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Effect of roasting process on various quality parameters, antioxidant activity and mineral contents in hazelnuts

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SUMMARY: This study investigates various quality parameters, antioxidant activities and mineral compositions of different hazelnut varieties. In addition, samples were analyzed in terms of various qualitative properties (moisture, L*, a*, b*, Chroma*, Hue°). The moisture contents in the samples were found to be in the following order: Tombul > Sivri > Karafındık, with statistically significant differences being determined ($P < 0.01$). The mineral contents in the samples varied between 10.13 and 1799.77 ppm, with statistically significant differences being found ($P < 0.01$). The main minerals present in the hazelnut samples were determined to be K, Mg and Ca. The study concluded that both hazelnut variety and roasting time had statistically significant effects ($P < 0.01$) on the total phenolic content (TPC) (1083.32-1974.76 mg GAE/kg) and total flavonoid content (TFC) (780.58-1920.38 mg QE/kg), DPPH (0.21-0.36 mM TE/100 g) and ABTS (0.27-0.64 mM TE/100 g) contents.

KEY-WORDS: *Antioxidant activity; Color; Hazelnut; Mineral profile; PCA; Roasting.*

RESUMEN: ***Efecto del proceso de tostado sobre diversos parámetros de calidad, actividad antioxidante y contenido mineral de las avellanas***. Este estudio investiga diversos parámetros de calidad, actividades antioxidantes y composiciones minerales de diferentes variedades de avellana. Además, se analizaron las muestras en función de diversas propiedades cualitativas (humedad, L*, a*, b*, croma*, tono). El contenido de humedad de las muestras está en el siguiente orden de clasificación: Tombul > Sivri > Karafındık, con diferencias estadísticamente significativas ($P<0{,}01$). El contenido mineral de las muestras varió entre 10,13 y 1799,77 ppm, con diferencias estadísticamente significativas ($P<0{,}01$). Los principales minerales presentes en las muestras de avellana fueron K, Mg y Ca. El estudio observó que tanto la variedad de avellana como el tiempo de tostado tuvieron efectos estadísticamente significativos ($P<0{,}01$) en el contenido fenólico total (CFT) (1083,32-1974,76 mg GAE/kg) y el contenido total de flavonoides (CFT) (780,58-1920,38 mg QE/kg), DPPH (0,21-0,36 mM TE/100 g) y ABTS (0,27-0,64 mM TE/100 g).

PALABRAS CLAVE: *Actividad antioxidante; Avellana; Color; PCA; Perfil mineral; Tostado.*

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1. INTRODUCTION

Fruits and vegetables are considered essential dietary components due to their macronutrient and micronutrient contents. Nuts are foods that have an important place among fruits and vegetables. Nuts are notable for their high content of monounsaturated and polyunsaturated fatty acids, high-quality protein, fiber, minerals, and bioactive components (Ros *et al.,* 2021; Binici and Savaş, 2024).

The hazelnut is one of the most produced and consumed nuts worldwide (Savaş, 2024). Turkey, Italy, the USA, Azerbaijan and Spain are among the most significant producer countries of hazelnut (*Corylus avellana* L.), a member of the Betulaceae family. Hazelnuts demonstrate optimal characteristics in climates characterized by humidity, mild conditions, an average annual rainfall of 755 mm, and an average temperature range of 13-16 °C. The global demand for hazelnuts is driven by their high nutritional value, offering amino acids, fatty acids, vitamins and minerals which are essential for human health. In addition to their direct consumption, hazelnut kernels are utilized in various industrial applications, particularly in the chocolate industry (Gonçalves *et al.,* 2023; Savaş, 2024). Hazelnuts can be consumed in a raw state, but are more commonly consumed after being roasted.

The roasting process is instrumental in determining the distinctive taste, aroma and flavor of hazelnuts. Indeed, during the process of roasting, a number of reactions (such as Maillard reaction) and physico-chemical changes occur (Saklar *et al.,* 2001). During the process of roasting, there is a significant decrease in the water content of the product, from 5-6 to 1-2 %. This is accompanied by notable changes in the product's texture. Additionally, it has been stated that color changes, which are considered to be one of the most significant consumer parameters, occur during the roasting process (Rothkopf *et al.,* 2025). As a matter of fact, it is noteworthy that the roasting process exerts a significant influence on the composition of antioxidant compounds. These bioactive components have important functions in minimizing oxidative processes and the harmful effects of ROS in both food systems and the human body. Moreover, it has been stated that they contribute to the prevention of the formation of various oxidation products and the preservation of the quality parameters of the food product during storage (Gulçin, 2020).

