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Effect of Drying Temperature and Duration on Biochemical Composition and Quality of Black Tea (*Camellia sinensis* L.) O. Kuntze at Wush Wush, South Western Ethiopia

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Abstract: This study evaluates the effect of different drying temperature and duration on biochemical composition and quality of black tea. In black tea processing drying is the last step and it gives quality to the brew. In Wush Wush regardless of clones, tea leaves conditions and quality of the final product; a drying temperature of 110°C for 25 min was used to dry tea leaves. Furthermore, there was little research done so far to optimize drying temperature and duration and only subjective judgment had been used by factory cup tasters to determine the optimum drying temperature and duration. Therefore, this research was conducted at Wush Wush tea plantation and JUCAVM post-harvest laboratory in the year 2012/2013 on clone 11/4 to identify the optimum combination of drying temperature and duration using five drying temperature and three drying durations. The experiment was laid out using factorial design arranged in Randomized Complete Block Design (RCBD) in three replicates. Analysis of variance indicated that there were significant differences ($p<0.05$) among the treatment combinations (interaction effect) for all the traits (Total brightness, Total liquid color, Thearubigin, Aroma, Flavor, Moisture content and Leaf infusion) considered except Theaflavine whose main effect was observed to be significant. Generally it was observed that as temperature increased with duration the biochemical composition and quality of black tea were decreased. From this research to produce good quality of black tea a treatment combination of 100°C with 25 min was identified as the optimum treatment combination to be used in this production and other sites who are engaged in tea production in Ethiopia.

Key words: Drying temperature, drying duration, theaflavine, thearubgin, total brightness, total liquid color

INTRODUCTION

Tea (*Camellia sinensis* (L.) O. Kuntze) is an ancient crop originated in South Eastern Asia (Krafczyk and Glomb, 2008; Sultana *et al*., 2008). It is an evergreen plant that grows mainly in tropical and subtropical climates. The two basic botanical varieties of tea are *Camellia sinensis* variety *assamica* and *Camellia sinensis* variety *sinensis* (Wium, 2009). *C. sinensis* is the species of plant whose leaves and leaf buds are used to produce tea. It is consumed either as a black (fermented), green (non-fermented) or oolong (semi-fermented) beverage (Kamunya *et al*., 2009). Nowadays, consumption of tea is part of people's daily routine everyday drink and as a therapeutic aid in many illnesses. Tea is an exotic crop to Ethiopia and all tea plantations in Ethiopia produce only black tea that passes through a series of processing steps starting from harvesting of fresh tea leaves and passes to withering, rolling, fermentation finally to, drying and sieving (Wakjira *et al*., 2005).

The factory process of black tea, in particular, entails an oxidation of the polyphenolic compounds during which certain chemical changes take place (Kamunya *et al*., 2009). Quality of made tea, is directly influenced by the taste and aroma of tea liquor indicating good manufacturing practices are necessary to produces good quality tea (Botheju *et al*., 2011). The flavor of tea is balanced during drying (firing) because some of the undesirable compounds are removed at this processing step, thus accentuating the presence of more useful compounds (Naheed *et al*., 2007). Drying of tea is a necessary processing step to give quality to the brew as well as to remove moisture, arrest fermentation, reduce volume and increase shelf life. The drying temperature below 80°C is inadequate for generating the blackness. On the other hand, exposure of tea leaves to temperature of more than 140°C generates a burnt taint product (Temple *et al*., 2001). The initial temperature of drying is also important and must be high enough to inhibit enzyme activity; otherwise it may lead to deterioration.

In Ethiopia Wush Wush tea industry regardless of clones, tea leaves condition and quality of the final product; a temperature of 110°C for 25 min drying duration had been used to dry tea leaves. In addition, there was

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little research done so far to determine the optimum drying temperature and duration for developing good quality tea. However, the company approaches the quality problems by its cup tasters experience which usually results to subjective assessment and visual inspection method. Using this approach it will be difficult to produce competitive product in the international market. Apart from subjective assessment and visual inspection, biochemical parameters need to be investigated to improve black tea quality at different drying temperatures and durations. Therefore, this research was initiated with the objective of evaluating effects of drying temperature and duration on biochemical composition and quality of black tea at Wush Wush tea production, South Western Ethiopia.

