CHANGES IN CHEMICAL CONSTITUENTS AND POLYPHENOL OXIDASE ACTIVITY OF TEA LEAVES WITH SHOOT MATURITY AND COLD STORAGE

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ABSTRACT

The variation in the composition of fresh tea leaves with season and shoot maturity, and to the applicability of cold storage (4C and 90% relative humidity [RH]) for the purpose of withering of tea leaves were studied. The results showed that the levels of polyphenol oxidase (PPO) activity and the polyphenolic content changed significantly with plucking season and shoot maturity. No significant difference was observed between the total polyphenolic content of the cold storage-withered and traditionally withered samples, whereas the loss of PPO activity was less in the cold-stored leaves. No significant difference was observed between the cold storage-withered and traditionally withered samples in terms of the end product quality. Results showed that cold storage at 4C and at 90% RH was suitable for storing fresh leaves after plucking until the time of processing and it is possible to achieve withering during the cold storage of tea leaves.

PRACTICAL APPLICATIONS

The tea growing season is very short in Turkey. Therefore, the tea processing factories sometimes experience capacity problems, and high amounts of tea leaves are lost because of poor storage conditions until the time of processing. Moreover, the quality losses in fresh tea leaves between the time of harvesting and processing have a negative impact on the final black tea quality. The application of cold storage for long-term withering of fresh tea leaves can help to prevent the postharvest losses and can prolong the period for black tea production.

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INTRODUCTION

Tea is the most widely consumed beverage in Turkey and a most common one all over the world. Apart from preharvest agronomic practices, there are two main factors affecting black tea quality; plucking standard and processing. In general, the recommended plucking standard is two leaves and a bud. It is well known that coarse plucking standards impairs black tea quality because of the reduced levels of aroma and flavor precursors, namely the polyphenolic compounds and also polyphenol oxidase (PPO) activity (Thanaraj and Seshadri 1990; Obanda and Owuor 1992). Therefore, it is important to use young leaves and obey the plucking standards for achieving optimum black tea quality. Moreover, the amount of catechins (Cs) also changes with the plucking season of tea (Bokuchava and Skobeleva 1980; Lin et al. 1996; Singh et al. 1999; Yao et al. 2005).

The traditional method of black tea production involves four basic steps: withering; maceration or rolling; fermentation; and drying. Withering involves both chemical and physical changes through which green tea leaves are prepared for maceration (Tomlins and Mashingaidze 1997). Green tea leaves contain about 70–83% moisture. During withering this reduces to about 68–72% or 60–66% for maceration with the cut–tear–curl method or with the orthodox method, respectively (Hampton 1992; Kacar 1992). In the orthodox method, withering takes about 16–20 h. Time, temperature and relative humidity (RH) of withering have significant effects on the final product quality (Obanda et al. 2004).

Withering also causes changes in the level of Cs, gallic acid and PPO activity. Cs constitute the main group of polyphenolic compounds in tea leaves (Chen et al. 2003). They may constitute up to 30% of the dry mass of tea leaves. They include catechin (C), epicatechin (EC), epicatechin gallate (ECG), epigallocatechin (EGC), EGC gallate (EGCG) and gallicatechin (GC).

Depending on the season and variety, the levels of total catechins and caffeine in tea leaves were found to be in the range of 2.12–6.90 g/100 g and 0.68–4.35 g/100 g, respectively (Lin et al. 1996). Lin et al. (2003) reported that the levels of total C and caffeine in tea leaves and various teas ranged from 2 to 126 mg/g and 23 to 49 mg/g, respectively. The total C content is highest in young leaves and decreases significantly with leaf aging (Forrest and Bendall 1969; Thanaraj and Seshadri 1990; Lin et al. 1996; Aucamp et al. 2000). The bud and the first leaf contain the largest amount of Cs, followed by the second and third leaves. The total C content of young shoots averages 25–30% (Bokuchava and Skobeleva 1980). EGCG is quantitatively the major constituent in all parts of the tea shoot (Lin et al. 1996; Singh et al. 1999). A positive correlation has been found between the quality of
made black tea and the C composition in fresh leaves of Kenyan cultivars (Owuor and Obanda 1998). The amount of EGC, GC, ECG and EGCG decreases during withering, whereas EC increases (Bokuchava and Skobeleva 1980). It was reported that the increase in EC might be related to the degradation of EGCG whereas the decrease in the former ones might be associated with oxidative transformations (Dzhemukhadze 1966).

