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Research Article

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Study of the biological activity of hazelnut, cinnamon and barberry extracts

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ABSTRACT

In this study, a plant-based mixture composed of hazelnut (*Corylus avellana*), cinnamon (*Cinnamomum verum*), and barberry (*Berberis vulgaris*) was formulated based on its antioxidant activity, and its bioactive and mineral composition was subsequently evaluated. Water-soluble vitamins, flavonoids, and macro- and microelements in the optimised mixture were quantified using high-performance liquid chromatography (HPLC) and inductively coupled plasma optical emission spectrometry (ICP-OES). The results revealed high levels of B-complex vitamins, particularly folic acid, niacin, and riboflavin, as well as potent antioxidant flavonoids such as apigenin, quercetin, and rutin. Essential minerals, including calcium, magnesium, iron, and zinc, were also present in significant concentrations, while the levels of heavy metals such as arsenic and cadmium remained within acceptable safety limits. Overall, the mixture demonstrates promising potential as a functional food or nutraceutical formulation due to its rich antioxidant and micronutrient content.

KEYWORDS: Hazelnut, Cinnamon, Barberry, Phytochemicals, Vitamins, Flavonoids, Minerals, HPLC, ICP-OES

INTRODUCTION

In recent years, interest in health-promoting products and biologically active food supplements has increased sharply. The main reason for this is the growing public inclination toward a healthy lifestyle and the rising demand for natural products that are beneficial to the body and have minimal adverse effects. In particular, the increasing prevalence of chronic diseases associated with oxidative stress and micronutrient deficiencies has intensified scientific research in this area (Biesalski, 2002; Scalbert *et al.*, 2005; Liu, 2013).

Oxidative stress results from an imbalance between free radicals and the body's antioxidant defence system, and it is considered a key factor in the development of cardiovascular, cancerous, and neurodegenerative diseases (Alasalvar *et al.*, 2009). Plant-derived antioxidants—including polyphenols, flavonoids, vitamins, and certain micronutrients—are known to neutralise free radicals, reduce inflammation, and regulate biochemical processes (Ranasinghe *et al.*, 2013; Gunawardena *et al.*, 2015).

Plants such as hazelnut (*Corylus avellana*), cinnamon (*Cinnamomum verum*), and barberry (*Berberis vulgaris*) have individually been scientifically proven to possess health-promoting properties. Hazelnuts are rich in B-group vitamins, flavonoids, and essential minerals (Alasalvar *et al.*, 2009). Bioactive compounds in cinnamon, particularly zinc, apigenin, and rutin, exhibit strong antioxidant, antidiabetic, and neuroprotective properties (Ranasinghe *et al.*, 2013; Gunawardena *et al.*, 2015). Barberry, traditionally used in herbal medicine, contains active substances such as vitamin C, quercetin, and berberine, which are known for their anti-inflammatory, antimicrobial, and hepatoprotective effects (Ivanovska & Philipov, 1996; Kulkarni & Dhir, 2010; Shen *et al.*, 2021; Di Sotto & Di Giacomo, 2023).

Nevertheless, the combined effects of extracts prepared from a mixture of these plants, especially their comprehensive profile of vitamins, flavonoids, and mineral elements, have not been thoroughly studied. Existing research is often based on limited analytical approaches that do not provide a complete compositional evaluation of such products.

The innovative aspect of this study lies in the formulation of a hazelnut–cinnamon–barberry blend optimised based on antioxidant activity, and in its in-depth compositional analysis using high-performance liquid chromatography (HPLC) and inductively coupled plasma–optical emission spectrometry (ICP-OES). This integrated approach enables a comprehensive assessment of the mixture's biologically active and mineral

composition. The results provide scientific substantiation for the potential application of this natural mixture, rich in vitamins, flavonoids, and minerals, as a health-promoting product or biologically active food supplement. We believe this study could serve as a foundation for future in vivo or clinical research and may have practical significance in the development of health-beneficial products.

MATERIALS AND METHODS

Samples Collected

In this study, hazelnut (*Corylus avellana*) kernels harvested in 2024 from trees cultivated in Uzbekistan and dried barberry (*Berberis vulgaris*) fruits collected from the same region were used. In addition, powdered cinnamon (*Cinnamomum verum*), imported from India to Uzbekistan as a food product, was purchased from a certified local food store in Andijan following confirmation of official import documentation. These samples were used in subsequent chemical analyses.

Reagents, Standard Substances, and Analytical Instruments

Vitamin B_{12} was obtained from "Rhydburg Pharmaceuticals" (Germany), Vitamin C from "Carl Roth GmbH" (Germany), Vitamin B_9 from "DSM Nutritional Products GmbH" (Germany), and Vitamins B_1, B_2, B_3, B_6, and PP from "BLDPharm" (China). For the analysis, reagents of HPLC grade purity, including water, acetonitrile, chemically pure acetic acid, and sodium hydroxide, were used. The water-soluble vitamin content in the plant extract was determined using the LC-40 Nexera Lite high-performance liquid chromatography (HPLC) manufactured by Shimadzu (Japan) (Asqarov *et al.*, 2024).

Gallic acid was obtained from "Macklin" (China), salicylic acid from "Rhydburg Pharmaceuticals" (Germany), quercetin, apigenin, and kaempferol from "Regal" (China), and rutin was isolated using extraction and column chromatography methods from natural sources.

