

Full Length Research Paper

Effect of tea processing methods on biochemical composition and sensory quality of black tea (*Camellia sinensis* (L.) O. Kuntze): A review

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Final quality of black tea depends mainly on the chemical composition of the raw tea leaves. Various plucking methods have direct effect both on yield and quality in different cultivated variety and environments. Different literature reports indicated that polyphenols, caffeine, essential oils and amino acids are responsible for aroma and flavor of black tea. The oxidation process begins at rolling step and ends at initial stages of drying process until the heat denature the enzymes, which convert tea polyphenols (catechins) to theaflavins and thearubigins; both are responsible for brightness, color and taste of black tea. TR increased by increasing fermentation period. TF decreased by increasing fermentation period. The essential oils and the amino acids also contribute to characteristic tea taste and aroma. It was found that the essential oils content increased during the withering, rolling and fermentation steps; however this amount decreased during the drying step. But this reduction is compensated by the Millard reaction which is the reaction of amino acids with the sugars during drying, contributing positively to the tea flavor and color. Theaflavin, thearubigins and total color content of black tea stored in accelerated storage condition decreased slightly when compared with tea stored under normal conditions. It is concluded that plucking (interval, season and standard), processing steps and storage system plays major role in maintaining black tea quality.

Key words: Tea processing, black tea, biochemical composition, sensory quality.

INTRODUCTION

Tea (*Camellia sinensis* (L.) O. Kuntze) is an ancient crop that has been cultivated for thousands of years (Jianwei et al., 2016). Tea plant belongs to the *Theaceae* family. It is a woody perennial tree crop and it is diploid crop with a chromosomal number of 30 ($2n=30$), though some triploid cultivar (*C. sinensis* var. *macrophylla* and *C. rosaeflora*) have been reported (Devarumath et al., 2002).

Tea plant grows within an air temperature of 18 to 25°C. Below 13°C and above 30°C has been found to reduce shoot growth (Carr, 1972). It is also grown at an altitude of 2200 m.a.s.l. Tea plant requires a minimum rainfall of 1200 mm per annum, but 2500 to 3000 mm per annum is considered as an optimum (Hajiboland, 2017). The soil pH requirement for the growth of tea plant is in

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the range of 4.5 to 5.6. The optimum soil conditions recommended for tea plant growth is a well-drained, deep and well-aerated soil with more than 2% organic matter (de Silva, 2007).

Tea leaves are probably earliest and most consumed herbs. Black tea, processed from the young tender shoot of *Camellia sinensis* (L.) O. Kuntze (Muthumani and Kumar, 2007). Black tea is produced from tea plant after a series of physical and chemical reactions in the various tea processing procedures (Xiaoli et al., 2012). It is the most widely consumed fluids next to water. Approximately worldwide annual production of dry leaves and consumption reaches up to 1.8 million tons and 40 L per year, respectively (Seetohul et al., 2006).

Because of its high content of catechins and tea flavonoids, tea consumption protect against the development of cardiovascular diseases (Hodgson and Croft, 2010). In our world tea consumed as white, green, black, or oolong tea. White and green teas are known as unfermented tea. The polyphenol oxidase enzyme of green tea is inactivated by steaming. Oolong tea is produced by withering and half fermenting the leaves. Thus oolong tea is called "partially fermented tea". Black tea is known as fermented tea because the leaves are fully fermented, allowing enzymic oxidation of the polyphenols. Different tea processing methods results in variation of chemical component in tea beverages (Hara et al., 1995).

Tea quality mainly depends on the variety of leaf, growing environment, plucking standard, plucking interval and plucking season, manufacturing methods, size of ground tea leaves and infusion preparation. Quality is measured on the basis of liquor brightness, briskness, color, aroma and flavor and leaf appearance (Ramadurai, 2000; Astill et al., 2001).

Studies showed that the main constituents of tea leaves belong to the polyphenol group accounting for 25 to 35% on a dry weight basis also contains various chemical constituents including methylxanthines, amino acids, chlorophyll, carotenoids, lipids, carbohydrates, vitamins, and more than 600 volatile compounds (Chaturvedula and Prakash, 2011). Tea leaf is distinguished by its remarkable content of methylxathines and polyphenol and they are predominantly responsible for those unique properties of tea that account for its popularity as beverage. Taste, flavor, aroma color, brightness and astringency in tea infusions are influenced by polyphenols, caffeine, sugars, organic acids, amino acids and volatile flavor compounds (Obanda et al., 2004).

TEA MANUFACTURING PROCESS AND ITS EFFECT ON THE QUALITY ATTRIBUTES OF BLACK TEA

Black tea quality is greatly deepened on physical and

chemical processes involved in its manufacturing.

