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Effect of altitude, shooting period, and tea grade on the catechins, caffeine, theaflavin, and thearubigin of Turkish black tea

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Abstract: The effect of altitude, shooting period, and tea grade on the catechins and caffeine contents of Turkish black tea was investigated. The experimental factors significantly affected all of the parameters analyzed. Epigallocatechin gallate was the major catechin of black tea (0.719–1.007 g 100 g^{-1} dm) followed by epigallocatechin (0.627–0.791 g 100 g^{-1} dm). Additionally, caffeine (1.810–2.175 g 100 g^{-1} dm), theaflavin (3.201–6.000 µmol g^{-1}), and thearubigin (8.577–12.635 g 100 g^{-1} dm) contents were determined. Samples of tea grown at high altitude generally produced a considerably greater amount of the catechins that improve tea quality. Shooting period, which is specific to tea cultivation in Turkey, significantly affected almost all of the quality parameters of black tea. Tea produced in the first shooting period contained more catechins than the samples plucked in the following shooting periods. Dust and orange pekoe 1 contained the most catechins of the tea grades analyzed.

Key words: Altitude, black tea, catechins, caffeine, shooting period

1. Introduction

Tea (*Camellia sinensis* L.) is one of the world's oldest beverages with approximately 5000 years of history and is the second most consumed nonalcoholic beverage in the world after water. The world's tea production in 2014 was 5,561,339 MT with 226,800 MT (FAOSTAT-Tea Production, www.fao.org) of it being produced in Turkey, a country with more than 76,000 ha of tea fields.

Turkey has produced tea for more than 80 years. Unlike other tea-producing countries, the distribution of tea plantations is atypical in Turkey. After a severe winter, the temperature suddenly rises in the spring. The tea season starts in May, and the plant is ready for harvesting at nearly the same time at different locations in the eastern Black Sea region of the country. Tea is plucked three times until October depending on the weather conditions. Therefore, there are three shooting (flushing) periods in a season. However, there can be a fourth shooting period caused by variations in the weather conditions, especially in areas of low altitudes along the Black Sea coast. Almost all of the tea in Turkey is processed into black tea (Ozdemir et al., 1992, 1993; Tontul et al., 2013). However, green tea and white tea processing in Turkey have become more commonplace during the last decade.

Black tea consists of a considerable amount of bioactive compounds and phytochemicals (Serpen et al., 2012; Kelebek, 2016). Black tea contains theaflavins (TFs), thearubigins (TRs), catechins, and phenolics. Among these compounds, TFs are responsible for the astringency and orange/red color, while TRs give the deep red color to tea. TRs are the most abundant group of phenolic pigments found in black tea, accounting for an estimated about 60% of the solids in a typical black tea infusion (Kuhnert, 2010). Their biological activity on a molecular basis has recently been reviewed (Kuhnert, 2013). Additionally, tea phytochemicals are reported to possess antioxidant, antithrombogenic, and antiinflammatory activities and to protect against different diseases. da Silva Pinto (2013) and Khan and Mukhtar (2007) recently reviewed the various health benefits of tea components.

Although processing systems and technologies have an impact on the quality and properties of black tea (Owuor and McDowell, 1994; Tomlins and Mashingaidze, 1997), the genetic properties of the tea bushes and the environmental conditions are the primary factors affecting these variables (Ozdemir et al., 1993). Among these factors, clones (Owuor and Obanda, 2001), altitude (Owuor et al., 1990), geographical location (Zhang et al., 2018), varying soil

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conditions (Owuor et al., 2000), pruning (Ravichandran, 2004; Asil, 2008), and other environmental factors (Dutta et al., 2010; Zhang et al., 2018) have been investigated in different types of tea. Additionally, shooting period also affects the quality and properties of the black tea within Turkey, unlike in other tea-producing countries. The quality of the tea leaves is highly related to shooting periods. For example, the leaves declined in quality from the first to the third shooting period (Ozdemir et al., 1992; Balci and Özdemir, 2016).

