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Nut Quality Characteristics and Mineral Content of Chestnut Germplasm from Diverse Sources

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Abstract

Chestnut is among the important fruit species in human health and nutrition due to its rich biochemical content. This study determined the nut characteristics and mineral contents of chestnut genotype/cultivars grown in the same ecological conditions (same plot, same soil, same cultural practices, etc.). Correlation between chestnut genotypes/cultivars and physicochemical characteristics was determined by Principal Component Analysis (PCA) analysis. The first two principal components explained 50.1% of the variation. The highest Coefficient of Variation (CV) was for nut weight (45.05%), total phenol (46.13%), kernel color (a; -56.85%) and magnesium (60.01%). 'Bouche de Betizac', J9 genotype, A41 genotype and 'Akyüz' had the highest nut weight, highest total phenol, thinnest shell, and highest nitrogen (N), respectively. In this study, chestnut genotypes and cultivars had rich biochemical compounds, especially when the genotypes were compared with the cultivars. The J9 in terms of total phenol, J6 in terms of calcium, A41 in terms of thin shell, and A30 in terms of phosphorus and magnesium are promising.

Thirteen different types of chestnut grow naturally in Asia, Europe, and North America (Soylu, 2004). Today, European chestnut (*Castanea sativa*), Chinese chestnut (*Castanea mollissima*) and Japanese chestnut (*Castanea crenata*) species and hybrids are mostly cultivated for commercial nut production (Pereira-Lorenzo et al., 2016; Soylu, 2004). Chestnut is grown for its nuts, timber, and honey (Serdar et al., 2018). Chestnut species differ in terms of nut characteristics, growth characteristics, and resistance to diseases and pests. While *C. sativa*, from Turkey, stands out in terms of nut characteristics; *C. crenata* and *C. mollissima* are more resistant to diseases and pests (Pereira-Lorenzo et al., 2012). The most important factors threatening chestnut cultivation are chestnut blight (*Cryphonectria parasitica*) and root rot (*Phytophthora* spp.) and chestnut gall wasp (*Dryocosmus kuriphilus*). For example, Turkey's chestnut production fell from 90,000 tons in 1988 to 47.000 tons in 2001, due to chestnut blight (*C. parasitica*).

To obtain cultivars resistant to diseases and pests and expand the variation in our genetic resources, some hybrid chestnut genotypes were imported to Turkey as seeds in 2004 from the Connecticut Agricultural Research Station in the USA. The seeds from the controlled crossing study were evaluated for plant growth, yield, and pomological characteristics between 2006 and 2014. In addition, in 2014, 'Bouche de Betizac', which is known to be resistant to chestnut gall wasp (*D. kuriphilus*), was included. Although many studies have been conducted on these chestnut cultivars and genotypes in Turkey (Akyüz, 2019; Akyüz & Serdar, 2020; Çil, 2018; Macit et al., 2018), studies on nut characteristics have been limited.

Chestnut is a unique and healthy fruit with its high starch, carbohydrate and protein content and low fat and cholesterol ratio (Ertürk et al., 2006). Phenology, morphology

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and biochemical contents of fruits are affected by factors such as ecological conditions, cultural practices and genetic characteristics (Geçer et al., 2020). Although phenolics, which are secondary metabolites, are very important for human health (Quideau et al., 2011), studies to determine phenolics of nuts are very limited in chestnuts. In recent years, studies were conducted to determine the biochemical contents of various tissues of chestnut trees. Tuyen et al. (2017) examined the shell, flower, inner membrane, nuts and leaves of the chestnut in terms of total phenolic, flavonoid and tannin contents. They found that the highest total phenolic and tannin content was in the testa and concluded that Chinese chestnut (*C. mollissima*) was a good source of antioxidants. In another study, Gonçalves et al. (2010) investigated the effects of boiling and roasting practices on chestnuts and found that these heating methods changed the primary and secondary metabolite contents. Liu et al. (2017) stated that steam cooking was better for preserving phenolics. This study investigated nut characteristics, total phenolic content, and macro and micronutrient content of some chestnut cultivars and genotypes grown in Turkey.

