

Original Research

Chemical Composition, Antioxidant Properties, and Nutritional Value of *Diospyros kaki* L. as a Potential Functional FoodBojana Anđelković ¹, Biljana P. Dojčinović ², Ivona Mihajlović ¹, Jelena M. Živković ³, Nebojša Đ. Pantelić ^{1, *}

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2026, volume 11, issue 1
doi:10.21926/obm.icm.2601008**Received:** November 10, 2025**Accepted:** February 09, 2026**Published:** February 12, 2026**Abstract**

Persimmon (*Diospyros kaki* L.) is increasingly recognized as a nutrient-dense fruit rich in health-promoting compounds. This study aimed to comprehensively evaluate the nutritional composition, phenolic profile, antioxidant potential, and elemental content of *D. kaki* fruit and its contribution to dietary mineral intake. Proximate analysis revealed a high moisture content, low fat, and appreciable fiber and carbohydrate levels, supporting its classification as a low-calorie, fiber-rich food. Methanolic extracts exhibited superior yields of pigments, total polyphenols ($1236.20 \pm 19.24 \mu\text{g GAE/g}$), and flavonoids ($413.43 \pm 34.37 \mu\text{g QE/g}$) compared to ethanolic extracts. HPLC analysis identified gallic acid as the predominant phenolic compound, followed by ellagic and *p*-coumaric acids. Antioxidant evaluation demonstrated strong radical-scavenging and reducing capacities across the DPPH ($2310.38 \mu\text{g}$



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AAE/g), FRAP (2246.45 µg AAE/g), and CUPRAC (8274.36 µg AAE/g) assays, confirming a broad antioxidant spectrum. Mineral analysis indicated potassium (1652.84 mg/kg), phosphorus (1091.78 mg/kg), and magnesium (73.47 mg/kg) as dominant macroelements, while iron (4.94 mg/kg), manganese (0.66 mg/kg), zinc (0.26 mg/kg), and copper (0.11 mg/kg) were the primary microelements. Toxic metals (As, Cd, Pb) were below quantification limits, verifying the fruit's safety. Estimated dietary intakes suggested notable contributions to daily requirements, particularly for phosphorus (15.6%), potassium (6.4%), and selenium (60%). Overall, *D. kaki* demonstrates considerable nutritional and functional potential, providing essential nutrients, antioxidant phytochemicals, and dietary minerals beneficial for metabolic health. These findings suggest that persimmon may contribute to balanced diets and indicate its potential as a candidate ingredient for functional food formulations, warranting further investigation.

Keywords

Diospyros kaki L.; bioactive compounds; antioxidant activity; minerals; nutritional quality; functional food

1. Introduction

The persimmon (*Diospyros kaki* L.) is a deciduous fruit tree in the family Ebenaceae, widely cultivated in East Asia and increasingly introduced to other regions due to its high nutritional and commercial value [1, 2]. Native to China, where it has been cultivated for centuries, the persimmon is also considered the national fruit of Japan. It has gained global recognition as both a fresh and processed fruit [3, 4]. In traditional medicine, various parts of the persimmon tree, including the fruit, leaves, and calyx, have been used to treat hypertension, diarrhea, and hemorrhage, reflecting their bioactive potential [5, 6]. The fruit is not only appreciated for its unique sensory properties but also as a source of compounds with potential health-promoting effects [7].

Numerous studies have demonstrated that *D. kaki* fruit is a rich source of bioactive phytochemicals, including polyphenolic compounds such as flavonoids, tannins, and phenolic acids, which contribute to its antioxidant capacity [8, 9]. In addition, persimmon contains significant amounts of dietary fiber, carotenoids, and essential vitamins, including vitamin A, vitamin C, and vitamin E [10, 11]. The mineral composition is also notable, with macroelements like potassium, calcium, and magnesium, as well as trace elements including iron, zinc, and manganese, all of which play essential roles in maintaining physiological functions [12]. The unique combination of phytochemicals, vitamins, and minerals positions persimmon as a valuable dietary component with both nutritional and functional potential [13, 14].

The rich chemical composition of *D. kaki* is directly associated with a wide spectrum of biological activities [15-17]. Its consumption has been linked to antioxidative, anti-inflammatory, antidiabetic, and anticancer effects, as well as cardioprotective and neuroprotective benefits [18-20]. Polyphenolic compounds, in particular, contribute to the scavenging of free radicals and the reduction of oxidative stress, which is implicated in the pathogenesis of numerous chronic diseases

[21, 22]. Due to these properties, persimmon is increasingly regarded as a promising candidate for developing functional foods and nutraceuticals that support human health.