Black tea is produced by different processing systems in Turkey as well as in the rest of the world. The four main processes of tea manufacture are orthodox, crushing/tearing/curling (CTC), rotorvane, and Lawrie tea processing (LTP). The main difference between these systems involves the rolling method applied. These methods can also be combined. A special application of a rotorvane and orthodox combined system called the Çaykur method has been used increasingly in Turkey (Ozdemir et al., 1993; Sari and Velioglu, 2013).

The black tea that is produced is generally classified into seven grades using five different sieves from 8- to 30-mesh. Black tea that is retained at 10-, 12-, and 20-mesh has no broken parts and is classified as grade 1, 2, and 3, respectively. These grades are generally recognized as orange pekoe. Tea particles on 8-mesh sieves are broken using different crushers and sieved again using the same system. The black tea remaining at 10-, 12-, and 20-mesh is classified as grade 4, 5, and 6, respectively. These grades are named broken orange pekoe. Tea passing through the 30-mesh sieve is designated as grade 7 or dust (Özdemir et al., 1999).

To the best of our knowledge, no research on the effect of altitude, shooting period, and tea grade on the properties of Turkish black tea has been reported. This study aimed to identify the effects of these factors on moisture content, water extraction yield, total phenolic content, catechin composition, and caffeine and condensed phenolic (thearubigin and theaflavin) contents of black tea.

2. Materials and methods

2.1. Material

The leaves of tea (*Camellia sinensis* var. *sinensis*) were harvested as a group of two or three leaves and a bud or mature leaves without a bud during three consecutive shooting periods (May, July, and September) from two different altitudes such as İyidere and Taşçılar. İyidere is a small town on the Black Sea coast with intensive tea plantations. In this town, tea plants are grown from sea level to 150 m in altitude. Taşçılar is 15 km away from the Black Sea coast, also an intensive tea region, with an altitude of 200 to 600 m. After plucking, the leaves were immediately processed into black tea according to the Turkish Tea Board (ÇAYKUR) standards and quality with seven different [orange pekoe (OP), broken orange pekoe (BOP), and dust] grades and were packaged separately for further analyses. The first three grades were referred to as OP1, OP2, and OP3; the next three grades as BOP1, BOP2, and BOP3; and the last grade as dust.

2.2. Moisture content and extraction yield

The moisture content of all of the samples was determined by drying in an oven (Memmert, Germany) at 70 °C until the weight was constant.

About 2 g of tea sample was added to 200 mL of hot water (90–95 °C) in a 500-mL round bottom flask, refluxed for 1 h, and cooled down to room temperature. The volume of the slurry was made up to 500 mL with distilled water at room temperature and filtered through coarse filter paper. Then 25 mL of filtrate was dried in an oven (Memmert, Germany) at 70 °C until a constant weight was obtained. The extraction yield was calculated according to Eq. (1).

$$EY = (DE \times 100)/W, \quad (1)$$

where EY is the extraction yield, DE is the dry matter of the total extract, and W is the weight of the sample dry matter (Gürses and Artık, 1987).

2.3. Preparation of extract

Phenolic extracts were prepared according to Zuo et al. (2002). First 50 mL of aqueous methanol (80%) containing 0.15% HCl was poured onto 2 g of tea sample, and the phenolic compounds were extracted at 40 °C for 3 h and filtered through coarse filter paper. The filtrate was used for the total phenolic content determination by Folin–Ciocalteu assay and the filtrate was further filtered through 0.45 µm of nylon membrane filter before HPLC analysis.

2.4. Total phenolic content

The total phenolic content was determined by the Folin–Ciocalteu method (Asami et al., 2003). For this purpose, 1 mL of the sample phenolic extract was treated with 5 mL of 0.2 N Folin–Ciocalteu's phenol reagent and 4 mL of Na_2CO_3 (75 g L^{-1}). After vortexing, the mixture was incubated at room temperature for 1 h. The absorbance of the final solution was recorded with a spectrophotometer (UV-Vis 160A, Shimadzu, Japan) at 765 nm using a blank of 1 mL of 80% aq. methanol. The results were calculated as the gallic acid equivalent (mg of GAE/100 g dm).

