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Hızlı Katı-Sıvı Dinamik Ekstraksiyonla Üretilen Türk Siyah Çay Deminin Kalitesinin Belirlenmesi

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Araştırma Makalesi

Determining the Quality of Turkish Black Tea Infusion Produced by Rapid Solid-Liquid Dynamic Extraction

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Abstract

Dynamic tea extraction with oxygenated (O) and non-oxygenated waters (OS) was carried out as a food process for ready-to-drink black tea. The tea samples produced with that process were compared with the black tea sample (R) brewed with the traditional tea brewing process. The qualities of all teas were determined by total phenols content, theaflavins, thearubigins, theabrownin, total color, brightness, hunter color and DPPH radical-scavenging activity parameters. The total phenolic contents of R, O and OS samples were respectively 3.137, in the range of 1.867-2.707 and 2.079-2.831 mg GAE/100g. The highest theaflavins (0.330%) was detected in R sample. Thearubigins contents were determined between 4.99-7.03%. The highest was found in R sample, and the lowest was found in O sample at 30.s. The ratios of theaflavins to thearubigins contents were determined as 0.0469, in the ranges of 0.0274-0.0299 and 0.0141-0.0309 for R, O and OS samples, respectively. The binary interactions between tea extraction process-time, tea extraction process-theabrownin, and time-theabrownin for theabrownin values of R, O and OS samples were statistically significant ($p<0.05$). The waters and the brewing times affected color values of the samples. O and OS samples had the higher antioxidant activity values than that of R sample and OS samples showed the highest antioxidant activity during all extraction times.

Hızlı Katı-Sıvı Dinamik Ekstraksiyonla Üretilen Türk Siyah Çay Deminin Kalitesinin Belirlenmesi

Öz

Oksijenlendirilmiş (O) ve oksijenlendirilmemiş sularla (OS) dinamik çay ekstraksiyonu, içime hazır siyah çay için bir gıda işlemi olarak gerçekleştirildi. Bu işlemle üretilen çay örnekleri, geleneksel çay demleme işlemiyle demlenen siyah çay örneği (R) ile karşılaştırıldı. Tüm çayların nitelikleri, toplam fenol içeriği, theaflavinler, thearubiginler, theabrownin, toplam renk, parlaklık, hunter rengi ve DPPH radikal giderici aktivite parametreleri ile belirlendi. R, O ve OS örneklerinin toplam fenolik içerikleri sırasıyla 3.137, 1.867-2.707 ve 2.079-2.831 mg GAE/g aralığındA bulundu. En yüksek theaflavinler (%0.330) R örneğinde tespit edildi. Thearubigin içerikleri %4.99-7.03 arasında belirlendi. En yüksek R örneğinde, en düşük ise O örneğinde 30. saniyede bulundu. Theaflavinlerin thearubiginlere oranı R, O ve OS örnekleri için sırasıyla 0.0274-0.0299 ve 0.0141-0.0309 aralığında 0.0469 olarak belirlendi. R, O ve OS örneklerinin theabrownin değerleri için çay ekstraksiyon işlemi-zaman, çay ekstraksiyon işlemi-theabrownin ve zaman-theabrownin arasındaki ikili etkileşimler istatistiksel olarak anlamlı bulundu ($p<0.05$). Sular ve demleme süreleri örneklerin renk değerlerini etkiledi. O ve OS örnekleri R örneğine göre daha yüksek antioksidan aktivite değerlerine sahipken, OS örnekleri tüm ekstraksiyon süreleri boyunca en yüksek antioksidan aktiviteyi gösterdi.

1. INTRODUCTION

Tea (*Camellia sinensis*) is the manufactured drink most consumed in the world and considered to be healthier than coffee and cocoa and is highly recommended by the World Health Organization. It is one of the three most consumed nonalcoholic beverages, and its global consumption has risen significantly in recent years. The economic and social significance of tea is easily understood from the fact that

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approximately 20 billion cups of brewed tea are consumed daily worldwide. World black tea production is projected to grow (at 2.9 percent annually to reach 4.17 million tonnes) at a slightly higher rate compared to the previous decade by 2023 [1-4]. The reason for this increase may be a positive effect on health. The major chemical compounds which play a pivotal role in determining the health benefits of tea include catechins, alkaloids (caffeine, theobromine and theophylline), amino acids, volatile compounds, carbohydrates, lipids, vitamins, inorganic elements and organic acids. Black Tea is rich in polyphenols, especially Theaflavins and Thearubigins [5-8]. Theaflavin is thought to be responsible for the medicinal value of black tea. Tea infusion may be a significant source of most important basic nutrients such as calcium, magnesium, potassium, and fluoride. Some metals found in tea are components of important enzymes or participants in a number of physiological processes. Among the essential elements in black teas depending on the kinds, K, Mg, Ca and Al; respectively, could be present at the highest concentration. Pb and Mn contents of several tea samples would be over the Tolerable Daily Intake levels. It was reported that theaflavin and theaflavin gallate derivatives shown broad-spectrum antiviral activity against several viruses, including influenza A and B viruses and hepatitis C virus. [9-12]. Chen et al. (2005) reported that the theaflavins derivatives have potent inhibitory activity against SARS, by inhibiting SARS-CoV 3CLpro activity [13]. Moreover, Lung et al. (2020) found that theaflavin was able to dock in the catalytic pocket near the active site of RdRp in SARS-CoV-2, SARS-CoV, and MERS-CoV [14].

