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Effect of Microwave Technology on Some Quality Parameters and Sensory Attributes of Black Tea

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Abstract

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Although the quality of black tea mainly depends on the constituents and conditions of raw material, the manufacturing process also plays a significant role in obtaining high quality tea products. In this study, microwave technology is used for black tea production in withering and drying steps to increase its quality characteristics. Total polyphenols, theaflavin (TF), total thearubigins (TR), liquor brightness, and total colour were measured by spectrophotometric methods. Total antioxidant activity was determined by the DPPH method. Microwaved black teas showed higher amounts of quality constituents with similar phenolic contents and antioxidant activities compared to commercial Turkish teas. The plucking season was also found to have an effect on these constituents of black teas. Generally, microvawed black teas have higher spectrophotometric brightness and lower total colour values. The analytical and sensory results showed that using a microwave dryer during the black tea process is highly acceptable in respect to these quality parameters when compared with other commercial black teas obtained from the markets in Turkey and other countries.

Keywords: hot drink; microwave drying; polyphenols; antioxidant activity; quality characteristics; sensory analysis

Tea is one of the most pleasant and popular non-alcoholic beverages in the world (Alasalvar *et al.* 2013). Teas are usually classified as black tea, green tea, oolong tea, yellow tea, and white tea (Carvalho Rodrigues *et al.* 2015). The world tea production in 2012 was around 4 723 256 metric tonnes. Black tea is manufactured from the shoots of *Camellia sinensis* (L) O. Kuntze in Turkey, the world's fifth biggest producer with a production of 225,000 metric tonnes (FAO 2014).

Orthodox and crush-tear-curl are two principal categories of black teas, processed through withering-rolling-fermentation and firing stages. Black tea is a fermented tea. During the black tea fermentation, an enzymatic oxidation of tea catechins takes place, leading to the formation of a series of coloured compounds such as theaflavins (TFs) and thearubigins (TRs), which are characteristics of the black tea liquors (Obanda *et al.* 2001). In Turkey, withering of the leaves takes about 6 h on troughs followed by fermentation that is done in the open environment without any control. When the desired quality has been reached during fermentation, drying is used to terminate the reactions due to heat denaturation of enzymes or loss of moisture. During the drying process, other chemical changes occur under the driving force of heat rather than enzymatic action. Once the free moisture has been removed, i.e. tea is 'dry', further exposure to heat will raise the particle temperature to a level where loss of quality and burnt taste start to appear (Temple *et al.* 2001). In conventional hot air-drying, high temperatures and long drying times can cause thermal degradation or volatilisation of important flavour compounds.

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Microwave drying offers an alternative way to improve the quality of dried products. The interior of the sample quickly is heated to evaporation temperature and the vapour is forced outwards permitting the hot air to remove water. Due to a direct heating mechanism, the fermentation reaction is terminated in a shorter time and some volatiles are retained. Studies have been conducted to determine the effects of microwave applications on the quality constituents of various tea samples (Tsubaki *et al.* 2008; Dong *et al.* 2011). Huang *et al.* (2007) studied the inactivation of enzymes in tea leaves using oven and microwave heating methods and found that microwave treatment was more effective in preserving the quality of processed green tea in terms of polyphenol content and colour properties. Tea has been reported to have a high content of polyphenolics, about 36% of polyphenols on a dry weight basis (Shahidi 2000). High content and free radical scavenging activity have been observed in green and black teas in comparison with other herbs (Atoui *et al.* 2005).

The present study was aimed to use microwave technology in withering and drying steps of black tea processing. Quality attributes of the final products were analysed and compared with black teas from local markets produced by a conventional Turkish processing method and black teas bought from different markets in other countries.

MATERIAL AND METHODS

Tea samples. Turkish black tea samples having common consumption, brand 1B, 2B with best quality claim; and standard quality teas – brand 2, 3, and 4 were purchased from local supermarkets. MT black tea were produced in a pilot plant at the 1st, 2nd, and 3rd plucking season of 2005. Ceylon loose tea and tea bags were ordered from Ceylon. North East Indian black tea (Assam) and Chinese black tea were purchased from supermarkets in England. Each of MT samples (1st, 2nd, and 3rd season) was gathered from three batches within three replicates whereas other commercial tea samples were analysed in duplicate.