Materials and Methods

This study was carried out at the Black Sea Agricultural Research Institute (Samsun/Turkey) between 2019 and 2020.

Plant Materials. The material of the study consists of cultivars and genotypes obtained from European chestnuts, Japanese chestnuts and interspecific hybrids (Table 1). 'Erfelek' (*C. sativa*) was selected from Erfelek district of Sinop (Turkey) in 1992 and registered by the Seed Registration and Certification Center in 2009 (TTSM, 2021). It is a mid-season cultivar and is productive and suitable for fresh consumption (Serdar et al., 2013). 'Marigoule' and 'Bouche de Betizac' were developed at the French National Research Institute of Agriculture (INRA-Paris) by natural hybridization of *C. sativa* (female) and *C. crenata* (male) (Chapa and Verlhac, 1978). 'Marigoule' is a popular cultivar for its fast-growing characteristic and tolerance to the chestnut blight (C. *parasitica*) (Hennion, 2010). 'Bouche de Betizac' is male sterile and is resistant to the chestnut gall wasp (*D. kuriphilus*) (Sartor et al., 2007). In 2004, a hybridization study was performed at the Connecticut Agricultural Research Institute in the USA. Two Japanese chestnut (*C. crenata*) genotypes resistant to chestnut blight and late spring frost were hybridized and 'King Arthur' (*C. mollissima* x *C. seguinii*) and 'Lockwood' (*C. crenata* x *C. sativa* x *C. dentata*) were also hybridized (Macit et al., 2018). In 2005, Ondokuz Mayıs University imported the seeds from the USA. Seeds were planted in the Black Sea Agricultural Research Institute Plant Genetic Resources Land Gene Bank orchard cooperating with Ondokuz Mayıs University (Serdar & Macit, 2010). J6, J9, J17, J29 genotypes were obtained from the first hybridization and 'Akyüz', 'Ali Nihat', 'Macit 55' and A8, A11, A30, A41 genotypes were from the second hybridization (Macit et

Table 1. The cultivars/genotypes tested in the study.

Genetic Background	Cultivars	Genotypes
C. sativa	'Erfelek'	
C. crenata		J6, J9, J17, J29
C. sativa x *C. crenata*	'Marigoule'	
	'Bouche de Betizac'	
'King Arthur' (*C. mollissima* × *C. seguinii*)	'Akyüz',	A8, A11, A30, A41
×	'Ali Nihat',	
'Lockwood' (*C.crenata* × *C. sativa* × *C. dentata*)	'Macit 55'	

al., 2018, TTSM, 2021).

Tree Culture. The study material is preserved in the field gene bank of the chestnut genetic resources in the B1 parcel of the Black Sea Agricultural Research Institute, where trees were planted in 2005 at a spacing of 7×5 m. This region has a mild climate, and it is neither excessively cold and hot in winters and summers, and spring frosts rarely occur. The altitude of the B1 parcel is 4m and it receives approximately 700mm rain per year. The soil texture is clayey and it has 7.19 pH. Its electrical conductivity is 0.2dS/m and organic matter content is 2.31%. In the chestnut genetic parcel, there is one tree for each cultivar or genotype. Plants needed no irrigation due to the rainfall. Dry branches were removed at the beginning of the spring.

Pomological characteristics of nuts. In 2019 and 2020, nuts were harvested from one tree for each genotype or cultivar when their burs were open naturally and brought directly to the laboratory and analyzed immediately. Nuts were divided into three samples of 15 nuts, and a total of 45 nuts were measured every year. Middle nuts were not used in the study. Some initial pomological characteristics of cultivars/ genotypes were recorded and included nut weight (with 0.01 g sensitive scales), shell thickness (with 0.01 mm sensitive caliper), numbers of nuts per bur, shell color and nut color (with colorimeter (Minolta CR-310)). Shell thickness, shell color and nut color were measured from the middle of the nuts. For this purpose, L, a, b, c and h values were measured. The L* value ranges from 0 (black) to 100 (white). Chroma (C) is the departure from white toward pure hue color and represents brightness (McGuire, 1992). Hue (H) angle quantifies color, where 0º=purplish red, 90º=yellow, 180º=bluish green, and 270º=blue (Voss, 1992).