The quality of the brewed tea depends on many factors such as the color, brightness, taste and aroma of the brew, the brewing conditions, as well as the chemical qualitative and quantitative composition of the tea leaf, the genetic strain, the production process, the size of the tea leaf. [15-18]. Also, the changes in composition of some chemical compounds such as mineral material could be occurred depending on tea variety, tea concentration, and steeping time (19).

Brewing tea is an extraction process. Extraction is described as a process where certain substances of a solid or a liquid mixture are dissolved, washed or leached by the aid of a liquid solvent in food engineering operations [20]. Many tea drinkers prefer to prepare their drinks in the traditional process because it is the best way to make tea. The traditional black tea drink is basically made by extraction (steeping or brewing) tea leaves in hot water for 5-15 minutes [21-24]. The time for the beverage to reach the customer could be problem at offices where every minute is valuable. It could be resolved by tea vending machines [25]. Tegeltija et al. (2020) reported that vending machines such as tea making machine are mostly installed in busy big places such as shopping malls, bus and train stations, airports, schools, university campuses, companies [26]. There are two distinct types of tea and coffee vending machines (Household Tea and Coffee Machine and Tea and Coffee Vending Machine). The operation of Household Tea and Coffee Machine is quite simple. It consists of a vessel containing tea or coffee premix powder and water vessel which is connected to the heater. The water is heated and added into the container there by providing the required beverage. Tea and Coffee Vending Machine is quite complex in view of mechanical and electronic circuits. The water is always heated and remains at the required temperature. The powder falls into a second cup where a stream of hot water mixes with the powder and the beverage is produced which then flows into the main cup. The amount of water flowing is controlled by valves which are operated using timing circuits [25]. Drinker or consumer's satisfaction is related to tea of quality. Persons tasted tea from a vending machine say that it was not as good as tea made in home or tea got in shops [27].

It was designed a food operation process for a tea vending machine that provides the desired tea drink of the quality in a shorter time. Tea brewed by the traditional process was accepted as the desired quality tea drink and it was investigated how much the quality of tea drinks obtained from the designed process approached to the quality of tea brewed by the traditional process.

2. MATERIAL AND METHOD

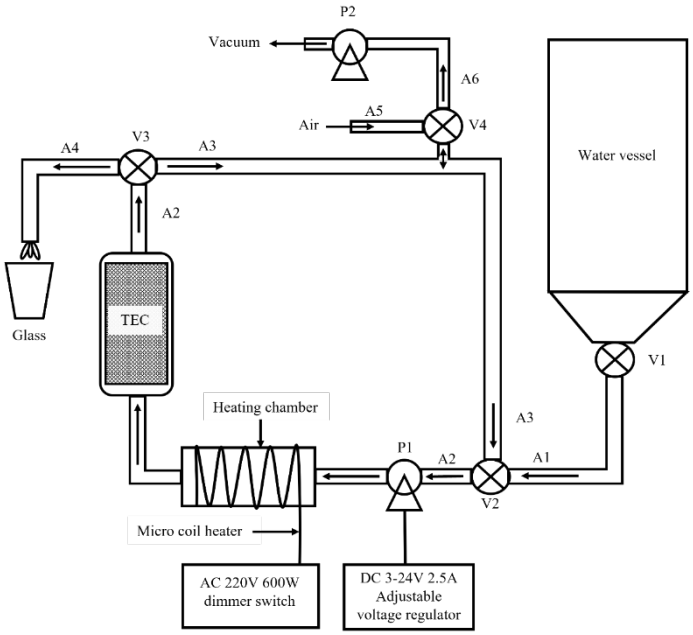
2.1. Material

Black tea (Altınbaş, Çaykur, Rize, Turkey) was purchased 1 kg from a local market. The standard reagents and methanol were chromatographic grade, and the others were all analytical grade chemicals. Chemicals were purchased from Merck Group.

2.2. Method

2.2.1. Dynamic tea extraction process

Dynamic tea extraction process for tea brewing was carried out in a laboratory-built apparatus. Schematic diagram of it is illustrated in Fig. 1. It consists of a water vessel (2.5L PET bottle with cap fitted with two way mini ball valve), a mini water pump (Pandoraplanet; model 385, DC 6V-12V, high temperature resistance 100°C), a 316 stainless steel cylindrical heating chamber (L:130, ID: 8 and OD: 18; mm) installed a coiled heater (500W, 220V AC, L:82 and ID: 18; mm) on, a rotary dimmer switch (3-600W, 230V AC), a 316 stainless steel cylindrical tea extraction chamber (TEC); having L:100, ID: 27 and OD: 50; mm, high temperature silicone tubing hose-food grade (9x14; mm), an Universal DC 3-24V adjustable voltage regulator (LED Display screen, Input:100-240VAC 50-60Hz, output: 2.5A 60W), three stainless steel 304 high pressure high temperature ¾ inch L port three-way mini ball female valves (port size: 9mm), a stainless steel 304 ¾ inch two-way mini ball female valves (port size: 12mm), a mini vacuum pump (Boeco, R-300), ¾ inch BSPT male x 10mm hose barbed 304 stainless steel pipe fitting hose tail connectors and hose clamps.