Chemicals. Ferrous sulphate, potassium phosphate, ethanol, methanol, isobutyl methyl ketone, $NaHCO_3$, and chloroform were purchased from Riedel (Seelze, Germany), Potassium sodium tartrate tetrahydrate, flavognost reagent, and oxalic acid were purchased from Fluka (Buschs, Switzerland), isobutyl methyl ketone (IBMK), hydrochloric acid, sulfuric acid, and lead acetate were purchased from Merck (Damstadt, Germany).

Tea production. Fresh tea leaves, harvested at the 1st, 2nd, and 3rd plucking season of 2005 in Rize in the Black Sea Region of Turkey were used for black tea production by using a microwave technique at a tea pilot plant (Figure 1).

Withering – Fresh tea leaves with 72–80% moisture were physically withered to 66–68% moisture content and became limp and flaccid, suitable for rolling without breaking. Tea leaves, having 8 cm in depth, were spread out on a continuous system perforated Teflon band. The microwave system was composed of 22 magnetrons, having the power of 860 W/h and the frequency of 2450 MHz each. Tea leaves were exposed to microwaves for 9 min and the velocity of the circulating air was 1.8 m^3/s and the air temperature was always below 26°C.

Rolling –After withering, tea leaves were subjected to the first rolling process for 60 minutes. The aim of this rolling was to twist the leaves by a mechanical process, in order to rupture the cells. During this process phenolic substances from the sap and enzymes from the cytoplasm were liberated and mixed. Rolled leaves passed through a wet tea sieve and sieved tea

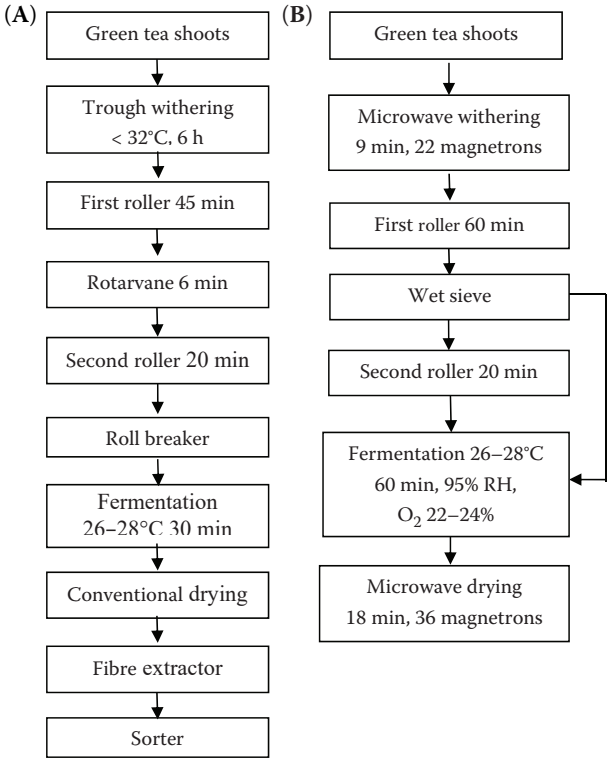

Figure 1. Flow chart of the black tea production process: (**A**) conventional Turkish type production; (**B**) microwave technology for black tea production

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was directly transported to the fermentation unit. The coarse tea that remained over the wet sieve was loaded on a conical rolling machine (2nd roller) for additional 20 minutes.

Fermentation – Rolled tea leaves having 5 cm in depth were entered into a fermentation tunnel and spread out on a continuous system perforated Teflon band. The fermentation tunnel was a closed system with controlled air velocity, atmosphere with controlled humidity, temperature, and oxygen content. The air passing through the heater at 27 ± 1°C was blown onto the leaves. Water was pulverised into the tunnel to reach ~95% humidity, oxygen level was adjusted to 23 ± 1%. Tea leaves remained in this conditioned tunnel for 60 min before entering the dryer.