Chemical analyses of nuts. N analysis was done as reported by Horneck et al. (1998), and the P analysis was performed with the method of Kacar (1984). Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), ferrum/iron (Fe), manganese (Mn) and zinc (Zn) were measured by atomic absorption spectrometry in 2020 (Kacar, 1984). For total phenolic content (TPC), the extraction process 5.0 g of chestnut sample was crushed in a mortar, to which 20 ml of 80% ethyl alcohol to 5 g was added. Then, samples were separated from the pulp via centrifuging at 12 000×g at 4 °C for 35 min. The total phenol was detected using an automated UV–Vis spectrophotometer (Shimadzu, Kyoto, Japan) by adhering to the principles established by Singleton and Rossi (1965) in 2020. The results were presented as % (gallic acid equivalent) fresh weight (fw).

The minimum (Min.) and maximum (Max.) values, standard deviation (SD), and coefficient of variations (CV%; SD/ mean×100) were calculated for each trait. The coefficient of variation was used as a variability index. Principle component analysis (PCA) was used to find which traits were most strongly correlated with each principal component with R software (ggplot2) (Wickham, 2016).

Results and Discussion

Nut characteristics and color of nuts. Descriptive statistics are presented in Table 2. Among the nut characteristics, nut weight had the highest CV (45.05%) and kernel color (h) had the lowest CV (4.07 %) (Table 2). Nut traits with low within-tree variation are considered stable because they have higher heritability (Yao and Mechlenbacher, 2000) and are much more homogeneous among samples (Khadivi et al., 2019). Nut weights ranged from 5.76 to 23.95 g (Table 3). The biggest nuts were obtained from ‘Bouche de Betizac’ and ‘Marigoule’ (23.95 and 20.70 g respectively). The smallest chestnuts were harvested from J9, A30, J29, J17 and J6. In other studies with chestnut, nut weight varied between 4.9-16.1g (Bolvansky and Mendel, 1999) 4.6-14.4 g (Serdar et al., 2007), 10.7-31.7 g (Koyuncu et al., 2008), 1.69-3.89 g (Yu-min et al., 2008), 5.7-11.9 g (Yarılgaç

Table 2. Descriptive statistics for horticultural, nutrient, and bioactive traits.

No.	Properties	Abbreviation	Mean	CV (%)
	Nut and color characteristics			
1	Nut weight (g)	FW	11.98 ± 5.40	45.05
2	Number of nuts in bur	NNB	2.24 ± 0.38	16.81
3	Shell thickness (mm)	ST	0.74 ± 0.20	27.04
4	Shell brigtness (L)	SC (L)	31.66 ± 2.65	8.36
5	Shell color (c)	SC (c)	19.42 ± 2.78	14.32
6	Shell color (h)	SC (h)	48.35 ± 4.12	8.51
7	Kernel brigtness (L)	KC (L)	81.82 ± 4.61	5.63
8	Kernel color (c)	KC (c)	31.33 ± 4.07	13.00
9	Kernel color (h)	KC (h)	95.83 ± 3.90	4.07
	Total phenolic and mineral contents			
10	Total Phenol (%)	TP	6.69 ± 3.09	46.13
11	Nitrogen (ppm)	N	13322.64 ± 2092.39	15.71
12	Phosphorus (ppm)	P	1639.04 ± 273.60	16.69
13	Potassium (ppm)	K	5777.40 ± 883.50	15.29
14	Calcium (ppm)	Ca	388.07 ± 123.55	31.84
15	Magnesium (ppm)	Mg	613.26 ± 82.26	13.41
16	Copper (ppm)	Cu	7.73 ± 1.42	18.42
17	Ferrum/Iron (ppm)	Fe	13.54 ± 3.32	24.50
18	Manganese (ppm)	Mn	5.07 ± 3.04	60.01
19	Zinc (ppm)	Zn	12.13 ± 1.71	14.11

Table 3. Some nut characteristics and total phenolic content of chestnut genotypes and cultivars.