While numerous studies have addressed the phenolic composition, antioxidant activity, or mineral profile of persimmon fruit individually, integrated evaluations combining nutritional composition, detailed phenolic profiling, antioxidant capacity, and dietary mineral intake assessment remain scarce. To address this gap, the present study provides a comprehensive, multi-parameter evaluation of *Diospyros kaki* fruit from the Serbian market, combining proximate analysis, detailed phenolic profiling, antioxidant assessment, and mineral characterization within a single integrated framework. The aim of this study was therefore to assess the nutritional and chemical composition of *D. kaki* fruit and to discuss its potential as a functional food ingredient relevant for human health.

2. Materials and Methods

2.1 Samples

Fresh persimmon (*Diospyros kaki* L.) fruits were purchased from a local supermarket in Belgrade, Serbia. Fruits were obtained at commercial eating ripeness, characterized by typical orange coloration and a ready-to-eat stage. Three fruits were randomly selected, transported to the laboratory, and homogenized using a blender. The prepared homogenate was stored at 4°C until further analysis.

2.2 Proximate Analysis

The primary chemical constituents of the samples, including protein, fat, ash, moisture, and fiber, were quantified following the official AOAC analytical procedures [23]. Each measurement was carried out in triplicate ($n = 3$). Specifically, protein content was assessed using AOAC Method 920.87, fat by Method 922.06, ash by Method 923.03, moisture by Method 925.09, and fiber by Method 991.43, in accordance with the AOAC (2000) standardized protocols. The total carbohydrate content was calculated indirectly by deducting the combined amounts of moisture, protein, fat, and ash (g/100 g of sample) from the total sample mass.

2.3 Extract Preparation

For the determination of total pigments, phenolics, flavonoid content, and antioxidant capacity of *D. kaki* fruit, methanol and ethanol were used as extraction solvents. Ethanol was included as a food-grade solvent relevant to potential food and functional applications, while methanol was used as a reference solvent commonly employed for analytical-scale extraction of phenolics and pigments, thereby enabling comparison with the literature. Briefly, 0.5 g of the sample was extracted three times with 15 mL of the selected solvent for 45 min, followed by centrifugation for 10 min. The resulting supernatants were combined in a flask and brought to a final volume of 10 mL with methanol or ethanol.

2.4 Determination of Pigment Content

The pigment content of D. kaki fruit samples in methanol and ethanol was determined using a spectrophotometer (Du-8200 Single Beam UV/Vis spectrophotometer, Shanghai, China), and the results were expressed as micrograms per gram of sample. The absorbance of methanolic extracts was measured at 666 nm, 653 nm, and 470 nm, and the concentrations of pigments were calculated using the following equations:

$$\text{Chlorophyll } a = 12.21 \times A_{666} - 2.81 \times A_{653}$$

$$\text{Chlorophyll } b = 20.13 \times A_{653} - 5.03 \times A_{666}$$

$$\text{Carotenoids} = (1000 \times A_{470} - 3.27 \times \text{chlorophyll } a - 104.0 \times \text{chlorophyll } b)/227$$

On the other side, the absorbance of ethanolic extracts was measured at 664 nm, 649 nm, and 470 nm, and the concentrations of pigments were calculated using the following equations:

$$\text{Chlorophyll } a = 13.36 \times A_{664} - 5.19 \times A_{649}$$

$$\text{Chlorophyll } b = 27.43 \times A_{649} - 8.12 \times A_{664}$$

$$\text{Carotenoids} = (1000 \times A_{470} - 2.13 \times \text{chlorophyll } a - 97.63 \times \text{chlorophyll } b)/209$$

2.5 Determination of Total Phenolic Content

The total polyphenol content (TPC) in the samples was determined using the standard Folin-Ciocalteu method as described by Singleton and Rossi [24]. Briefly, 0.5 mL of the prepared extract was mixed with 30 mL of distilled water, followed by the addition of 2.5 mL of Folin-Ciocalteu reagent and 7.5 mL of 7.5% sodium carbonate solution. The mixture was left in the dark for 60 minutes, allowing the formation of a characteristic blue coloration. Afterwards, absorbance was measured at 725 nm on a spectrophotometer (Du-8200 Single Beam UV/Vis spectrophotometer, Shanghai, China). Results were expressed as micrograms of gallic acid equivalents (GAE) per gram of sample ($\mu\text{g GAE/g}$).