A review of the extant literature reveals that a multitude of roasting processes are employed for hazelnut varieties. A thorough examination of these processes reveals a pronounced emphasis on various temperature and time factors (Amaral *et al.,* 2006; Marzocchi *et al.,* 2017; Lamberti *et al.,* 2021; Rothkopf *et al.,* 2025). However, to the best of our knowledge, there is limited research on the preservation and evaluation of the nutrient contents in different types of hazelnuts. In this study, the quality parameters (L*, a*, b*, Chroma*, Hue°, moisture), antioxidant activities (DPPH, ABTS, TPC, TFC) and mineral profile of different hazelnut varieties (Sivri, Karafındık, Tombul) were investigated in terms of roasting in an oven for different time periods (10, 15 and 20 mins).

2. MATERIALS AND METHODS

2.1. Materials

Hazelnut samples were collected from hazelnut traders in the Giresun province in 2024 (Turkey, Piraziz, "40.954559 N, "38.119641" E). After the hazelnuts were obtained, they were graded according to size. The aim was to have hazelnuts of the same size and weight. Tombul, Sivri and Karafındık hazelnuts were used as hazelnut varieties.

2.2. Chemicals

All standards and chemicals (ABTS, DPPH, Trolox, Quercetin, gallic acid, Folin–Ciocalteu reagent, potassium persulfate, and chemicals) were purchased from Sigma (MO, USA) and Merck (Darmstadt, Germany).

2.3. Roasting hazelnuts

A series of hazelnut varieties were subjected to the process of roasting in a domestic oven (Arçelik, AFC 471G, Turkey). The initial trials established a roasting temperature of 200 ºC, and the oven was calibrated for 30 minutes prior to the commencement of the roasting process. The oven temperature was measured with the aid of a food thermometer. Each hazelnut group was then subjected to the roasting process for 10, 15 and 20 minutes, respectively. The roasted samples were then permitted to cool for a period of 20 minutes. Subsequently, the roasted samples were transferred to zip-lock bags for subsequent analysis.

2.4. Moisture

The moisture content in hazelnut samples was determined by drying at 103 ± 2 °C until constant weight was reached (Oz *et al.,* 2021).

2.5. Color

A color measuring instrument (Konica Minolta CR-400, Korea) was used to measure the color values of the hazelnut samples. Then, L*, a*, b*, Chroma* and Hue° values were determined. In this system, L* values are used to represent lightness (0= black, 100= white), whilst a* values are used to represent greenness-redness (-60= green, +60= red), and b* values are used to represent blueness-yellowness (-60= blue, 60= yellow). Another color component that is used to express color is the Hue (H^o) degree. The chroma (C*) value is indicative of the intensity or opacity of the color.

2.6. Extraction

Roasted hazelnut samples were ground with the help of a blender and weighed to one gram. Ten milliliters of a methanol-water mixture were added and shaken in a blender and treated in an ultrasonic water bath for a certain time. After this procedure, the filtrate was filtered using filter paper (Whatman No. 1) and the final filtrate was used as stock. This solution was then used to determine TFC, TPC, DPPH and ABTS.

2.6.1. Total phenolic content (TPC)

For the determination of total phenolic content, 0.1 mL of the extract was mixed with 0.5 mL of Folin–Ciocalteu reagent and 1.5 mL of a 10% sodium carbonate (Na_2CO_3) solution. The mixture was incubated at room temperature in the dark for 30 minutes. Absorbance was then measured at 760 nm using a spectrophotometer (PG Instruments T60V). The results were calculated as gallic acid equivalents (GAE) using a standard curve prepared with gallic acid (Singleton *et al.,* 1999; *Zor et al*., 2024).

2.6.2. Total flavonoid content (TFC)

The total flavonoid content was determined spectrophotometrically (510 nm wavelength, PG Instruments T60V) using aluminum chloride and sodium nitrite reagents, in accordance with the method described by Taş and Gökmen (2015) and Karakütük *et al.* (2023). The calibration curve was determined using the equation determined at 10-250 mg/L quercetin concentration and the total flavonoid content was given as quercetin equivalent.