Cultivars / Genotypes	Nut weight (g)	Number of nuts/ bur	Shell thickness (mm)	Total phenol (%)
Erfelek	10.63 ± 0.52	2.16 ± 0.26	0.55 ± 0.08	1.82 ± 0.01
J6	8.62 ± 0.43	2.50 ± 0.21	0.77 ± 0.06	1.53 ± 0.01
J9	5.76 ± 0.66	2.21 ± 0.18	0.68 ± 0.05	10.16 ± 0.11
J17	8.40 ± 0.35	2.22 ± 0.22	0.57 ± 0.11	9.62 ± 0.07
J29	6.53 ± 1.87	2.46 ± 0.28	0.56 ± 0.13	8.93 ± 0.09
Bouche de Betizac	23.95 ± 4.04	2.33 ± 0.21	0.98 ± 0.13	7.85 ± 0.05
Marigoule	20.70 ± 0.26	2.16 ± 0.17	0.91 ± 0.08	9.75 ± 0.13
A8	10.62 ± 1.15	1.62 ± 0.36	0.70 ± 0.16	7.14 ± 0.04
A11	10.30 ± 2.04	2.14 ± 0.13	0.96 ± 0.13	6.55 ± 0.01
A30	5.81 ± 0.52	2.19 ± 0.32	0.61 ± 0.14	7.57 ± 0.02
A41	13.00 ± 1.82	2.48 ± 0.17	0.53 ± 0.03	1.50 ± 0.01
Akyüz	15.24 ± 0.76	2.65 ± 0.22	1.10 ± 0.12	9.01 ± 0.06
Ali Nihat	13.70 ± 0.37	1.56 ± 0.12	0.77 ± 0.12	3.93 ± 0.01
Macit 55	14.44 ± 0.78	2.75 ± 0.07	0.64 ± 0.05	8.33 ± 0.90

et al., 2009), 3.8-8.8 g (Idžojtić et al., 2009), 5.03-10.10 g (Akbulut et al., 2017), 5.23-16.27 (Pandit et al., 2011), 7.2-14.0 g (Bilgen and Bostan, 2018) and 5.87-11.13 g (Ozkan et al., 2020). Yu-min et al. (2008), conducted their study on Chinese chestnut (*C. mollissima*). As indicated before, they had the smallest nut weight. In our study, the smallest nuts were harvested from Japanese chestnut (*C. crenata*) genotypes. Nut weight is affected by many factors, mainly by genetics. For fresh market and industrial chestnut products bigger nuts are preferred (more than 18 g) (Ayfer et al., 1977).

However, smaller nuts also can be used for industrial chestnut products.

The number of nuts per bur (NNB) and shell thickness values varied between 2.75 - 1.56 and 1.10 - 0.53 mm, respectively. Higher NNB can be related to higher yield. Shell thickness is an important factor for chestnuts. Thicker shells can help to protect nuts from Chestnut weevil (*Curculio elephas (Gyllenhal)*) and extend the storage period. However, it can reduce the quality of nuts for processing. The range of shell color values of L, c and h were 34.93-28.27, 22.72-14.46 and 56.01-43.11, respectively (Table 4). For industrial chestnut products shell color and brightness are not an important factor (Ayfer et al., 1977). For the fresh market, consumers prefer typical chestnut brown nuts rather than dark-colored nuts (Ayfer et al., 1977). Kernel color affects nut quality and attractiveness. The kernel's brightness (L) ranged from 85.88 for 'Marigoule' to 72.63 for J29 (Table 5). Ayfer et al. (1977), divided kernel color into three categories: light cream, cream

Table 4. Color values of nut shells of chestnut genotype and cultivars.