Various processes involved in tea manufacturing after picking of leaves are weathering rolling, fermentation, drying, sorting, grading, storage and packaging (Javed, 2015). All the stages are associated with several chemical reactions which determine the quality of end product (Bhuyan et al., 2012)

Harvesting/plucking

Plucking standards

Plucking standards has important aspects to determine black tea quality. The plucking standard has a large effect on yield and quality of the tea. Generally the plucking standard can be explained as fine, medium or coarse. With fine plucking only the first two leaves and the bud are plucked, with coarse plucking standard three or four leaves and the bud are plucked (Wright, 2005). Two leaves and a bud plucking standards are considered the best compromise between yield and quality (Banerjee, 1992). However, some producers use less tender shoots to realize extra biomass production in a plucking round. But coarse plucking standard reduces plucking frequency as longer periods are needed for the development of new shoots to that standard. Over extended period, the advantages in cumulative biomass production may not be significant (Okinda and Bowa, 2012).

Indeed, fine plucking standards of young shoots also improves yields (Waheed, 2002). The black tea caffeine, teaflavins, total ash and total water soluble solids contents declined while thearubigins (Amiri, 2007), crude fiber (Smiechwska et al., 2006) and florid (Lu et al., 2004) increased with course plucking standards.

The quality of black tea declined with coarse plucking standards (Mahanta et al., 1988), in terms of the plain and aroma quality parameters. The observations were attributed to the fact that young tea shoots have high levels of polyphenols (Owuor and Obanda, 1995) making the plain quality parameters of the resultant tea beverages to drop as the leaves become older. Thus the catechins (Flavan-3-ols) responsible for the formation of black tea quality parameters (theaflavins and thearubigins) decreased (Owuor and Obanda, 1995). But chlorophyll whose high level reduces black tea quality increased with maturation of the leaves (Taylor et al., 1992). There is a marked reduction in quality of black tea when the raw material used for processing includes the more mature leaves of the tea shoot. Earlier studies of polyphenolales in Assam tea and in Malawi tea grown at Cambridge, England, had shown that the level of cactine in gallates, galic acid, Theogaline and compound G 36 were maximum in the flush and decreased as the leaf matured. On the other hand, the levels of myricetine glycosides and epigallocatechin were markedly higher in

Table 1. Variation (dry weight basis) of the chemical composition of black tea to plucking standards.

Variable	Plucking standards					
	Bud	1 leaf and bud	2 leaves and bud	3 leaves and bud	4 leaves and bud	5 leaves and bud
Caffeine (%)	3.89	3.42	2.11	1.56	1.29	1.22
Theaflavins (%)	23.21	33.43	34.71	29.99	27.33	22.42
Thearubigens (%)	8.26	12.93	17.81	18.19	18.99	16.68
Total water soluble solids (%)	48.2	50.6	47.9	45.0	41.9	42.6
Ash (%)	7.11	6.78	6.1	6.38	6.37	6.65
Crude fiber (%)	6.76	8.12	10.22	13.68	14.86	16.65
VFC	-	-	-	-	-	-
Sum of Group I	3.61	4.47	4.63	4.86	5.23	5.74
Sum of Group II	8.18	8.30	6.94	5.50	5.06	4.54
F.I. (II/I)	2.26	1.86	1.50	1.13	0.97	0.79

VFC= Volatile flavor compounds, F.I.=Flavor index.
Source: Philip et al. (1987).

mature leaves, whilst derivatives of the flavinols, apigenin and juteolin, were detected in mature leaves only. Again other study of (Obanda et al., 2002) shows that there are differences in yield potential from region to region in different genotypes.

Generally, the variation of plucking standard was shown in the Table 1. According to Philip et al. (1987) investigation fine plucking standard produced high contents of caffeine, TF and total water-soluble solids, whereas the ash content and crude fiber, being lowest. The highest TF content, optimum levels of catechin concentration and polyphenol oxidase activity existed in two leaves and a bud. A coarse plucking standard produced very high TR contents and low TF content due to coarse plucking being attributed because of increased polyphenol oxidase level in mature shoots.

Although the plucking standards of a bud, and one leaf and a bud produced very high-quality teas as indicated by Flavor index, caffeine, TF, total water-soluble solids, crude fiber and Group II Volatile flavor compounds contents, The study suggested that plucking two leaves and a bud, which compromises both the yield and quality should be practiced.

Plucking intervals

The choice of a plucking interval may control the shoot distribution as well as the quality and quantity of crop (Odhiambo, 1988). Frequent interval of plucking result in higher yields as it causes enhanced rates of auxiliary buds development (Grice, 1982). Since apical dominance is more frequently overcome through decapitation of apical shoots (Odhiambo, 1988). Conflicting results have been obtained on the effects of plucking intervals on yields. In Malawi (Mitini, 1989) yield increased with long

plucking intervals while in Kenya (Owuor et al., 1997) long plucking intervals decreased yields. When all available leaf was harvested, fine shoots declined and course leaf increased as plucking rounds lengthened. The total theaflavins, caffeine, group 2 VFC and flavor index declined while group 1 VFC and thearubigins increased with longer plucking rounds (Owuor et al., 1997) leading to a decline in quality with long intervals (Asil, 2008 and Okal et al., 2012). The decline was partially attributed to the increase in unsaturated fatty acids (Okal et al., 2012), leading to increase in group 1 VFC in black tea (Owuor et al., 1990). Thus short plucking intervals improves both crop yields and quality.