Drying – Fermented tea leaves were entered into a dryer immediately to stop the fermentation reaction. In a pilot system, fermented tea leaves, having 2.5 cm in depth, were spread out on a continuous system perforated Teflon band. 36 magnetrons, having the power of 860 W/h and the frequency of 2450 MHz each, were used during the process. Tea leaves were exposed to microwaves for 18 minutes. The air was circulated with a velocity of 1.8 m^3/s through the dryer and the moisture content of the final tea product was ~5%.

Determination of total polyphenol content

Ferrous tartrate method. Total polyphenol contents of tea samples were determined according to Liang *et al.* (2003). Three g of tea was mixed with 150 ml of boiling distilled water. The mixture was left in a boiling water bath for 10 minutes. The filtered infusion (1 ml) was reacted with 4 ml water, 5 ml dyeing solution, and 15 ml 0.067 M potassium phosphate buffer solution (pH 7.5). The mixture was left at room temperature for 3 min to develop the colour. Absorbance of the reaction solution was determined spectrophotometrically at 540 nm (A1). The content of tea polyphenols was calculated by the following equation:

$$\text{Polyphenols (mg/g)} = (A1 - A_{control}) \times 3.9133 \times 150/3$$

where: 3.9133 – constant meaning that polyphenol concentration was 3.9133 mg/ml when absorbance at 540 nm was 1.0; 150/3 – constant meaning that 3 g of tea sample was extracted in 150 ml water

Folin-Ciocalteu method. Samples from the 2nd (S2) and 3rd (S3) season of MT black teas were randomly selected for total polyphenol and total antioxidant activity determination and results were compared with some commercial black teas purchased from the markets. Tea sample (1 g) was mixed with 60 ml of boiling distilled water and left on a magnetic stirrer for 1 minute. The mixture was left in a boiling water bath for 10 min and allowed to cool to room temperature. The filtrate was diluted to 100 ml and centrifuged at 5000 rpm for 10 min (Bramati *et al.* 2003). The total polyphenol analysis was conducted according to the method of Singleton and Rossi (1965). Tea extracts were diluted at a 1 : 10 ratio. Diluted extract (0.25 ml) was reacted with 1 ml of distilled water and 0.25 ml of Folin-Ciocalteu reagent. After 6 min, 2.5 ml of sodium carbonate solution (7%) was added and the content was diluted with 2 ml of distilled water and vortexed. Test tubes were allowed to stand for 90 min in dark and at room temperature for the completion of the reaction. The formed blue colour was measured with a spectrophotometer (Perkin Elmer Lamda-25; Perkin Elmer, Boston, USA) at 760 nm. Results were expressed as gallic acid equivalents (GAE).

Theaflavin (TF) determination. TF analysis was done on dried tea samples using the flavognost method (Hilton 1973). The black tea infusion was prepared by extracting 9 g of tea with 375 ml of boiling distilled water and the mixture was shaken on a horizontal shaker for 5 min and left in a boiling water bath for 10 minutes. The tea extract was then filtered and allowed to cool to room temperature. Filtrate (10 ml) was extracted with 10 ml of IBMK. The mixture was shaken for 2 min and allowed to stand until the separation phase. The upper IBMK phase (2 ml) were transferred into a test tube, and 4 ml of ethanol and 2 ml of flavognost reagent were added. The content of the test tube was allowed to develop colour for 15 min after having been vortexed. The absorbance (A) at 625 nm was read against an IBMK/ethanol blank of (1 : 1, v/v) using a UV-Vis spectrophotometer. The TF level was calculated as:

$$\text{TF } \mu\text{mol/g} = A_{625} \times 47.9 \times 100/DM$$

where: A_{625} – absorbance value at 625 nm; DM – percentage of dry matter in black tea

Spectrophotometric measurements of total thearubigins, liquor brightness, and total colour. Total thearubigins (TR), liquor brightness, and total colour were measured according to the method of Roberts and Smith (1963). Fifty ml of the cool, well-shaken, and filtered tea infusion from the theaflavin analysis was mixed with 50 ml of IBMK and gently