Cultivars / Genotypes	L	a	b	c	h
Erfelek	29.15 ± 0.64	11.65 ± 0.78	16.72 ± 1.64	20.49 ± 1.62	54.59 ± 2.25
J6	30.81 ± 0.73	11.65 ± 1.14	12.55 ± 1.87	17.18 ± 2.13	46.29 ± 1.92
J9	34.93 ± 4.70	11.91 ± 0.86	14.63 ± 2.02	19.04 ± 1.49	51.62 ± 5.27
J17	34.27 ± 4.04	11.52 ± 1.49	16.11 ± 2.09	20.47 ± 1.75	51.16 ± 3.83
J29	34.35 ± 0.91	12.12 ± 0.32	18.80 ± 1.17	22.50 ± 1.02	56.01 ± 1.79
Bouche de Betizac	29.12 ± 0.69	11.24 ± 0.78	12.12 ± 0.25	16.57 ± 0.70	46.43 ± 1.14
Marigoule	28.66 ± 0.88	10.50 ± 1.20	9.92 ± 1.65	14.46 ± 2.00	43.11 ± 1.52
A8	33.35 ± 0.50	15.51 ± 0.47	16.59 ± 0.82	22.72 ± 0.91	46.88 ± 0.63
A11	32.67 ± 0.39	14.66 ± 0.78	16.85 ± 1.75	22.39 ± 1.85	48.39 ± 1.34
A30	32.79 ± 0.60	13.04 ± 0.55	15.26 ± 1.35	20.10 ± 1.37	48.95 ± 1.43
A41	30.54 ± 0.92	11.11 ± 0.44	11.46 ± 1.44	15.98 ± 1.35	45.58 ± 2.21
Akyüz	31.52 ± 0.45	13.77 ± 0.21	13.57 ± 0.41	19.36 ± 0.36	44.27 ± 0.47
Ali Nihat	28.27 ± 0.74	12.35 ± 0.45	13.49 ± 0.72	18.83 ± 0.64	45.57 ± 0.68
Macit 55	32.83 ± 0.26	14.48 ± 0.40	16.29 ± 0.52	21.84 ± 0.63	48.05 ± 0.24

Table 5. Color values of kernels of chestnut genotype and cultivars.

Cultivars / Genotypes	L	a	b	c	h
Erfelek	79.67 ± 0.98	2.16 ± 0.54	25.64 ± 0.74	25.75 ± 0.72	85.11 ± 1.26
J6	79.65 ± 2.45	-2.68 ± 1.02	28.24 ± 2.97	28.49 ± 3.00	94.47 ± 1.55
J9	76.52 ± 9.39	-2.44 ± 2.45	33.90 ± 2.05	34.30 ± 1.79	92.63 ± 6.21
J17	78.24 ± 1.13	-2.97 ± 0.65	34.92 ± 4.37	35.08 ± 4.36	94.46 ± 1.17
J29	72.63 ± 4.19	-2.55 ± 0.24	32.65 ± 0.53	34.35 ± 0.53	94.38 ± 1.11
Bouche de Betizac	81.74 ± 1.12	-3.65 ± 0.63	34.87 ± 0.71	35.08 ± 0.75	95.89 ± 1.04
Marigoule	85.88 ± 2.14	-3.21 ± 0.98	24.83 ± 3.70	25.07 ± 3.77	97.30 ± 1.22
A8	85.55 ± 0.13	-4.87 ± 0.25	31.90 ± 1.17	32.27 ± 1.18	98.70 ± 0.23
A11	82.29 ± 1.09	-4.29 ± 0.72	34.28 ± 1.17	34.59 ± 1.22	96.98 ± 1.03
A30	84.44 ± 0.77	-5.03 ± 0.41	36.50 ± 1.95	36.85 ± 1.98	97.87 ± 0.23
A41	84.52 ± 1.26	-4.38 ± 0.46	29.76 ± 0.92	30.09 ± 0.98	98.38 ± 0.62
Akyüz	85.40 ± 1.06	-4.59 ± 0.23	29.23 ± 1.81	29.59 ± 1.82	98.91 ± 0.08
Ali Nihat	84.14 ± 0.37	-4.14 ± 0.20	28.18 ± 0.35	28.54 ± 0.91	98.11 ± 0.43
Macit 55	84.85 ± 0.14	-4.29 ± 0.36	28.29 ± 1.55	28.62 ± 1.58	98.49 ± 0.45

Table 6. Macro nutrient contents of chestnut genotype and cultivars (ppm).