For the analysis, reagents of high-performance liquid chromatography (HPLC) grade purity, including water, acetonitrile, chemically pure acetic acid, and sodium hydroxide, were used.

The total polyphenol content in the plant extract was determined using the LC-40 Nexera Lite high-performance liquid chromatography (HPLC) manufactured by Shimadzu (Japan).

Balance (Navigator™, OHAUS®), porcelain crucible, muffle furnace (Nabertherm, Germany), concentrated nitric acid, hydrogen peroxide, heating plate, 100 mL volume polypropylene measuring flask, syringe filter, water, iCAP PRO X Duo ICP-OES: Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) from Thermo Fisher Scientific, USA

Sample Preparation

Determining the water-soluble vitamin concentrations in the extract using the HPLC method

Preparation of standard solutions

Standard solutions of vitamins C (CAS 50-81-7), B_1 (CAS 59-43-8), B_6 (CAS 58-56-0), B_3 (CAS 59-67-6), B_{12} (CAS 68-19-9), and PP (CAS 98-92-0) were prepared by dissolving 5 mg of each vitamin in 50 mL of 0.1 N hydrochloric acid (HCl) to obtain a concentration of 100 mg/L. Standard solutions of vitamins B_2 (CAS 83-88-5) and B_9 (CAS 59-30-3) were prepared by dissolving 5 mg of each vitamin in 50 mL of 0.025% sodium hydroxide (NaOH) solution.

Subsequently, 200 µL of each of the B_1, B_6, B_3, B_{12}, and PP vitamin stock solutions were combined to prepare a mixed standard solution, resulting in a final concentration of 14.286 mg/L for each vitamin. Further dilutions were performed to prepare standard solutions with concentrations of 7.143, 3.571, and 1.786 mg/L.

Standard solutions of vitamin C were also prepared at concentrations of 286, 143, 71.5, and 57.2 mg/L. For the 0 mg/L concentration point used in calibration curve construction, distilled water was used as the blank.

Sample extract preparation

To extract the water-soluble vitamins, 1 gram of the test sample was weighed and placed into a 50 mL conical flask. Then, 25 mL of 0.1 N hydrochloric acid (HCl) solution was added. The mixture was subjected to ultrasonic extraction using a GT SONIC-D3 (China) ultrasonic bath at 60 °C for 20 minutes.

After extraction, the mixture was cooled and filtered. The filtrate was transferred to a volumetric flask and diluted to 25 mL with distilled water. A 1.5 mL portion of the extract was further filtered through a 0.22 µm syringe filter, transferred into a vial, and used for analysis.

Determining the phenolic compound concentrations in the extract using the HPLC method

Preparation of standard solutions

Gallic acid (5.2 mg), salicylic acid (5.2 mg), rutin (5 mg), quercetin (5 mg), apigenin (5 mg), and kaempferol (5 mg) were each dissolved in 96% ethanol using ultrasonic extraction in a bath for 20 minutes. The solutions were transferred to 50 mL volumetric flasks and made up to the mark with ethanol. From each stock solution, 200 µL was taken and mixed to prepare a combined standard solution. This mixed solution was then serially diluted to prepare four different concentrations. Each diluted solution was transferred into vials and used for analysis.

Preparation of plant extract

For the extraction of phenolic compounds, 1 g of the test sample was accurately weighed using an NV222 analytical balance (OHAUS, USA) with a precision of 0.01 g and transferred into a 50 mL conical flask. Then, 25 mL of 96% ethanol was added. The mixture was subjected to ultrasonic extraction using a GT SONIC-D3 ultrasonic bath (China) at 60 °C for 20 minutes.

After extraction, the mixture was cooled, filtered, and the filtrate was transferred to a volumetric flask and brought up to 25 mL with ethanol. A 1.5 mL portion of the extract was then centrifuged using a Mini-7 centrifuge (BIOBASE, China) at 7000 rpm. The supernatant was filtered through a 0.45 μm syringe filter and used for analysis.

Determining the amount of chemical elements in the sample using the Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) method

Preparation of working sample solution

A 1.000 g portion of the pre-dried and finely ground sample was weighed using a high-precision analytical balance (Navigator™, OHAUS®, USA; 0.001 g accuracy) and transferred into a porcelain crucible. The sample was subjected to dry ashing in a muffle furnace (Nabertherm, Germany), where the temperature was initially increased at a rate of 100 °C per hour until reaching 550 °C. The sample was then maintained at this temperature for 5 hours.

The resulting ash was treated with 6 mL of 70% nitric acid (HNO_3, ICP-MS grade, Sigma-Aldrich, USA) and 2 mL of 60% hydrogen peroxide (H_2O_2). The mixture was gently heated on a hot plate inside a fume hood until white fumes ceased to evolve, indicating complete digestion.

After cooling, the solution was transferred into a 100 mL polypropylene volumetric flask and diluted to the mark with ultrapure water. The resulting working solution was filtered using a syringe filter and used for elemental analysis.

Preparation of standard solutions

A multi-element standard solution containing 68 elements at a concentration of 10 mg/L in 2% HNO_3 (High-Purity Standards, USA), a mercury standard solution at 1000 mg/L in 2 mol/L HNO_3 (Sigma-Aldrich, Germany), and a second multi-element standard containing 25 elements at 10 mg/L in 2% HNO_3 (Aristar, USA), along with 70% HNO_3 (Sigma-Aldrich, USA), were used to prepare a working standard solution of trace elements in 2% HNO_3.