MATERIALS AND METHODS

Processing procedures in the factory: Tea leaves of clone “11/4” were plucked from Wush Wush Tea Plantation farm (altitude 1950 m.a.s.l., latitude 7°16’N and longitude 36°11’E) in Southern Nations, Nationalities and Peoples Regional State (SNNRP) of Ethiopia, in Kafa zone at an interval of 7-10 days. After plucking the leaves were immediately delivered to the factory. The harvested leaves were loaded in 18 by 4 m closed withering cabinet for withering. Ambient air was allowed to pass through the leaves for 18 h to bring about adequate physical and chemical withering. The withered leaves were passed through a CTC (Crush, Tear and Curl) machine to be rolled for 15 min in a miniature roller and fed into a miniature spiral rotor vane to achieve a fine dhool. The macerated leaf (dhool) was fermented for 120 min at 25°C and passed to the drying cabinet where they were dried depend on treatment combinations of five drying temperature (90,100,110, 120 and 130°C) and three drying duration (20, 25 and 30 min) to give fully dried black tea. The experiment was laid out in a 5×3 (temperature and duration) factorial design arranged in Randomized Complete Block Design (RCBD) with three replications.

Chemical analysis: All black tea samples were subjected to chemical analyses at postharvest laboratory of Jimma University, College of Agriculture and Veterinary Medicine (JUCAVM), (altitude 1710 m above sea level and 70°42’ N latitude and 36°50’ E longitudes) is located at the southwestern part of Ethiopia in Oromia Regional state. Spectrophotometric measurements were conducted to measure the quality parameters of black Tea for theaflavins (TFs), thearubigins (TRs), total liquid color as well as total brightness as per the procedures developed by Roberts and Smith (1961). Following these measurements amounts of quality parameters of tea samples were determined using the following equation proposed by Ullah *et al.* (1984):

$$\text{At 380 nm TF (\%)} = 2.3\times E3$$

$$\text{At 460 nm total color (\%)} = 6.25\times 4E2$$

$$\text{At 380 nm total brightness (\%)} = \frac{E2}{4E2}\times 100$$

$$\text{At 460 nm TR (\%)} = 7.06\,(4E3-E1)$$

Where:
E1 = Reading obtained from the mixture of organic layer, ethyl acetate and methanol
E2 = Reading obtained from the mixture of tea leaves infusion, oxalic acid, water and methanol
E3 = Reading obtained from the mixture of leaf infusion, water and methanol

In all case spectrophotometric readings were taken at both 380 and 460 nm.

Sensory evaluations: Tea leaf (5.6 g) was added to boiled water (200 mL) and infused for 5 min. The sensory evaluation for flavor, aroma and leaf infusion was done by three professional tasters and the scores were taken on a scale of 1-5 (Owuor and Obanda, 2003). The range value was described as follows: (1) Poor, (2) Satisfactory, (3) Good, (4) Very good and (5) Excellent according to Wush Wush tasting method. During cup tasting tea evaluation room was kept clean with adequate lighting.

Methods of data analysis: The collected data were checked for assumptions of ANOVA subjected to analysis of variance using SAS version 9.2 Statistical Software (SAS, 2008). The mean differences were separated by Least Significant Difference (LSD) when significant treatment effects were observed. Pearson correlation was used to evaluate the relationships between taster’s scores and spectrophotometric measurements of each quality variables of processed black tea.

RESULTS AND DISCUSSION

Effect of drying temperature and duration on biochemical characteristic of black tea

Total brightness (TB): Total brightness indicates the ability of black tea liquor to reflect light from the surface. The result of this study showed that there was significant

Table 1: Interaction effect of drying temperature and duration on total brightness, total liquid color and thearubigins of processed black tea

	Duration of drying (min)								
	Total brightness			Total liquid color			Thearubigins (TR)		
Temperature (°C)	20	25	30	20	25	30	20	25	30
90	82.23^{a}	76.13^{bc}	61.53^{f}	4.80^{g}	6.47^{d}	8.57^{a}	6.77^{i}	11.13^{g}	11.50^{g}
100	78.10^{b}	73.67^{cd}	51.20^{h}	5.60^{e}	8.13^{b}	7.13^{c}	9.60^{h}	11.17^{g}	13.03^{f}
110	72.17^{d}	63.17^{ef}	36.57^{j}	6.67^{d}	8.80^{a}	7.03^{c}	13.63^{f}	11.67^{g}	15.43^{e}
120	65.67^{e}	55.37^{g}	33.80^{j}	7.07^{c}	7.07^{c}	6.50^{d}	11.53^{g}	15.70^{de}	16.40^{cd}
130	66.20^{e}	47.30^{i}	28.23^{k}	7.90^{b}	6.60^{d}	5.07^{f}	17.27^{bc}	17.93^{b}	19.33^{a}
LSD (5%)	3.47			0.24			0.95		
CV (%)	3.50			2.05			4.23		