Cultivars / Genotypes	N	Ca	K	P	Mg
Erfelek	11352.00 ± 43.27	379.27 ± 2.08	5594.56 ± 75.83	1088.86 ± 9.850	554.71 ± 2.68
J6	12230.67 ± 206.9	731.38 ± 6.72	4860.36 ± 42.48	1876.98 ± 9.710	744.49 ± 9.87
J9	10316.67 ± 104.1	272.67 ± 2.62	5016.70 ± 21.57	1525.74 ± 21.50	513.11 ± 5.20
J17	14024.00 ± 67.29	428.97 ± 3.45	5003.89 ± 24.15	1509.23 ± 13.11	555.92 ± 5.11
J29	14921.67 ± 31.63	342.90 ± 4.92	4054.83 ± 51.73	1646.95 ± 35.74	587.83 ± 5.78
Bouche de Betizac	12054.00 ± 75.97	202.97 ± 0.76	5916.95 ± 16.73	1399.29 ± 14.33	504.54 ± 6.81
Marigoule	10618.67 ± 159.5	409.05 ± 6.13	4940.69 ± 114.54	1365.77 ± 17.28	622.95 ± 7.55
A8	12382.67 ± 30.02	284.77 ± 2.09	6295.03 ± 34.04	1375.11 ± 12.07	595.19 ± 0.80
A11	15830.00 ± 10.00	331.69 ± 4.55	5965.74 ± 24.95	1864.34 ± 8.320	697.66 ± 6.80
A30	14471.67 ± 26.31	530.19 ± 5.70	6530.38 ± 72.12	2114.43 ± 22.35	768.50 ± 2.98
A41	14358.33 ± 187.1	382.81 ± 5.64	6112.66 ± 57.50	1757.73 ± 12.13	548.74 ± 6.00
Akyüz	16286.00 ± 23.07	428.97 ± 3.45	7301.97 ± 81.76	1932.85 ± 32.54	590.63 ± 2.62
Ali Nihat	16554.00 ± 82.16	371.81 ± 2.74	6433.67 ± 14.22	1865.08 ± 3.750	708.09 ± 9.59
Macit 55	11116.67 ± 115.1	335.56 ± 1.69	6856.24 ± 13.81	1624.25 ± 31.52	593.21 ± 1.79

Table 7. Micro nutrient contents of chestnut genotype and cultivars (ppm).

Cultivars / Genotypes	Cu	Fe	Mn	Zn
Erfelek	5.15 ± 0.04	9.94 ± 0.07	15.05 ± 0.41	9.76 ± 0.05
J6	10.07 ± 0.13	21.76 ± 0.32	5.51 ± 0.09	13.66 ± 0.03
J9	5.80 ± 0.07	12.69 ± 0.15	2.85 ± 0.03	8.70 ± 0.11
J17	8.63 ± 0.12	19.45 ± 0.27	6.58 ± 0.10	13.49 ± 0.08
J29	10.16 ± 0.16	8.93 ± 0.03	4.83 ± 0.02	13.17 ± 0.14
Bouche de Betizac	8.04 ± 0.11	11.26 ± 0.27	2.75 ± 0.06	12.56 ± 0.05
Marigoule	6.76 ± 0.03	12.51 ± 0.16	2.71 ± 0.02	13.25 ± 0.10
A8	7.59 ± 0.14	12.30 ± 0.11	5.79 ± 0.08	10.34 ± 0.03
A11	7.68 ± 0.16	12.57 ± 0.15	3.52 ± 0.02	14.48 ± 0.05
A30	7.60 ± 0.12	14.15 ± 0.33	3.60 ± 0.01	13.05 ± 0.03
A41	7.62 ± 0.11	13.84 ± 0.21	3.79 ± 0.06	12.12 ± 0.15
Akyüz	8.63 ± 0.12	14.59 ± 0.04	4.54 ± 0.05	13.09 ± 0.10
Ali Nihat	8.43 ± 0.08	13.46 ± 0.11	5.55 ± 0.03	12.28 ± 0.03
Macit 55	6.09 ± 0.04	12.08 ± 0.21	3.98 ± 0.07	9.83 ± 0.03

and dark cream. For both fresh market and industrial products light cream nuts are preferred. Serdar et al. (2011) reported that the 'Serdar' and 'Marigoule' had light cream and cream kernel color.