2.6 Determination of Total Flavonoid Content

The flavonoid content in the extracts was determined using the standard aluminum chloride colorimetric method as previously described [25]. Shortly, 0.5 mL of the prepared extract was mixed with 2 mL of distilled water, followed by the addition of 150 μL of 5% sodium nitrite and 150 μL of 10% aluminum chloride solution. The mixture was incubated in the dark for 30 minutes to allow the reaction to occur. Subsequently, the absorbance was measured at 510 nm using a spectrophotometer (DU-8200 Single Beam UV/spectrophotometer, Shanghai, China). The results were expressed as micrograms of quercetin equivalents per gram of sample ($\mu\text{g QE/g}$).

2.7 Polyphenolic Analysis

Phenolic compounds were separated and quantified using high-resolution liquid chromatography (HPLC) following a procedure similar to that described by Vinha et al. [26]. Analysis of polyphenolic compounds, both qualitative and quantitative, was carried out in triplicate ($n = 3$) on a Shimadzu Prominence system (Shimadzu, Kyoto, Japan). The system was equipped with an LC-20AT binary pump, CTO-20A column oven, SIL-20A autosampler, and SPD-M20A detector. Compound separation was achieved on a Luna C18 reversed-phase column (250 $\times$ 4.6 mm; 5 μm , Phenomenex, Torrance, CA, USA) fitted with a C18 guard cartridge (4 $\times$ 30 mm, Phenomenex). The

mobile phase consisted of solvent A (acetonitrile) and solvent B (1% formic acid), delivered at 1 mL min⁻¹ under the following linear gradient: 0-10 min, 10-25% A; 10-20 min, increase to 60% A; 20-30 min, increase to 70% A. The column was re-equilibrated to the initial 10% A for 10 min, followed by a 5 min stabilization period. Chromatograms were acquired over the wavelength range 190-800 nm, with identification and quantification of each polyphenolic compound performed at its specific absorption maximum. Concentrations were calculated from calibration curves prepared with polyphenolic standards and expressed as mg per 100 g of sample.

2.8 Determination of Antioxidant Activity

2.8.1 DPPH Radical Scavenging Assay

The antioxidant potential of the samples was determined using the DPPH radical scavenging assay, following the procedure outlined by Jaćimović et al. [27]. In brief, 100 µL of each extract was mixed with 4 mL of a DPPH solution at 150 µM. The reaction mixtures were kept in the dark at ambient temperature for about 30 minutes. After incubation, absorbance was recorded at 515 nm using a spectrophotometer (DU-8200 Single Beam UV/VIS Spectrophotometer, Shanghai, China). DPPH radical scavenging activity was expressed as µg of ascorbic acid (AA) equivalent antioxidant capacity per gram of the sample (µg AAE/g).

2.8.2 FRAP Assay

The ferric reducing antioxidant power (FRAP) assay was carried out according to the procedure reported by Mitrevski et al. [28]. In brief, 100 µL of the extract solution (0.05 g/mL) was combined with 300 µL of distilled water and 3 mL of FRAP reagent. The FRAP reagent was freshly prepared by mixing 2.5 mL of 10 mM 2,4,6-tripyridyl-s-triazine (TPTZ) solution, 2.5 mL of 20 mM FeCl₃·6H₂O, and 25 mL of 300 mM acetate buffer at pH 3.6. After a reaction time of 40 minutes, absorbance was read at 593 nm on a spectrophotometer (Du-8200 Single Beam UV/Vis spectrophotometer, Shanghai, China). Antioxidant capacity was expressed as µg of ascorbic acid (AA) equivalents per gram of sample (µg AAE/g).

2.8.3 CUPRAC Assay

To evaluate the cupric ion-reducing capacity (CUPRAC), a modified version of the method reported by Apak et al. [29] was employed. In brief, 1 mL of a 1×10^{-2} mol/L CuCl₂ solution was mixed with 1 mL of an alcoholic neocuproine solution (7.5×10^{-3} mol/L) and 1 mL of acetate-ammonium buffer (1 mol/L, pH = 7). Subsequently, 0.5 mL of the tested extract and 0.5 mL of distilled water were added. The mixture was then kept in the dark at room temperature for 30 minutes. Finally, absorbance was recorded at 450 nm using a spectrophotometer (DU-8200 Single Beam UV/VIS Spectrophotometer, Shanghai, China). Antioxidant capacity was expressed as µg of ascorbic acid (AA) equivalents per gram of sample (µg AAE/g).

