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Fermentation: The Key Step in the Processing of Black Tea

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Abstract

Background: The same plant, *Camellia sinensis*, is used to produce all types of tea, and the differences among the various types arise from the different processing steps that are used. Based on the degree of fermentation, tea can be classified as black, green, white, or oolong tea. Of these, black tea is the most or fully fermented tea. The oxidized polyphenolic compounds such as theaflavins (TF) and thearubigins (TR) formed during fermentation are responsible for the color, taste, flavor, and aroma of black tea. **Results:** Research indicates that an optimum ratio of TF and TR (1:10) is required to ensure a quality cup of tea. The concentrations of TF and TR as well as desirable quality characteristics increase as fermentation time increases, reaching optimum levels and then degrading if the fermentation time is prolonged. It is also necessary to control the environment for oxidation. There are no established environment conditions that must be maintained during the fermentation of the ruptured tea leaves. However, in most cases, the process is performed at a temperature of 24-29°C for 2-4 h or 55-110 min for orthodox tea or crush, tear, and curl (CTC) black tea, respectively, under a high relative humidity of 95-98% with an adequate amount of oxygen. **Conclusion:** The polyphenolic compounds in black tea such as TF and TR as well as un-oxidized catechins are responsible for the health benefits of tea consumption. Tea is rich in natural antioxidant activities and is reported to have great potential for the management of various types of cancers, oral health problems, heart disease and stroke, and diabetes and to have other health benefits such as the ability to detoxify, improve urine and blood flow, stimulate, and improve the immune system.

Keywords: Black tea, Fermentation, Health benefits, Theaflavins, Thearubigins

Introduction

Tea is one of the cheapest and most commonly consumed aromatic beverages. It is processed from the tender shoots of the tea plant, consisting of two or three leaves and an unopened apical bud. The plant is of the genus *Camellia*, a genus of flowering plants in the family *Theaceae*, and has two main varieties: *Camellia sinensis* var. *sinensis* and *Camellia sinensis* var. *assamica* (Hara et al., 1995). Tea is grown commercially worldwide. Next to water, tea is the second most frequently consumed drink worldwide, and 2/3rd of the world's population drinks tea (Heneberry, 2006). India is the second largest producer of tea next to China. It occupies an important place and plays a very vital role in India's national economy. Tea is perhaps the only industry for which India has retained its leadership over the last 150 years (Gupta and Dey, 2010). Based on the degree of fermentation, tea can be classified as black, green, white, or oolong tea, where black tea is a fully fermented or oxidized tea, green and white teas are un-oxidized or non-fermented, and oolong tea is a semi-fermented form of tea. The process for producing oolong tea is similar to that for black tea except for a shorter fermentation time (Schillinger et al., 2010).

There are two major methods for manufacturing tea: crush, tear, and curl (CTC) and orthodox. CTC tea is produced using a suitable maceration device, and the

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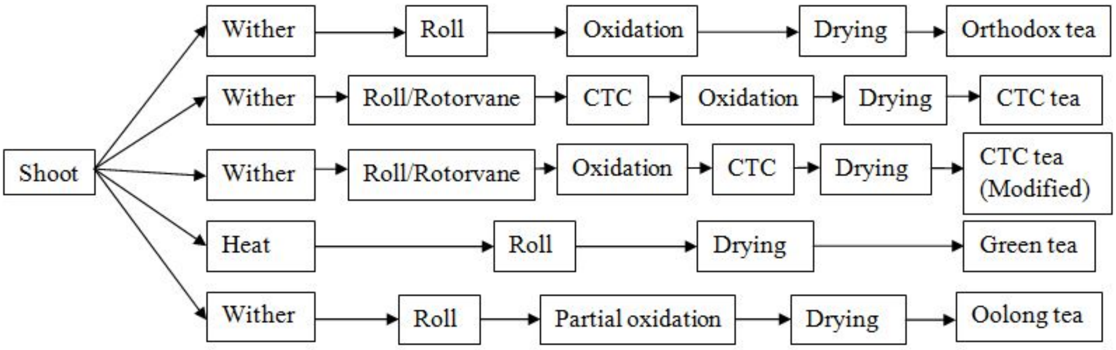

Figure 1. Major steps in tea processing and the corresponding types of tea.