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shaken to avoid the formation of an emulsion. The layers were allowed to separate and a 4 ml portion of the IBMK layer was taken and made up to 25 ml with methanol in a volumetric flask (Solution A). The portions (2 ml) of the aqueous layer were diluted to 10 ml with distilled water and then to 25 ml with methanol (Solution B). Saturated oxalic acid aqueous solution (2 ml) and 6 ml of water added to a 2 ml portion of the aqueous layer were diluted to 25 ml with methanol (Solution D). Twenty-five ml of the remaining IBMK layer were taken in a separate flask and mixed with 25 ml of 2.5% aqueous sodium hydrogen carbonate. The mixture was vigorously shaken before the layers were allowed to separate and the aqueous layer was discarded. A 4 ml portion of the IBMK layer was made up to 25 ml with methanol (Solution C).

The absorbance of solutions A, B, C, and D at 380 and 460 nm were obtained using a UV-Vis spectrophotometer, with a water/methanol blank (1 : 1.5, v/v) for solutions D and B and an IBMK/methanol blank (4 : 21, v/v) for solutions A and C. By following the above procedures for the solvent partitioning of black tea liquor components and based on the fact that the mean absorbance of thearubigin fractions at 380 nm was 0.733 (Roberts & Smith 1963), the following equation for estimating total thearubigins was derived:

At 380 nm:

$$\%TR = [375 \times 0.02 \times 6.25(2\ A_D + A_A - A_C)]/(0.733 \times 9 \times \times DM/100)$$

$$\%TF = 6.25 \times A_C \times 0.36$$

At 460 nm:

$$\text{Brightness (\%)} = (100 \times A_C)/(A_A + 2\ A_B)$$

$$\text{Total colour} = 6.25 \times (A_A + 2\ A_B)$$

Determination of total antioxidant activity. Many methods have been developed and tested in the literature for determination of total antioxidant capacity (Karadag *et al.* 2009; Apak *et al.* 2013; Carloni *et al*. 2013). Among them, the DPPH method has commonly been used due to a simple, rapid, sensitive, and reproducible procedure (Ozcelik *et al.* 2003; Nowak *et al.* 2016). The antioxidant activity was evaluated in terms of the radical scavenging ability of tea using a 1,1-diphenyl-2-picrylhydrazyl (DPPH$^{\bullet}$) free radical assay adapted from Brand-Williams *et al*. (1995). Tea extracts (0.1 ml) diluted with water at a 1 : 10 ratio were added to 3.9 ml of DPPH solution (6×10^{-5} M in methanol). Test tubes were vortexed for 2 min and allowed to stand for 2 h until the reaction reached the steady state in dark and at room temperature. The decrease in the absorbance was determined spectrophotometrically at 515 nm and the antioxidant activity of the samples was expressed in mg Trolox equivalents per g by comparing EC_{50} of the tea extracts with EC_{50} of Trolox.

Sensory analysis. Magnitude estimation of the descriptive analysis test was conducted to assess sensory quality of black tea samples (Hu *et al.* 2001). Fifteen panellists were selected at the Food Engineering Department of Istanbul Technical University. The age range was between 18 and 30 and none of them declared to have positive Daltonism. Panellists were chosen as people who are used to consume tea in their daily lives. Since the raw material to produce black tea was obtained from the same region, sensory analyses were conducted between Turkish black tea samples, namely three commercial Turkish black teas: brand 1B, 2B, and 4, 1st and 3rd season MT teas. Assam black tea was used for astringency standard and scored at 10. Black tea samples were infused with 140 ml of freshly boiled water and allowed to stand for 5 minutes. Panellists were not permitted to use sugar for evaluation. They were asked to score the tea liquors on a ten-point scale for aroma, flavour, astringency, colour, brightness, and overall liking. The following scales were used for aroma, flavour, and overall liking (0 – dislike extremely; 10 – like extremely), for astringency (0 – extremely weak; 10 – extremely strong), for colour (0 – extremely light; 10 – extremely dark), and for brightness (0 – very dull; 10 – very bright).

Statistical analysis. Statistical analysis of black tea quality parameters was performed according to the ANOVA procedure, using Minitab® Release 14.11 (Minitab Inc., State College, USA) and Statistica™ (Version 6.0). Tukey pairwise comparison was conducted to determine differences between samples. Duncan comparison test was conducted for sensory attributes.

