels were also identified in pistachios (37.1 mg/kg) and dried apricots (33.6 mg/kg). In contrast, white soya raisins (1.75 mg/kg) exhibited the lowest level. These findings suggest that rosehip and certain nuts serve as particularly rich sources of strontium, while grapes tend to contain very low amounts [27].

Zinc is essential for immune regulation, enzymatic processes, and growth. In our analysis, zinc concentrations ranged from 5.8 mg/kg in dried prunes to 63.9 mg/kg in pumpkin seeds. Nuts and seeds, including hazelnuts (20.5 mg/kg) and almonds (43.5 mg/kg), were identified as particularly rich sources of zinc, indicating that these foods can be significant contributors to zinc intake in the human diet [28].

The study results demonstrate that Kazakhstan dried fruits and nuts are significant sources of trace elements, though their concentrations vary by product type. For example, dried apples and various grape varieties are characterized by elevated levels of aluminum and boron. At the same time, rosehips are particularly noteworthy for their high concentrations of strontium, manganese, and copper. Pumpkin seeds and pistachios stand out for their richness in iron and zinc. In contrast, nuts such as almonds, hazelnuts, and walnuts provide a diverse array of essential elements, placing them in an intermediate position. Compared to findings from other regions, including Saudi Arabia, Pakistan, and the Balkans, Kazakh dried fruits and nuts frequently contain higher levels of trace elements. This discrepancy may be attributed to the geochemical properties of local soils, along with agronomic practices and post-harvest conditions. These findings underscore the importance of these products as functional components of the diet, capable of addressing deficiencies in crucial elements. However, moderation is key to preventing potential toxic effects.

3.3. Analysis of Certified Reference Material (CRM)

The method's accuracy was evaluated using the NIST-SRM 1515 - Apple Leaves CRM. A 0.25 g sample of the CRM was placed in a Teflon vessel and dissolved following the same procedure used for nut digestion. The solution was subsequently diluted to a final volume of 25 mL. The results revealed recoveries ranging from 95% to 105% for all elements assessed, confirming the method's accuracy. Measured values, reference values, standard deviations, and recovery percentages are summarized in Table 6.

Table 6. NIST-SRM 1515 - Apple Leaves ICP-OES results (mg/kg)

Element	Found value	Reference value	Recovery %
Al	296.7 ± 5.2	284.5 ± 5.8	104.29
B	27.1 ± 2.3	27.6 ± 2.8	98.19
Cu	5.52 ± 0.12	5.69 ± 0.13	97.01
Fe	83.8 ± 2.8	82.7 ± 2.6	101.33
Mn	52.9 ± 1.3	54.1 ± 1.1	97.78
Ni	0.918 ± 0.096	0.936 ± 0.094	98.07
Sr	24.1 ± 0.9	25.1 ± 1.1	96.01
Zn	12.37 ± 0.45	12.45 ± 0.43	99.36

3.4. Analytical Performance Parameters

This study presents the plotted calibration curves for the eight elements, ranging from 0.1 to 6 mg/L, analyzed using ICP-OES.

Table 7. Analytical performance parameters of measured elements

Element	Limit of detection (LOD) (mg/L)	Equation	R^2
Al	0.0118	$y = 5.2*10^5x + 52293$	0.9990
B	0.00449	$y = 1.1*10^5x + 8921$	0.9999
Cu	0.00266	$y = 3.4*10^5x + 20594$	0.9997
Fe	0.0168	$y = 1.3*10^5x + 12272$	0.9998
Mn	0.00293	$y = 5.3*10^5x + 20303$	0.9996
Ni	0.00259	$y = 0.4*10^5x + 6363$	0.9996
Sr	0.00751	$y = 2x10^7x + 565249$	0.9998
Zn	0.0021	$y = 2.1*10^5x + 22469$	0.9993

Table 7 provides information on the detection limits, equations of the curves, and the corresponding correlation coefficients for each element. The results reveal that the regression coefficients for all calibration curves are closely approaching 1, indicating a strong linear relationship. Also, all the element calibration equations have steeper slopes, which leads to increased sensitivity rather than calculation error. Furthermore, the low detection limits for each element facilitate precise measurement at low concentrations using the developed method.