From this stock solution, three additional working standard solutions were prepared through serial dilution. A 2% HNO_3 solution was used as the blank sample. Using these working standard solutions, calibration curves were constructed for 69 elements.

Laboratory equipment analysis and condition

Chromatographic Conditions and Determination of Vitamins

Standard solutions and the sample extract were analysed using a high-performance liquid chromatography (HPLC) system consisting of an LC-40D pump, SIL-40 autosampler, and SPD-M40 photodiode array (PDA) detector, all part of the LC-40 Nexera Lite system, controlled by LabSolutions software version 6.92. A Shim-pack GIST C18 reverse-phase column (150 × 4.6 mm; 5 μm, Shimadzu, Japan) was used, with a gradient mobile phase composed of acetonitrile (A) and a 0.5% aqueous solution of acetic acid (B) (Table 1). The injection volume was set to 10 μL, the flow rate to 0.6 mL/min, and the column thermostat temperature was maintained at 40 °C. The analytical signal (peak area) for each vitamin was recorded at three wavelengths: 265, 291, and 550 nm (Figures 1 and 2). For the determination of vitamin C, a 15-minute gradient program was applied (Table 2), and the analytical signal was measured at a wavelength of 265 nm.

Chromatographic conditions and determination of phenolic compounds

The standard solution and sample extract were analysed using a Shim-pack GIST C18 reverse-phase column (150 × 4.6 mm; 5 μm, Shimadzu, Japan) with a gradient mobile phase consisting of acetonitrile (A) and a 0.5% aqueous solution of acetic acid (B) (Table 3). The injection volume was set at 10 μL, the flow rate at 0.5 mL/min, and the column thermostat temperature was maintained at 40 °C. The analytical signal (peak area) of the phenolic compounds was recorded at a wavelength of 300 nm (Figure 3).

Spectrometric analysis

The analysis was carried out using an iCAP PRO X Duo ICP-OES (Inductively Coupled Plasma Optical Emission

Table 1: Mobile phase gradient program for vitamin analysis

Time (min)	Mobile Phase A (Acetonitrile), %	Mobile Phase B (0.5% Acetic Acid in Water), %
0	0	100
3	0	100
14	20	80
17	50	50
18	0	100
25	Ending	

Table 2: Mobile phase gradient program for determining Vitamin C content

Time (min)	Mobile phase A (Acetonitrile), %	Mobile phase B (0.5% Acetic acid in water), %
0	0	100
2	0	100
6	50	50
6.01	0	100
15	Ending	