A, flow direction; P1, water pump; P2, vacuum pump; TEC, tea extraction chamber; V, valve

Figure 1*. Schematic diagram of the tea extraction system*

Both ends of the main body of the extraction chamber were sealed with nipples fitted with quick couplings (3/8-inch male thread socket; 506 EGB 17 and 10mm hose tail socket; 506 H 10). Disc filters (Stainless Steel Woven Wire 100 mesh) were placed between the nipples and the body to retain solid tea particles. The chambers, valves and hoses were entirely surrounded by thermal insulation materials. The operation principle of the process consisted of bleeding the air from the system, adjusting the temperature of the system to 85±3°C by circulating water without being present tea in TEC chamber, and water cycle for tea extraction. The total internal volume of the hoses between valves V1 and V2 was 200 ml. When A2-A3 ports of V2 and V3 valves were open (A1, A4 ports and V4 valve were closed), the total internal volume of the system (including valves, hoses, pumps and hoses) was 200mL, too. The circulation time of 200 ml water, which left from V2 valve (A2 direction) and entered to V2 valve (A3 direction) again, was adjusted to 30 seconds and the temperature to 85±3°C by the voltages of the water pump and heater. That is one cycle of water passing through the tea chamber. Putting 5 g of tea into TEC chamber, 1-5 cycles were performed. A2-A4 port of the V3 valve (A3 was closed) and A3-A5 port of V4 valve (A6 was closed) were opened and the brewed tea sample was taken from the A4 line after the desired number of cycles. All controls (opening and closing of the valves, adjusting the pumps) were manually done. The volume of

brewed tea obtained from the process was 180±3 ml. Two kinds of pure water were used in the process; the oxygenated (O) and non-oxygenated (OS) water. The HI-98193 portable dissolved oxygen meter (Hanna, UK) was used to been determined the dissolved oxygen amounts in the waters. Non-oxygenated (OS) water had 7.5±0.02 mg/L of dissolved oxygen concentration. Oxygenated (O) water which had 35.7±0.04 mg/L of dissolved oxygen concentration was obtained as described below. Half of the PET bottle volume was filled with oxygen-free water at room temperature. After cap with valve was closed, the other half was filled by pressing oxygen from the pure oxygen tube. It was kept for 24 hours at room temperature to bring to equilibrium it by shaking the bottle for 15 minutes.

2.2.2. Traditional tea brewing process

The non-oxygenated water of 200 ml at 85±3°C was poured into a thermal isolated vessel then black tea of 5 g was added on it and it was left to brew for 20 minutes (the time that the tea manufacturer recommended). The brewed tea in the vessel was passed through filter (Stainless Steel Woven Wire 100 Mesh) and a 180±3 ml volume of brewed tea sample was obtained. That tea was accepted as the reference sample (R).

2.3. Analysis

2.3.1. Total phenolic content

The contents of phenolics in tea drinks were determined by a spectrophotometric method [28]. 2.5 ml of the diluted (1/10) Folin-Ciocalteu reagent and 2 ml of 75 g/l Na_2CO_3 (after 8 min) was added to 0.5 ml of tea drink sample. The sample was incubated for 5 min at 50°C and then cooled to room temperature. The absorbance was measured at 760 nm according to the blank (water). The results were expressed as mg gallic acid (GA)/g sample.

2.3.2. Theaflavins, thearubigins, theabrownin, total color and brightness

Theaflavins (TF), thearubigins (TR) and theabrownin (TB) were estimated according to the method described by Roberts and Smith, (1961) (29). Details of the method used are as follows. Tea drinks obtained from dynamic tea extraction or traditional brewing processes were allowed to cool to room temperature. A portion of the tea drink (50 ml) was mixed with isobutyl methyl ketone (50 ml) in a separating funnel and shaken for 5 min. It was allowed the layers (isobutyl methyl ketone layer and aqueous layer). Part of the isobutyl methyl ketone layer (4 ml) was diluted to 25 ml with methanol (solution A). The absorption of solution A was recorded as E_A. A portion of the aqueous layer (2 ml) was mixed with water (10 ml) and shaken for 3 min, and then diluted to 25 ml with methanol (solution B). The absorption of solution B was recorded as E_B. Another portion (25 ml) of the isobutyl methyl ketone layer was mixed with 2.5% (w/v) $NaHCO_3$ (15 ml) and shaken for 30s. The aqueous layer was discarded, and part of the isobutyl methyl ketone layer (4 ml) was diluted to 25 ml with methanol (solution C). The absorption of solution C was recorded as E_C. A portion of the aqueous layer of (2 ml) left from the first extraction with isobutyl methyl ketone was mixed with a saturated oxalic acid (2 ml) and distilled water (6 ml), and then diluted to 25 ml with methanol (solution D). The absorption of solution D was recorded as E_D. The absorbances (E_A, E_B, E_C, and E_D of the above solutions (A, B, C and D) were measured with a spectrophotometer (Shimadzu, UV-1800) at 380 and 460 nm, with methanol-water solution (1:4 v/v) as a blank. The percentages of theaflavins (TF%), thearubigin (TR%) and theabrownin (TB%) were calculated the followings equations (1, 2, 3);

$$TF\% = 2.25E_C^{380} \quad (1)$$

$$TR\% = 7.06(1.77E_D^{380} + E_A^{380} - E_C^{380}) \quad (2)$$

$$TB(\%) = 14.12E_B^{380} \quad (3)$$

The following expressions were used for measure of the total color and brightness of the tea drink (eqs. 4, 5),

$$total\ colour = 6.25\left(E_A^{460} + 2E_B^{460}\right) \quad (4)$$

$$Brightness\ \% = 100\left(\frac{E_C^{460}}{E_A^{460}} + 2E_B^{460}\right) \quad (5)$$

The method was performed in duplicate.

2.3.3. Hunter color (L*a*b* values)

Color values of samples expressed as CIELAB L*a*b* units were determined with a spectrophometer (ColorFlex EZ, Hunter Associates Laboratory, Virginia, USA). L*, a*, and b* values represent dark (0) to white (100) colors, green (-) to red (+) colors and b* blue (-) to yellow (+) colors, respectively.