4. Conclusions

This research thoroughly evaluates the antioxidant potential and essential trace element composition found in dried fruits and nuts. It employs both in vitro antioxidant assays (DPPH, ABTS, TPC) and ICP-OES elemental analysis following microwave digestion. The findings emphasize these foods' dual nutritional and toxicological aspects, highlighting their health benefits while stressing the importance of careful monitoring. Regarding antioxidant capacity, raisins, dried apples, and dried apricots showed the most significant radical-scavenging activities, primarily due to their elevated levels of phenolic and flavonoid compounds. These bioactive constituents are recognized for their ability to reduce oxidative stress, prevent DNA damage, and offer protective effects against cardiovascular disease, diabetes, obesity, and various forms of cancer. Thus, regular consumption of phenolic-rich dried fruits may decrease the risk of chronic diseases, among the leading causes of global morbidity and mortality. The elemental analysis revealed notable variability among the samples. Dried apples were particularly distinguished by their remarkably high aluminum content (172.1 mg/kg), while Malyar raisins and almonds displayed significant boron levels. Rosehip emerged as a key source of strontium, manganese, and copper, while pumpkin seeds and pistachios contained substantial iron and zinc concentrations. These micronutrients play vital roles in immune function, bone health, and enzymatic activity; however, their excessive accumulation may lead to long-term toxic effects.

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References

[1] J. L. Slavin and B. Lloyd (2012). Health benefits of fruits and vegetables, *Adv. Nutr.* **3**, 506–516.
[2] E. Ros (2010). Health benefits of nut consumption, *Nutrients* **2**, 652–682.
[3] J. A. Vinson, X. Su, L. Zubik and P. Bose (2001). Phenol antioxidant quantity and quality in foods: fruits, *J. Agric. Food Chem.* **49**, 5315–5321.
[4] P. M. Kris-Etherton, F. B. Hu, E. Ros and J. Sabaté (2008). The role of tree nuts and peanuts in the prevention of coronary heart disease: multiple potential mechanisms, *J. Nutr.* **138**, 1746S–1751S.
[5] F. Shahidi and P. Ambigaipalan (2015). Phenolics and polyphenolics in foods, beverages and properties in nuts and dried fruits: antioxidant activity and health effects – a review, *J. Funct. Foods* **18**, 820–897.
[6] C. Alasalvar, J. S. Salvadó and E. Ros (2020). Bioactives and health benefits of nuts and dried fruits, *Food Chem.* **314**, 126192.
[7] J. Sabaté and Y. Ang (2009). Nuts and health outcomes: new epidemiologic evidence, *Am. J. Clin. Nutr.* **89**, 1643S–1648S.
[8] B. Halliwell and J. M. C. Gutteridge (2015). Free Radicals in Biology and Medicine, 5th ed., Oxford University Press, Oxford.
[9] M. Valko, D. Leibfritz, J. Moncol, M. T. Cronin, M. Mazur and J. Telser (2007). Free radicals and antioxidants in normal physiological functions and human disease, *Int. J. Biochem. Cell Biol.* **39**, 44–84.
[10] L .A. Pham-Huy, H. He and C. Pham-Huy (2008). Free radicals, antioxidants in disease and health, *Int. J. Biomed. Sci.* **4**, 89–96.
[11] M. M. Özcan (2004). Mineral contents of some plants used as condiments in Turkey, *Food Chem.* **84**, 437–440.