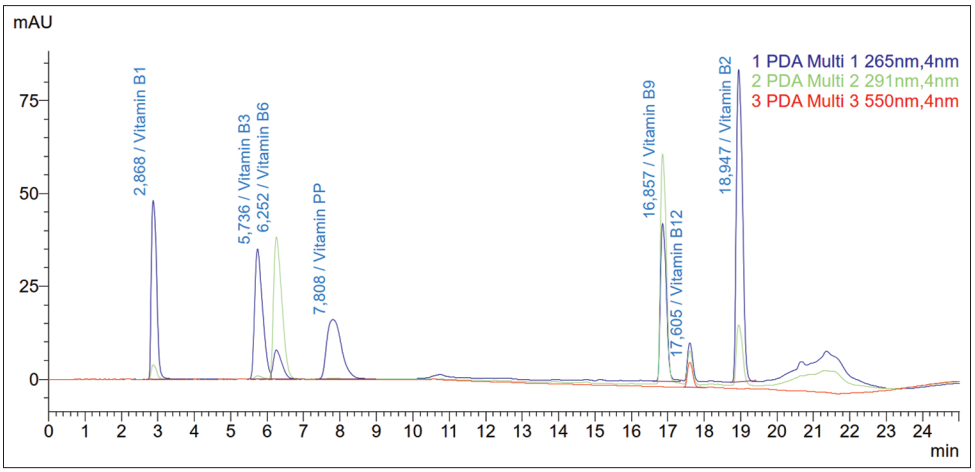

Figure 1: Chromatogram of the vitamin standard solution

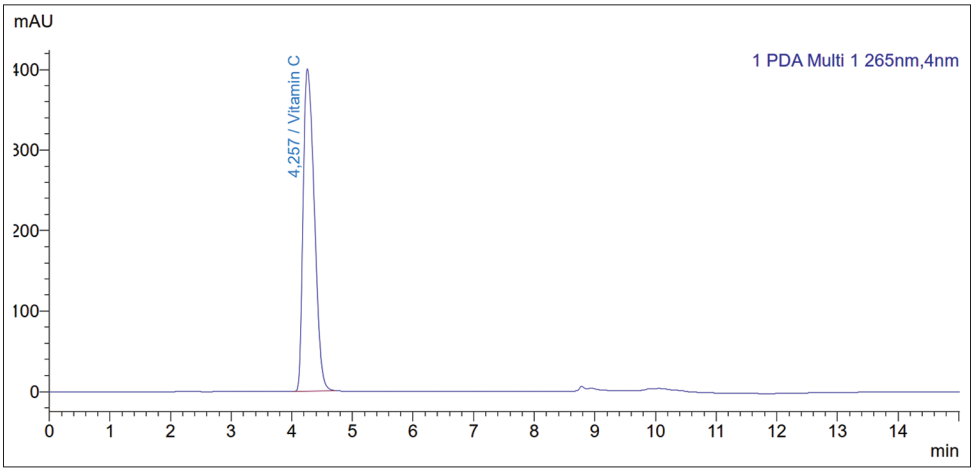

Figure 2: Chromatogram of the vitamin C standard solution

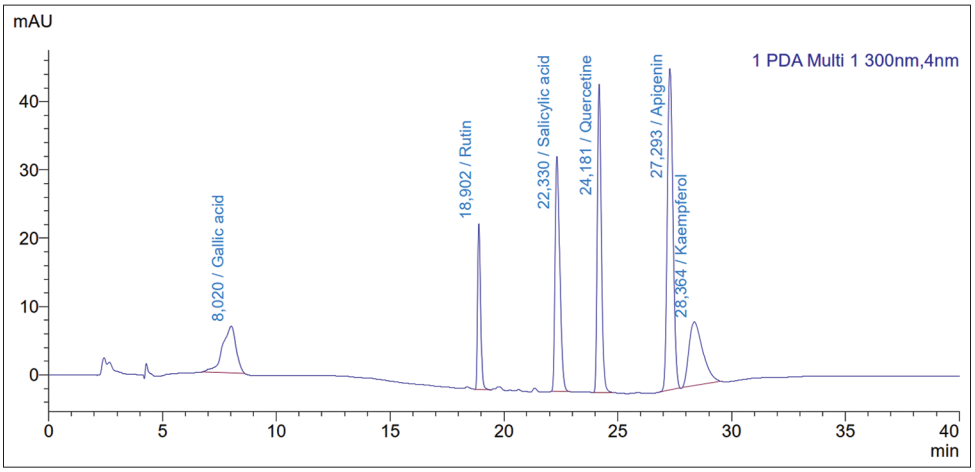

Figure 3: Chromatogram of standards at 300 nm

Spectrometer) manufactured by Thermo Fisher Scientific (USA). Method development and data analysis were performed using the QTegra ISDS software. The parameters of the analysis method are presented in Table 4.

Table 3: Mobile phase gradient program

Time (min)	Mobile phase A (Acetonitrile), %	Mobile phase B (0.5% Acetic acid in water), %
0	5	95
5	5	95
17	40	60
22	40	60
22.1	5	95
40	Ending	

Table 4: Parameters of the analytical method

Parameter	Value/Setting	
Pump pipe	For the sample Tygon® yellow/white	For drainage, Tygon ® white/white
Instrument	iCAP PRO X Duo ICP-OES	
Method	Inductively coupled plasma optical emission spectrometry (ICP-OES)	
Pump speed	30 around/s	
The spray camera	Glass cyclonic	
Nebulizer	Concentric glass	
Nebulising gas flow	0,6 L min^{-1}	
Cooling gas flow	12,5 L min^{-1}	
Auxiliary gas flow	0,5 L min^{-1}	
Central pipe	2 mm	
RF power	1150 Vt	
Recurrence	3 times	
Time of the analysis	Aqueous	Radially
	15 s	15 s
Analysis software	QTegra ISDS	

RESULTS AND DISCUSSION

Results of Determining the Vitamins in the Sample Extract

The chromatogram of the sample extract (Figures 4 and 5) was obtained, and based on the results, the amounts of vitamins in 100 grams of the fruit were calculated using the following formula:

$$X = \frac{C_{vit} \cdot V_{extract}}{m_{sample}} .100\,g$$

Where:
X is the amount of vitamins in 100 grams of fruit, expressed in mg
C_{vit} - is the concentration of the vitamin in the extract, determined by the HPLC method, expressed in mg/L
$V_{extract}$ - the volume of the sample extract, in litres
m_{sample} - is the mass of the sample used for extraction, in grams

The calculated results are presented in Table 5, which shows the amount of vitamins per 100 grams of fruit based on the above formula.

The analysed plant mixture (hazelnut, cinnamon, and barberry) was found to contain significant levels of water-soluble vitamins, which indicates its potential as a functional food product. Particularly notable are the high concentrations of Vitamin B_9 (folic acid) at 25.058 mg/100 g and Vitamin B_3 (niacin or PP) at 15.648 mg/100 g. Folic acid is essential for DNA synthesis and cell division, while niacin plays a key role in energy metabolism by serving as a precursor for the coenzymes NAD^+ and $NADP^+$ (Scott & Weir, 1994; Ilkhani *et al.*, 2016).

Table 5: Amount of vitamins in the extract and retention times

Vitamin	Retention time (s)	Concentration (mg/L)	Amount in extract (mg)
Vitamin B_1	2.738	0.365	0.913
Vitamin B_3	5.54	6.259	15.648
Vitamin PP	8.026	0.222	0.555
Vitamin B_9	16.859	10.023	25.058
Vitamin B_2	18.785	0.933	2.333
Vitamin B_6	6.254	0.383	0.958
Vitamin B_{12}	Not Found	0	0.000
Vitamin C	4.452	0.192	0.480

Additionally, the presence of vitamins B_1, B_2, and B_6 supports the idea that this mixture may aid in maintaining proper nervous system function and provide antioxidant effects. Riboflavin (Vitamin B_2), identified at 2.333 mg/100 g, is especially beneficial for skin health and visual function (Combs, 2012).