2.7. Antioxidant activity

2.7.1. DPPH (2,2-diphenyl-1-picrylhydrazyl) analysis

The DPPH free radical scavenging activity of the samples was determined spectrophotometrically at 517 nm. For the analysis, 0.1 mL of the extract was mixed with 2 mL of methanol, followed by the addition of 0.5 mL of DPPH solution. The mixture was vortexed and then incubated in the dark for a specific period of time.

The absorbance was measured at 517 nm, and the antioxidant activity was expressed as Trolox equivalent (Savaş *et al.,* 2023; Zor *et al*., 2024).

2.7.2. ABTS analysis

To evaluate the ABTS radical scavenging activity, a 7 mM ABTS solution containing 2.45 mM potassium persulfate ($K_2S_2O_8$) was prepared and incubated in the dark at room temperature for 12–16 hours to generate ABTS$\bullet^+$ radicals. For the assay, 0.1 mL of the extract was added to test tubes, followed by the addition of 1.9 mL of the prepared ABTS$\bullet^+$ solution. The mixture was incubated for a specific period in the dark, and the absorbance was measured at 734 nm against a blank. The antioxidant activity was expressed as Trolox equivalent (Köksal *et al*., 2009; Zor *et al.*, 2024).

2.8. Mineral analysis

Mineral analysis was performed on an ICP-MS (Thermo Xseries II) device. Firstly, hazelnut samples were burned in a Milestone brand microwave device (Milestone Start D, Italy) according to the Roasted Peanuts burning procedure. Approximately 0.5 g of sample (7 ml HNO_3 65% + 1 ml H_2O_2 30%) was added to 8 ml of acid and treated for 15-20 min. The burning process of the samples prepared in this way was carried out according to the Milestone microwave burning procedure, with 200 °C and 1500 W applied in each step, in two stages of 15 minutes, for a total of 30 minutes. Appropriate dilutions were made from the burned samples and completed to 25 ml, and readings were taken. The results obtained were determined in ppm (Binici *et al.,* 2025).

2.9. Statistical analysis

The research data were statistically analyzed using IBM SPSS Statistics Version 25.0. A two-way analysis of variance (ANOVA) was conducted to evaluate the effects of roasting time and variety, and Duncan's multiple range test was employed to assess significant differences among the means. In addition, principal component analysis (PCA) was performed on selected data to better visualize and interpret the similarities and differences among the samples (SIMCA-P+14.1, UMETRICS).

3. RESULTS

In Table 1 presents the results of the statistical analysis of the moisture and color parameters of various hazelnut varieties. The analysis indicates a statistically significant effect of both hazelnut variety and roasting time on the samples ($P < 0.01$). The moisture contents in the samples exhibited a range from 1.53 to 1.77 %, with the highest dry matter content being observed in the Sivri hazelnut group and the lowest in the Tombul hazelnut group. These findings are consistent with the existing literature on the subject (Oz *et al.,* 2021). For instance, according to the findings of Sarıca *et al.* (2021), the moisture contents in hazelnut samples subjected to varying roasting times and temperatures exhibited a range between 0.96 and 2.38%. On the other hand, as expected, the moisture contents in the samples decreased as the roasting time increased. In fact, it is thought that this is due to the increase in exposure to heat treatment during the roasting stage. It is stated that parameters such as geographical region, season, maturity level, harvest time, soil type and species diversity and growing conditions can affect moisture content (Oz *et al.,* 2021).

Color is one of the important parameters affecting consumer preference. As a matter of fact, as a result of the roasting process, hazelnuts undergo physico-chemical changes (such as dehydration, color modifications, lipid structure modification) (Alamprese *et al.,* 2009; Marzocchi *et al.,* 2017). It was determined that hazelnut variety and roasting time affected the samples statistically significantly and the L* value of the samples varied between 40.71 and 56.48. It was also determined that the L* value decreased as the roasting time increased. It is stated that the main reason for this situation is the changes that occur in the color pigments with roasting and that many chemical reactions such as Maillard cause the formation of brown pigments. There are different results in the literature regarding the roasting process. Because roasting process temperatures, times and varieties are thought to affect many parameters regarding color values. Sarıca *et al*., (2021) reported that the L* value of hazelnut samples applied with different roasting times and temperatures varied between 56.37 and 70.68, and that there were statistical differences ($P < 0.05$). In a similar vein, Apaydın *et al.,* (2024) documented that the L* value of hazelnut samples ranged from 57.04 to 85.13.