2.9 Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) Analysis

Elemental composition was determined using inductively coupled plasma optical emission spectrometry (ICP-OES), with a Thermo Scientific iCAP 6500 Duo ICP system (Thermo Fisher

Scientific, Cambridge, UK) [30]. Sample preparation was carried out using a microwave digestion system (*Advanced Microwave Digestion System*, ETHOS 1, Milestone, Italy), equipped with a high-pressure segmented rotor (HPR-1000/10S). The samples were placed directly into quartz inserts before processing. Following initial handling, oxidizing agents were added: 4.5 mL of nitric acid (65%, Suprapur®, Merck KGaA, Darmstadt, Germany) and 0.5 mL of hydrogen peroxide (30%, Suprapur®, Merck KGaA). The digestion vessels were sealed according to the manufacturer's instructions and inserted into the rotor assembly. The digestion process was conducted over 20 minutes at 180°C and 100 bar. Once digestion was complete, the solutions were allowed to cool to room temperature and then diluted to a final volume of 25 mL with ultrapure water (conductivity 0.05 µS/cm).

Samples were introduced into the plasma by direct aspiration. Calibration was performed using certified standard solutions: SS-Low Level Elements ICV Stock and ILM 05.2 ICS Stock 1 (both from VHG Labs, Inc., part of LGC Standards, Manchester, NH, USA). The calibration standards covered a concentration range of 1-50,000 µg/L, and all elements exhibited correlation coefficients greater than 0.99. For quantification, the emission wavelength that best matches between the standard and the sample, based on all spectrometric criteria, was selected. Each sample was analyzed in triplicate ($n = 3$), with a relative standard deviation (RSD) of less than 1%. Limits of detection (LOD) ranged from 0.05 to 1.5 µg/L, while limits of quantification (LOQ) were between 0.1 and 5 µg/L. Final elemental concentrations in the samples were calculated in mg/kg (ppm), accounting for sample mass, dilution factors, and measured concentrations. Analytical quality assurance was ensured by using certified reference materials (CRMs): fish protein for trace metals (DORM-4, NRCC – National Research Council Canada, Ottawa, Ontario) and EPA Method 200.7 LPC Solution (ULTRA Scientific, USA). Recovery values for all certified elements ranged between 98% and 103%, confirming the method's accuracy.

2.10 Statistical Analysis

Statistical analysis of the mean values for the examined parameters was performed using XLSTAT (version 2023.3.1, Addinsoft, New York, NY, USA). Differences between sample means were evaluated by analysis of variance (ANOVA), followed by Tukey's honest significant difference test, with statistical significance set at $p < 0.05$.

3. Results and Discussion

3.1 Proximate Composition

The proximate composition analysis of persimmon fruit (Table 1) revealed a high moisture content ($80.15 \pm 3.41\%$), which is characteristic of fresh fruits and consistent with values reported for *Diospyros kaki* in previous studies [3, 11]. Such high water content contributes to the fruit's juiciness and sensory appeal but also reduces its post-harvest shelf life, thereby increasing its perishability.

Table 1 Proximate composition of analyzed sample [%].

	Moisture	Ash	Fat	Protein	Fiber	Carbohydrate
Sample	80.15 ± 3.41	0.35 ± 0.03	0.25 ± 0.02	0.61 ± 0.02	2.91 ± 0.65	15.73 ± 1.95

The ash content was relatively low ($0.35 \pm 0.03\%$), reflecting the mineral fraction of the fruit, and was comparable to literature values for persimmon. Fat content was minimal ($0.25 \pm 0.02\%$), typical for fresh fruits and indicative of a naturally low lipid content in persimmon. Protein levels were also low ($0.61 \pm 0.02\%$), as expected for fruit matrices where protein is not a major macronutrient. The crude fiber content ($2.91 \pm 0.65\%$) is consistent with previous reports and supports the role of persimmon as a source of dietary fiber, which is important for digestive health. Carbohydrates constituted $15.73 \pm 1.95\%$ of the fruit, representing the primary macronutrient and contributing to the characteristic sweetness of the persimmon due to its natural sugars.

3.2 Total Pigment Content

In this study, the methanolic extract of persimmon fruit exhibited significantly higher concentrations of chlorophyll *a*, chlorophyll *b*, and carotenoids compared to the ethanolic extract (Table 2). While this observation highlights the greater extraction efficiency of methanol for pigment compounds, the primary aim of the present work was to evaluate the bioactive composition of the fruit rather than to optimize extraction solvents.

Table 2 Total pigment content in analyzed samples [$\mu\text{g/g}$]. Statistically significant differences ($p < 0.05$) are shown with different superscript letters (a, b).

Sample*	Chlorophyll <i>a</i>	Chlorophyll <i>b</i>	Carotenoids
SM	5.97 ± 0.02^a	9.45 ± 0.03^a	74.06 ± 1.05^a
SE	2.53 ± 0.01^b	3.91 ± 0.01^b	54.74 ± 0.95^b

* SM – methanolic extract; SE – ethanolic extract.