Interestingly, Vitamin B_{12} was not detected in the mixture, which is consistent with the fact that B_{12} is naturally found only in animal-derived foods (Allen, 2008). Vitamin C was also present in relatively low amounts (0.480 mg/100 g), suggesting that this blend is not a primary source of ascorbic acid. However, the high levels of several B vitamins indicate that the mixture could serve as a valuable dietary supplement to support immunity and energy metabolism.

The results of Determining the Amount of Phenolic Compounds in the Sample Extract

The chromatogram of the 1 g sample extract was obtained (Figure 6), and based on the results, the amount of phenolic compounds in 100 g of the sample was calculated using the following formula:

$$X = \frac{C_{phen} \cdot V_{extract}}{m_{sample}} .100\,g$$

Where:
X is the amount of phenolic compounds in 100 grams of the sample, expressed in mg
C_{phen} - is the concentration of phenolic compounds in the extract, determined using the HPLC method, expressed in mg/L
$V_{extract}$ - is the volume of the sample extract, in litres
m_{sample} - is the mass of the sample used for the extraction, in grams

The calculated results are presented in Table 6, which shows the amount of phenolic compounds in the sample extract per 100 grams of the sample based on the above formula.

This figure shows the chromatographic peaks corresponding to the polyphenolic compounds present in the sample extract.

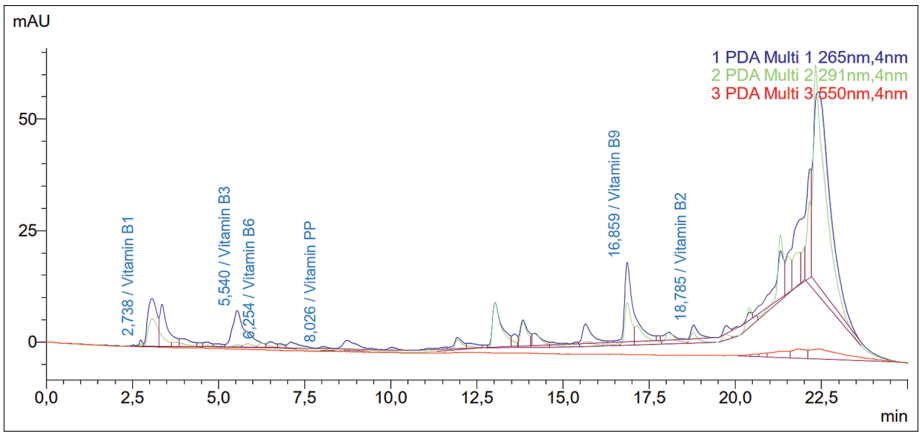

Figure 4: Chromatogram of vitamin determination in the sample extract

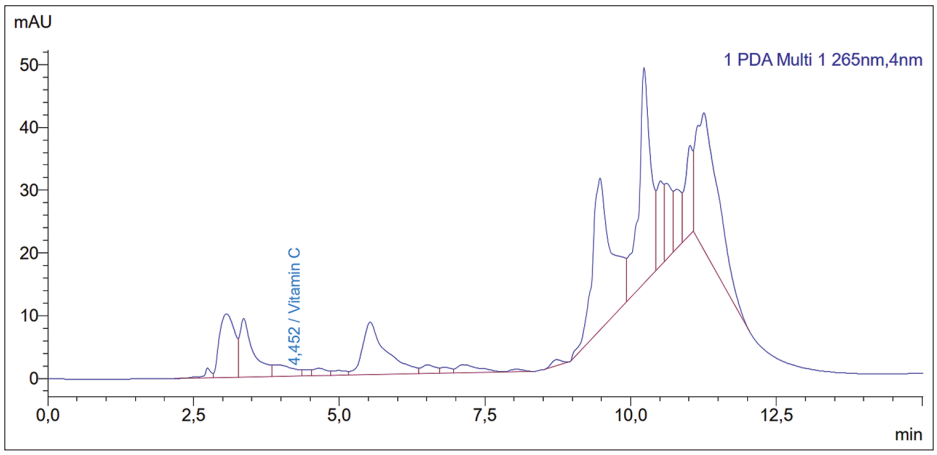

Figure 5: Chromatogram for the determination of Vitamin C in the sample extract

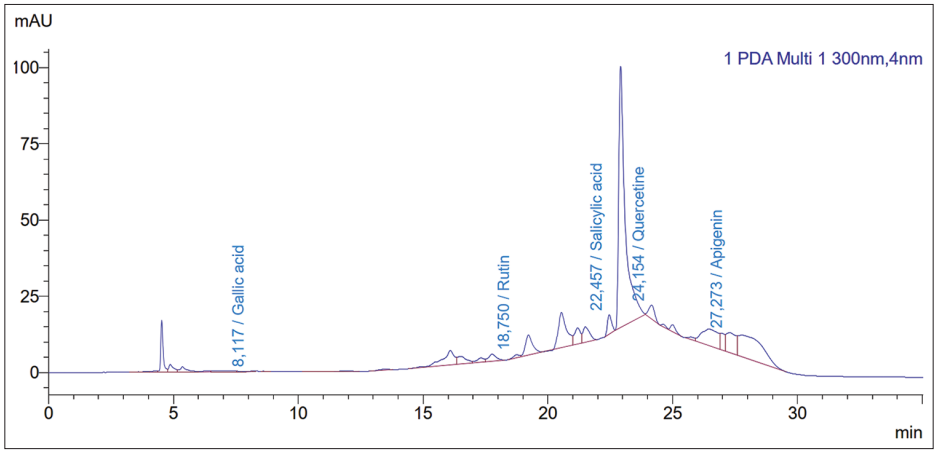

Figure 6: Chromatogram for the determination of polyphenols in the sample extract