Means followed by the same letter(s) are not significantly different at 5% for each of treatment combinations

($p<0.05$) interaction effect between treatments on total brightness of black tea (Table 1). As temperature level and duration of drying were increased the amount of total brightness was significantly declined. The highest TB values were obtained when tea leaves were dried at the inlet temperature of 90 and 100°C for duration of 20 min. An increase in the drying temperature from 100 to 130°C, significantly decreased TB at all drying durations. This result was in line with the previous findings of Temple (1999) who indicated that high temperature led to a loss of brightness resulting to dullness in the liquors because the fat content of the leaves were oxidized into brown and black pigment products. As indicated in, TB was positively and significantly correlated with aroma (r = 0.91**) and dried leaf moisture content (r = 0.82**) (Table 4).

Total liquid color (TLC): Total liquid color of black tea is an indicator of the depth of color. Result from analysis of variance indicated that there were significant ($p<0.05$) interaction effects of drying duration and temperature on the formation of Total Liquid Color (TLC) (Table 1). In this study, the highest value of total liquid color was recorded at a temperature of 110°C at a drying duration of 25 min whereas the lowest value was obtained at treatment combinations of 90°C duration of 20 min and 130°C at duration of 30 min. This imposed darkness on the liquid color of black tea. But the acceptable result of total liquid color was observed at a treatment combination of 110°C with 25 min. This result was in agreement with the findings of Ali *et al.* (2012) who observed the increase in temperature decreased the total liquid color. Similar results were also observed by Prachayawarakorn *et al.* (2004) demonstrating that drying temperature and durations are the main factors affecting tea color during drying process. This study demonstrated that total liquid color was positively and significantly correlated with leaf infusion (r = 0.82**) (Table 4).

Thearubigins (TR): Body and color are associated with TR contents and TR is reddish-brown in color. Thearubigin is a collective name for the largely unidentified, highly colored flavanol oxidation products. Their quantity in dry black tea has been given as 10-20% (Ullah *et al.*, 1984) and they are substantially water extractable. The analysis of variance showed that the interaction effect between drying temperature and drying duration was significant ($p<0.05$) with respect to Thearubigins (TR) content of the dried tea leaves (Table 1). The highest TR value was observed at a treatment combination of 130°C with the drying duration of 30 min. This finding was in line with the findings of Sanderson *et al.* (1972) who reported that drying reduced the extractable solids but increased the amount of TR of the dried tea leaves. Also the finding of Temple *et al.* (2001) shows that, a decline in the gallated flavan-3-ols with increased drying temperature could be attributable to thermally driven rearrangement or their incorporation into thearubigins. Generally, in this experiment decreasing drying temperature from 130-90°C and drying duration from 30-20 min significantly decreased the amount of extractable thearubigines from the dried leaves therefore increasing drying temperature and duration increase TR content. This result was also observed by Ali *et al.* (2012). The correlation coefficients (Table 4) showed that, thearubigins was significantly correlated with the moisture content dried leaf (r = -0.91**).

Theaflavin (TF): Brightness, briskness and strength are determined by the TF contents and TF is golden yellow in color. TF is formed in black tea by oxidation of quinines derived from the epicatechins and present in the extent of 1-2% in dry black tea and are substantially water extractable (Millin, 1987). There was no significant interaction effect of drying duration and temperature on the formation of theaflavin in the dried leaves. Each main factor has showed significant differences at ($p<0.05$) with respect to this variable (Table 2). As observed from this experiment, TF percentage in the dried leaves decreases as the drying temperature and the drying duration increase. The highest content of TF was observed at 90°C. But, the percentage of TF decreased as the drying

Table 2: Effect of drying temperature and duration on black tea Theaflavin of processed black tea

Parameters	TF
Temperature (°C)	
90	1.92[a]
100	1.79[b]
110	1.67[c]
120	1.63[c]
130	1.56[c]
LSD (5%)	0.12
Duration (min)	
20	1.88[a]
25	1.68[b]
30	1.57[c]
LSD (5%)	0.09
CV (%)	7.33

Means followed by the same letter in the same column are not significantly different at 5% for each of treatment combinations

temperature increased to 130°C at an interval of 10°C. According to Temple *et al.* (2001) TF content decreases as the drying temperature increases. Similarly, TF content decreased as the drying duration increased from 20-30 min. This observation is also supported by the findings of Temple *et al.* (2001) who indicated rapid drying in the initial stages is vital to prevent loss of theaflavin. The correlation coefficients (Table 4) showed that theaflavin was positively and significantly correlated with total brightness (r = 0.78**).