As a report of Mridul et al. (1985) indicate in Table 2 Organoleptically, teas made from 5-day plucking round are considered to be very good due to the lower content of ash and fiber. On the other hand, black teas made from 7-day plucking round have a balance of VFC, ash, soluble solids and caffeine, and are judged as good tea by tea-tasters. Theaflavine (TF) and thearubigines (TR), which are the most important characteristic compounds in black tea but the amount of such components increased as an interval of plucking extends.

Plucking seasons

The presence of phenolic compounds that are found in young tea shoots are main factors in determining Quality of black tea (Hara et al., 1995). Low total polyphenol content is responsible for low quality black teas (Obanda, 1997). Thus, the total polyphenol levels are important to the quality of black tea, and those levels are affected by their levels occurring in the fresh tea shoots (Harbowy and Balentine, 1997). An early study in central Africa showed that the level of flavanols in the fresh apical

Table 2. Chemical composition of black tea at different plucking round on a dry weight basis with the tasters' evaluation.

Variable	Plucking Interval			
	5 days	7 days	9 days	11days
Ash (%)	5.95	6.15	6.16	6.15
Crude fiber (%)	6.7	7.0	9.4	10.5
Total water soluble solids (%)	44.36	42.47	42.5	41.44
Caffeine (%)	4.4	4.79	4.32	3.81
Theaflavin(TF) (%)	1.12	1.22	1.25	1.4
Thearubigins, (TR) (%)	13.56	13.98	14.19	15.74
TF/TR (%)	0.08	0.09	0.09	0.09
Tasters evaluation	Very good	Good	Good	Fair

Source: Mridul et al. (1985).

shoots was highest during the cold season. As indicated by Lihu et al. (2005) tea shoots plucked during slow growth conditions such as in the winter contained a higher proportion of simple catechins relative to catechin gallates, with epigallocatechin (EGC) being the most significantly affected. In contrast, in the northern hemisphere, total flavanol content is greatest during the height of the growing season (that is, summer) and the least at the end of the season (late autumn). The cool seasons characterized by slow growth usually translate into low production but high quality black teas. Warm wet seasons are characterized by fast growth, high production and low quality black teas (Owuor and Obanda, 2001).

A direct relationship between the level of EGC in tea shoots and the level of total theaflavins, which are known to be quality indicators, in the resultant black tea, has been found by Sanderson et al. (1972). Thus, the seasonal variations of EGC in green leaves could be a chemical indicator of the seasonal variations in tea quality in central Africa. As a report of Lihu et al. (2005) EGC, epicatechin gallate (ECG), and epigallocatechin gallate (EGCG) were the main flavanols in tea shoots for both *C. sinensis* var. *sinensis* and *C. sinensis* var. *assamica* grown, with EGCG predominating. EGC showed a higher level in spring than in summer, whereas ECG and EGCG showed higher levels in summer than in spring. Furthermore, it was reported that the levels of ECG and EGCG were higher in young and tender shoots, whereas EGC was higher in the fully developed shoots. This variation of leaf flavanol constituents is thought to be the main factor affecting the quality of the resulting tea (Graham, 1992). Thus, data on EGCG, ECG and EGC levels in the green shoots of fresh tea grown in Australia could be used as an indicator of the seasonal variations in the quality of the resultant black tea. The main black tea polyphenols, theaflavins, impart to black tea the distinct sensory characteristics such as color and taste.

The level of total theaflavins of the resultant black tea is highly correlated with the content of EGC in the fresh shoots (Lihu et al., 2005).

As a report of Lihu et al. (2005) indicated in Figure 1 the seasonal variation in the ratio of Cactines Gallates (CGs) to Cactines (Cs) appears to be season dependent, with harvests in the warmer months showing higher ratios and harvests in the cooler months showing lower ratios on the same variety, var. *assamica*.

Withering

The foremost concept of withering of plucked tea shoots was to condition the shoots for subsequent stages of black tea processing (Bhuyan et al., 2012). Following plucking, many biochemical and physiological processes occur. It is a procedure which brings about physical and chemical changes in the fresh shoots to produce quality (Vicky et al., 2012). Withering refers to the changes (physical and chemical) that occur in tea leaf from the time it is detached from the plant to the time of maceration. For practical purpose, withering is often meant for dehydration (through forced or natural air) of fresh tea leaf brought about up to a partial removal of moisture content in the tea manufacturing factory. Excessive manual handling of green tea leaf in normal withering practices invariably causes damage to tea fresh leaves and consequent degradation to made tea quality (Das and Tewari, 2006).