Caffeine and gallic acid are two other important polyphenolic compounds in tea. The caffeine content of various teas was found to range from 2.64 to 4.0% in various studies (Lo and Chu 1945; Owuor and Obanda 1998). Caffeine content decreases with increasing leaf maturity of tea (*Camellia sinensis*) (Owuor and Chavanji 1986; Lin et al. 1996). It was found that gallic acid (Dzhemukhadze 1966) and caffeine contents increase during withering (Bhatia 1962; Stagg and Millin 1975; Bhuyan and Mahanta 1989; Astill et al. 2001). The increase in caffeine concentration appears to be related to amino acid metabolism (Roberts and Sanderson 1966), whereas that of gallic acid is suggested to be caused by the degradation of EGCG as in the case of EC (Dzhemukhadze 1966).

PPO plays a vital role in black tea production. It is found in all parts of the tea plant (Buzun et al. 1984) and tea quality is positively correlated with its content (Biswas et al. 1971). PPO activity is higher in tender leaves than that of in mature leaves (Takeo and Baker 1973; Thanaraj and Seshadri 1990). Because of the loss of moisture, the PPO activity reduces during withering or storage of the fresh leaves. Very hard withering or high reduction of moisture could result in as high as 50–55% reduction in PPO activity (Ullah and Roy 1982).

As there occurs many chemical and physical changes during withering that directly or indirectly affect the final quality of black tea, it is crucial to control these changes during withering, and understand the relation between these changes and withering parameters, namely time, temperature and humidity. A considerable amount of tea leaves is lost before withering, because of poor handling practices and uncontrolled conditions. Moreover, the tea growing season in Turkey is very short, about 3–4 months. Therefore, the tea processing factories sometimes experience capacity problems, and need a way to store the fresh tea leaves until the time of processing. Thus, the purposes of this study were to investigate the changes that occur during cold storage, and to judge whether it is possible to achieve withering during cold storage, and to compare traditional withering with cold storage withering and exploring the possibility of applying it as an alternative withering technique.
MATERIALS AND METHODS

Raw Material

Fresh tea shoots (C. sinensis) comprising a bud and four leaves were plucked from a tea farm in Rize, which is the main city of tea production in Turkey. The first shoots were harvested in May 2003 and the second shoots in June 2003.

Chemicals

EC, EGC, EGCG, C, gallic acid and caffeine were purchased from Sigma-Aldrich (Steinheim, Germany). High-performance liquid chromatography (HPLC) grade phosphoric acid, acetonitrile (Merck, Darmstadt, Germany) and distilled water (Milli-Q, Millipore, Molsheim, France) were used for the HPLC analysis phenolic compounds. Acetone and anhydrous sodium sulphate were purchased from Merck Co. (Steinheim, Germany) to be used in the PPO analysis. Tromethamine [1,1,1-Tris-(hydroxymethyl)-methylamine] and pyrogallol were purchased from Sigma-Aldrich and potassium titannium oxalate from Alfa Aesar (Karlsruhe, Germany) to be used for the analysis of total polyphenols.

Methods

PPO and total polyphenols were assayed spectrophotometrically (Lambda 35 UV/VIS Spectro, Perkin Elmer, Huenenberg, Switzerland) according to the method of Ravichandran and Partibhan (1998) and Bendal and Hill (1969), respectively. Phenolic compounds and caffeine were determined by HPLC (Shimadzu Calss-VP, Kyoto, Japan) according to Lin et al. (1996). The column used was an ACE C18 reversed-phase column (25 cm × 4.6 mm × 5 μm; Advanced Chromatographic Technologies, Aberdeen, Scotland).

Withering was achieved by storing the fresh tea shoots in cold storage at 4C and 90% RH. Traditionally withered tea shoots obtained from a black-tea-producing factory in Rize were used as control samples. They were withered on troughs by blowing air at about 32C for 6–8 h under 60–70% RH.