2.3.4. DPPH radical-scavenging activity

The antioxidant activity of tea drink sample, based on the scavenging activity of the stable 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical, was determined by the method described by Kumaran, (2006). Tea drink sample of 0.1 ml was added to 2 ml of a 0.02 mM DPPH -methanol solution. Blank was prepared using water of 0.1 ml in place of tea drink was added to 2 ml of a 0.02 mM DPPH -methanol solution. The absorbance (A) of sample was read with a spectrophotometer (Shimadzu, UV-1800) against the blank at 517nm after 30 min. The percent inhibition activity was calculated the followings equation (6),

$$inhibition\ activity\ (\%) = 100\left(A_{blank} - \left(\frac{A_{sample}}{A_{blank}}\right)\right) \quad (6)$$

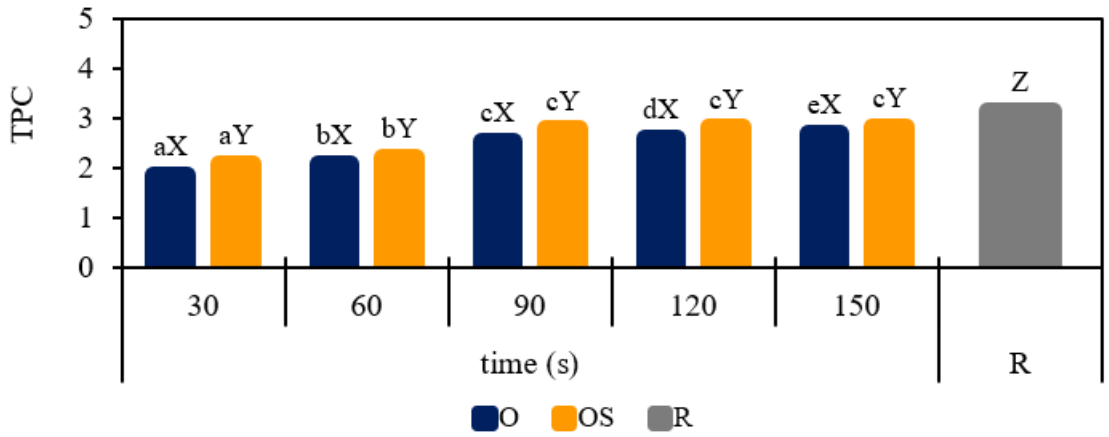
2.3.5. Statistical analysis

Statistical analyzes were carried out with the SPSS program (version 27). Variance analyzes were performed as one-way ANOVA and general linear model (GLM). Significant differences between the samples at each time and the times of each sample were determined by the Duncan multiple comparison test. Differences were considered significant at the $p<0.05$ level [30].

3. THE RESULTS AND DISCUSSION

3.1. Total Phenolic Content

The total phenolic contents (mg GA/g tea) were 3.137 for the R sample, in the range of 1.867-2.707 for O samples, and in the range of 2.079-2.831 for OS samples (Figure 2). It was determined that the total phenolic content of R sample was higher than the values of all of O and OS samples, and that the phenolic contents increased with increasing time.



R: black tea prepared with the traditional tea brewing process (Reference sample)
O: black tea produced using oxygenated water by the dynamic tea extraction process
OS: black tea produced using non-oxygenated water by a dynamic tea extraction process
"a-e" series shows the differences between the times of each sample, "X<Y<Z" sequence shows the differences between the samples (O and OS) at each time and the R sample, statistically ($p<0.05$).

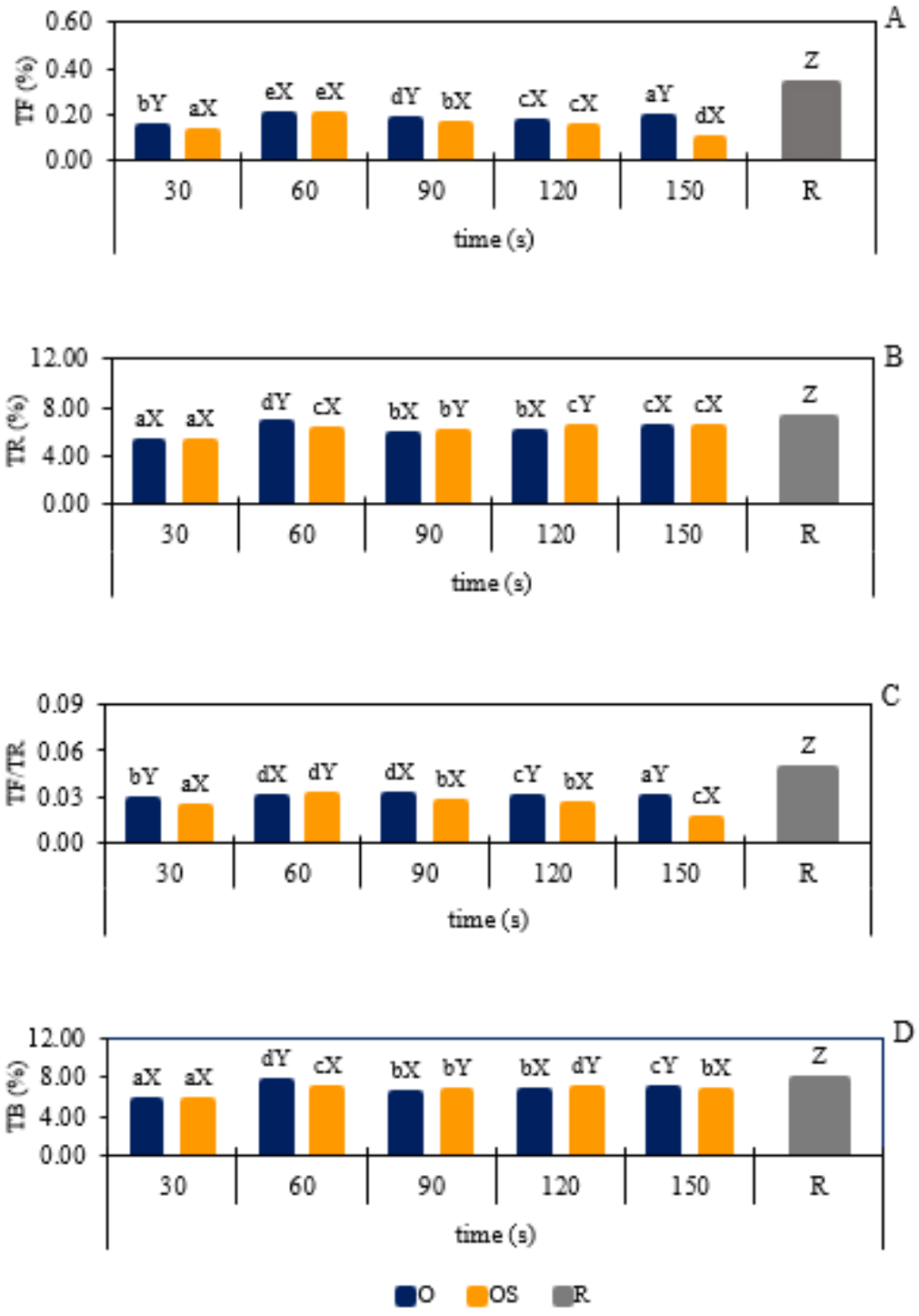
***Figure 2**. The total phenolic contents (TPC; mg GA/g sample) of the teas*