The present results are consistent with reports highlighting *D. kaki* as a rich source of carotenoids, including β -carotene, β -cryptoxanthin, lutein, and zeaxanthin, which are largely responsible for the characteristic orange-red coloration of the fruit and contribute to its antioxidant properties [6, 31]. Similar pigment levels have been linked to strong radical-scavenging activity and potential health benefits, such as protection against oxidative stress and support for immune function [9]. Chlorophyll, though primarily recognized for its role in photosynthesis, has also been associated with antioxidant and potential antimutagenic activities.

Taken together, the pigment profile observed in this study reinforces the nutritional value of persimmon fruit. Its richness in carotenoids and chlorophylls positions it as a promising dietary source of bioactive compounds, supporting its potential inclusion in functional food formulations aimed at promoting human health.

3.3 Total Polyphenols and Flavonoids Content

The results of this study revealed that the methanolic extract of persimmon fruit contained significantly higher amounts of total polyphenols and flavonoids compared to the ethanolic extract (Table 3). Nevertheless, the main implication of these results is the confirmation that *Diospyros kaki* fruit is a rich natural source of these bioactive constituents.

Table 3 Content of total polyphenols [$\mu\text{g GAE/g}$] and flavonoids [$\mu\text{g QE/g}$] in analyzed samples. Statistically significant differences ($p < 0.05$) are shown with different superscript letters (a, b).

Sample	Polyphenols	Flavonoids
SM	1236.20 ± 19.24^a	413.43 ± 34.37^a
SE	949.57 ± 57.15^b	362.38 ± 18.85^b

* SM – methanolic extract; SE – ethanolic extract.

Polyphenols are a diverse class of plant secondary metabolites that play important roles in plant defense and contribute to the organoleptic properties of fruits, including bitterness, astringency, and color stability. The high polyphenolic content observed in this study is consistent with previous reports describing persimmon as a phenolic-rich fruit, with compounds such as gallic acid, catechins, chlorogenic acid, and various tannins among the most abundant constituents [6, 7]. Flavonoids, a major subclass of polyphenols, were also present in substantial amounts, further confirming the biochemical richness of the fruit. These compounds are known to participate in various biological activities, including modulation of enzyme function, metal ion chelation, and free radical scavenging [21].

Overall, the polyphenolic and flavonoid profiles reported in this work underscore the nutritional and functional potential of persimmon fruit. The presence of these compounds, in quantities comparable to or exceeding those reported in the literature, suggests that *D. kaki* could be considered a valuable dietary source of bioactive phytochemicals, with potential applications in developing functional foods to support human health.

3.4 Phenolic Profile

The HPLC analysis of the methanolic extract of persimmon fruit provided detailed quantitative data on individual phenolic compounds (Table 4). Among the identified compounds, gallic acid was the most abundant (0.86 ± 0.04 mg/100 g), followed by ellagic acid (0.18 ± 0.03 mg/100 g), *p*-coumaric acid (0.16 ± 0.02 mg/100 g), and *p*-hydroxybenzoic acid (0.11 ± 0.01 mg/100 g). Other phenolic acids, such as chlorogenic acid and caffeic acid (both 0.05 ± 0.01 mg/100 g), vanillic acid (0.03 ± 0.00 mg/100 g), ferulic acid (0.03 ± 0.00 mg/100 g), and protocatechuic acid (0.01 ± 0.00 mg/100 g), were present in smaller amounts, while sinapic acid was not detected.

Table 4 Phenolic profile of analyzed sample [mg/100 g].

Compounds	SM*
Gallic acid	0.86 ± 0.04
<i>p</i> -Hydroxybenzoic acid	0.11 ± 0.01
Vanillic acid	0.03 ± 0.00
Ellagic acid	0.18 ± 0.03
Ferulic acid	0.03 ± 0.00
<i>p</i> -Coumaric acid	0.16 ± 0.02
Sinapic acid	n.d.**
Protocatechuic acid	0.01 ± 0.00
Chlorogenic acid	0.05 ± 0.01
Caffeic acid	0.05 ± 0.01

* SM – methanolic extract; ** n.d. – not detected.

The sum of individually quantified phenolic compounds appears lower than the total polyphenol content determined by the Folin-Ciocalteu method. This discrepancy is expected, as the Folin assay measures overall reducing capacity and responds not only to low-molecular-weight phenolics but also to polymeric tannins, proanthocyanidins, and other unidentified phenolic structures that were not specifically quantified by HPLC. Therefore, the total polyphenol value likely reflects a broader spectrum of phenolic constituents beyond the targeted compounds.