Both the cold storage and traditionally withered tea samples were processed in a laboratory scale unit under the same conditions and the end product was analyzed for theaflavin (TF), thearubigin (TR), liquor brightness and color levels. TF analysis were performed spectrophotometrically (Lambda 35 UV/VIS Spectro, Perkin Elmer) according to the Flavognost method by measuring the absorbance at 625 nm (Hilton 1973). TRs, brightness and color were analyzed according to Roberts and Smith (1961).
Statistical Analysis

Cold storage-withering studies were performed in two parallel cold storages. At each sampling time, one sample was taken from each of the cold storages and two parallel determinations were done in each of the sample. All the values are means of four determinations. Differences between data were analyzed using analysis of variance followed by least significant difference test at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Changes in PPO and Polyphenols with Season and Shoot Maturity

The changes in the composition of green tea leaves with shoot maturity and season is given in Table 1. The PPO activity, total polyphenolic content and the polyphenolic compounds, except for gallic acid, showed a significant ($P < 0.05$) increase in the second shoot harvested in July 2003 compared with that harvested in May 2003. Seasonal variations in PPO activity was attributed to the water availability. It was reported that the PPO activity was greater during high crop seasons by Ravichandran and Partibhan (1998). In general, the levels of polyphenolic compounds determined were in consistent with the findings in previous studies (Obanda and Owuor 1997; Jeyaramraja et al. 2003). EGCG was found to be the most abundant polyphenolic compound present in green leaves as also reported by Obanda and Owuor (1997). Among the polyphenolic compunds, the highest increase was observed in EGCG and then in EGC depending on the season. Similarly, Bhatia and Ullah (1968) also observed an increase in the polypehnolic content, especially in the amounts of EGCG and EGC, and reported that it was higher in the rainy season. The increase in polyphenolic compounds with season was expalined by the active synthesis of EGCG and ECG (Bokuchava and Skobeleva 1980). Yao et al. (2005) reported that the levels of EGCG in Australia-grown fresh tea shoots were higher in warm harvesting season than that of in cool months, whereas the levels of EGC were higher in cooler months. It was reported that the possible explanation for this might be the consumption of EGC because of the increase in the active biosynthesis of EGCG during summer months. Moreover, Lin et al. (1996) found that polyphenolic content of tea leaves was higher in summer than in spring. They were stated that the growth rate and metabolic activities were higher in summer, resulting in a higher total Cs content in tea leaves. In general, the seasonal variations in polyphenolic content of fresh tea shoots were attributed to the differences in the length of daytime, amount of sunlight received and temperature, which changes significantly depending on the season (Yao et al. 2005). They are also changing significantly owing to
TABLE 1.
CHANGES IN CHEMICAL COMPOSITION (g/kg) AND PPO ACTIVITY (units) WITH SHOOT MATURITY AND SEASON*

<table>
<thead>
<tr>
<th>Shoot maturity</th>
<th>PPO†</th>
<th>Total polyphenol‡</th>
<th>Caffeine‡</th>
<th>Gallic acid‡</th>
<th>EGCG‡</th>
<th>EC‡</th>
<th>EGC‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>First shoot (May 2003)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bud and two leaf</td>
<td>49 ± 0.49</td>
<td>198.0 ± 1.1</td>
<td>15.5 ± 0.2</td>
<td>4.5 ± 0.2</td>
<td>78.5 ± 0.9</td>
<td>3.8 ± 0.2</td>
<td>21.4 ± 0.1</td>
</tr>
<tr>
<td>Third leaf</td>
<td>28 ± 0.28</td>
<td>160.3 ± 2.8</td>
<td>14.6 ± 0.2</td>
<td>3.8 ± 0.1</td>
<td>48.6 ± 0.5</td>
<td>3.1 ± 0.1</td>
<td>20.5 ± 0.2</td>
</tr>
<tr>
<td>Second shoot (June 2003)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bud and two leaf</td>
<td>52 ± 0.64</td>
<td>235.8 ± 1.1</td>
<td>21.4 ± 0.4</td>
<td>4.2 ± 0.1</td>
<td>110.2 ± 0.5</td>
<td>5.1 ± 0.1</td>
<td>28.2 ± 0.3</td>
</tr>
<tr>
<td>Third leaf</td>
<td>21 ± 0.42</td>
<td>191.0 ± 1.8</td>
<td>17.4 ± 0.4</td>
<td>4.0 ± 0.2</td>
<td>108.7 ± 0.1</td>
<td>4.5 ± 0.1</td>
<td>26.5 ± 0.5</td>
</tr>
<tr>
<td>LSD§</td>
<td>1.3</td>
<td>5.1</td>
<td>0.9</td>
<td>0.4</td>
<td>2.3</td>
<td>0.4</td>
<td>0.9</td>
</tr>
</tbody>
</table>