orthodox method involves a roller or manual hand rolling. In the CTC method, the tea leaves are chopped into small and uniform pieces, producing granular leaf particles, whereas orthodox teas are whole leaf teas. There are different operation stages and methods using during tea processing depending on the factory and region. The general stages in the processing of tea include plucking (picking), withering, macerating, rolling, fermenting (oxidizing), and drying (firing), as shown in Figure 1 (Sanyal, 2011). Plucking tea is synonymous with harvesting for other crops. The freshly plucked leaves are conditioned physically and chemically. During this period, the shoots lose moisture, and the turgid shoots become flaccid. The main objective of maceration and rolling is to rupture the cells of the withered tea leaves, which exposes the cell sap. The process results in a chemical reaction between the chemical constituents and enzymes in the presence of atmospheric oxygen. This step determines whether the tea is orthodox or CTC tea. Fermentation involves biochemical enzymatic activities, in which the enzymes present in the leaves come in contact with atmospheric oxygen, and oxygen is absorbed. Fermentation begins from the moment the rolling or maceration starts. The primary objectives of drying are to arrest the enzymatic reactions and oxidation, remove moisture from the tea particles to a predetermined level, and produce a stable product with a good keeping quality that can be safely stored as well as easily handled and transported. In the processing of tea, fermentation plays an important role in determining the quality of both CTC and orthodox black teas. Therefore, it is necessary to understand and monitor the fermentation process to produce black tea of superior quality. This review focuses on the various aspects of fermentation in the processing of black tea.

Composition of the tea shoot components

The principle constituents of the individual components of the tea shoot are polyphenols and caffeine, and their levels are highest in the bud and decrease with the coarseness of leaves, as shown in Table 1 (Sanyal, 2011). The leaves on the shoot are numbered as follows: the leaf next to the apical bud is assigned as the 1st leaf, and the following leaves are designated as the 2nd and 3rd leaves consecutively. Young tea shoots are rich in different types of polyphenols, of which the flavon-3-ols (catechins) are the most abundant and most important for the manufacturing of black tea. The major catechins present in tea leaves are catechin (C), epicatechin (EC), epicatechin gallate (ECG),

Table 1. Constituents of the individual components of the tea shoot

Shoot content	Polyphenol content	Polyphenol content in relation to the bud	Caffeine content	Caffeine content in relation to the bud
Bud	26.5	100.0	4.7	100.0
1st leaf	25.9	97.7	4.2	89.4
2nd leaf	20.7	78.1	3.5	74.5
3rd leaf	17.1	64.5	2.9	61.7
Upper stem	11.5	43.4	2.5	53.2
Lower stem	5.3	20.0	1.4	29.8

epigallocatechin (EGC), epigallocatechin gallate (EGCG), and gallocatechin (GC) (Hara et al., 1995; Muthumani and Kumar, 2007; Samanta et al., 2015).

Fermentation (oxidation) process

Fermentation involves enzymatic oxidation; briefly, after the cells of the leaves are ruptured exposing the cell sap, the chemical constituents and enzymes react in the presence of atmospheric oxygen. Fermentation begins the moment the rolling or maceration starts. Fermentation is an exothermic reaction, and during the process, heat, moisture, and carbon dioxide are released (Sanyal, 2011). The enzymes polyphenol oxidase (PPO) and peroxidase (PO) act on catechins in the presence of oxygen and form oxidized polyphenolic compounds such as theaflavins (TF) and thearubigins (TR) (Kuhnert et al., 2010; Sanyal, 2011; Chen et al., 2012; Samanta et al., 2015). TF include simple theaflavin (TF), theaflavin-3-gallate (TF3G), theaflavin -3′-gallate (TF3′G), theaflavin-3,3′-digallate (TF33′DG), isotheaflavin, and neotheaflavin (Collier et al., 1973; Owuor and Obanda, 1995; Sanyal, 2011). Catechins react in pairs to form various compositions of TF as shown in Table 2 (Hilal and Engelhardt, 2007; Sanyal, 2011). Not much is known about the structures of TR, and no structures have been elucidated to date; however, it has been suggested that the B-ring interflavonoid bond (2′-2′ as present in the bisflavanols) might be a backbone of all TR or a fraction of them (Subramanian et al., 1999; Hilal and Engelhardt, 2007; Sharma and Rao, 2009).