The predominance of gallic acid in our samples is in agreement with several previous studies. Esteban-Muñoz et al. [32] reported gallic acid as the dominant phenolic in the ‘Rojo Brillante’ variety, with concentrations around 0.95 mg/100 g, which is very close to the value obtained in this work. Similarly, Direito et al. [10] and Butt et al. [6] identified gallic acid as a key phenolic compound in persimmon, often linked to its astringency and strong radical-scavenging capacity.

Ellagic acid, the second most abundant compound in our analysis, has also been highlighted in the literature as a relevant bioactive component of certain persimmon varieties. Renai et al. [33] observed particularly high ellagic acid levels in the ‘Farmacista Honorati’ variety after deastringency treatment, noting its contribution to the fruit’s antioxidant and anti-inflammatory potential. Although our value is lower than that reported in that study, it still confirms the presence of this important phenolic in *D. kaki*.

p-Coumaric acid and *p*-hydroxybenzoic acid, present in moderate amounts, have been frequently detected in persimmon fruit, with concentrations generally within the same range as our findings [32, 34]. These compounds are known for their antimicrobial and antioxidant activities, and their presence in persimmon further enhances the fruit’s functional potential. The detection of chlorogenic and caffeic acids, even at relatively low concentrations, is noteworthy as these compounds contribute to both sensory properties and bioactivity. Similar low-level presence of these acids has been reported in several persimmon cultivars [10].

The phenolic profile obtained in this study complements the spectrophotometric data for total polyphenols and flavonoids, confirming that *D. kaki* is a rich source of structurally diverse phenolic acids. The predominance of gallic acid, together with ellagic acid, hydroxybenzoic acids, and hydroxycinnamic acids, underscores the nutritional and functional value of persimmon fruit. These findings support its potential role as a functional food ingredient with relevance to human health.

3.5 Antioxidant Capacity Evaluation

The antioxidant capacity of *Diospyros kaki* extracts was evaluated using three complementary assays, DPPH, FRAP, and CUPRAC (Table 5). In all three assays, the methanolic extract (SM) significantly outperformed the ethanolic extract (SE), consistent with its higher total phenolic and flavonoid contents, which are known to contribute prominently to antioxidant activity [35, 36]. These findings highlight the direct relationship between phenolic composition and antioxidant potential, as previously emphasized in similar studies on persimmon and other fruit species [37, 38].

Table 5 Antioxidant capacity of analyzed samples using DPPH, FRAP, and CUPRAC assays [$\mu\text{g AAE/g}$]. Statistically significant differences ($p < 0.05$) are shown with different superscript letters (a, b).

Sample*	DPPH	FRAP	CUPRAC
SM	2310.38 $\pm$ 20.48 ^a	2246.45 $\pm$ 46.56 ^a	8274.36 $\pm$ 34.58 ^a
SE	1878.78 $\pm$ 41.62 ^b	1452.22 $\pm$ 34.41 ^b	2444.95 $\pm$ 113.72 ^b

* SM – methanolic extract; SE – ethanolic extract.

While the DPPH and FRAP assays yielded comparable antioxidant values for the methanolic extract (2310.38 and 2246.45 $\mu\text{g AAE/g}$, respectively), the CUPRAC assay produced markedly higher values (8274.36 $\mu\text{g AAE/g}$). A similar, though less pronounced, pattern was observed for the ethanolic extract. This difference reflects the distinct reaction mechanisms of the assays: DPPH mainly measures hydrogen-donating capacity, whereas FRAP assesses reducing power under acidic conditions. In contrast, CUPRAC operates at near-physiological pH and is responsive to a broader range of phenolic structures, including flavonoids, catechins, and polymeric tannins that exhibit strong electron-transfer and complex-forming properties [29]. Consequently, the higher CUPRAC values likely indicate the presence of phenolic constituents that are particularly reactive under these conditions, revealing a broader antioxidant spectrum than would be evident from a single assay.

These observations underscore the importance of applying multiple methods to assess antioxidant potential, as each assay captures different aspects of antioxidant behavior. Collectively, the results confirm that persimmon is a fruit rich in bioactive compounds, with substantial radical-scavenging and reducing capacities, supporting its potential role as a functional food.

Although methanolic extracts exhibited higher measured values of phenolics, flavonoids, and antioxidant activity than ethanolic extracts, methanol is not suitable for food or nutraceutical applications. Therefore, the methanolic data should be interpreted primarily as an analytical reference for maximum extractable bioactive content, whereas the ethanolic extract is more relevant for practical functional food development. The lower, yet still considerable, bioactive levels obtained with ethanol indicate that *D. kaki* fruit can serve as a viable source of health-promoting compounds using food-grade extraction systems.