* Mean ± standard deviation.
† 1 unit = 1 μmol of catechin oxidized/min/g acetone powder.
‡ On dry weight basis.
§ LSD values calculated for shoot maturity × season at $P < 0.05$.
EC, epicatechin; EGC, epigallocatechin; EGCG, EGC gallate; LSD, least significant difference; PPO, polyphenol oxidase.
both drought and waterlogging stress (Jeyaramraja et al. 2003). There was an increase of about 38% in the caffeine content of tea shoots harvested in June 2003. Cloughley (1982) reported over 60% variations in caffeine content under Malawi conditions through the year. But, as the mean temperature variations during the tea growing season in Turkey are not large, the change in caffeine content was not found as high as the Malawi data. Owuor and Chavanji (1986) reported the seasonal variation in caffeine content of different tea clones as between 24 and 30% under Kenyan conditions, where the temperature fluctuations are not large during the tea growing season like Turkey.

A marked decline was observed in PPO activity with shoot maturity (Table 1). This observation agrees well with the previous data (Takeo and Baker 1973; Thanaraj and Seshadri 1990; Ravichandran and Partibhan 1998). The PPO activity changed significantly with both season \((P < 0.05)\) and shoot maturity \((P < 0.001)\). But the effect of shoot maturity was significantly higher than the effect of season. The total polyphenol content and the EC content were found to be equally affected by the shoot maturity \((P < 0.001)\) ans season \((P < 0.001)\). Only shoot maturity had a significant \((P < 0.05)\) effect on the GA level, whereas seasonal differences were found to be insignificant. On the other hand, the effect of season \((P < 0.001)\) was more pronounced for the caffeine, EGCG and EGC contents compared with the effect of shoot maturity \((P < 0.05)\). In general, the total polyphenolic content, caffeine and the polyphenolic compounds showed a significant \((P < 0.05)\) decrease with shoot maturity that is similar to that observed in previous studies (Bhatia and Ullah 1968; Owuor and Chavanji 1986; Owuor and Obanda 1998; Chen et al. 2003).

Changes in PPO Activity and Polyphenols During Withering

Fresh tea leaves were stored at 4°C and 90% RH, as this is the recommended cold storage condition for most of the green leafy vegetables and herbs (Hardenburg et al. 1986). During 22–27 days of cold storage at 4°C at 90% RH, about 8–10% of moisture loss was observed from the fresh tea shoots, which was far less than that normally achieved by traditional withering methods (Table 2). Moreover, no significant \((P < 0.05)\) change was observed in the concentration of total polyphenolic content, both for the control samples and for the cold-stored samples.

A small decrease was observed in PPO activity during storage. Ullah and Roy (1982) attributed the loss of PPO activity to the loss of moisture during withering. Moreover, Cloughley (1979) reported that the PPO activity also decreased with increasing temperature. Thus, as there occurred less moisture loss during cold storage as compared with traditional withering and as the temperature is low, the loss of PPO activity was also less than that of during traditional withering.
The slight increase in gallic acid during storage can be attributed to the decrease in EGCG and EGC as stated by Dzhemukhadze (1966). In both of the storage studies, the caffeine content showed a significant \((P < 0.05)\) increase during the storage time (Table 3). Similarly, Astill et al. (2001) found a significant increase in caffeine content as a result of withering process, being higher in short withered leaf in green tea processing. Roberts and Sanderson (1966) reported that the increase in caffeine content can be because of the amino acid metabolism. No significant change was observed in the concentrations of EC, which might be related to the degradation of EGCG (Bokuchava and Skobeleva 1980).

The decrease in the EGCG levels in the first shoot is higher than that of in the second shoot. Contrary to our data, Chen et al. (2003) reported that caffeine content did not change significantly during withering, whereas EGC, EGCG and EC increased markedly.