Total phenolic and mineral contents of nuts. The CV value for total phenolic was 46.13% (Table 2). The CV for manganese (60.01%) was the highest and magnesium (13.41%) was the lowest among the elements. The highest and lowest total phenol content, effective in many physiological developments and the formation of nut quality, were 10.16% for J9 and 1.50% for A41 (Table 3). Akbulut et al. (2017) determined that the total polyphenol content of chestnut genotypes ranged from 1.66 g GAE/kg to 2.56 g GAE/kg. Suárez et al. (2012) determined that total phenol contents were a mean value for all the samples of 2.84 g gallic acid kg^{-1}. Cosmulescu et al. (2020) reported that the total phenolic content of 6 chestnut cultivars ranged from 1.65 mg GAE/g to 19.60 mg GAE/g. In hazelnut studies, total phenolic compound ranged between 3.74-8.14 TE/g (Altun et al., 2011), 54.8-149.3 mg GAE/kg (Schmitzer et al., 2011), 1.40 GAE, g/kg (Ghirardello, 2013) and in walnut, 954-2106 mgGAE/100g (Tosun et al., 2011), 17.60-30.45 mg GAE/g DW (Amini and Ghoranneviss, 2016), 3791.13–9408.6 mg GAE/100 g (Trandafir and Cosmulescu, 2020). Results obtained in this study largely overlap with the results of other researchers. Different results may be caused by ecological factors, cultural practices and genetic factors. Chestnuts are an important source of total phenols with antioxidant properties. Dietary intake of phenolic compounds is not recommended (Suárez et al., 2012), but the American Cancer Society (Krebs-Smith et al., 1995) determined 100 mg of flavonoids per day as an adequate amount for the prevention of cancer and degenerative diseases. Therefore, it is obvious that this type of nut has an important place in human health and nutrition in terms of biochemical compound content.

The nuts' nitrogen (N) content was higher than other elements and varied between 16554.00 ppm for 'Ali Nihat' to - 10316.67 ppm for J9 (Table 6). J6 had the highest Ca (731.38 ppm) and 'Bouche de Betizac' had the lowest Ca (202.97 ppm). Potassium (K), phosphorus (P) and magnesium (Mg) contents were 7301.97 ppm for 'Akyüz' - 4054.83 ppm for J29, 2114.43 ppm for A30 - 1088.86 ppm for 'Erfelek' and 768.50 ppm for A30 – 504.54 ppm for 'Bouche de Betizac'), respectively (Table 6). For the micronutrients, the highest Cu, Fe, Mn and Zn levels were obtained from J29, J6, 'Erfelek' and A11, respectively (Table 7). The mineral content of chestnuts (*C. sativa* Mill.) grown in different regions of Turkey (Özel, 2015) showed that Ca varied from 2040 to 2937 mg/kg and this range is much smaller than we obtained in the present study. In another study crude protein content of chestnuts varied between 4.4% and 6.3% (Er et al., 2013). In a study investigating the mineral content of 'Judia' chestnut, the contents of phosphorus, potassium, calcium magnesium, copper, iron, manganese, and zinc were reported to be 130 mg/100g, 905 mg/100g, 40.80 mg/100g, 66.7 mg/100 g, 1.93 mg/100g, 10.87 mg/100g, 5.60 mg/100g and 1.43 mg/100g, respectively (Borges et al., 2008). Since ecological conditions, cultural practices, and genetic factors influence nutrient levels of nuts (Er et al., 2013), we expected differences between genotypes/cultivars in terms of nutrient content.