RESULTS AND DISCUSSION

The oxidation of catechins occurs through enzyme-catalysed reactions to form theaflavins (TF) and thearubigins (TR); theaflavins are bright and orange-red while thearubigins are more chemically heterogeneous and tend to be brownish red. Theaflavins have astringent tastes and contribute to briskness, astringency, and colour of black tea while thearubigins are responsible for the mouth feel (thickness) and colour of tea (Obanda *et al.* 2001; Liang *et al.* 2003).

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Theaflavins and thearubigins. Roberts and Smith (1963) showed that theaflavin content is an important chemical compound in determining black tea quality, Hilton and Ellis (1972) and Cloughley (1980) confirmed that there was a close linear relation between theaflavin content and valuation of black tea. TF content of the 1st season of MT black tea was higher than that of other Turkish brands and Chinese and Ceylon tea bag. The 2nd season of MT black tea had a higher amount of TF than other Turkish black teas except brand 1B. The 3rd season black tea produced by MT black teas had lower amounts of TF than other Turkish black tea samples, but the differences were not significant (Table 1). According to the results of MT black teas, TF content tended to decrease through the plucking seasons. Assam black tea (11.051 μmol/g) had the highest TF content among samples followed by MT tea samples (especially the 1st and 2nd season), and finally Turkish teas in general (Table 1). TF content of Turkish black teas varied between 2.724 and 3.938 μmol/g.

The ratio of TF to TR was accepted as an effective quality parameter of black tea (Ullah *et al.* 1984). The ideal ratio was accepted as 1/10 for briskness, brightness, and astringent properties. The quality of tea tended to decrease when it was lower than 1/25 (Kacar 1987).

The ratio of TF to TR was similar for the three seasons of MT black teas and always higher than that of the other Turkish tea samples except for brand 1B. The ratio of TF to TR for Turkish black teas varied between 1/35.724 and 1/54.450. The ratio of Assam black tea was higher than in all other samples. The differences of MT black teas from Ceylon loose and Chinese black teas were not found to be significant (Table 1).

Although generally Turkish black teas have a lower TF content, the 1st and 2nd season of MT black teas has significantly higher TF values than the other Turkish black tea samples. This value is generally 12.7 μmol/g for good quality teas and 8.64 μmol/g for low quality ones (Wright *et al.* 2002) whereas the TF content of black teas produced in Turkey ranges between 0.17 and 5.04 μmol/g (Tufekci & Guner 1997).

The differences in TF and TR between MT black teas and other Turkish black teas could be assigned to the novel manufacturing method including microwave withering, drying, and the controlled fermentation tunnel. In Turkey, other tea manufacturers do

Table 1. Polyphenol, theaflavin, and thearubigin content of MT black teas, commercial black teas purchased from the markets in Turkey, and teas from other countries

Samples	Polyphenols (mg/g)	Theaflavins (TF) (μmol/g)	Thearubigins (TR) (%)	$(TF/TR)^{-1}$*
MT				
1st season	88.88 ± 0.17^{a}	4.66 ± 0.03^{ab}	8.35 ± 0.01^{ab}	30.52 ± 0.60^{ab}
2nd season	88.58 ± 0.21^{a}	3.59 ± 0.07^{bcd}	6.87 ± 0.17^{c}	31.03 ± 0.66^{ab}
3rd season	68.60 ± 0.16^{bc}	2.50 ± 0.03^{d}	8.40 ± 0.05^{ab}	33.35 ± 1.38^{ab}
Turkish				
Brand 1B	73.65 ± 1.17^{b}	3.94 ± 0.14^{bc}	9.25 ± 0.26^{ad}	35.72 ± 1.81^{bc}
Brand 2B	70.01 ± 1.29^{bc}	3.03 ± 0.11^{cd}	8.79 ± 0.06^{ab}	44.39 ± 0.95^{cd}
Brand 2	68.35 ± 0.92^{bc}	2.93 ± 0.07^{cd}	8.22 ± 0.01^{abe}	54.45 ± 3.62^{de}
Brand 3	64.41 ± 5.99^{c}	2.76 ± 0.26^{d}	8.52 ± 0.22^{ab}	51.17 ± 1.95^{de}
Brand 4	70.77 ± 1.81^{bc}	2.72 ± 0.25^{d}	8.14 ± 0.08^{be}	44.14 ± 1.73^{cd}
Other countries				
Ceylon tea bag	131.6 ± 0.85^{d}	3.15 ± 0.07^{cd}	10.26 ± 0.07^{f}	57.12 ± 0.33^{e}
Assam	156.6 ± 0.85^{e}	11.05 ± 0.56^{e}	10.96 ± 0.70^{f}	13.46 ± 0.36^{f}
Ceylon loose tea	149.12 ± 2.65^{e}	5.32 ± 0.13^{a}	7.25 ± 0.04^{ce}	25.08 ± 0.74^{a}
Chinese	124.6 ± 1.98^{d}	3.50 ± 0.67^{cd}	9.99 ± 0.01^{df}	40.05 ± 7.66^{bc}