Sensory characteristics

Color

Catechins are colorless, odorless, soluble substances that have a low molecular weight. With oxidation, catechins start to form larger molecules through condensation, and non-volatile compounds such as TF and TR are formed. These produced compounds are responsible for the color and taste of black tea liquor (Obanda et al., 2001; Bhattacharyya et al., 2007). During the fermentation process, the green color of tea leaves changes to coppery brown. TF are responsible for the brightness, briskness, and quality of tea liquor, and the color, taste, and body are determined by the content of TR. TF and TR are responsible for two main color pigments, orange-red and reddish-brown, respectively (Chen et al., 2010; Chen et al., 2012; Stodt et al., 2014).

Aroma

In addition to the formation of TF and TR during the fermentation process, some volatile compounds are generated due to the transformation of certain aroma precursors. These volatile compounds include essential oils and amino acids. Amino acids combine with orthoquinone, which is an oxidized form of catechin, and play the most important role in determining the aroma of black tea (Co and Sanderson, 1970; Mahanta and Hazarika, 1985; Bhattacharyya et al., 2007). In the Indian tea industry, the fermentation process is judged using two defined smell peaks: the first nose and second nose. Experienced floor supervisors can detect distinct peaks of the intense emission of volatile compounds by manually smelling the teas. The ruptured leaf is green in color and has a raw smell, which subsides over time. As the fermentation continues, at a particular time, a fruity aroma develops that also subsides over time. This is called the first nose. With the passing of time, the green color of tea leaves changes to a coppery brown, and a more distinct fruity aroma appears. This is called the second nose. Once the second nose is detected, the fermentation process is ended. Such practices are subjective and prone to human error. There have been successful demonstrations of an electronic nose to overcome the problems of human error (Bhattacharyya et al., 2007). Tocklai (Tea Research

Table 2. Precursors of theaflavins

Precursors	Products
EGC+EC	Theaflavin
EGCG+EC	Theaflavin-3-monogallate
EGCG+ECG	Theaflavin-3,3′-digallate
EGC+ECG	Theaflavin-3′-monogallate
GC+EC	Isotheaflavin
GC+C	Neotheaflavin

Table 3. Biochemical compounds in black tea responsible for flavor and odor

Compounds	Flavor	Odor
Linalool, Linalool oxide	Sweet	Citrus/Lemon
Geraniol	Floral	Rose
Phenyl acetaldehyde	Floral	Hyacinth
Benzaldehyde	Fruity	Almond
Methyl salicylate	Fruity	Minty
Phenyl ethanol	Fruity	Honey
Hexanal	Grassy	Fresh

Association, Assam, India) has identified major flavor- and odor-determining chemical compounds present in black tea, as reported by Bhattacharyya et al. (2007) and Sharma and Rao (2009); these compounds are listed in Table 3.

Taste

Generally, foods have six basic tastes: sweetness, bitterness, astringency, sourness, saltiness, and umami (Tamura et al., 1969; Chaturvedula and Prakash, 2011). Good quality black tea infusion is characterized by a bright reddish brown color; brisk, strong taste; and rich flavor (Chaturvedula and Prakash, 2011). Astringency in black tea can be a tangy or non-tangy type. The former is characterized by a sharp and puckering action with little aftertaste, whereas the latter is characterized as tasteless, mouth drying, and mouth coating, with a lingering (more than 60 s) aftertaste. Decaffeination may result in the formation of non-tangy from tangy, altering the nature of astringency. Caffeine together with black tea polyphenols is necessary for the expression of reasonable levels of tangy astringency (Sanderson et al., 1976; Chaturvedula and Prakash, 2011). The biochemical compounds responsible for the taste of black tea are shown in Table 4 (Sharma and Rao, 2009; Chaturvedula and Prakash, 2011). Both TF and TR derived from the oxidation of catechins and their gallates during the fermentation stage contribute to the taste of black tea brews/beverages (Sharma and Rao, 2009; Asil et al., 2012).