3.6 Content of Macro- and Microelements

The mineral composition of food plays a crucial role in evaluating its nutritional and functional properties, as these elements are essential for numerous physiological processes. The analyzed *Diospyros kaki* L. fruit showed a well-balanced mineral profile, with potassium, phosphorus, and magnesium being the predominant macroelements, followed by calcium and sulfur (Table 6). Among these, K was the most abundant, confirming the general trend observed in most fruits, in which it is the major mineral component contributing to osmotic regulation, enzyme activation, and acid-base balance. A similar dominance of K in persimmon fruit was reported by Gorinstein et al. [37] and Veberic et al. [38], highlighting its importance in maintaining cellular homeostasis and cardiovascular health.

Table 6 The content of macroelements [mg/kg].

Element	Sample
Na	<0.005
K	1652.84 ± 12.54
Mg	73.47 ± 8.27
Ca	93.46 ± 5.06
P	1091.78 ± 10.02
S	145.54 ± 4.67

Phosphorus was the second most abundant macroelement, consistent with previous findings for persimmon and other fruit matrices. Magnesium levels were also substantial, reflecting the fruit's contribution to overall mineral balance. The presence of Ca, although lower compared to K and P, further enhances the nutritional profile of the fruit.

Sodium concentration was below the limit of detection, aligning with the low-Na pattern typical for fruits, which is nutritionally favorable for consumers adhering to low-sodium diets. Sulfur content, primarily associated with sulfur-containing amino acids and antioxidants, also supports the potential of *D. kaki* as a health-promoting food. Overall, the obtained macroelement profile confirms that *D. kaki* can contribute significantly to dietary mineral intake, particularly for K, P, and Mg. These nutrients are generally recognized as important for maintaining normal physiological functions.

Regarding microelements (Table 7), the analyzed sample contained appreciable amounts of Fe, Zn, Mn, and Cu, while trace levels of Se and Co were also detected. Iron content was comparable to levels reported for other fruits, suggesting that persimmon could serve as a supplementary dietary source of bioavailable Fe [39, 40]. Zinc, an element essential for immune function and enzymatic activity, was also present in moderate amounts. Manganese, found at levels consistent with literature data for similar fruit species [41], contributes to the overall micronutrient value. Copper was detected at low, non-toxic levels, whereas selenium, although present in trace amounts, confers functional value due to its role in antioxidant defense.

Table 7 The content of microelements [mg/kg].

Element	Sample
Al	3.93 ± 0.95
As	<0.005
B	0.98 ± 0.24
Cd	<0.005
Co	0.01 ± 0.00
Cr	0.01 ± 0.00
Cu	0.11 ± 0.01
Fe	4.94 ± 0.34
Li	0.09 ± 0.01
Mn	0.66 ± 0.09
Ni	0.34 ± 0.08
Pb	<0.005
Se	0.28 ± 0.01
Zn	0.26 ± 0.04

It should be emphasized that the concentrations of potentially toxic elements, such as As, Cd, and Pb, were below the limits of quantification, confirming the safety of the analyzed sample for human consumption. The balanced content of both macro- and microelements in *Diospyros kaki* L. indicates its potential as a functional food with promising nutritional benefits.

3.7 Nutritional Assessment

The estimated daily intakes of macro- and microelements from the consumption of 100 g of *Diospyros kaki* L. were calculated and compared with the Recommended Daily Allowance (RDA) or Adequate Intake (AI) values established by the National Institutes of Health and the Institute of Medicine for adult females and males aged 31-50 years (Table 8). These estimations provide insight into the nutritional relevance of persimmon consumption.

Table 8 Estimated daily intake of selected macro- and microelements from 100 g of analyzed persimmon fruit.

Element	Daily Intake (mg/100 g)	RDA/AI* (F) (mg/day)	RDA/AI* (M) (mg/day)	% Intake (F)	% Intake (M)
Mg	7.35	320	420	2.3	1.7
P	109.18	700	700	15.6	15.6
K	165.28	2600	3400	6.4	4.9
Ca	9.35	1000	1000	0.9	0.9
Mn	0.07	1.80*	2.30*	3.9	3.0
Fe	0.50	18.00	8.00	2.8	6.3
Cu	0.01	0.90	0.90	1.1	1.1
Zn	0.03	8.00	11.00	0.4	0.3
Se	0.03	0.055	0.055	60.0	60.0

* AI: Adequate Intake; RDA: Recommended Daily Allowance; M: male 31-50 years old; F: female 31-50 years old.