TABLE 1. Moisture (%) and color (L*, a*, b*, Chroma*, Hue°) results of different hazelnut samples

Hazelnut Varieties (HV)	Moisture (%)±SD	L*±SD	a*±SD	b*±SD	*C**±SD	*H°*±SD
Karafındık	1.71±0.10b	40.71±3.04c	7.11±0.32a	12.26±2.57c	14.22±2.31c	59.24±4.58c
Sivri	1.53±0.17c	50.77±9.01b	5.92±2.51b	17.52±1.66b	18.68±1.22b	71.11±8.47b
Tombul	1.77±0.03a	56.48±9.48a	6.87±2.94a	23.19±1.89a	24.37±1.41a	73.33±7.60a
Sign.	**	**	**	**	**	**
Roasting Time (RT)						
10 min	1.76±0.07a	58.67±10.83a	4.28±2.26c	19.72±3.88a	20.38±3.34a	76.77±8.86a
15 min	1.62±0.17b	43.15±4.09c	7.99±0.98a	15.51±4.62c	17.51±4.49c	61.65±5.21c
20 min	1.63±0.15b	46.15±6.11b	7.63±0.69b	17.74±5.80b	19.39±5.55b	65.27±5.82b
Sign.	**	**	**	**	**	**
HV x RT	**	**	**	**	**	**

a-d: Means with different letters in the same column are significantly different ($P < 0.05$); Sign: Significance; ns: not significant ($P > 0.05$); *$P < 0.05$; **$P < 0.01$. (n=3)according to two-way ANOVA and Duncan's multiple range test.

It was determined that hazelnut variety and roasting time affected the samples statistically significantly and the *a** value of the samples varied between 5.92 and 7.11. The highest *a** value was determined in the Karafındık hazelnut group. An increase in the *a** value was determined as the roasting time increased. Similarly, Sarıca *et al.,* (2021) reported that the *a** value of hazelnut samples applied with different roasting times and temperatures varied between 1.59 and 8.19 and that there were statistical differences ($P < 0.05$). Again, Apaydın *et al.,* (2024) reported that the *a** value of hazelnut samples ranged between 2.45 and 23.89.

The findings of the study indicated a statistically significant impact of hazelnut variety and roasting time on the samples, with the *b** value ranging from 12.26 to 23.19. Additionally, it was observed that an increase in roasting time resulted in a decrease in the b* value compared to the 10-minute setting. Sarıca *et al*. (2021) reported that the b* value of hazelnut samples applied with different roasting times and temperatures varied between 15.94 and 27.74, and that there were statistical differences ($P < 0.05$). In a similar vein, Apaydın *et al*., (2024) documented that the b* value of hazelnut samples ranged from 25.04 to 40.08, also indicating statistical significance ($P < 0.05$).

It was determined that hazelnut variety and roasting time affected the samples statistically significantly and the *C** value of the samples varied between 14.22 and 24.37. The highest *C** value was determined in the Tombul hazelnut group, while the lowest was determined in the Karafındık hazelnut group. In addition, there is an inverse correlation between roasting time and *C** value.

It was determined that hazelnut variety and roasting time affected the samples statistically significantly and the H° value of the samples varied between 59.24 and 73.33. The highest H° value was determined in the Tombul hazelnut group, while the lowest was determined in the Karafındık hazelnut group. In addition, it was determined that the H° value decreased with roasting time.

Phenolic compounds are secondary metabolites of plants that affect food quality parameters (color, flavor, odor, etc.) (Solar *et al.,* 2022). The total phenolic contents in the hazelnut samples were found to vary between 1083.32 mg GAE/kg and 1974.76 mg GAE/kg. The highest TPC content was determined in the Karafındık hazelnut group, and the lowest was determined in the Tombul hazelnut group. In a recent study, Özcan and Uslu (2023) examined the total phenolic contents (TPC) in hazelnut samples subjected to various roasting processes. Their findings revealed a range of TPC levels between 64.25 and 82.98 mg GAE/100 g, indicating an increase in TPC content compared to the control group. On the other hand, an increase in the amount of TFC was observed with an increase in roasting time, in comparison to 10 minutes. As posited by Marzocchi *et al.,* (2017), an increase in the phenolic substance contents in hazelnuts was observed in correlation with an increase in the roasting temperature. And they stated that this was due to a greater matrix destruction caused by high temperature application. On the other hand, there are studies with different results in terms of total phenolic contents (Altun *et al.,* 2011; Schmitzer *et al.,* 2011; Taş and Gökmen, 2015). It has been stated that many parameters such as species, variety, roasting temperature, roasting time and process, extraction and growing conditions affect the phenolic compound contents in the samples (Schmitzer *et al.,* 2011; Marzocchi *et al.,* 2017; Solar *et al.,* 2022).