### Table 2.
<table>
<thead>
<tr>
<th>Time (days)</th>
<th>Moisture (g/kg)</th>
<th>Total polyphenols (g/kg)†</th>
<th>PPO acitivity (units‡)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First shoot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 (fresh leaves)</td>
<td>711.3 ± 0.6</td>
<td>198.0 ± 1.1</td>
<td>49 ± 0.49</td>
</tr>
<tr>
<td>4</td>
<td>704.2 ± 0.8</td>
<td>206.6 ± 1.6</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>691.0 ± 1.2</td>
<td>198.0 ± 2.0</td>
<td>49 ± 0.42</td>
</tr>
<tr>
<td>12</td>
<td>675.0 ± 0.7</td>
<td>182.6 ± 0.4</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>664.3 ± 1.1</td>
<td>202.2 ± 3.0</td>
<td>45 ± 0.57</td>
</tr>
<tr>
<td>19</td>
<td>649.2 ± 1.3</td>
<td>217.5 ± 1.8</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>651.5 ± 0.5</td>
<td>216.2 ± 2.0</td>
<td>46 ± 0.28</td>
</tr>
<tr>
<td>Control for first shoot (traditional withering)</td>
<td>580.5 ± 0.5</td>
<td>193.3 ± 1.2</td>
<td>40 ± 0.32</td>
</tr>
<tr>
<td>Second shoot</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 (fresh leaves)</td>
<td>757.3 ± 0.4</td>
<td>235.8 ± 1.1</td>
<td>52 ± 0.64</td>
</tr>
<tr>
<td>8</td>
<td>751.0 ± 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>747.8 ± 0.8</td>
<td>221.0 ± 1.0</td>
<td>51 ± 0.57</td>
</tr>
<tr>
<td>22</td>
<td>699.5 ± 1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>672.7 ± 1.1</td>
<td>243.0 ± 2.8</td>
<td>47 ± 0.07</td>
</tr>
<tr>
<td>Control for second shoot (traditional withering)</td>
<td>593.7 ± 0.4</td>
<td>229.7 ± 2.3</td>
<td>42 ± 0.64</td>
</tr>
</tbody>
</table>

† On dry weight basis.
‡ 1 unit of PPO activity = 1 μmol catechin oxidized/min/g acetone powder.
* Mean ± standard deviation.
PPO, polyphenol oxidase.
Comparison of the Quality Parameters of Cold-Withered and Traditionally Withered Tea Samples

TFs and TRs are two important quality parameters for black tea. In general, the brightness and color of the tea liquor are attributed to TFs and TRs, respectively (Owuor and Obanda 1998). A positive correlation is usually observed between liquor brightness and total TF content of black tea, such that processing conditions that result in higher total TF content tend to give brighter liquors and vice versa (Obanda et al. 2001). The brightness and the colour of black tea liquor are two deterministic trade parameters for the price of the product.

Owuor and Obanda (1998) reported that withering at 10°C resulted in higher levels of TF and liquor brightness compared with high temperature withering at 32°C. On the other hand, the TR levels and liquor color levels decreased at lower withering temperatures. The effect of withering method on the final product quality was compared in Table 4. As shown, no significant differences ($P < 0.05$) were observed in terms of brightness, TF and caffeine levels between the black tea liquors produced through cold storage withering and traditional withering. Moreover, although statistically significant at a level of $P < 0.05$, the differences between the TR levels and the liquor color values of cold storage withered and traditionally withered tea samples were negligibly low. Thus, it may be stated that cold storage withering did not impair the black tea quality. The TF values in this study were found to be much lower than