Among the analyzed elements, phosphorus (15.6%) and potassium (6.4% for females, 4.9% for males) showed the highest contribution to daily mineral requirements, suggesting that *D. kaki* can meaningfully support dietary intake of these essential nutrients. Magnesium (2.3-1.7%) and manganese (3.9-3.0%) also contributed modestly but notably, underscoring the fruit's role in complementing other dietary sources. Calcium, though present at lower levels (<1%), adds to the overall mineral diversity of the fruit.

Regarding trace elements, iron (2.8-6.3%), copper (1.1%), and zinc (0.4-0.3%) made measurable contributions to daily requirements. Although fruits are generally limited sources of these micronutrients, persimmon may still offer a supplementary intake, especially when consumed regularly. The theoretical selenium intake (60%) is particularly noteworthy, as Se is an important cofactor for antioxidant enzymes and immune defense. Although the estimated selenium contribution is relatively high for a fruit, this value should be interpreted with caution. Selenium content in plants is highly dependent on soil composition, geographic location, and agricultural practices, and may vary considerably across different growing regions. In addition, analytical variability and sample heterogeneity may influence the measured concentration. Therefore, further studies including fruits from multiple origins are needed to confirm the general dietary significance of persimmon as a selenium source.

Collectively, these results indicate that *Diospyros kaki* can make a meaningful contribution to dietary mineral intake, particularly for P, K, Mg, Mn, and Se. Although persimmons cannot serve as a sole source of these nutrients, regular consumption may complement a balanced diet by providing additional micronutrients alongside other foods.

A limitation of this study is that the analysis was based on three fruits purchased from a single local supermarket, which may not fully represent the variability of persimmon fruit available on the market. Consequently, the study includes limited biological replication, and the findings should be interpreted as indicative rather than fully generalizable. Factors such as cultivar, geographical origin, soil composition, harvest season, and maturity stage can influence phenolic composition, antioxidant activity, and mineral content. Therefore, future studies that include multiple cultivars,

harvest seasons, and broader sampling across regions would be valuable to strengthen the generalizability of these findings.

4. Conclusions

The present study provides a comprehensive evaluation of *Diospyros kaki* L., confirming its nutritional value as a balanced, bioactive-rich fruit. Its composition, characterized by high moisture, low fat, substantial fiber, and abundant phenolic compounds, positions persimmon as a functional ingredient that supports antioxidant defense and overall metabolic health. The predominance of gallic acid and other phenolic acids, combined with strong antioxidant capacities demonstrated across multiple assays, suggests that persimmon possesses considerable potential as a source of antioxidant compounds.

The mineral profile indicated a favorable balance of macro- and microelements, with phosphorus, potassium, magnesium, and iron as key contributors to dietary mineral intake. Importantly, the absence of detectable levels of toxic elements further affirms its safety for regular consumption. Nutritional intake modeling highlighted persimmons' capacity to supplement daily requirements of essential minerals, notably selenium, phosphorus, and potassium, reinforcing their role as a supportive component of a mineral-rich diet.

Overall, the findings indicate that *D. kaki* warrants further exploration as a candidate ingredient for functional foods and nutraceutical formulations. However, additional studies addressing bioavailability, cultivar-specific variations, and *in vivo* effects are needed to better elucidate the mechanisms underlying its potential health-related benefits and to guide its optimal utilization in innovative food products.

Author Contributions

Conceptualization and supervision: N.Đ.P.; Methodology: B.A., B.P.D., I.M., J.M.Ž.; Investigation and formal analysis: B.A., B.P.D., I.M.; Writing-original draft preparation: B.A., J.M.Ž. N.Đ.P.; Writing—review and editing: N.Đ.P.

Funding

This research was funded by the Ministry of Science, Technological Development and Innovation, Republic of Serbia (Contract numbers: 451-03-34/2026-03/200116, 451-03-136/2025-03/200026 and 451-03-136/2025-03/200168).

Competing Interests

The authors have declared that no competing interests exist.

AI-Assisted Technologies Statement

Artificial intelligence (AI) tools were used solely for basic grammar correction and language refinement in the preparation of the manuscript. Specifically, OpenAI's ChatGPT was employed to improve the readability and linguistic clarity of the English text. All scientific ideas, data interpretation, and conclusions were conceived and developed independently by the authors. The

authors have thoroughly reviewed and edited the AI-assisted text to ensure its accuracy and accepts full responsibility for the content of the manuscript.

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