Flavonoids are flavan nuclei consisting of 15 carbon atoms arranged in three rings and have several subclasses (Oliveira *et al.,* 2014; Solar *et al.,* 2022). The total flavonoid contents in the samples were found to be significantly affected by both the variety of hazelnut and the duration of the roasting process ($P < 0.01$). The total flavonoid contents (TFC) in the samples were found to vary between 780.58 mg QE/kg and 1920.38 mg QE/kg. The highest TFC content was determined in the Karafındık hazelnut group. Conversely, as the duration of the roasting process increased, there was a concomitant increase in the TFC contents in the samples, and statistical differences were identified between them. Özcan and Uslu (2023) determined the TFC contents in hazelnut samples with different roasting processes to be between 193.57 and 234.05 mg Catechol (CE)/100 g and reported that TFC contents increased compared to the control group.

The DPPH results for various hazelnut samples are presented in Table 2. A statistically significant effect of diversity on the samples was determined ($p < 0.01$), and it was established that the DPPH values of the samples varied between 0.21 and 0.36 mM TE/100 g. It was also observed that the roasting time had a significant effect on the DPPH values of the samples ($P < 0.05$) and there was no statistical difference between the samples roasted for 15 min and 20 min. In their 2023 study, Özcan and Uslu sought to determine the DPPH contents in hazelnut samples that had undergone various roasting processes. Their findings ranged from 6.80 to 7.46 mmol trolox (TE)/kg. It is thought that many parameters such as roasting times applied, hazelnut variety and roasting time affect the results.

TABLE 2. Total phenolic content, total flavonoid content, DPPH and ABTS results of hazelnut samples

Hazelnut Varieties (HV)	**TPC (mg GAE/kg)±SD**	**TFC (mg QE/kg) ±SD**	**DPPH (mM TE/100 g) ±SD**	**ABTS (mM TE/100 g) ±SD**
Karafındık	1974.76±85.51a	1920.38±446.25a	0.36±0.04a	0.64±0.05a
Sivri	1461.86±268.79b	1628.48±279.88b	0.32±0.03b	0.51±0.09b
Tombul	1083.32±174.86c	780.58±226.41c	0.21±0.02c	0.27±0.07c
Sign.	**	**	**	**
Roasting Time (CT)				
10 min	1338.33±465.94c	1352.81±675.11c	0.28±0.09b	0.43±0.22ca
15 min	1682.92±306.23a	1457.05±397.29b	0.29±0.05a	0.51±0.13a
20 min	1498.71±427.49b	1519.61±698.48a	0.29±0.07a	0.47±0.16b
Sign.	**	**	*	**
HV x RT	**	**	**	**

a-d: Means with different letters in the same column are significantly different ($P < 0.05$); Sign: Significance; ns: not significant ($P > 0.05$); *$P < 0.05$; **$P < 0.01$. (n=3)

The findings in the study demonstrated that both the variety of hazelnut and the duration of the roasting process exerted a statistically significant influence on the ABTS values of the samples ($P < 0.01$). The ABTS values of the samples were found to range from 0.27 to 0.64 mM TE/100 g, and it was also observed that there were statistical differences between the samples as the roasting time increased. In a related study, Pelvan *et al.* (2018) observed that the ABTS activity of samples subjected to the roasting process varied between 0.08 and 27 µg TE/100 g, with roasted hazelnuts exhibiting the lowest activity. Similarly, Altun *et al.* (2011) reported that the ABTS values of different hazelnut varieties ranged from 1.34 to 2.52 mmol TE/g.