2.5. Determination of catechins and caffeine

The catechin composition (epigallocatechin gallate ((-)-EGCG), epigallocatechin ((-)-EGC), epicatechin ((-)-EC), epicatechin gallate ((-)-ECG), catechin gallate ((-)-CG), gallocatechin gallate ((-)-GCG), catechin ((+)-C)) and caffeine were determined by HPLC. The chromatographic separation, described by Zuo et al. (2002), was used with some modifications in the mobile phase and UV detection. The analysis was performed on a solvent delivery system (Varian 9010) coupled to an auto-sampler (Marathon) using a column with a guard column (Nucleosil 5 C_{18}) and maintained at 40 °C in a column oven. Individual peaks were detected by the UV detector (Varian 9050), controlled by the system's software. HPLC grade (assay >99.9%) methanol (Solvent A) and trifluoroacetic acid solution (0.2% in water, solvent B) were used as the mobile phase in the following gradient elution at 1 mL/min flow rate: initial A:B 5:95 (v/v), at 1 min A:B 63:37 (v/v), at 28 min 5:95 (v/v). The chromatographic separation lasted 33 min (Zuo et al., 2002). The absorbance of the catechins ((-)-EGCG, (-)-EGC, (-)-EC, (-)-ECG, (-)-CG, (-)-GCG, (+)-C) and caffeine were determined at 280 nm. Individual peaks were identified by comparison of the retention time of their authentic standards. They were also validated by spiking. Quantifications were performed by plotting of four different concentrations for each external standard versus their peak areas. The results were expressed as g 100 g^{-1} dm.

2.6. Determination of theaflavin and thearubigin content

The thearubigin and theaflavin contents of the black tea were determined using the Flavognost method (Obanda et al., 2004). A tea infusion prepared with 9 g of black tea and 375 mL of fresh-boiled water in a flask was used. The flask was shaken for 10 min in a water bath at 98 °C, and the infusion was filtered through coarse filter paper and cooled to room temperature. Then 10 mL of cooled infusion was treated with 10 mL of isobutylmethylketone (4-methylpentan-2-one, IBMK). The mixture was shaken for 10 min and allowed to stand until the phases separated. Next 2 mL of the upper layer was decanted into a test tube with 4 mL of ethanol and 2 mL of the Flavognost reagent (2 g of diphenylboric acid-2-aminoethyl ester dissolved in 100 mL of ethanol) was added. After vortexing, the mixture was allowed to stand for 15 min to develop color. Finally, the absorbance of the solution was recorded against IBMK/ethanol (1:1 v/v) at 625 nm in a spectrophotometer (Shimadzu UV-Vis 160A). The TF content was calculated using Eq. (2).

$$TF\ (\mu mol/g) = \frac{A_{625} \times 47.9 \times 100}{DM} \quad (2)$$

The TR content was determined using the same infusion except that the amount of IBMK used was 50 mL. The mixture was shaken gently to prevent emulsion formation. After the phases were separated, 4 mL of the IBMK phase was transferred into a 25-mL volumetric flask and diluted to 25 mL with methanol (solution A). Separately, 25 mL of the IBMK phase was mixed with 25 mL of 2.5% aq. $NaHCO_3$ solution. Then 4 mL of the IBMK layer was pipetted into a 25-mL volumetric flask and made up with methanol (solution B). Next 2 mL of the initial IBMK layer was added to 2 mL of saturated oxalic acid and 6 mL of pure water. This mixture was diluted to 25 mL with methanol (solution C). The absorbance of the three solutions obtained was measured against water at 380 nm. The TR content was calculated using Eq. (3) (Obanda et al., 2004).

$$TR\ (\%) = \frac{375 \times 0.02 \times 6.25 \times [2A_C + A_A - A_B}{(0.733 \times 9 \times DM)/100} \quad (3)$$

where DM is the dry matter of the tea sample.