O and OS samples were different from each other at all times and also from R sample. There were the differences between times of O samples. The samples at 90, 120 and 150th s were similar, and the samples at 30 and 60th s were different from each other for OS samples ($p<0.05$). Other researchers reported that total phenolic content depends on time and temperature, too [27-29]. Additionally, Guzel-Seydim et al. (2021) determined that brewing techniques had a significant effect along with long brewing time [21]. The total phenolic contents of Turkish black teas are generally around 6-7% [34,35].

3.2. Teaflavin (TF), Thearubigin (TR), TF/TR Ratio and Theabrownin (TB) Theaflavin (TF)

TF, TR, TF/TR and TB values of the teas are given in Figure 3. The highest TF value (0.330%) was detected in R sample. OS sample at 150th s had the lowest value whereas it was in the range of 0.137%-0.193% for O samples. O and OS samples at 60 and 120th s were the same but different from R; O and OS samples at 30, 90 and 150th s were statistically different from each other and from R. Also, it was determined that each time was different from each other in O and OS samples ($p<0.05$). Salman et al. (2019) found TF values between 0.10-0.16% at different brewing times, whereas Karaküçük, (2018) found that it varied between 0.16-0.24% in the tea samples brewing by six different drinkable waters [35, 36]. Efe, (2017) reported that it varied between 0.28% and 0.47% on average in different brewing times, and that the highest TF contents were obtained at 60. minute [37].

TR values for all samples were determined between 4.99-7.03%. The highest was found in the R sample, and the lowest was found in the O sample at 30th s.



R: black tea prepared with the traditional tea brewing process (Reference sample)

O: black tea produced using oxygenated water by the dynamic tea extraction process

OS: black tea produced using non-oxygenated water by a dynamic tea extraction process

"a-e" series shows the differences between the times of each sample, "X<Y<Z" sequence shows the differences between the samples (O and OS) at each time and the R sample, statistically ($p<0.05$).

Figure 3. *Teaflavin (TF), Tearubigin (TR), TF/TR and Teabrownin (TB) values of the teas*

The lowest (5.10%) and the highest (6.17%) values for OS samples were respectively at 30, and at both 120 and 150th s. O sample at 30th s and OS sample at 150th s were the same, but different from R; O and OS samples were different from each other at 60, 90 and 120th s and from R. In time-TR evaluation, it was determined that 90 and 120th s were similar, and 30, 60 and 150th s were different from each other for O samples. On the other hand, 60, 120 and 150th s were similar and 30 and 90th s were different for OS samples ($p<0.05$). As the present results were close to Efe's (2017) study (3.09-6.85), Karaküçük, (2018) results (13.32-17.63) were very high [36, 37].

TF/TR ratios were determined as 0.0469 for R sample, in the ranges of 0.0274-0.0299 and 0.0141-0.0309 for O and OS samples. As the highest TF/TR value was detected in R sample, the lowest value was detected in OS sample at the 150th s, O and OS samples in each time were found to be statistically different from each other and from the R sample ($p<0.05$). The samples at both 60 and 90th s were similar but the samples at other times were different from each other for O teas. The samples at 90 and 120th s were similar for OS teas.

TB values were detected in the range of 5.48-7.66%. The highest was found in the R sample, and the lowest in both the O and OS samples at 30th s. The values in O sample at 30th and OS sample at 150th s were the same, but R sample was different from all other samples ($p<0.05$). It shows that the results are close to Efe's (2017) study (3.09-6.85), but different from Karaküçük, (2018) results (13.32-17.63) [36, 37]. The binary interactions between tea extraction process-time, tea extraction process-TB, and time-TB for TB values of R, O and OS samples were statistically significant ($p<0.05$).