The calcium (Ca), magnesium (Mg), copper (Cu), zinc (Zn), sodium (Na) and potassium (K) contents in the hazelnut samples are presented in Table 3. The findings demonstrate that both hazelnut variety and roasting time have a statistically significant impact on the samples ($P < 0.01$). A comprehensive review of the extant literature indicates that the macromolecular and micromolecular components of hazelnuts are influenced by a multitude of factors, including variety, soil composition, fertilization and irrigation practices, cultivation methodology, harvest year, and geographical origin (Özenç and Özenç, 2015).

TABLE 3. Results of mineral contents in hazelnut samples

Hazelnut Varieties (HV)	Ca (ppm) ±SD	Mg (ppm) ±SD	Cu (ppm) ±SD	Zn (ppm) ±SD	Na (ppm) ±SD	K (ppm) ±SD
Karafındık	1413.74±891.72a	438.86±13.73a	11.04±1.93b	152.97±81.88b	301.78±251.95a	1799.77±123.71a
Sivri	832.81±230.87b	403.82±22.96c	10.13±1.35c	198.37±199.68a	119.43±20.53b	1552.19±205.55c
Tombul	624.11±40.15c	434.73±13.89b	14.13±1.41a	71.32±2.85c	106.44±19.28c	1691.86±84.41b
Sign.	**	**	**	**	**	**
Roasting Time (CT)						
10 min	731.65±261.04c	426.36±7.03a	12.62±2.21a	199.72±198.56a	113.35±22.34c	1651.58±145.16b
15 min	918.90±297.93b	423.35±4.16b	11.31±2.99b	97.46±38.45c	280.29±265.96a	1794.09±154.48a
20 min	1220.11±966.04a	427.71±40.69a	11.36±1.54b	125.48±93.39b	134.01±35.31b	1598.15±177.01c
Sign.	**	**	**	**	**	**
HV x CT	**	**	**	**	**	**

a-d: Means with different letters in the same column are significantly different ($P < 0.05$); Sign: Significance; ns: not significant ($P > 0.05$); *$P < 0.05$; **$P < 0.01$. (n=3) according two-way ANOVA and Duncan's multiple range test.

Hazelnuts have been found to be rich in minerals, including trace minerals such as calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P) (Rondanelli *et al.,* 2023). The calcium content in the hazelnut samples was found to vary between 624.11 and 1413.74 ppm. The highest calcium content was observed in the Karafındık hazelnut group, while the lowest was recorded in the Tombul hazelnut group. In addition, it was observed that the calcium contents in the samples increased with increasing roasting time, with the highest calcium content being recorded in the group roasted for 20 minutes. Karaosmanoğlu (2022) determined the calcium contents in organic and conventional hazelnuts to be 144.65 mg/100 g and 117.83 mg/100 g, respectively. As reported by Cosmulescu *et al*. (2013), the calcium (Ca) contents in various hazelnut samples were found to range from 72.07 to 130.92 milligrams per 100 grams.

The magnesium (Mg) contents in the hazelnut samples ranged from 403.82 to 438.86 ppm, with the highest Mg content observed in the Karafındık hazelnut group, followed by the Tombul and Sivri hazelnut groups. In contrast, no statistical differences were detected between 10 and 20 minutes of roasting time, while statistical differences were identified with 15 minutes. A substantial body of research has been conducted in the extant literature examining the mineral content in hazelnuts. For instance, Karaosmanoğlu (2022) ascertained the calcium contents in organic and conventional hazelnuts to be 143.36 mg/100 g and 127.69 mg/100 g, respectively. The results of this study are higher compared to the results of the above-mentioned study. It is thought that the observed results can be attributed to the applied temperature, variety and duration.

The copper contents in the hazelnut samples ranged from 10.13 to 14.13 ppm, with the highest concentrations observed in the Tombul hazelnut group, followed by the Karafındık and Sivri hazelnut groups. It was also observed that the copper contents in the hazelnut samples decreased as the roasting time increased. There are studies supporting the current copper results (Cosmulescu *et al*., 2013; Karaosmanoğlu, 2022).

The zinc (Zn) contents in the hazelnut samples exhibited a range from 71.32 to 198.37 ppm, with the highest Zn content observed in the Sivri hazelnut group, followed by the Karafındık and Tombul hazelnut groups. Additionally, it was observed that the Zn contents in the hazelnut samples decreased with an increase in roasting time. Karaosmanoğlu (2022) determined the zinc contents in organic and conventional hazelnuts to be 2.56 mg/100 g and 2.63 mg/100 g, respectively.