2.7. Statistical analyses

The research was carried out in two replicates using a factorial design with three factors: 2 altitudes (low, high), 3 shooting periods (1st, 2nd, 3rd), and 7 tea grades (OP1, OP2, OP3, BOP1, BOP2, BOP3, dust). The production and measurements were performed in duplicate. The data were subjected to analysis of variance, and appropriate mean separations were determined using Duncan's multiple range test in SAS software (SAS Institute, Cary, NC, USA).

3. Results and discussion

Different physicochemical properties of the black tea samples were evaluated depending on the altitude, shooting periods, and grades of the tea.

3.1. Moisture content, extraction yield, and total phenolic content of the samples

The moisture content of the black tea samples was in the range of 4.78–5.45 g 100 g^{-1} (Table 1) and significantly affected by all experimental factors and their interactions except altitude ($P < 0.01$). According to Othieno and Owuor (1984), black tea with a moisture content lower than 2.5 g 100 g^{-1} has a burnt flavor due to excessive drying, while tea with a moisture content of greater than 6.5 g 100 g^{-1} is susceptible to chemical and microbiological damage. Indeed, the ideal moisture content for postdrying was reported as 3–5 g 100 g^{-1} (Millin, 1985; Özdemir, 1992). As indicated in Table 1, all of the tea samples had moisture contents lower than 6.5 g 100 g^{-1}, which made them very suitable for storage.

Black tea produced in the second shooting period had the highest moisture content, followed by the third and first shooting periods. The moisture content of the black tea is mainly governed by the drying conditions (Özdemir, 1992). Thus, black tea samples produced in two different factories at different altitudes had statistically similar moisture contents (Table 1). The differences between varying shooting periods may have arisen from the freshness and quality (Nas, 1990) or environmental factors such as rainfall and relative humidity. In short, they could be due to the weather conditions on the day of classification of the tea (Özdemir, 1992). Among the grades, OP1 and dust had lower moisture contents than the other tea samples, since smaller particles result in a decrease in the amount of humid air inside the package. The tenderness of the fresh tea shoots may also affect the drying characteristics in the oven. Indeed, water removal from tender tea leaves

Table 1. Moisture content, extraction yield, and total phenolic content of different Turkish black tea samples.

		Moisture content (g 100 g^{-1})	Extraction yield (g 100 g^{-1})	Total phenolic content (g GAE 100 g^{-1} dm)
Altitude (N = 42)	low	5.21 ± 0.05a	29.09 ± 0.30b	5.59 ± 0.18a
	high	5.18 ± 0.09a	29.77 ± 0.30a	5.78 ± 0.17a
Shooting period (N = 28)	1st	4.88 ± 0.06c	30.66 ± 0.34a	6.97 ± 0.15a
	2nd	5.45 ± 0.09a	28.94 ± 0.35b	5.33 ± 0.09b
	3rd	5.24 ± 0.07b	28.69 ± 0.31b	4.75 ± 0.10c
Grade (N = 12)	OP1	4.78 ± 0.15c	31.02 ± 0.35a	6.32 ± 0.33a
	OP2	5.22 ± 0.11ab	29.46 ± 0.34c	5.85 ± 0.28b
	OP3	5.34 ± 0.14a	28.48 ± 0.40d	5.38 ± 0.24c
	BOP1	5.36 ± 0.13a	30.35 ± 0.42b	5.71 ± 0.22b
	BOP2	5.33 ± 0.10a	28.14 ± 0.38d	5.28 ± 0.34c
	BOP3	5.23 ± 0.11ab	27.12 ± 0.38e	4.93 ± 0.26d
	Dust	5.09 ± 0.13b	31.45 ± 0.39a	6.34 ± 0.42a

Results are means ± standard error. The values within a column with different letters for each factor are significantly ($P < 0.05$) different.