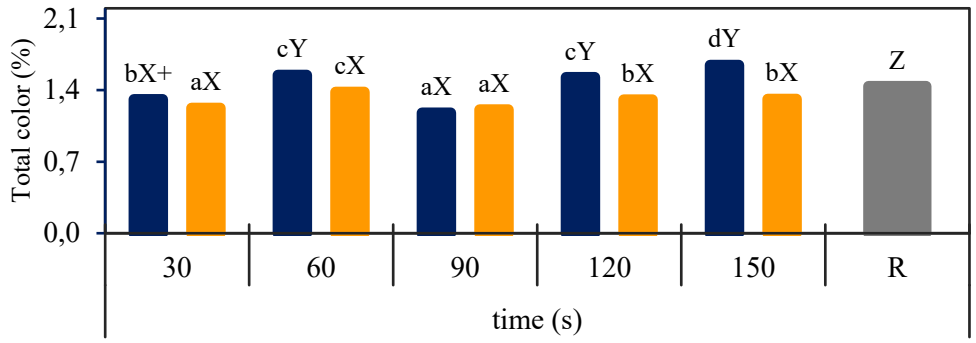
Theaflavin and thearubigins begin to form with the oxidation of primary secondary compounds at black tea production stages, and therefore TF/TR ratio gradually increases (0.014-0.046). As TFs are responsible for the light-yellow color, astringency and bitterness in black tea liquor, TRs are the compounds responsible for the dark, dull color [38]. Additionally, as the size of the tea leaves decreases in sorted black teas and the particle size decreases in tea powders, the TF/TR ratio increases [39]. Similar results were observed in the study of Efe, (2017) and irregular increases and decreases were detected. Jiang et al. (2019) found the TB value of Black tea obtained from fresh tea (Camellia sinensis L.) leaves was 2.71 mg/g, but Xu et al. (2019) determined it as 0.32 mg/g [37, 40, 41]. However, in the simulation of drought severity and rainfall on volatile and non-volatile metabolites of tea, it was found that the TB amount was 0.016 mg/mg in the tea sample in 100% rainfall treatment, 0.018 mg/mg in the tea sample in 75% rainfall treatment, and 0.041 mg/mg in the tea sample in 50% rainfall treatment. Therefore, variations in TB amounts are revealed [42].

The quality of black tea is considered optimum when the ratio between TF and TR is 1/10. In this case, the color is copper red or dark orange. Astringency, brightness, strength and aroma are at their highest level and tea tasters confirm the high quality of those teas in which the ratio of theaflavins to thearubigins is greater than 0.1. [43, 44]. Although the ratio of theaflavins to thearubigins in a good tea is 1/10, when this ratio is 1/25 or less, the brightness, astringency and strength in the tea brew decrease significantly [45, 46]. TBs are advanced oxidation and polymerization products that are responsible for the dark brown-reddish color of the tea brew. Those products, which are an important component of black tea and have a negative effect on tea quality, are formed from polyphenols, TFs and TRs [47]. The determinations of TF, TR, TF/TR and TB amounts in teas; since it significantly affects the sensory properties of tea, is very important to determine the quality of the tea liquor [48-57]. In black tea liquor, the total content of TB is 4 to 9% (w/w), but in the dark tea liquor this value will be higher [58,59].

3.3. Total Color, Brightness and Hunter Color Values

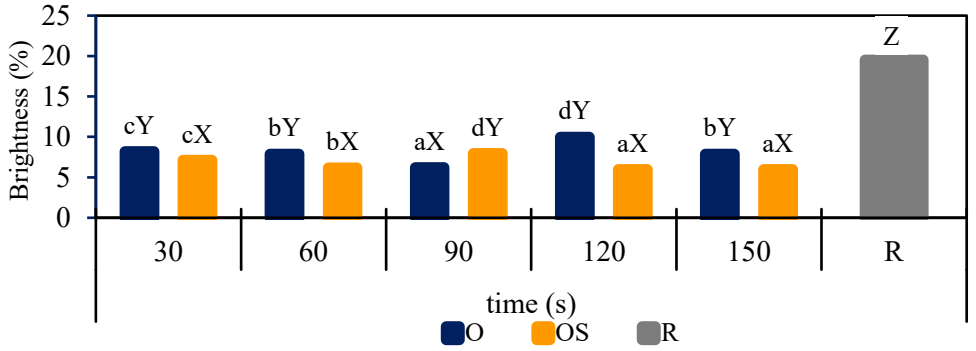
The total color values of the samples are given in Figure 4a. The highest (1.64%) and the lowest (1.18%) values were detected at the 150 and 90. second in O samples. It was determined that the total color values of OS samples varied between 1.21-1.38%, and 1.44% for R sample. O and OS samples were statistically different from each other at all times, except 90. second, and from the R sample ($p<0.05$). The brightness values of R, O and OS samples are given in Figure 4b. The brightness values varied in range of 6.24-9.98% and 5.98-7.97% for O and OS samples and was 19.51% for R sample. It was found that there were the similarities between 60 and 150th s for O samples and between 120 and 150th s for OS samples although the other times were different from each other ($p<0.05$). The total color value depends on the level of theaflavin and thearubigins contained in a tea. Therefore, if theaflavin and thearubigins levels are high, the total color value may increase. It increases with increasing brewing time, and there may be unnoticeable increase and

decrease during that increase time. Poyrazoğlu and Gürses, (2004) found that the total color value of the teas brewed in different quantities and for different periods of time were between 0.725 and 2.875 [45].