Principal components analysis of nuts. Principal Component Analysis (PCA) was performed to determine the correlation between chestnut genotype/varieties and various traits. The primary purpose of PCA is to minimize the number of influencing factors while segregating individuals. Because of this, the superior feature has been frequently used in breeding and population genetics studies in recent years (Hassemi and Khadivi, 2020). The first principle component explained 31.8% of the variation and the second principle component explained 19% (Fig. 1). Genotypes/varieties and biochemical characteristics were distributed in four different regions on the PCA plane. 'Erfelek' and J6 were statistically different from other cultivars in terms of biochemical contents. 'Bouche de Betizac', 'Marigoule' and 'Macit 55' were in the first region; 'Akyüz' and A11 were in the second region; J9, A8 and 'Erfelek' were in the third region; and A41, J29, J17, J6, 'Ali Nihat' and A30 all grouped in the fourth region. Shell thickness was positively correlated with K, and shell thickness and K were negatively correlated with Mn. N, Zn, P and Cu were in the second region in the PCA plane and were positively correlated. In general, 'Erfelek' came to the fore in terms of manganese content and J6 genotype in terms of calcium content. Nut weight and total phenol were positively correlated, whereas they were both negatively correlated with Ca, Fe and Mg.

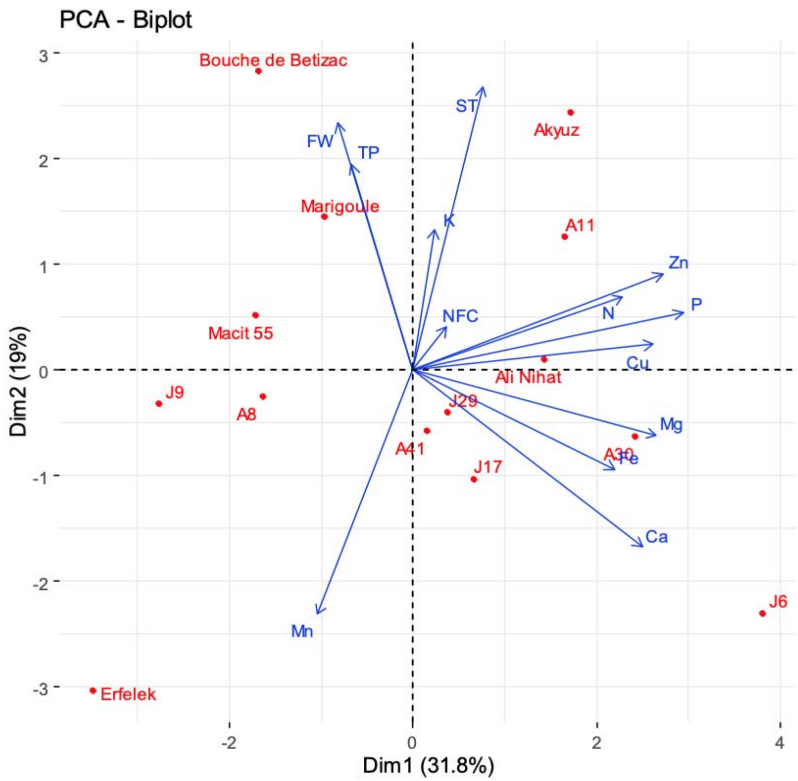

Figure 1. Biplot showing variation among chestnut cultivars and genotypes according to nut characteristics and mineral contents by principal component analysis (PCA).

Conclusion

In the study, nut characteristics and mineral content of the six chestnut cultivars and eight genotypes were determined. Nut weight of 'Bouche de Betizac' was higher than other genotypes and cultivars. In terms of total phenolic contents, J9 was the highest. A41 had the thinnest shell. N was the highest element, followed by K, P and Mg, respectively. 'Ali Nihat' had the highest N content, 'Akyüz' had the highest K content, J6 had the highest calcium content, and A30 had the highest P and Mg content. This is the first time these genotypes were examined in detail, and they will be evaluated further and used for breeding cultivars to increase the world chestnut gene resources.

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