Table 6: Amount of polyphenols in the extract and retention times

Phenolic Compound	Retention time (s)	Concentration (mg/L)	Amount in 100 mL sample (mg)
Gallic acid	8.117	0.098	0.245
Rutin	18.75	1.229	3.073
Salicylic acid	22.457	2.6	6.500
Quercetin	24.154	2.156	5.390
Apigenin	27.273	3.768	9.420
Kaempferol	Not detected	0	0.000

Each peak would represent a specific polyphenol, and the retention times (the time it takes for each compound to elute from the chromatograph column) would be indicated on the x-axis. The area under the peaks can be used to quantify the amount of each polyphenolic compound in the extract.

The chromatographic analysis of the plant mixture (hazelnut, cinnamon, and barberry) revealed the presence of several

biologically active polyphenolic compounds with strong antioxidant potential. Among these, apigenin was detected in the highest amount, 7.680 mg/100 g, which is significant given its known anti-inflammatory, antioxidant, and anticancer properties (Shukla & Gupta, 2010). Apigenin has also been shown to modulate key signalling pathways involved in oxidative stress and apoptosis, supporting its role in chronic disease prevention.

Salicylic acid (6.500 mg/100 g) and quercetin (5.390 mg/100 g) were also found in considerable amounts. Quercetin is a well-known flavonol with strong free radical scavenging capacity and the ability to chelate metal ions, making it a powerful antioxidant (Boots *et al.*, 2008). Salicylic acid, apart from being a precursor to aspirin, has known anti-inflammatory and antimicrobial activity, which further supports the therapeutic potential of this extract (Rainsford, 2004).

Rutin, at 3.073 mg/100 g, contributes to vascular health by strengthening blood vessels and reducing capillary fragility. It has also been reported to exhibit neuroprotective and antihypertensive effects (Ganeshpurkar & Saluja, 2017).

On the other hand, gallic acid was present in lower amounts (0.245 mg/100 g), yet it is still notable due to its strong antioxidant and antimicrobial properties. Kaempferol, however, was not detected in this extract. This could be due to its absence in the original plant materials or limitations in extraction conditions.

Overall, the identified polyphenolic profile highlights the plant mixture's potential as a source of natural antioxidants, which may contribute to its health-promoting effects and justify its inclusion in functional food or nutraceutical formulations (Lu & Yeap Foo, 2001).

Quantitative Analysis

Quantitative analysis of macro- and microelements in C. verum was performed using ICP-OES. Table 7 summarises key values and compares them with literature data.

In addition to vitamins and polyphenols, the elemental analysis of the plant mixture extract (hazelnut, cinnamon, and barberry) revealed the presence of both essential macro- and microelements. Among the macroelements, calcium (Ca) was particularly abundant, with a concentration of 89,621.9±479.8 μg/g (≈ 89.6 mg/g), which indicates its potential contribution to bone health and cellular signalling. Magnesium (Mg) and potassium (K) were also present in significant amounts (24082.3±74.3 μg/g and 15378.1±6 μg/g, respectively), both of which are crucial for muscle function, nerve transmission, and cardiovascular health.

Trace elements such as iron (Fe) (927.6±1.8 μg/g) and zinc (Zn) (479.2±1.2 μg/g) were also detected in relatively high concentrations. Iron is essential for haemoglobin synthesis and energy metabolism, while zinc plays a pivotal role in immune function and antioxidant defence mechanisms (Prasad, 2013).

Table 7: Results of chemical element determination in the sample by the ICP-OES method, μg/100 g