Effect of drying temperature and duration on sensory characteristics of black tea (depending on scales)

Aroma (AR): The volatile components comprise the aroma which is detected by sense of smell. The result of this study showed that there was significant ($p<0.05$) interaction effect of drying duration and temperature on the formation of Aroma (Table 3). The combination of numerous volatile compounds found in dried tea leaves determine the aroma of any given sample of tea (Hara *et al.*, 1995). Much of these compounds are generated during tea drying (Balentine *et al.*, 1998). In this experiment, highest aroma content was obtained at a treatment combination of 110°C with 20 min. On the other hand, relatively lowest aroma content was observed at a drying temperature of 120 and 130°C dried at 30 min drying durations. Similar results were also obtained by Ali *et al.* (2012) who demonstrated that higher temperature with longer drying duration affect the amount of the essential compounds responsible for tea aroma and result to 70-80% loss of the aroma constituents.. The correlation coefficients obtained from this result (Table 4) showed that aroma was positively and significantly correlated with teaflavine (r = 0.80**), moisture content (r = 0.77**) and total brightness (r = 0.91**).

Flavor (FL): The non-volatile components are responsible for taste (flavor) detected by the sense of taste. The result of this experiment showed that the interaction between temperature and duration of drying was significant ($p<0.05$) with respect to flavor development (Table 3). Black tea is generally stronger in flavor than the less oxidized teas. In this experiment, black tea with good flavor was observed in a treatment combination of 100°C with 30 and 25 min. But increasing the temperature to 130°C decreased the flavor in all drying durations. Hazarika *et al.* (1984) indicated appropriate drying temperature must be used to have tea with good flavor quality. The flavor of tea was balanced during firing because some of the undesirable compounds were removed, thus accentuating the presence of the more useful compounds (Naheed *et al.*, 2007). According to Ali *et al.* (2012), temperature affect the essential oil content during drying step and leads for the development of some flavor components due to the reaction between the amino acids and sugars. The positive impact of drying on the volatile components of tea has been demonstrated by Ravichandran and Parthiban (1998). According to these authors, the Volatile Flavor Index (VFI) increases during drying. However, drying tea leaves above certain temperature ranges results to the loss of flavor content. The correlation coefficients indicated in Table 4 showed that flavor was positively and significantly correlated with moisture content (r = 0.68***).

Effect of drying temperature and duration on leaf appearance of black tea

Moisture content (MC): Water content or moisture content is the quantity of water contained in a dried tea leaf infusion. Results obtained from this study showed that there were significant differences ($p<0.05$) in moisture content due to the interaction effects of temperature and drying durations (Table 3). At the time of processing, increasing drying temperature with duration, decrease moisture content of the dried leaves by causing much more water loss via evaporation. If the drying rate is fast enough at the start of the drying process, stewing will be minimized.. The purpose of drying was to remove moisture up to 95-97%, to maximize the shelf life. In this experiment the highest and the lowest moisture content was observed at treatment combinations of 90°C for 20 min and 130°C for 30 min, respectively.

Generally to gain suitable moisture content between 2.5 and 3.0% it is advisable to use increased temperature with short drying duration or reduced temperature with relatively long drying duration. According to Temple *et al.* (2001) the exposure time was bearing an inverse relationship to temperature. If there is very high temperature with long duration it will cause case hardening and burning of the leaves. However, the tea

Table 3: Interaction effect of drying temperature and duration on aroma, flavor, moisture content and leaf infusion of processed black tea