### Table 3.

<table>
<thead>
<tr>
<th>Time (days)</th>
<th>Caffeine</th>
<th>Gallic acid</th>
<th>EGCG</th>
<th>EGC</th>
<th>EC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First shoot</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>15.5 ± 0.2</td>
<td>4.5 ± 0.1</td>
<td>78.5 ± 0.9</td>
<td>21.4 ± 0.1</td>
<td>3.8 ± 0.2</td>
</tr>
<tr>
<td>9</td>
<td>16.7 ± 0.3</td>
<td>5.5 ± 0.6</td>
<td>61.3 ± 0.3</td>
<td>19.4 ± 0.5</td>
<td>2.9 ± 0.5</td>
</tr>
<tr>
<td>15</td>
<td>20.3 ± 0.6</td>
<td>4.5 ± 0.1</td>
<td>54.5 ± 0.6</td>
<td>18.2 ± 0.3</td>
<td>2.7 ± 0.3</td>
</tr>
<tr>
<td>22</td>
<td>22.8 ± 0.8</td>
<td>6.0 ± 0.3</td>
<td>53.2 ± 1.0</td>
<td>14.9 ± 0.3</td>
<td>3.5 ± 0.5</td>
</tr>
<tr>
<td>LSD*</td>
<td>1.6</td>
<td>0.9</td>
<td>2.1</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td><strong>Second shoot</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>21.4 ± 0.4</td>
<td>4.2 ± 0.1</td>
<td>110.2 ± 0.5</td>
<td>28.2 ± 0.3</td>
<td>5.1 ± 0.1</td>
</tr>
<tr>
<td>17</td>
<td>19.4 ± 0.1</td>
<td>5.1 ± 0.2</td>
<td>111.9 ± 0.4</td>
<td>25.6 ± 0.6</td>
<td>4.8 ± 0.5</td>
</tr>
<tr>
<td>27</td>
<td>23.3 ± 0.1</td>
<td>5.5 ± 0.1</td>
<td>107.4 ± 0.5</td>
<td>22.9 ± 0.4</td>
<td>4.8 ± 0.2</td>
</tr>
<tr>
<td>LSD*</td>
<td>0.4</td>
<td>0.4</td>
<td>1.3</td>
<td>1.2</td>
<td>0.9</td>
</tr>
</tbody>
</table>

* $P < 0.05$.  
† On dry weight basis.  
‡ Mean ± standard deviation.

EC, epicatechin; EGC, epigallocatechin; EGCG, EGC gallate; LSD, least significant difference.

Chemical Constituents and Polyphenol Oxidase Activity
that of reported for the Kenyan teas, which was given around 25 μmol/g (Owuor and Obanda 1998; Obanda et al. 2004). On the other hand, the TF values were found to be around 2 μmol/g in this study (Table 4). The TF values in Turkish teas were reported to be in the range of 0.17–5.04 μmol/g and this low TF levels were explained to be a result of using seed for tea planting (Tüfekçi and Güner 1997).

**CONCLUSION**

The composition of tea leaves varies significantly with increasing maturity and time of plucking. The PPO activity and total polyphenolic content decreased significantly with increasing leaf maturity. At the end of the 22–27 days of cold storage of fresh tea leaves, a final moisture content of 65–67% was achieved, and the PPO activity was found to be higher than that of the traditionally withered samples. Moreover, the quality of tea liquors obtained by means of cold storage withering and traditional withering were not significantly different. Long-time cold storage withering did not adversely affect the quality of the end product. Thus, it was concluded that it is possible to store fresh tea leaves at controlled temperature and RH conditions to preserve them until the time of processing and at the same period it is possible to achieve withering. This can give the opportunity to small capacity tea processing factories to store their raw tea for about 1 month and continue processing without loss of product quality because of poor preprocess handling conditions.

**ACKNOWLEDGMENT**

The author wish to thank Muradoğlu Tea Industry for supplying fresh tea shoots during the project.

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**TABLE 4.**

**COMPARISON OF TRADITIONALLY WITHERED AND COLD STORAGE Withered BLACK TEA QUALITY PARAMETERS* (FIRST SHOOT, BUD AND TWO LEAVES)**

<table>
<thead>
<tr>
<th>Quality parameters</th>
<th>Traditional withering</th>
<th>Cold storage withering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness (%)</td>
<td>9.9 ± 0.3a</td>
<td>9.5 ± 0.2a</td>
</tr>
<tr>
<td>Theaflavins (μmol/g)</td>
<td>2.1 ± 0.3a</td>
<td>2.4 ± 0.3a</td>
</tr>
<tr>
<td>Thearubigins (%)</td>
<td>12.6 ± 0.2a</td>
<td>11.7 ± 0.3b</td>
</tr>
<tr>
<td>Total liquor color (%)</td>
<td>2.7 ± 0.1a</td>
<td>2.3 ± 0.2b</td>
</tr>
<tr>
<td>Caffeine (%)</td>
<td>2.3 ± 0.05a</td>
<td>2.1 ± 0.06a</td>
</tr>
</tbody>
</table>

* Mean ± standard deviation.
Values in the same row with a common letter are not significantly different ($P < 0.05$).
REFERENCES