Values represent the average of 3 × 3 measurements ± standard deviation for MT samples, and the average of two measurements ± standard deviation for the other samples; $^{a–f}$different letters in each column represent significant differences at $P < 0.05$; *TF (%) values according to the method of Roberts and Smith (1963) were used for calculation; brand 1B, 2B – best quality tea; brand 2, 3, 4 – standard quality tea

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fermentation in an air-open system. Tea leaves are spread out on a continuous system perforated band and heated air at 30–32°C is blown under the tea leaves bed without any moisture or oxygen control and it takes about 30 minutes (Figure 1).

Total phenolics. The differences between total phenolics of the 1st and 2nd seasons of MT black teas and other Turkish black teas were significant. The phenolic content of the 3rd season of MT black teas was not significantly different from other Turkish black teas (Table 2). The phenolic content of MT teas (1st and 2nd season) was significantly higher than in Turkish teas. However, it was even twice lower than that of teas from other countries in accordance with the theaflavin contents. As the plucking season of other Turkish black teas was not exactly known, this difference could be attributed to the production process. A study that investigated the effects of different cooking methods on total phenolic contents of some vegetables indicated that using microwaves had preservative effects on total phenolic contents when compared to other processes (Turkmen *et al.* 2005). Total phenolics of Turkish black teas varied between 56.41 and 76.52 mg GAE/g (Table 2) and were comparable with the total polyphenol content that ranged from 50.2 to 131 mg GAE/g which was indicated for seventeen samples of black tea from China (Liang *et al*. 2003). On the other hand, Khokhar and Magnusdottir (2002) reported higher total phenolic contents of commercial black tea samples as 80.5–134.9 mg GAE/g belonging to different brands in the United Kingdom. Furthermore, the phenolic contents of samples determined by the ferrous tartrate method were in a similar range as described in the literature (Liang *et al.* 2003). A good correlation (R^2 = 0.99) was reported between the ferrous tartrate method and the Folin-Ciocalteu method for black tea and mate tea infusions (Liang *et al*. 2003). However, the correlation within these methods was found to be 0.87 in our study.

Table 2. Total antioxidant activity and total phenolic content of MT black teas, commercial black teas purchased from the markets in Turkey, and teas from other countries

Samples	Polyphenols (mg GAE/g)	Total antioxidant activity*
MT		
2nd season	93.60 ± 1.38^{a}	0.64 ± 0.03^{a}
3rd season	66.82 ± 0.30^{abc}	0.63 ± 0.08^{a}
Turkish		
Brand 1B	76.52 ± 2.90^{b}	0.43 ± 0.07^{b}
Brand 2B	56.41 ± 4.34^{c}	0.45 ± 0.02^{b}
Brand 3	64.50 ± 1.41^{ac}	0.62 ± 0.04^{a}
Brand 4	74.28 ± 3.24^{ab}	0.52 ± 0.01^{ab}
Other countries		
Assam	114.05 ± 3.18^{d}	0.89 ± 0.01^{c}
Ceylon loose tea	118.99 ± 2.30^{d}	0.86 ± 0.01^{c}
Chinese	108.69 ± 3.02^{d}	0.94 ± 0.01^{c}