The Na contents in the hazelnut samples exhibited a similar trend, ranging from 106.44 to 301.78 ppm, with the highest Na content observed in the Karafındık hazelnut group, followed by the Sivri and Tombul hazelnut groups. It was also determined that the Na contents in the hazelnut samples increased with increasing roasting time, particularly in comparison to samples roasted for 10 minutes. Karaosmanoğlu (2022) determined the Na contents in organic and conventional hazelnuts to be 0.38 mg/100 g and 0.30 mg/100 g, respectively. As reported by Cosmulescu *et al.* (2013), the sodium (Na) contents in various hazelnut varieties ranged from 0.36 to 0.97 milligrams per 100 grams. As is known, the composition of hazelnut samples is influenced by a number of factors (Oz *et al.,* 2021). In addition to these factors, the applied processing parameters appear to affect the nutritional composition.

The K contents in the hazelnut samples ranged from 1552.19 to 1799.77 ppm, with the highest K content observed in the Karafındık hazelnut group, followed by the Tombul and Sivri hazelnut groups. Furthermore, it was determined that there were differences between the roasting time and the samples, and the lowest potassium content was found in the sample group roasted for 20 minutes. Karaosmanoğlu (2022) determined the K contents in organic and conventional hazelnuts to be 559.07 mg/100 g and 605.69 mg/100 g, respectively. In a similar vein, Cosmulescu *et al.* (2013) reported in their study that hazelnut samples had higher potassium contents than the results obtained in the present study.

The results from a general mineral analysis indicate significant variations in mineral contents among different hazelnut varieties. The Karafındık hazelnut group exhibited the highest mineral content, followed by the Pointed and Tombul hazelnut groups. However, the application of roasting time resulted in a decline in Cu, Zn, and K, while Ca, Na, and Mg levels increased, leading to statistical differences among the samples. A survey of the extant literature reveals a paucity of studies that have examined the effect of roasting on hazelnut samples (Özcan and Uslu, 2023; Apaydın *et al.,* 2024). Consequently, the possibility of comparing the present study's findings with those of other research results is greatly diminished.

Discrimination of hazelnut samples with PCA analysis. Principal component analysis (PCA) is a descriptive method that has been increasingly used in recent years, allowing for the visualization of the main directions of variability in a dataset, the relationships among samples, and the relationships between samples and variables (Kavcı *et al.,* 2025; Binici *et al.,* 2025; Engin *et al.,* 2025; Savaş, 2025). Principal Component Analysis (PCA) was performed to evaluate the effect of roasting time and hazelnut variety on Tombul, Sivri and Karafındık hazelnuts. The results of this analysis are presented in Figure 1 (a-d) as score scatterplot (a), loading scatter plot (b), biplot (c) and dendogram (d) plots graphs of hazelnut samples. The first two principal components (PC1 = 50.8% and PC2 = 16%) explained 66.8% of the variance. Significant differences were found between hazelnut varieties with respect to various quality parameters, antioxidant activities and mineral contents. As seen in Figures 1a and 1d, it was determined that four different groups were formed. While moisture, L*, Hue, b*, C* and Cu were collected on the left side of the figure, Zn, Mg, K, Ca, Na, TFC, TPC, ABTS, DPPH and a* were found on the right side (Figure 1b). Additionally, when the biplot was examined, it was observed that K-15 and K-20 showed the highest antioxidant activity and T-10 had the highest color parameters (Figure 1c). On the other hand, in addition to PCA analysis, heat map and cluster analysis were also performed. The results obtained are consistent with PCA analysis (Figure 1e).