Analyte, Emission Wavelength, nm (Detection Method)	A mixture of hazelnut, cinnamon, and barberry at a specified ratio
Ag 338.289 (Axial)	3.066±1.3
Al 396.152 (Axial)	995.891±9.8
As 189.042 (Axial)	7.736±3.1
Au 242.795 (Axial)	11.639±0.3
B 249.773 (Axial)	173.538±1.6
Ba 455.403 (Axial)	595.072±3.3
Be 313.042 (Axial)	7.373±0
Bi 223.061 (Axial)	1.429±0.8
Ca 393.366 (Radial)	89621.94±479.8
Ca 396.847 (Axial)	24082.317±74.3
Cd 228.802 (Axial)	5.365±0.1
Ce 413.765 (Axial)	6.286±0.1
Co 238.892 (Axial)	<LOQ
Cr 283.563 (Axial)	89.091±0.4
Cs 852.113 (Axial)	479.23±1.2
Cu 324.754 (Axial)	126.79±0.9
Dy 400.045 (Axial)	1.696±0.2
Er 323.058 (Axial)	4.292±0.2
Eu 381.967 (Axial)	4.822±0
Fe 259.940 (Axial)	927.568±1.8
Ga 294.364 (Axial)	<LOQ
Gd 335.047 (Axial)	<LOQ
Ge 265.118 (Axial)	<LOQ
Hf 339.980 (Axial)	1.336±0.6
Hg 184.950 (Axial)	2.428±0
Ho 345.600 (Axial)	5.414±0
In 325.609 (Axial)	41.416±1.2
Ir 224.268 (Axial)	2.513±0.3
K 766.490 (Radial)	90769.088±1,142.9
La 333.749 (Axial)	4.904±0.1
Li 670.776 (Axial)	62.995±0.4
Lu 261.542 (Axial)	4.554±0
Mg 279.553 (Radial)	23386.411±78.9
Mg 285.213 (Axial)	25695.487±126.1
Mn 257.610 (Axial)	1391.729±9.4
Mo 202.030 (Axial)	31.87±0.1
Na 589.592 (Radial)	1329.034±9.5
Nb 309.418 (Axial)	1.457±0
Nb 316.340 (Axial)	0.02±0.3
Nd 378.425 (Axial)	11.914±0.2
Ni 221.647 (Axial)	34.746±0.2
Os 225.585 (Axial)	<LOQ
P 185.942 (Axial)	17658.044±62.4
Pb 220.353 (Axial)	<LOQ
Pd 340.458 (Axial)	<LOQ
Pr 390.844 (Axial)	<LOQ
Pt 203.646 (Axial)	3.918±1.1
Pt 265.945 (Axial)	<LOQ
Rb 214.383 (Axial)	93.923±11.2
Re 227.525 (Axial)	<LOQ
Rh 343.489 (Axial)	0.056±0.2
Ru 240.272 (Axial)	<LOQ
Sb 206.833 (Axial)	7.959±5.1
Sc 361.384 (Axial)	4.962±0
Se 196.090 (Axial)	<LOQ
Si 251.611 (Axial)	466.7±5.2
Sm 363.429 (Axial)	6.981±0.4
Sn 189.989 (Axial)	484.797±9.6
Sr 407.771 (Axial)	145.68±1.5
Ta 268.517 (Axial)	0.362±1.5
Tb 350.917 (Axial)	6.854±0.2
Te 238.578 (Axial)	37.742±10.3
Th 283.231 (Axial)	11.356±0.1
Ti 334.941 (Axial)	9.69±0.1
Tl 190.856 (Axial)	24.41±0.7
Tm 342.508 (Axial)	<LOQ
U 264.547 (Axial)	161.435±2.3
U 367.007 (Axial)	208.314±6.3
V 309.311 (Axial)	16.202±0.3

<LOQ=smaller than the limit of quantification

Copper (Cu) (126.7±0.9 μg/g), manganese (Mn) (not shown but often found in similar matrices), and chromium (Cr) (89.0±1.4 μg/g) were also identified, suggesting potential roles in enzymatic activity and glucose metabolism (Tapiero & Tew, 2003). The presence of selenium (Se) was not listed, but other rare earth elements such as erbium (Er) and europium (Eu) were found in trace amounts, indicating a rich and diverse elemental profile. Heavy metals such as arsenic (As) and cadmium (Cd) were detected at low concentrations (7.7±3.1 and 5.6±0.1 μg/g, respectively), but within tolerable limits. Nonetheless, their presence underscores the importance of source quality and safety monitoring in the preparation of plant-based nutraceuticals.

These findings reinforce the value of the mixture not only as a source of antioxidants and vitamins but also as a mineral-rich formulation with potential dietary and therapeutic benefits.

CONCLUSION

The conducted study comprehensively analysed the chemical composition of a functional plant-based mixture consisting of hazelnut (*Corylus avellana*), cinnamon (*Cinnamomum verum*), and barberry (*Berberis vulgaris*), with particular emphasis on its water-soluble vitamins, polyphenolic compounds, and mineral content. The findings revealed that the extract is an excellent source of essential vitamins such as folic acid (Vitamin B_9), niacin (Vitamin B_3), and riboflavin (Vitamin B_2), which plays key roles in energy metabolism, neurological health, and cellular function.

Moreover, the extract demonstrated a rich polyphenolic profile, including high concentrations of apigenin, quercetin, salicylic acid, and rutin - compounds known for their strong antioxidant, anti-inflammatory, and potential anticancer properties. These bioactive flavonoids contribute significantly to the extract's therapeutic potential.

Elemental analysis confirmed the presence of vital macro- and microelements. Calcium, magnesium, potassium, and iron were found in high concentrations, suggesting their contribution to bone strength, cardiovascular health, and oxygen transport. Additionally, essential trace elements like zinc, copper, and chromium were also detected, supporting enzymatic activity and immune function. The levels of toxic elements such as arsenic and cadmium were within acceptable limits, indicating good safety of the sample.

In conclusion, the hazelnut–cinnamon–barberry mixture is a promising source of biologically active compounds with nutritional, antioxidant, and therapeutic value. Its balanced combination of vitamins, polyphenols, and minerals supports its potential application in the development of natural supplements or functional foods. Future in vivo studies and clinical trials are recommended to evaluate its bioavailability, efficacy, and safety in human health applications.