4A

X<X+<Z<Y" sequences shows the differences between the samples (O and OS) at each time and the R sample, statistically ($p<0.05$).



4B

R: black tea prepared with the traditional tea brewing process (Reference sample)

O: black tea produced using oxygenated water by the dynamic tea extraction process

OS: black tea produced using non-oxygenated water by a dynamic tea extraction process

"a-e" series shows the differences between the times of each sample, "X<Y<Z"sequence shows the differences between the samples (O and OS) at each time and the R sample, statistically ($p<0.05$).

Figure 4. *Total color and brightness of the samples*

Figure 5 shows Hunter Lab color values of the samples. The waters and the brewing times affected L values of the samples. O and OS samples were different from each other all times and from the R sample ($p<0.05$). Similarly, there are studies reported that brewing water affected L value [36, 60,61].

a* values of the samples varied from -0.06 to 0.27. The value of R sample was within the range of the values of O and OS samples, and it was observed that the brewing process, brewing water properties and different brewing times influenced a* value. O and OS samples at each time were different from each other ($p<0.05$). The present study shows the like some previous studies. For example, in brewing process of the different teas (green tea, black tea, oolong tea, yellow tea, white tea and dark tea) with the different waters (ultrafiltration water, natural spring water, pure water and natural mineral water); the brewing waters had negative or positive effects on the a* value of the tea liquor due to their chemical compositions [60]. Wang et al. (2021) determined that the a* values increased sharply during black tea processing stages. Balaban, (2019) found the highest a* value to be approximately 5.6 [62, 63].

In addition, it was found that the a* values of black tea brewed using six different drinkable waters (tap water, borehole water, softened water, pure water and 2 different commercially packaged water) varied between 0.17 and 1.10 [32]. The present results are partially similar to those reported that prolonged time and higher temperatures lead to more greenness and yellowness in the teas by [64]. Kadiroğlu and Dıblan, (2017) found in the range of (-0.67)-39.93 for the a* value of black teas [65]. Kelebek, (2016) reported that the a* values of tea increased positively with increasing brewing time and temperature, and that the color values of tea brewed in 3 minutes were lighter, less red, and less yellow than those obtained from brewing times of 6. and 10. minutes [66].

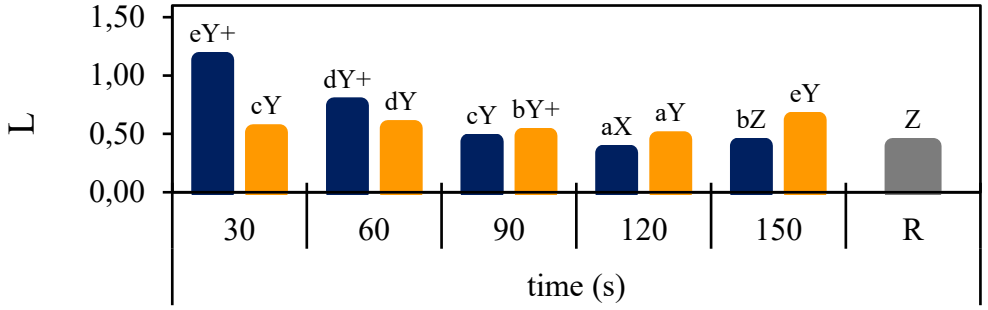
The b* values were determined as 0.280 for R sample, in the range of 0.135-0.605 for O samples and 0.300-0.530 for OS samples. It was found that both O and OS samples in each time were different from each other and from R. Significant differences were detected in the b* values when the time and the type of the water changed ($p<0.05$). It was determined that the b* value varied depending on the brewing time and the type of water used in brewing in previous similar studies, too [36, 60, 62-66].

3.4. Antioxidant Activity

Figure 4.5 shows antioxidant activity of all samples. O and OS samples had the higher antioxidant activity values compared to R sample and the black teas prepared with oxygenated water showed the highest antioxidant activity at all times. The antioxidant activity differed from tea extraction process, extraction time and water characteristics ($p<0.05$). Especially, the low antioxidant activity of the reference sample could be due to the long brewing time. Somewhat, there was the same trend observed in the antioxidant activity results as comparing the total phenolic compound content. Basically, antioxidant activity could depend on the total amount of phenolic compounds of black tea extracts [66]. The degradation of the antioxidant activity of tea might have been because of the degradation of the native antioxidants and the formation of new ones during tea brewing as coffee roasting [67]. Unfortunately, little information is available on the effect of oxygenated water on tea in relation to antioxidant activity, but Duan et al. (2011), investigated the effects of pure oxygen on pericarp browning, reactive oxygen species metabolism, antioxidant enzyme and antioxidant activity of harvested litchi fruit and it was reported that treatment with pure oxygen markedly increased antioxidant ability [68]. Reducing power and scavenging activities of DPPH radicals, superoxide anions and hydroxyl radical of methanol extracts from the fruit pericarp decreased progressively as increasing the storage time. Application of pure oxygen delayed the decrease of reducing power and free radical scavenging activity of the fruit.