	Duration of drying (min)											
	Aroma			Flavor			Moisture content			Leaf infusion		
Temperature (^{0}C)	20	25	30	20	25	30	20	25	30	20	25	30
90	4.43^b	3.80^c	3.10^d	3.20^d	3.57^c	3.90^b	3.17^a	3.00^b	2.60^{cd}	2.67^{fg}	3.20^d	4.10^b
100	4.57^b	3.30^d	2.57^{ef}	3.57^b	4.00^{ab}	4.20^a	2.97^b	2.70^c	2.40^e	3.10^{de}	3.90^{bc}	3.30^d
11	4.90^a	3.20^d	2.10^g	4.00^{ab}	3.57^c	3.00^d	2.57^{cd}	2.23^f	1.93^g	3.20^d	4.53^a	2.80^{ef}
120	4.00^c	2.80^e	1.80^h	3.57^c	2.57^e	2.10^f	2.17^f	1.50^h	1.27^i	3.20^d	3.90^{bc}	2.43^g
130	3.80^c	2.30^{fg}	1.43^i	3.00^d	2.20^f	1.70^g	1.83^g	1.20^i	0.97^j	3.70^c	3.10^{de}	1.90^h
LSD (5%)	0.29			0.28			0.12			0.34		
CV (%)	5.42			5.19			3.37			6.31		

Means followed by the same letter(s) are not significantly different at 5% for each of treatment combinations

Table 4: Pearson correlations among biochemical composition and quality of black tea

Parameters	AR	FL	MC	TF	TR	TLC	LIN	TB
AR	1	0.33**	0.77**	0.80**	-0.68**	-0.03ns	0.30**	0.91**
FL		1	0.68**	0.46**	-0.64**	0.06ns	0.20*	0.42**
MC			1	0.75**	-0.91**	0.03ns	0.30**	0.85**
TF				1	-0.72**	-0.12*	0.19*	0.78**
TR					1	0.02ns	-0.27**	-0.78**
TLC						1	0.82**	0.07ns
LIN							1	0.44**
TB								1

ns, *,**Non-significant, significant and highly significant differences at 0.5 and 0.1% levels of probability level, respectively. TF: Teaflavin, TR: Tearubigin, TLC: Total liquid color, TB: Total brightness, AR: Aroma, FL: Flavor, MC: Moisture content, LIN: Leaf infusion

with high moisture contents can be stored only for short period of time. On the other hand, removing more moisture from the dried leaves causes loss of valuable micro components and changes taste of tea liquor. As indicated by Javanmard *et al*. (2009) high temperature and long duration may cause the product to lose more moisture which is not desired. The correlation coefficients (Table 4) showed that moisture content was positively and significantly correlated with total brightness (r = 0.85**), theaflavin (r = 0.75***).

Leaf infusion (LIN): Leaf infusion is a drink, remedy, or extract prepared by soaking tea leaves in liquid. There was significant effect due to interaction of the two factors ($p<0.05$) on the leaf infusion of black tea (Table 3). In this study drying process held at 110°C for 25 min and 90°C for 30 min gave very good leaf infusion appearance than the other treatment combinations. At a time of drying process the coppery red color of fermented leaf turns to black. As indicated in experiment done by Temple *et al.* (2001) it was observed that the low drying temperature is inadequate for generating the blackness required and the exposure of tea leaves to temperature of 120° C and above generates a burnt characteristics. Mahanta and Hazarika (1985) related blackness to the amount of chlorophyll breakdown products and to the interaction between these and the TR. According to the report of UPASI (2012) chlorophyll decreases by 75%, falling from 1201-375 μg g^{-1} dry weight during drying.

Generally, as the study showed that the appearance of leaf infusion was high at a drying duration of 20 min with the combination of five different temperatures (90, 100, 110, 120 and 130°C). The correlation coefficients (Table 4) showed that leaf infusion was positively and significantly correlated with total liquid color (r = 0.82***).

CONCLUSION

The result of the study showed that interaction of drying temperature and duration had significant difference ($p<0.05$) on Aroma, flavor, Moisture Content, Tearubigin, Total Liquid Color, Leaf infusion, Total Brightness. But the interaction of the two factors had not resulted to any significant differences on theaflavin. Results from correlations between characteristics related to quality of black tea indicated that due to the complicated relationships between them, the quality of black tea cannot be assessed on the basis of a limited number of characteristics. In other words, when one of the characteristics is at highest level, the other characteristics may be at lower levels. Thus, to produce good quality of black tea it is necessary to follow that all the characteristics are at optimum levels. Generally from this research to develop good quality of black tea with optimum biochemical composition, a treatment combination of 100°C with 25 min was identified as the optimum combination of drying temperatures and drying duration. Therefore this optimization of drying temperature and duration helps to maintain tea quality by reducing the loss of biochemical compounds responsible for developing good quality tea. Also it helps to minimize cost of time and power of energy during drying.

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