Values represent the average of 3 × 3 measurements ± standard deviation for MT samples and the average of two measurements ± standard deviation for the other samples; $^{a–d}$different letters in each column represent significant differences at $P < 0.05$; *in mg Trolox equivalents/g; brand 1B, 2B – best quality tea; brand 3, 4 – standard quality tea

Total antioxidant activity. Total antioxidant activity of the 2nd and 3rd season MT black teas was higher than that of the other Turkish black teas. This value for Chinese, Assam, and Ceylon tea was higher than in the other Turkish tea samples (Table 2). The EC_{50} values for the antioxidant activity of black tea samples were comparable with the literature (Atoui *et al*. 2005; Buyukbalci & El 2008). Similarly with total polyphenols, the antioxidant activity for teas from other countries was highest, followed by MT teas and then Turkish teas. However, it was seen that the MT process does not affect antioxidant properties of black tea when compared to other Turkish tea samples that were produced by conventional methods.

Due to the high correlation coefficient (0.852) between total phenols and antioxidant activity, the significant differences in antioxidant activity could be related to differences in the polyphenol content of tea samples. Black tea is also consumed for the presence of poly-

The differences in phenolics between black teas purchased from markets of other countries (Assam, Ceylon, and Chinese) and from Turkey were significant. The differences in total phenolics of Turkish black teas from Assam, Ceylon, and Chinese teas were attributed to the difference in phenolic contents of green tea shoots, raw material of black tea. The total phenolic content of green tea shoots used for black tea production was 140–290 mg/g in Central Africa (Wright *et al.* 2000). The average total phenolic content of green tea shoots of Chinese and Assam hybrids was 270 and 258.7 mg/g, respectively (Ravichandran & Parthiban 1998; Baruah & Mahanta 2003). While the total phenolic content of generally plucked Turkish green tea shoots was found to be 100–150 mg/g and it was maximum with the value of 220 mg/g in shoots consisting of two leaves and a bud.

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Table 3. Spectrophotometric brightness and colour values of MT black teas, commercial black teas purchased from the markets in Turkey, and teas from other countries

Samples	Brightness (%)	Total colour (%)
MT		
1st season	13.27 ± 0.15^{a}	2.03 ± 0.05^{abc}
2nd season	12.58 ± 0.37^{a}	1.65 ± 0.03^{bc}
3rd season	7.42 ± 0.02^{bcd}	1.83 ± 0.01^{abc}
Turkish		
Brand 1B	10.47 ± 0.50^{f}	2.12 ± 0.05^{abc}
Brand 2B	8.96 ± 0.25^{e}	1.85 ± 0.03^{abc}
Brand 2	6.51 ± 0.12^{d}	1.62 ± 0.30^{c}
Brand 3	7.18 ± 0.33^{cd}	1.95 ± 0.35^{abc}
Brand 4	8.62 ± 0.81^{be}	1.86 ± 0.28^{abc}
Other countries		
Ceylon tea bag	6.73 ± 0.21^{cd}	2.06 ± 0.07^{abc}
Assam	18.57 ± 0.24^{g}	3.73 ± 0.45^{d}
Ceylon loose tea	13.16 ± 0.06^{a}	2.48 ± 0.21^{a}
Chinese	7.99 ± 0.22^{bce}	2.41 ± 0.15^{ab}

Values represent the average of 3 × 3 measurements ± standard deviation for MT samples and the average of two measurements ± standard deviation for the other samples; $^{a–f}$different letters in each column represent significant differences at $P < 0.05$; brand 1B, 2B – best quality tea; brand 2, 3, 4 – standard quality tea

phenols such as theaflavins and thearubigins as well as catechins, mainly responsible for antioxidant activities.