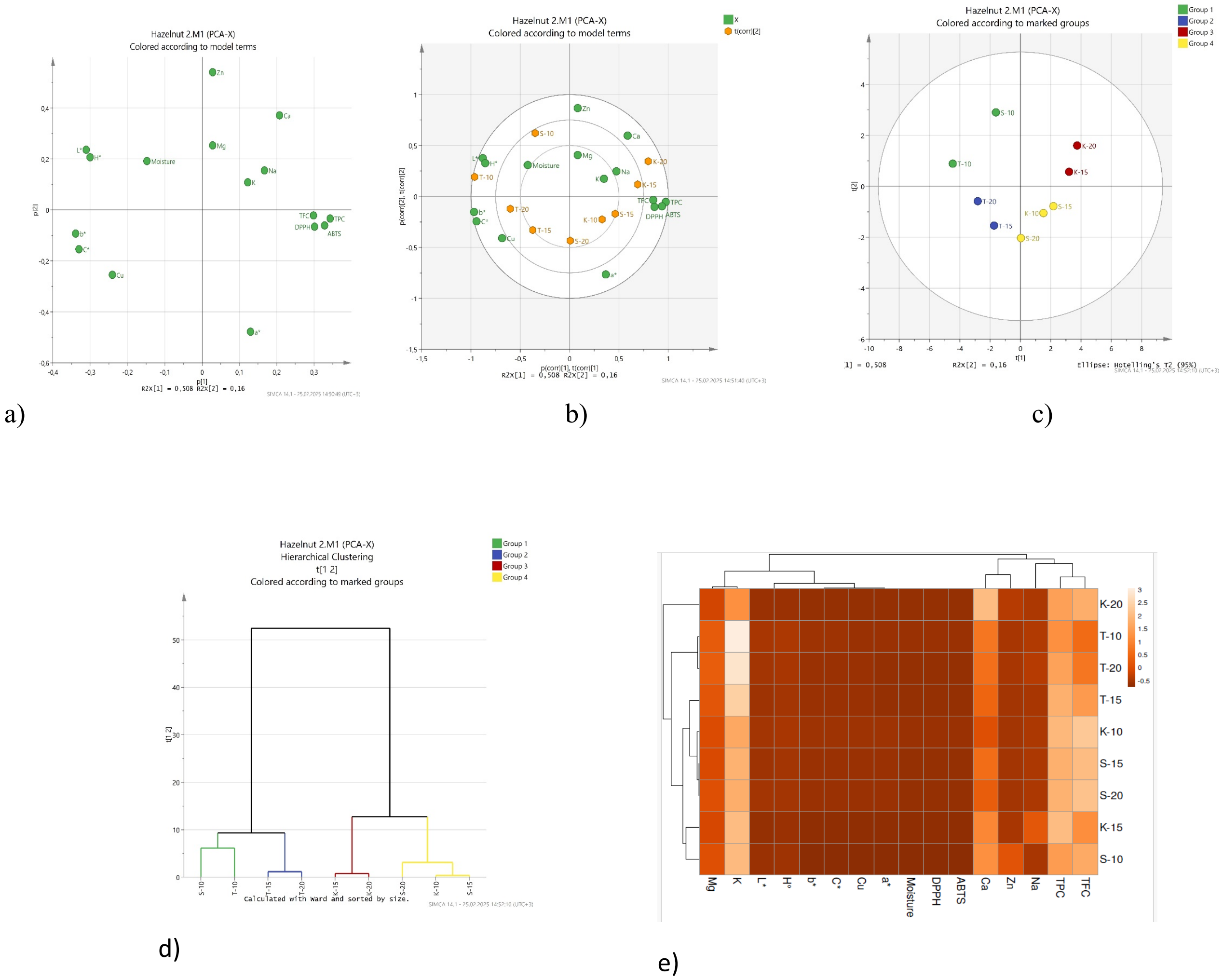

FIGURE 1. Hazelnut samples of score scatterplot (a), loading scatter plot (b), biplot (c) ve dendogram (d), heat map (e) figures. K: Karafındık (10,15,20 min); S: Sivri (10,15, 20 min); T:Tombul (10, 15, 20 min) (10, 15, 20 min).

4. CONCLUSIONS

Nuts are typically roasted prior to consumption, a process which imbues them with their distinctive flavor and aroma. However, this process can also result in nutritional degradation if the roasting conditions are not optimal. In this study, a range of hazelnut varieties were subjected to different roasting times to assess their impact on consumption and nutritional composition. The roasting experiments were conducted in a domestic oven. The study elucidates the impact of hazelnut variety and roasting time on various quality parameters, antioxidant activities, and mineral profiles. The results demonstrate that the Karafındık exhibited the highest antioxidant activity, and that the hazelnut group had the highest average mineral content. In general, an increase in roasting time resulted in changes in mineral content. Consequently, it was determined that both roasting time and hazelnut variety significantly affect nutritional composition.

RESEARCH DATA POLICY

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DECLARATION OF COMPETING INTEREST

The author of this article declares that there are no financial, professional or personal conflicts of interest that could have inappropriately influenced this work.

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Savaş: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing, Review & editing.

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