The withering stage has two purposes. Chemical withering begins immediately after the tea leaves are plucked from the tea plant tree. During this process, complex chemical compounds are breaking down into simpler compounds. The other one is physical withering it is the removal of moisture from the tea leaf. During this process, the turgid leaf becomes flaccid. This process also leads to the concentration of sap in the cells of the

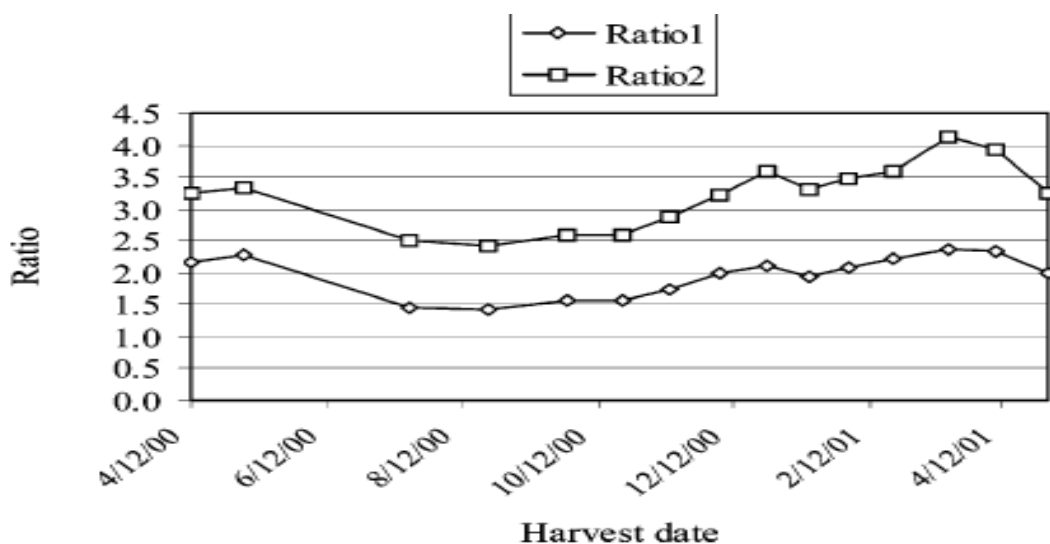


Figure 1. Seasonal variation of the ratios of cactines gallates to cactines in fresh tea shoots (ratio1= (EGCG+ECG)/EGC; Ratio 2=CGs/Cs).Epigallocatechin (EGC), Catechin (C), Epigallocatechin 3-gallate (EGCG) and Epicatechin 3-gallate (ECG), cactines gallates(CGs)
Source: Lihu et al. (2005).

tea leaf. The desired level of moisture can be removed by passing air through the piled leaves (Saptashish and Jolvis, 2016). Studies have shown that during physical withering the moisture content of green leaves is reduced to 60 to 70% (Omiadze et al., 2014; Jabeen et al., 2015). Time, temperature, and relative humidity are the major factors affecting physical withering (Obanda et al., 2004). Tocklai (Tea Research Association, Assam, India) has reported that physical withering requires shorter duration as compared to chemical withering.

Experimental studies have shown that the withering time beyond 20 h leads to the deterioration of the quality of black tea (Owuor and Orchard, 1989), and hence, withering time should be limited to 18 h (Omiadze et al., 2014). There is no specified withering duration, but 14 to 18 h is generally considered the optimum period (Saptashish and Jolvis (2016).

During withering, a certain amount of the solid matter, as well as moisture, is lost from the leaf. This is due to the loss of carbon dioxide by respiration, and can account for 3 to 4% of the dry weight content of the incoming leaf. The relationship between the process of withering and the aroma characteristics of black tea were examined by Mahanta (1988). Many studies have established that the characteristic volatile flavor compounds (VFC) consisting of terpenoids, fresh green (fatty acid derivatives) and aromatic/benzenoids are developed from the nonvolatile aroma precursors with the leaf softening techniques used during withering (Mahanta, 1988; Saikia and Mahanta, 2002). Black tea quality chemical parameters are adversely affected by unsafe practices of withering.

The quality of black tea depends on the commencement of chemical withering or senescence, anaerobic or catabolic phase. Withering involves decrease in protein, increase in amino acids, soluble proteins (Baruah et al., 2012) and cell membrane permeability. Withering is accompanied by reduction of polyphenoloxidase (PPO) activity of tea shoots and affects the oxidative condensation of flavanols (Ullah, 1984). Lipids degradation takes place to an extent of 20% during withering (Hatanaka et al., 1987). Withering temperature is another important factor for quality of tea. Excessive high temperature during withering led to leaf cell matrix destruction which resulted in early uncontrolled fermentation-like reactions.