Effect of the fermentation process parameters on the quality attributes of black tea

Time

The process parameters, namely, time, temperature, oxygen, relative humidity, and pH, are the crucial factors that affect the quality of the tea (Cloughley, 1980; Cloughley and Ellis, 1980; Obanda et al., 2001). Among these, the duration of fermentation plays a vital role because the fermentation time has a great impact on the quality of black tea (Muthumani and Kumar, 2007). There is fixed fermentation time, and it depends on the type of tea, degree of maceration and rolling, degree of withering, and standard of plucking. The quality attributes, such as astringency, brightness, briskness, and strength, of the liquor reach their optimum levels at different times. Therefore, optimization has to be performed so that the overall effect is the best (Sanyal, 2011). The fermentation time for orthodox and CTC teas will vary from 2-4 h and 55-110 min, respectively (Sharma and Rao, 2009; Sanyal, 2011). In general, CTC tea requires a shorter fermentation time, as it involves extensive cell rupturing, thereby leading to more exposed area for the enzymes and oxygen. As shown in Figure 2, the concentrations of TF and TR as well as the desirable quality characteristics increase with fermentation time, reaching optimum levels and then degrading if the fermentation time is prolonged (Sanyal, 2011; Stodt et al., 2014). If fermentation time is extended, TF gradually degrade to TR, and the body of tea liquor becomes thick (Borah and Bhuyan, 2003; Gill et al., 2011). Over-fermented tea lacks many desirable qualities, although it has body. A quality cup of tea requires maintaining an optimum ratio of TF and TR (1:10) (Gill et al., 2011). At a 20°C fermentation temperature, total TF, total TR, brightness, briskness, and total color reach their maximum levels at 90, 120, 60, 60, and 120 min of fermentation, respectively (Obanda et al., 2001).

Table 4. Biochemical compounds responsible for taste in black tea

Compounds	Taste
Theaflavins	Mouth drying, rough astringent
Thearubigins	Ashy and slightly astringent
Catechin	Puckering astringent
Epigallocatechin gallate	Astringent and bitter
Caffeine	Bitter, brisk, and creamy
Amino acids	Brothy

Temperature

During fermentation, the chlorophyll in the tea leaves is enzymatically (PPO and PO) broken down. Control of

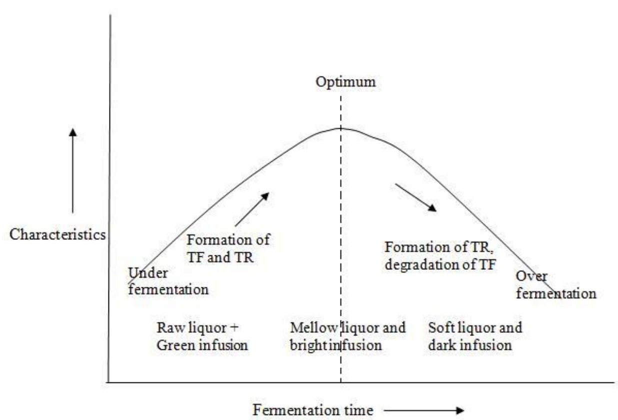

Figure 2. Development of the quality characteristics of tea during fermentation.

the fermentation temperature is necessary to produce superior quality tea, as fermentation under very low or high temperatures may lead to the inactivation of enzymes. For example, the fixing of green tea and drying of tea are performed to arrest the enzymatic reactions. Enzymes are proteins and denature at high temperatures (Ravichandran and Parthiban, 1998).Therefore, it is necessary to monitor the fermentation temperature so that it is favorable for enzymatic activity. The effect of air temperature (20-35°C) during fermentation (*Camellia sinensis var. assamica*) on the quality attributes of CTC black tea was analyzed by Smanta et al. (2013). They reported that the TF and TR ratio as well as brightness were at their maximum levels at 20°C. Fermentation performed at a temperature ranging from 20-30°C for 30-120 min, and the optimum conditions were found to be 25°C for 60 min for the Promising 100 and Chinese cultivars (Asil et al., 2012). The dhool (macerated tea leaves) of clones 6/8, SC12/28, and S15/10 were fermented at 15-30°C for 0-180 min, and for all clones, fermentation at 20°C produced the best quality tea. Fermentation at low temperatures produces quality black tea, whereas high temperatures and long fermentation times favor the production of black teas with high TF levels with more intense color (John, 1980). High fermentation temperatures produce teas with higher TR and total color values but lower TF, sensory evaluation, and brightness values. Comparatively, clone S15/10 has a better stability at higher temperatures than 6/8 and SC12/28 (Owuor and Obanda, 2001). Generally, fermentation is conducted at 24-27°C for 3-4 h, but the optimum conditions vary for different types of tea (Sharma and Rao, 2009). However, Sanyal (2011) recommended a temperature of 27-29°C for a duration of 2 h 30 min to 3 h 45 min or 55-110 min for orthodox tea or CTC black tea, respectively.