is easier than from mature ones. Therefore, OP1, coming from the tenderest leaves, had the lowest moisture content. Water extraction yield is an international standard for the quality control of black tea. In the current study, the water extraction yield of the black tea samples ranged between 27.12 and 31.45 g 100 g^{-1}. According to the International Organization for Standardization (ISO), the minimum water extraction yield must be 32 g 100 g^{-1} from black tea (Turkish Standards, 2003). We obtained water extraction yields lower than the ISO standard but very close to the values of Turkish black tea that have been reported previously (Nas, 1990; Özdemir, 1992).

Turkish black tea produced from leaves grown at high altitudes had a slightly higher water extraction yield than those grown at low altitude. In the first shooting period, the higher water extraction yield was compared to that from the other shooting periods. The quality of the fresh tea leaves significantly affects the water extraction yield. Thus, the higher water extraction yield was expected to occur in the first shooting period. Indeed, the ratio of tender tea shoots is the highest and the ratio of mature leaves is the lowest in the first shooting period in Turkey (Özdemir, 1992). Among the tea grades, dust and OP1 had higher water extraction yields, which may be due to their smaller particle sizes. The higher tender leaves of OP1 might have also caused the higher extraction yield. The fiber content of the tea samples also affected the water extraction yield of the black tea samples. BOP3, which has the highest fiber content, provided the lowest water extraction yield.

The total phenolic contents (TPC) of different Turkish black tea samples were in the range of 4.75 to 6.97 g GAE 100 g^{-1}. In another study on Turkish black tea, the TPC was 7.29–8.39 g GAE 100 g^{-1} dm (Karadeniz and Koca, 2009). Similarly, the TPC of the tea commonly sold in the UK was reported to be 8.05–13.5 g GAE 100 g^{-1} dm (Khokhar and Magnusdottir, 2002). The TPC determined in the present study was lower than those reported previously in the literature. This may be related to the differences in the plucking standards and processing conditions. Black tea produced from leaves grown at higher altitudes had a higher TPC than those from lower altitudes. Additionally, the TPC levels decreased during the shooting periods, which can be directly related to the TPC of the fresh tea leaves as reported in other studies (Nas, 1990; Özdemir, 1992). As with water extraction yield, OP1 and dust showed the highest TPC, followed by OP2 and BOP1. As expected, BOP3 had the lowest TPC. These results were consistent with those in the literature (Serpen et al., 2012).

3.2. Catechin composition of the samples

Individual catechin content of the samples is given in Table 2. Epigallocatechin gallate (EGCG) was the predominant catechin (0.719–1.007 g 100 g^{-1} dm), followed by epigallocatechin (EGC, 0.627–0.791 g 100 g^{-1} dm) and epicatechin gallate (ECG, 0.418–0.541 g 100 g^{-1} dm). Similar EGCG amounts in black tea have been reported previously (Khokhar and Magnusdottir, 2002; Serpen et al., 2012).

While the concentrations of EGC, ECG, catechin, gallate, and epigallocatechin gallate were determined to be higher in the high altitude tea samples, this was not the case for epicatechin. Additionally, EGCG amounts were not affected by altitude. All of the catechins decreased significantly from the first to the third shooting periods. Dust and OP1 had the greatest amount of individual catechins, while BOP3 had the lowest.

3.3. Caffeine, theaflavin and thearubigin content

The caffeine content of different Turkish black tea samples was in the range of 1.81–2.17 g 100 g^{-1} dm (Table 3). Black tea samples produced from the high-altitude plants contained higher amounts of caffeine than those from the low altitude plants. It is also reported that tea shoots grown under shade contain more caffeine compared to those grown under the sun (Song et al., 2012). The measurement of consecutive shooting periods indicated a decline in the caffeine content. The caffeine content of OP1, OP2, and dust was higher than 1.6 g 100 g^{-1} dm, which is the minimum desirable amount for black tea (Turkish Food

Table 2. Catechin content of different Turkish black tea samples (g 100 g^{-1} dm).