Shortly withered leaves produce tea with more brightness and briskness due to increase in TF formation. During withering, excessive loss in green leaves moisture content (e.g., long time or high temperature) causes reduction in PPO activity of the leaves (Nihal et al., 2009). Obanda et al. (2004) reported that TF levels decreased with an increase in wither duration and so, the longer the wither duration the less bright liquors became. In addition, Sud and Baru (2000) reported that the lowest values for TF and brightness were observed in rainy season teas, probably due to inconsistent and low degree of withering which decrease the PPO activity. On the other hand, a comparison of the ferment ability of normally withered and freeze withered leaves was carried out by Muthumani and Kumar (2007) and it was reported that TF levels were higher while the liquor was brighter in leaves freeze withered for 4 h.

Table 3. Effect of withering temperature on black tea quality parameters.

Temperature (°C)	Treatment	%TF	%TR	%TR (I)	%TR (II)	%TC	%B
22	6 h CPW+ 6 h PW	2.44	19.65	5.17	13.76	6.75	22.13
	12 h PW	1.77	19.46	4.62	14.73	5.62	19.35
30	6 h CPW+ 6 h PW	1.76	20.37	5.60	12.72	6.14	17.62
	12 h PW	1.46	17.88	3.84	14.02	4.73	14.28
35°	6 h CPW+ 6 h PW	1.36	16.20	4.31	0.88	5.10	14.00
	12 h PW	1.18	14.65	3.05	11.60	4.15	12.47

TF= Theaflavine, TR=Thearubigines, TC= Total color, B=Brightness, CPW= Initially kept in 100% humid condition for 6 h was followed by physical withering 6 h. PW= Only physical withering for 12 h.

Source: Baruah et al. (2012).

The extent of withering has been shown to directly affect the levels of volatile compounds, hard withered teas have higher proportion of linalool and its oxides, and the lower levels of hexenal, is the reasons why such teas are more fragrant (Mike, 1998).

In study of Baruah et al., (2012) as shown in Figure 2 storage of shoots before fast physical withering was highly essential for requisite chemical wither to produce quality product. In black tea processing, tea leaves are subjected to different physical stresses which result in the formation of certain reactive oxygen species. By proper regulation of moisture loss in withering, formation of these oxygen species can be controlled and hence oxidative degradation of catechin is minimized. Thus reduction of normal withering time of 12 h from traditional method to 4 h in the modified method gave some favorable biochemical changes for enhancement in brightness and quality of tea. The quality attributes like TF, and brightness increased in this modified method of withering. For a brighter tea infusion, increase of TF is very essential (Wright et al., 2002) and it was achieved here due to restricted oxidative degradation of catechins in W I and W2 where initially shoots were stored at 100% humid condition before fast moisture loss in normal withering

According to (Obanda et al., 1997) at high temperature some unfavorable enzymic reactions occur to produce undesirable amount of TF, TR which are responsible for decreasing or increasing of brightness, flavour index and also sensory parameters of black tea. As a finding of Baruah et al. (2012) shown in Tables 3, TF, TC and brightness was higher at low temperature (22°C).

Another report of Baruah et al. (2012) shows that flavor index is considered as an indicator of quality in tea. Due to optimum quantity in group II and group 1 volatile flavor components (VFC) in W2 flavor index was found to be maximum. Another important observation was made from this experiment was that restriction of moisture loss of tea

shoots for a longer period (W) prior to physical wither increased the amount of group II VFC, thus increasing overall quality of the aroma. On the other hand, group 1 volatile components were in the highest quantity when tea shoots were subjected to more stress. The flavor index needs to be optimum to have positive impact on quality.

Cutting and rolling

The primary objective of rolling is size reduction together with a degree of cell damage which permits the exposure of new surfaces to air, in the subsequent fermentation stage. In addition, it presses out the juice and a thin film of juice is coated on the surface of the leaf particle to enhance chemical changes (Javed, 2015). During rolling, cytoplasmic flavonoids are progressively oxidized into quinones as a result of chloroplast polyphenol oxidase and cell wall peroxidase generating yellow to red-brown colors (Harries and Ellis, 1981). The process of rolling releases the enzymes from the leaf as the leaf breaks exposing the juices to natural process of oxidation. The raw materials were rolled in different duration of rolling time. After the completion of rolling operation, the dholes (crush particles) were passed through Rotor vane machine for further crushing. The crushed material received was then passed through C.T.C (Crush, Tear and Curl) machine to make the crushed particles finer. The same materials were passed through a roll breaker to break the twisted balls and slow down the fermentation process. The effect of maceration method on the chemical composition and quality of black tea was examined by Owour et al., (1989). Rolling of tea shoots initiates oxidation of catechins by polyphenol oxidase (PPO), is responsible for the formation of theaflavins (TFs) and thearubigins (TRs). The theaflavins responsible for the formation of Briskness and brightness of the tea

Table 4. Rolling time and its effect on quality of black tea.