Brightness and colour. Spectrophotometric brightness values (%) of the 1st and 2nd season of MT black teas were higher than those of the other Turkish black teas. Brightness of the 3rd season of MT black teas was just lower in brand 3 and brand 4 best quality black teas. Brightness values of Turkish black teas varied between 6.51 and 10.47%. Brightness value of Assam black tea was higher than in all other samples, differences between Ceylon and the 1st and 2nd season of MT black teas were not significant. The differences in spectrophotometric colour values between MT black teas and other Turkish black teas were not significant. This value for Assam black tea was higher than in all other samples (Table 3).

Generally, MT black teas have higher spectrophotometric brightness and lower total colour values than the other Turkish black teas. Total colour increased with fermentation duration and the rate of increase tended to be faster in the early part of fermentation (Owuor & Obanda 2001). The lower colour values of MT black teas could be assigned to not having the Rotorvane in the manufacturing step (Figure 1). Other black tea manufacturers in Turkey use the Rotorvane in the early part of fermentation where the temperature is increased because of squeezing of leaves and their rollers in the Rotorvanes have cutting parts while MT uses just a conventional orthodox process. Robertson (1983) stated that under low oxygen tension, the catechins are diverted in some way to thearubigin formation and are not available for theaflavin production when oxygen is no longer limiting. So, thearubigins were increased for the favour of thicker and more colourful black teas.

Sensory attributes. The differences in aroma, flavour, and brightness scores between the 1st and 3rd season of MT black teas and other Turkish tea samples were not significant. The astringency scores of the 1st season of MT black tea were higher than in the other samples except for brand 4 best quality tea. The 3rd season of MT black tea had the highest overall liking score among the samples while its colour scores were lower than in the other samples (Figure 2). Similarly, Huang *et al.* (2007) indicated that the use of microwave heating significantly improves the sensory quality of green tea infusions through enzyme inactivation.

The linear correlation analysis showed that concentrations of polyphenols ($P = 0.019$) and theaflavins ($P = 0.001$) were positively correlated with astrin-

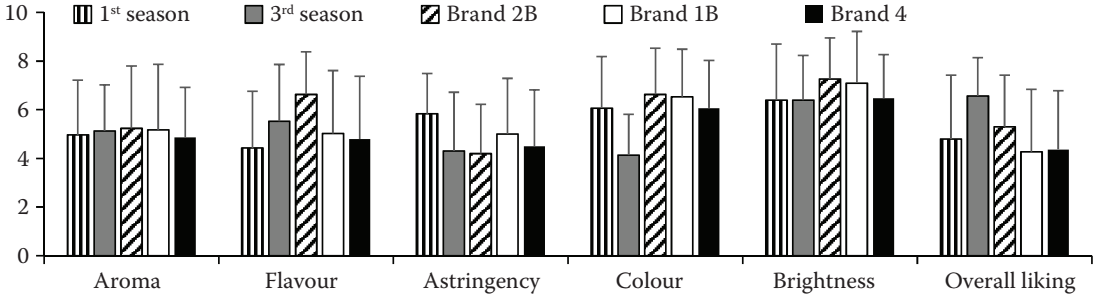

Figure 2. Sensory attributes of MT black teas and commercial Turkish black teas (brand 1B, 2B – best quality tea; brand 4 – standard quality tea)

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gency. Since theaflavins contribute to the astringent taste of black tea, this high correlation found between TF and astringency was an expected result. TF values of the 1st season of MT and brand 4 best quality black tea differed from the other samples similarly like the results of sensory astringency (Tables 1 and 2).

CONCLUSION

We analysed MT black teas to see the effects of a microwave process on the quality parameters of black tea including theaflavin and thearubigin, total polyphenol content, brightness, total colour, total antioxidant activity, and sensory attributes. While the black teas purchased from the markets around the world are generally seemed to be higher in quality constituents than Turkish teas, compared to commercial Turkish black teas, MT teas had higher amounts of quality constituents and similar phenolic contents and antioxidant activities. The plucking season was also found to have an effect on these constituents of black teas. The analytical and sensory results showed that using microwave energy during the black tea process with controlled fermentation tunnel resulted in the better quality the black teas produced by the conventional Turkish processing method. Due to the shorter process time of black tea production by using microwave energy in withering and drying, and acceptable quality attributes of MT teas, it could be concluded that microwave technology could be used as an alternative process for tea production.

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