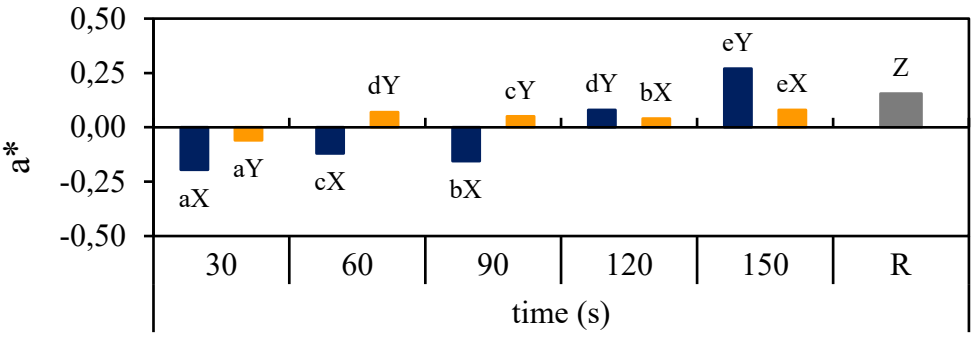
5. CONCLUSION

The black tea brewing processes were carried out using dynamic solid-liquid extraction and traditional processes (dynamic tea extraction and traditional brewing processes). The dynamic solid-liquid extraction method is designed to reach values close to the quality of classic tea quickly and in today's work tempo. Additionally, the effects of oxygenated water used in dynamic extraction on tea quality were determined. The differences between the brewed teas were determined by chemical components and physical properties, which are basic quality indicators. Accordingly, as expected, TP, TF, TR, TF/TR and TB amounts of the tea brewed with the traditional process were the highest, but these values in the tea obtained with oxygenated water at 150. seconds were almost higher than in the non-oxygenated. And the oxygenated water was more effective. Similarly, the positive effect of oxygenated water on total color and brightness values were higher than that of non-oxygenated water. That is, the properties of the brewing water markedly influenced the tea quality. Some concrete data were presented in the present study. However, consumer tastes of teas produced from the black tea brewing process with dynamic solid-liquid extraction have not been evaluated. In future, consumers' tastes in that food process designed for black tea should be revealed through sensory tests.



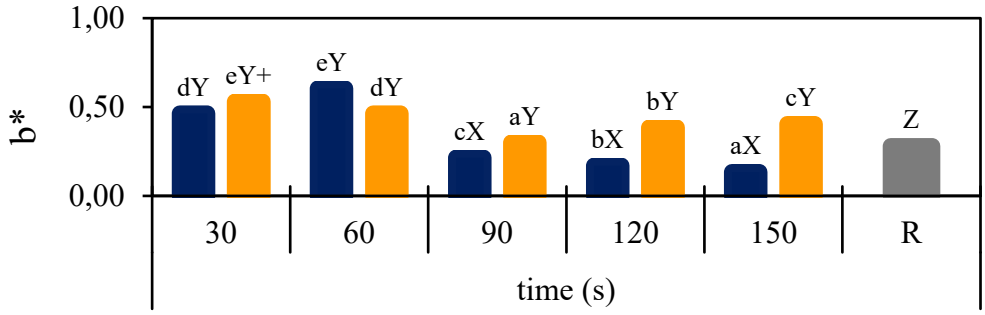
5A

"X<Z<Y<Y+" sequence shows the differences between the samples (O and OS) at each time and R sample, statistically ($p<0.05$)



5B

"X<Y<Z" sequence shows the differences between the samples (O and OS) at each time and R, statistically ($p<0.05$)



5C

"X<Z<Y<Y+" sequence shows the differences between the samples (O and OS) at each time and R sample, statistically ($p<0.05$)

O OS R

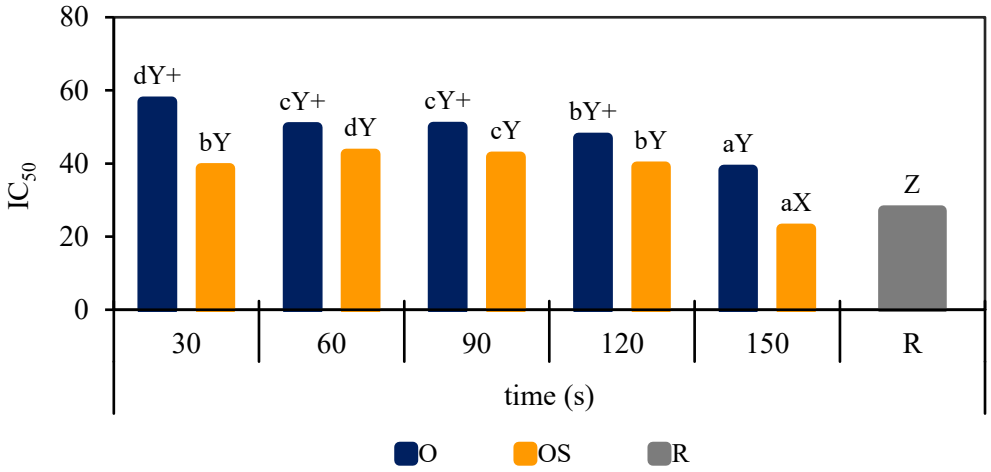
R: black tea prepared with the traditional tea brewing process (Reference sample)

O: black tea produced using oxygenated water by the dynamic tea extraction process

OS: black tea produced using non-oxygenated water by a dynamic tea extraction process

"a-e" series shows the differences between the times of each sample.

Figure 5. *Hunter color values of the samples*



R: black tea prepared with the classical tea brewing process (Reference sample)
O: black tea produced using oxygenated water by the dynamic tea extraction process
OS: black tea produced using non-oxygenated water by a dynamic tea extraction process
"a-e" series shows the differences between the times of each sample, "X<Z<Y<Y+" sequence shows the differences between the samples (O and OS) at each time and the R sample, statistically ($p<0.05$).

Figure 6. *Antioxidant activities (IC_{50}; µg/ml) of the samples*

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest between them.

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