		EGCG	EGC	EC	ECG	CG	GCG	C
Altitude (N = 42)	low	0.899 ± 0.018a	0.692 ± 0.012b	0.319 ± 0.006a	0.463 ± 0.009b	0.024 ± 0.001b	0.037 ± 0.001b	0.224 ± 0.014b
	high	0.887 ± 0.022a	0.747 ± 0.013a	0.291 ± 0.006b	0.507 ± 0.010a	0.028 ± 0.001a	0.041 ± 0.001a	0.253 ± 0.013a
Shooting period (N = 28)	1st	0.976 ± 0.027a	0.785 ± 0.015a	0.329 ± 0.008a	0.523 ± 0.012a	0.029 ± 0.001a	0.042 ± 0.001a	0.284 ± 0.016a
	2nd	0.884 ± 0.018b	0.712 ± 0.013b	0.311 ± 0.007b	0.494 ± 0.011b	0.026 ± 0.001b	0.040 ± 0.001b	0.256 ± 0.013b
	3rd	0.819 ± 0.019c	0.661 ± 0.011c	0.274 ± 0.005c	0.437 ± 0.008c	0.023 ± 0.001c	0.035 ± 0.001c	0.176 ± 0.016c
Grade (N = 12)	OP1	1.007 ± 0.024a	0.783 ± 0.019a	0.330 ± 0.010a	0.524 ± 0.015ab	0.028 ± 0.001a	0.043 ± 0.001a	0.213 ± 0.020ab
	OP2	0.908 ± 0.024c	0.713 ± 0.020c	0.317 ± 0.009b	0.505 ± 0.015bc	0.028 ± 0.001ab	0.041 ± 0.001ab	0.204 ± 0.020cd
	OP3	0.861 ± 0.020d	0.691 ± 0.018c	0.294 ± 0.006c	0.468 ± 0.010d	0.025 ± 0.002abc	0.038 ± 0.001cd	0.204 ± 0.016cd
	BOP1	0.972 ± 0.029b	0.739 ± 0.023b	0.311 ± 0.007b	0.495 ± 0.011c	0.028 ± 0.001ab	0.039 ± 0.001bc	0.226 ± 0.013a
	BOP2	0.799 ± 0.019e	0.693 ± 0.016c	0.278 ± 0.009d	0.443 ± 0.014e	0.024 ± 0.001bc	0.035 ± 0.002de	0.208 ± 0.014abc
	BOP3	0.719 ± 0.012f	0.627 ± 0.020d	0.263 ± 0.009e	0.418 ± 0.014f	0.022 ± 0.001c	0.033 ± 0.001e	0.191 ± 0.013d
	Dust	0.984 ± 0.040ab	0.791 ± 0.023a	0.340 ± 0.014a	0.541 ± 0.023a	0.028 ± 0.002a	0.043 ± 0.002a	0.222 ± 0.016ab

Results are means ± standard error. The values within a column with different letters for each factor are significantly (P < 0.05) different.

Table 3. Caffeine (g 100 g^{-1} dm), TF (µmol g^{-1}), and TR (g 100 g^{-1} dm) content of different Turkish black tea samples.

		Caffeine	TF	TR
Altitude (N = 42)	low	1.94 ± 0.03b	4.24 ± 0.25b	10.51 ± 0.25a
	high	2.03 ± 0.03a	4.45 ± 0.27a	10.35 ± 0.24b
Shooting period (N = 28)	1st	2.17 ± 0.03a	6.00 ± 0.29a	10.64 ± 0.35a
	2nd	1.98 ± 0.03b	3.84 ± 0.20b	10.41 ± 0.29b
	3rd	1.81 ± 0.03c	3.20 ± 0.18c	10.23 ± 0.24b
Grade (N = 12)	OP1	2.12 ± 0.06a	5.25 ± 0.53a	11.97 ± 0.22b
	OP2	2.08 ± 0.05a	4.52 ± 0.49b	10.44 ± 0.12d
	OP3	1.96 ± 0.04b	3.65 ± 0.35c	9.29 ± 0.19e
	BOP1	1.94 ± 0.04b	4.65 ± 0.48b	11.07 ± 0.18c
	BOP2	1.87 ± 0.06c	3.55 ± 0.24cd	9.03 ± 0.21e
	BOP3	1.83 ± 0.06c	3.34 ± 0.25d	8.58 ± 0.18f
	Dust	2.11 ± 0.08a	5.45 ± 0.66a	12.63 ± 0.19a