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REFERENCES

Alasalvar, C., Amaral, J. S., Satır, G., & Shahidi, F. (2009). Lipid characteristics and essential minerals of native Turkish hazelnut varieties (*Corylus avellana* L.). *Food Chemistry, 113*(4), 919-925. https://doi.org/10.1016/j.foodchem.2008.08.019

Allen, L. H. (2008). Causes of vitamin B_{12} and folate deficiency. *Food and Nutrition Bulletin, 29*(2 Suppl1), S20-S37. https://doi.org/10.1177/15648265080292S105

Asqarov, I. R., Abdullayev, Sh., Mamatqulova, S. A., Abdulloyev, O. Sh., Abdulloyev, Sh. X. (2024). Development of a methodology for determining the amount of water-soluble vitamins using the YSSX method (case study of Jujube). *FarDU. Ilmiy xabarlar –Scientific Journal of the Fergana State University,* 30(5), 32-38.

Biesalski, H. K. (2002). Nutraceuticals: the link between nutrition and medicine. *Journal of Toxicology: Cutaneous and Ocular Toxicology, 21*(1-2), 9-30. https://doi.org/10.1081/CUS-120004324

Boots, A. W., Haenen, G. R. M. M., & Bast, A. (2008). Health effects of quercetin: from antioxidant to nutraceutical. *European Journal of Pharmacology, 585*(2-3), 325-337. https://doi.org/10.1016/j.ejphar.2008.03.008

Combs, G. F. Jr. (2012). The vitamins: Fundamental aspects in nutrition and health. (4th ed.). Cambridge, US: Academic Press.

Di Sotto, A., & Di Giacomo, S. (2023). Plant polyphenols and human health: Novel findings for future therapeutic developments. *Nutrients, 15*(17), 3764. https://doi.org/10.3390/nu15173764

Ganeshpurkar, A., & Saluja, A. K. (2017). The pharmacological potential of rutin.

Saudi Pharmaceutical Journal, 25(2), 149-164. https://doi.org/10.1016/j.jsps.2016.04.025

Gunawardena, D., Karunaweera, N., Lee, S., van Der Kooy, F., Harman, D. G., Raju, R., Bennett, L., Gyengesi, E., Sucher, N. J., & Münch, G. (2015). Anti-inflammatory activity of cinnamon (*C. zeylanicum* and *C. cassia*) extracts – identification of E-cinnamaldehyde and o-methoxy cinnamaldehyde as the most potent bioactive compounds. Food & Function, 6(3), 910-919. https://doi.org/10.1039/C4FO00680A

Ilkhani, F., Hosseini, B., & Saedisomeolia, A. (2016). Niacin and oxidative stress: a mini-review. *Journal of Nutritional Medicine and Diet Care, 2*(1), 014.

Ivanovska, N., & Philipov, S. (1996). Study on the anti-inflammatory action of Berberis vulgaris root extract, alkaloid fractions and pure alkaloids. International Journal of Immunopharmacology, 18(10), 553-561. https://doi.org/10.1016/S0192-0561(96)00047-1

Kulkarni, S. K., & Dhir, A. (2010). Berberine: A plant alkaloid with therapeutic potential for central nervous system disorders. Phytotherapy Research, 24(3), 317-324. https://doi.org/10.1002/ptr.2968

Liu, R. H. (2013). Health-promoting components of fruits and vegetables in the diet. Advances in Nutrition, 4(3), 384S-392S. https://doi.org/10.3945/an.112.003517

Lu, Y., & Yeap Foo, L. (2001). Antioxidant activities of polyphenols from sage (Salvia officinalis). Food Chemistry, 75(2), 197-202. https://doi.org/10.1016/S0308-8146(01)00198-4

Prasad, A. S. (2013). Discovery of human zinc deficiency: Its impact on human health and disease. Advances in Nutrition, 4(2), 176-190. https://doi.org/10.3945/an.112.003210

Rainsford, K. D. (2004). Aspirin and the salicylates. Oxford, UK: Butterworth-Heinemann.

Ranasinghe, P., Pigera, S., Premakumara, G. A. S., Galappaththy, P., Constantine, G. R., & Katulanda, P. (2013). Medicinal properties of 'true' cinnamon (Cinnamomum zeylanicum): A systematic review. BMC Complementary and Alternative Medicine, 13, 275. https://doi.org/10.1186/1472-6882-13-275

Scalbert, A., Manach, C., Morand, C., Rémésy, C., & Jiménez, L. (2005).

Dietary polyphenols and the prevention of diseases. Critical Reviews in Food Science and Nutrition, 45(4), 287-306. https://doi.org/10.1080/1040869059096

Scott, J., & Weir, D. (1994). Folate/vitamin B12 inter-relationships. *Essays in Biochemistry, 28*, 63-72.

Shen, P., Lin, W., Deng, X., Ba, X., Han, L., Chen, Z., Qin, K., Huang, Y., & Tu, S. (2021). Potential implications of quercetin in autoimmune diseases. *Frontiers in Immunology, 12*, 689044. https://doi.org/10.3389/fimmu.2021.689044

Shukla, S., & Gupta, S. (2010). Apigenin: A promising molecule for cancer prevention. Pharmaceutical Research, 27, 962-978. https://doi.org/10.1007/s11095-010-0089-7

Tapiero, H., & Tew, K. D. (2003). Trace elements in human physiology and pathology: Zinc and metallothioneins. Biomedicine & Pharmacotherapy, 57(9), 399-411. https://doi.org/10.1016/S0753-3322(03)00081-7