It is also necessary to monitor other parameters such as oxygen and relative humidity to produce quality black tea. Sufficient oxygen is required for the proper enzymatic reactions to occur. Under inadequate oxygen, the processed leaf heats up, and chemical oxidation is impeded, leading to a dull liquor (Sanyal, 2011). Fermentation of ruptured tea leaves under low oxygen and high temperature results in higher concentrations of TR and lower concentrations of TF (Sharma and Rao, 2009). It is necessary to maintain relative humidity at 95-98% during fermentation. In the afternoon, the temperature is usually high with low relative humidity, and under these or similar conditions, the air must be humidified to keep the ruptured leaves fresh and cool during fermentation. The passing of dry air over the leaves should be avoided, as this leads to blackening and interferes with the rate of oxidation (Sanyal, 2011). It has been reported that the fermentation of macerated tea leaves at pH 4.5 results in higher levels TF compared with fermentation at pH 5.5 (Subramanian et al., 1999).

Health benefits of black tea

Tea is one of the oldest known medicines. It was consumed in China 5000 years ago for its ability to stimulate, detoxify, improve the immune system, improve blood and urine flow, and reduce joint pain (Dufresne and Farnworth, 2000). The main polyphenolic components of black tea, TF, TR, and un-oxidized catechins, are responsible for its antioxidant activities (Bhuyan et al., 2013). These antioxidative properties are due to the ability of these components to scavenge free radicals, inhibit the generation of free radicals, and chelate transition metal ions (Luczaj and Skrzydlewska, 2005). TF, which are formed during fermentation and found exclusively in black tea, have an antioxidative effect due to their ability to form complexes with metals. During the fermentation of tea, the conversion of catechins to TF does not significantly change the antioxidant activities of tea (Halder and Bhaduri, 1998; Chan et al., 2007). Black tea prevents cigarette smoke-induced oxidative damage of proteins in guinea pigs, as reported by Misra et al. (2003). It was reported that if these results were extrapolated to humans, black tea may prevent cigarette smoke-induced oxidative damage and consequent degenerative diseases. Black tea prevents the degradation of red blood cells and protein membranes due to oxidative stress (Halder and Bhaduri, 1998). Black tea has been shown to have anticancer activity in different types of cancers (oral, esophageal and gastric, intestinal, prostrate, lung, breast, skin, liver, urinary tract) (Bhattacharya et al., 2004; Sharma et al., 2007; Sharma and Rao, 2009). It has also been reported that the regular consumption of three or more cups of black tea per day reduces the risk of heart disease and stroke (Larsson et al., 2013). Black tea improves oral health by inhibiting the growth of bacteria and reducing the incidence of dental cavities. Thus, it can be used as a natural treatment for periodontal disease (Stefano and Scully, 2009; Sen and Bera, 2013). In addition, black tea consumption has been shown to reduce cholesterol levels. The blood cholesterol-lowering effect may be due to the action of TF, which can reduce intestinal cholesterol absorption (Vermeer et al., 2008). Research also indicates that black tea has the potential to alleviate the glucose and lipid metabolism disorders associated with type 2 diabetes (Anderson and Polansky, 2002; Sen and Bera, 2013).

Conclusions

The different types of tea, namely, black, green, oolong, and white, are classified based on the degree of fermentation. The fermentation step in the processing of black tea plays an important role in determining the quality of the final black tea. TF and TR are the main oxidized-polyphenolic compounds that influence the quality attributes of black tea. An optimum ratio of TF and TR (1:10) should be maintained to ensure the best quality tea. This optimum ratio can be adversely affected by processing parameters such as time, temperature, oxygen, and relative humidity. Generally, fermentation is carried out at a temperature range of 24-29°C for 2-4 h or 55-110 min for orthodox tea or CTC black tea, respectively. An adequate supply of oxygen and a relative humidity of 95-98% should be maintained during fermentation. Therefore, it is necessary to monitor the fermentation step carefully to ensure the health benefits of black tea and its various sensory quality parameters (color, aroma, taste, and flavor).

Conflict of Interest

The author has no conflicting financial or other interests.

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