Results are means ± standard error. The values within a column with different letters for each factor are significantly (P < 0.05) different.

Codex, 2015). The higher caffeine content of OP1, OP2, and dust may be related to their high contents of tender young leaves or buds, which tend to have more caffeine content. In previous studies, the caffeine content of different black tea samples was determined to be in the range of 1.43%–2.80% (Ozdemir et al., 1993; Khokhar and Magnusdottir, 2002; Karadeniz and Koca, 2009; Sari and Velioglu, 2013). The caffeine content obtained in the present study was consistent with values from the literature.

The TF content of the black tea samples was 3.20–6.00 μmol g^{-1} (Table 3). The results obtained in this study generally agreed with those reported for Turkish black tea (Nas, 1990; Özdemir et al., 1991, 1992). The quality of the fresh leaves, production time and method, and storage conditions generally affect the TF content of black tea (Özdemir, 1992). Additionally, altitude (Owuor et al., 1990), the plucking intervals (Owuor et al., 1990), and the plucking time (Ravichandran, 2004; Turkmen and Velioglu, 2007) were also found to affect the TF content. Black tea produced using leaves grown at high altitude had a higher content of TFs than those of the low altitude plants. Owuor et al. (1990) also reported similar differences in plants from different altitudes. They correlated this result with the higher TPC of the fresh tea leaves from high altitude plants. However, Zhang et al. (2018) reported that lower elevation tea samples had the highest amount of catechins and TFs. As expected, consecutive shooting periods resulted in a decline in the TF content. The greatest amount of TFs was identified in the dust and OP1, while the lowest was found in BOP3.

The TR content of the samples was in the range of 8.58–12.63 g 100 g^{-1} dm. These values were consistent with those reported previously (Obanda et al., 2004; Karadeniz and Koca, 2009). In contrast to the TF content, black tea samples produced from leaves grown at low altitude had a higher TR content than those from high altitude. In the oxidation step of black tea production, TFs are the first stable oxidation products and refer to the intermediate compounds formed during the oxidation of catechins and catechin gallates. TFs undergo further oxidation during fermentation, to form more polymerized TRs (Yao et al., 2006; Kuhnert 2010; Yassin et al., 2015; Zhang et al., 2018). Therefore, the higher content of TR was to be expected with decreasing TF concentrations. The highest TR content was identified from the first shooting period, but the second and third shooting periods did not vary significantly. Among the different grades, dust had the highest TR content, while BOP3 had the lowest. However, Serpen et al. (2012) did not observe any differences in the TR content from different grades of Turkish black tea.

In conclusion, this study was conducted to determine the water extraction yield, catechin composition, and caffeine and condensed phenolic content of seven grades of Turkish black tea depending on the growing altitudes of the tea leaves and the shooting periods. It is generally thought that high quality tea can be produced from plants grown at high altitude. In this study, the black tea produced from high altitude plants contained a considerably greater amount of catechin, which increased the quality of the tea. The shooting period, which is specific to Turkish tea cultivation, displayed significant effects on almost all of the quality parameters of black tea, and generally black tea produced during the first shooting period contained more catechin than those from the other shooting periods. Additionally, dust and OP1 contained the greatest amounts of catechin of all of the grades of tea. Overall, this study indicates that dust and OP1 of high altitude plants in the first shooting period are rich in functional components important for human nutrition.

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