Color	Taste/Flavor	Aroma	Strength	Infusion
Rolling times 20 min				
Light red and dull	Fair	Un-pleasant	Weak	Un-even
Rolling times 25 min				
Bright red	Good	Pleasant	Strong	Mixed
Rolling times 30 min				
Light red and dull	Poor	Un-pleasant	Light	Even

Source: Zobia et al. (2007).

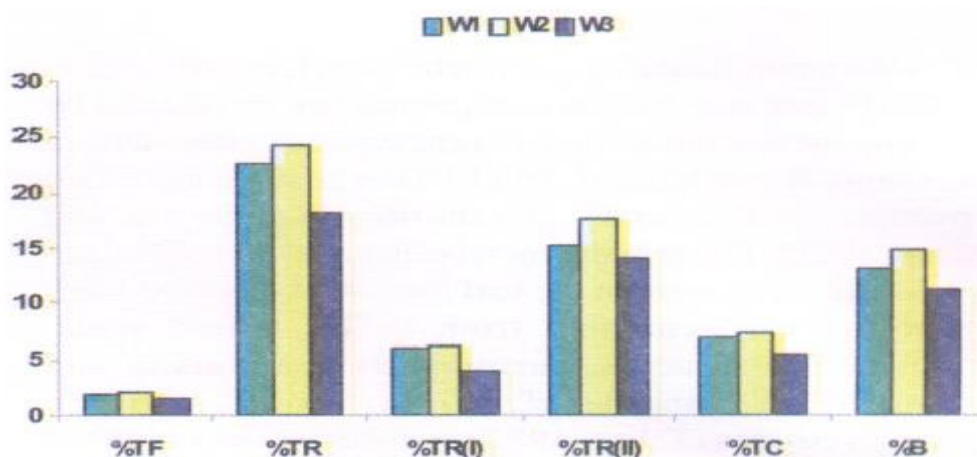


Figure 2. Effect of chemical and physical withering for different times on quality parameters of black tea. W1 = Initially kept in 100% humid condition for 4 h was followed by physical withering 8 h. W2= Initially stored for 8 h in 100% humid condition followed by 4 h physical withering. W3= Only physical withering for 12 h. TF= Teaflavine, TR=Thearubigines, TC= Total color, B=Brightness, TR1 and TR2 are fractions of TR.

Source: Baruah et al. (2012).

liquor and Thearubigins, are responsible for the color because of orange brown compounds and taste of tea (Hajiboland, 2017). If the exhaust temperature is less than 49°C, the post fermentation process will continue for a considerable time and will soften the liquor. If the exhaust temperature is greater than 57.2°C the rate of moisture removal is too rapid and results in case hardened tea in which the particles are hard on the outside but incompletely dried within such teas yield harsh liquors and do not keep well (Javed, 2015).

Rolling times have its own impact on general quality of black tea. As the finding of (Zobia et al., 2007) shows that duration of rolling stays for 25 mins gave better results as compared to below and above such minutes time. Table 4 shows rolling durations effect on black tea quality.

Fermentation

Following the leaf disruption stage fermentation is the other critical steps in black tea manufacture because of the significant chemical changes occurring during this phase (Tüfekci et al., 1997). In fermentation stage, an enzymatic oxidation of the polyphenols, especially tea catechins, takes place, leading to the formation of TFs and TRs, they are attributes for the special characteristics of black tea liquors. In black tea production process, about 75% of catechins contained in tea leaves undergo enzymatic transformation consisting in oxidation and partial polymerization (Łuczaj and Skrzydlewska, 2005). Enzymes involved in oxidation of catechins are mainly PPO and peroxidase (POD) (Wright et al., 2002).