[12] D. Kılıç and M. Yaman (2009). Determination of trace metals in nuts and dried fruits consumed in Turkey, *Food Addit. Contam. Part B* **2**, 52–56.
[13] M. Türkmen and M. Soylak (2007). Evaluation of trace metal levels in dried fruits from Turkey, *Food Chem. Toxicol.* **45**, 711–715.
[14] N. Khan, I. S. Jeong, I. M. Hwang, J. S. Kim, S. H. Choi and E. Y. Nho (2013). Analysis of toxic heavy metals in selected vegetables and fruits collected from markets in Korea, *Food Control* **30**, 485–491.
[15] L. Järup (2003). Hazards of heavy metal contamination, *Br. Med. Bull.* **68**, 167–182.
[16] P. Sharma and R.S. Dubey (2007). Involvement of oxidative stress and role of antioxidative defense system in growing rice seedlings exposed to toxic concentrations of aluminum, *Plant Cell Rep.* **26**, 2027–2038.
[17] S. S. Gill and N. Tuteja (2010). Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants, *Plant Physiol. Biochem.* **48**, 909–930.
[18] K. Jomova and M. Valko (2011). Advances in metal-induced oxidative stress and human disease, *Toxicology* **283**, 65–87. doi:10.1016/j.tox.2011.03.001.
[19] S. Gümrükçü, C. Caner, S. Balcioglu and H. Altundag (2024). Comprehensive analysis of heavy metals and antioxidant properties in various spices and propolis, *Int. J. Environ. Anal. Chem.* **7**(**10**),1-16. doi:10.1080/03067319.2024.2425993
[20] S. Keser, S. Celik and S. Turkoglu (2013). Total phenolic contents and free-radical scavenging activities of grape (Vitis vinifera L.) and grape products, *Int. J. Food Sci. Nutr.* **64**, 210–217.
[21] O. Yemis, E. Bakkalbasi and N. Artik (2008). Antioxidative activities of grape (*Vitis vinifera*) seed extracts obtained from different varieties grown in Turkey, *Int. J. Food Sci. Technol.* **43**, 154–159.
[22] M. S. Dundar, S. Arpaozu, C. Caner, H. Altundag, O. Gulec and M. Arslan (2024). Trace element analysis in corn by cloud point extraction, *J. Chem. Metrol.* **18**, 60-70.
[23] S. Kamiloglu, A. A. Pasli, B. Ozcelik and E. Capanoglu (2014). Evaluating the in vitro bioaccessibility of phenolics and antioxidant activity during consumption of dried fruits with nuts, *LWT -Food Sci. Technol.* **56**, 284-289.
[24] B. Peykarestan (2019). The concentration and non-carcinogenic risk assessment of aluminium in fruits, soil and water collected from Iran, *Int. J. Environ. Anal. Chem.* **99,** 1202–1213.
[25] L. Liv and N. Nakiboğlu (2019). Cost-effective voltammetric determination of boron in dried fruits and nuts using modified electrodes, *Food Chem.* **311**, 126013.
[26] M. Hydarian, A. Kazemi and Z. Ahmadi (2025). Applying Monte Carlo simulation to assess health risks of potentially toxic elements in fruits and nuts grown in the capital of Iran, *Food Chem. Toxicol.* **201**, 115431.
[27] D. A. Kulluk, M. M. Özcan, F. G. Yılmaz and N. Dursun (2021). Changes in mineral contents of processed nut, seed and fruits consumed as cookie, *J. Food Process. Preserv.* **45**, e16036.
[28] N. F. Curiel-Maciel, J. G. Arreola-Ávila, J. R. Esparza-Rivera, E. A. Luna-Zapién, J. R. Minjares-Fuentes, E. Sierra-Campos and J. A. Meza-Velázquez (2021). Nutritional quality, fatty acids content and antioxidant capacity of pecan nut fruits from Criolla and improved walnut varieties, *Not. Bot. Horti Agrobot. Cluj-Napoca* **49**, 12210.
[29] S. Köprü, M. Cadir and M. Soylak (2022). Investigation of trace elements in vegan foods by ICP-MS after microwave digestion, *Biol. Trace Elem. Res.* **200**, 5298–5306.
[30] N. Nasser, O. A. Fouad, M. M. S. Wahsh, M. S. Rizk, G. G. Mohamed and M. R. Mostafa (2024). Estimation of strontium ion in vegetarian foods using ion-selective electrode based on ceramic cordierite nanoparticles, *Microchem. J.* **199**, 109978.
[31] A. Jenkins, D. Murthy and A. Rangan (2024). Monitoring the mineral content of plant foods in food composition databases, *Dietetics* **3**, 235–248.