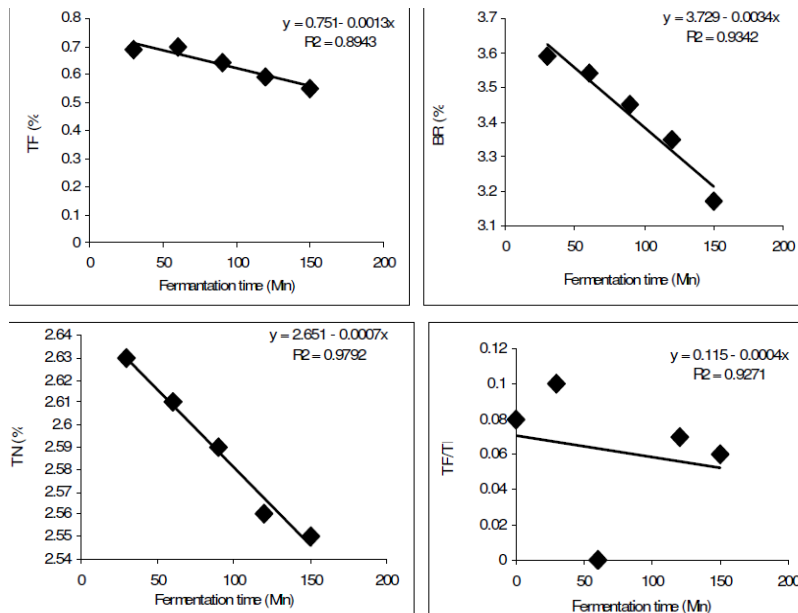


Figure 3. Linear regression between fermentation time as the independent variable (X) and theaflavin (TF), tannin (TN), brightness (BR) and TF/TR ratio as the dependent variables (Y).
Source: Ansari et al. (2011).

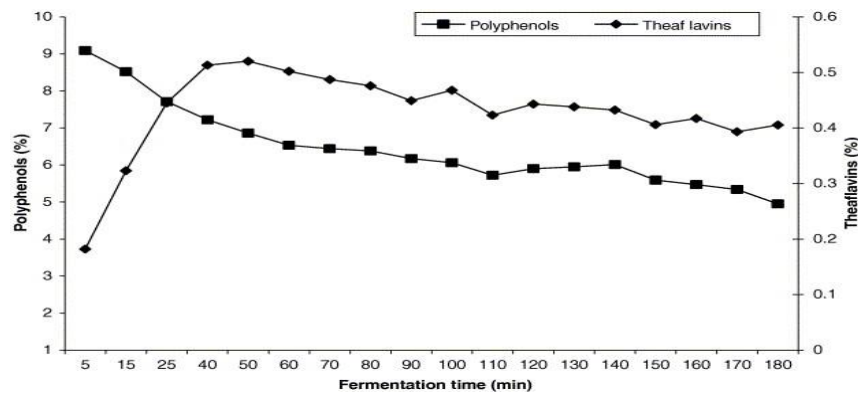


Figure 4. Influence of fermentation durations on the development of black tea quality.
Source: Muthumani and Kumar (2007).

The volatile flavor components are lower in non-fermented tea when compared to fermented tea. Linalool oxides are found in the essential oil extracted from fermented leaves, but not in the homogenates of fresh leaves. Rapid oxidation of polyphenols appears to hamper volatile flavor compound formation in tea leaves (Hazarika et al., 1984). Thus, both duration and temperature of fermentation should be controlled to ensure optimum production of flavor compounds. The enzymic oxidations in fermentation proceed maximally at 28°C, although a temperature range of between 24 and

28°C is thought to be optimal (Mike, 1998).

Ansari et al. (2011) result in Figure 3 that the relation between fermentation time and characteristics related to quality of black tea indicated that fermentation time significantly influences the content and changes of theaflavin (TF), tannin (TN), brightness (BR) and TF/TR characteristics such, characteristics depend on plant genetic potentials.

The study of Muthumani and Kumar (2007) showed in Figure 4 the formation curve of TFs climbed steadily, reaching a maximum at 45 min of fermentation. However,

after 110 min shows some fluctuations. This happened because of PPO activity changes.

One study which is done by Moazzam et al. (2012) shows that maintaining medium fermentation temperature (25°C) and short duration (60 min) was ensure greater formation of TFs. The resultant black teas are then brisk, bright, and astringent and probably offer more benefit to human health. A better prediction of liquor brightness and total color of black tea will be achieved with inclusion of TF and TR than could be obtained with TF or TR alone. Briskness and astringency were associated with TF than with TR. Therefore, they were best predicted with TF. Evaluation of brightness by taster was associated to TR, and was best predicted with TR. According to Obanda et al. (2004) the changes in theaflavin and thearubigins during the fermentation period and concluded that increasing the fermentation period decreases theaflavin content and brightness of black tea, whereas thearubigin and total color were increased.

According to Moazzam et al. (2012) variations in fermentation duration were used to achieve maximum levels of different black tea parameters in cultivars. Higher TR content and total color developed on medium fermentation temperature (25°C) with shorter duration of (60 min). Thus medium fermentation temperature and short temperature favors production of thicker and darker colored black tea. Formation of TRs increased with time during the early stages of fermentation. As the fermentation progressed, TRs reached a maximum and then declined slowly (Ping et al., 2018).

Maximum sensory evaluation scores, briskness, brightness and astringent levels at different fermentation temperatures were attained at different fermentation durations. At low fermentation temperature maximum sensory evaluation scores were obtained. Thus production of high quality black teas at lower fermentation temperature requires longer fermentation duration, and maintenance of low fermentation temperature, though requiring longer fermentation duration, ensures that the resultant black teas are of better quality.

Drying

The drying of fermented tea has three major objectives; to terminate the biochemical functions by heat denaturation of the enzyme; to reduce the moisture to increase the shelf stability of black tea and finally, to enhance chemical reactions responsible for black tea character and flavor (Mauskar, 2007).

Especially, the drying procedure dehydrates tea to reduce Moisture content (MC) and to improve tea's smell and taste after thermo-chemical reactions under high temperature. Therefore, the MC of tea not only determines the shelf life of tea, but also affects the physical and chemical reactions in tea processing, so

measurement of MC is an important task for producing high-quality of tea (Okamura et al., 2000).

Drying of black tea at 110°C temperature with 1.5 rpm dryer speed produces good quality tea (Table 5). All the lots were dried second time at low temperature (80°C) to remove 95 to 97% moisture, results in good keeping and storage quality. The black tea with high moisture content (more than 6%) loses its quality due to continue fermentation after drying. However Experiment done by Zobia et al. (2007) shows that the processed tea with high moisture contents have short shelf life. Kidist et al. (2013) indicated that as both temperature and duration increased biochemical composition and quality of black tea were decrease.

Storage method and duration

Quality of black tea in its broadest sense is the cumulative effect of all desirable attributes by which it is judged for its market value. Aroma, flavor, briskness, strength and color represent the quality of black tea in general and the concentration of chemical constituents present in a brew affects the quality of tea. Polyphenol (catechin) present in tea gets oxidized to theaflavin and thearubigins during processing of black tea. Caffeine 1, 3, 7-methylxanthine gives a bitter taste to tea. It was found that black tea kept under inappropriate storage conditions for prolonged period lost quality characteristics to a significant level (Cloughley et al., 1981). It was also observed that pigment profile of black tea in Northeast India changed during storage in noticeable level. After one month of manufacture some of the pigments increased and maintained for 8 months or so without much changes (Mahanta, 1988). It was also observed in an experiment at Tocklai that during initial period of storage rapid conversion of TR-3 took place with corresponding increase of TF. Further change of TR took place with length of storage and TR-3 was converted to TR-I after six months. The study of (Debnath et al., 2012) their experiment shows that (Table 6) theaflavin content of black tea stored in accelerated storage condition decreased slightly and compared with tea stored under normal conditions. It was observed that TR content of tea fluctuated during the period of storage and there was slight increase of TR (13.71%) in the first month when there was slight decrease of TR (11.81%) in the second month in the tea stored under accelerated conditions. There was slight increase of total color (4.73) in the first month and decrease (4.17) in the second month in the accelerated storage samples.

Brightness decreased in tea samples stored under accelerated conditions over control. Caffeine content showed decreasing trend in tea kept under accelerated conditions over normal storage while moisture content of tea increased over control. Microbial population increased

Table 5. Effect of drying temperature on black tea quality.

Color	Taste/Flavor	Aroma	Strength	Infusion
Tea drying at 100°C with dryer speed of 1.4 rpm second time dryer temperature 80°C				
Bright red	Good	Fair	Weak	Mixed
Tea drying at 110°C with dryer speed of 1.5 rpm second time dryer temperature 80°C				
Light red	Good	Good	Strong	Mixed
Tea drying at 120°C with dryer speed of 1.6 rpm second time dryer temperature 80°C				
Bright red and light red	Very good	Fair	Weak	Green

Source: Zobia et al. (2007).

Table 6. Showing changes of quality parameters of tea during storage.

Parameter	TF	TR	TC	BR	Caffeine	Moisture (%)	Mold (Cfu/g)%10
Fresh tea	0.99	12.46	3.9	16.51	3.25	3.1	83
1st month normal	0.72	12.41	4.43	13.92	-	10.04	38
Acc. storage	0.71	13.72	4.73	13.25	-	11.13	31
2nd month storage	1.08	12.65	4.65	18.54	2.88	10.97	57
Acc. storage	0.90	11.81	4.17	16.01	2.81	11.29	183
3rd month storage	0.76	19.65	-	-	2.94	9.94	45
Acc. storage	0.84	11.69	-	-	3.28	10.13	40

TF= Teaflavine, TR+Thearubiginines, TC= Total color, BR=Brightness.

Source: Debnath et al. (2012).

8 to 9 times in samples stored under accelerated storage over normal storage.

CONCLUSION

Literature reports indicated that quality of black tea is dependent on the chemical composition, in particular, the flavanols of the harvested shoots, and also by the way in which they are handled, processed and stored. Following plucking, many biochemical and physiological processes occur through processing. Among all the processing stages fermentation is the most vital process for determining major quality determining factors for black tea. At a time of drying it is also good to give attention to maintain the moisture content of processed tea otherwise easily deteriorated. Generally at a time of black tea processing it was important to give an attention for each of steps starting from harvesting up to storage systems. Otherwise it is difficult to fulfill the quality of marketable characteristics for black tea.

CONFLICT OF INTEREST

The author has not declared any conflict of interest.

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