Influence of withering, including leaf handling, on the manufacturing and quality of black teas — a review

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Literature on the influence of withering on maceration, fermentation and drying and on black tea quality is reviewed. The importance of including the handling of the leaf in the field and during transportation as an integral part of withering is stressed. The influence of physical and chemical changes in the green leaf, during withering, on the quality of black teas is discussed. Withering practices vary with climate, producing region, the type of manufacturing process and demands by the markets. Mechanised withering may improve quality by reduced handling of the leaf. The influence of plucking standards on withering and the effect of withering on the storage of tea are discussed. © 1997 Elsevier Science Ltd

INTRODUCTION

Black tea is manufactured in four distinct stages; withering, maceration or rolling, fermentation and drying (firing). Withering refers to the changes that occur in the green leaf from the time it is detached from the plant (plucked) to the time of maceration (Owuor & Orchard, 1989; Orchard, 1991). With improvements in tea manufacturing technology, the method and value of withering in relation to black tea quality appears to be changing. For the production of flavoury teas (Dev Choudhury & Bajaj, 1980a), where the tea is rolled, withering is considered vital for quality. In the production of plain teas, such as those manufactured in Kenya (Owuor & Orchard, 1989; Orchard, 1991) and Malawi (Hilton, 1975), the role of withering is less clear; some manufacturers now omit the factory withering stage altogether.

An aspect of withering that is now considered to be important is field withering, or leaf handling. Recent work in Malawi (Burton, 1995; Wilkie, 1995) suggests that up to 25% of the market value of tea can be lost before green leaf arrives at the factory door if it is poorly handled whilst in the field and during transit. This paper reviews the physical and chemical transformations during withering and the implication of these changes on subsequent manufacturing stages and on the overall quality of tea.

Technical aspects of withering and their effect on subsequent stages of manufacture

Withering of green leaf in a tea factory has much to do with the technical difficulties in handling wet or over dry leaf during maceration, fermentation and drying.

Maceration

Fresh green leaf arriving at the factory typically has a moisture content above 75% on a wet basis and can be as high as 83%. Maceration machines operate most effectively within a fairly narrow green-leaf moisture range (68 to 72% on a wet basis; Hampton, 1992) and hence some moisture must usually be lost during withering. For Lawrie tea processor (LTP) maceration, a target moisture content on a wet basis of 71 to 72% is considered desirable (Johnson, 1990; Hampton, 1992). Cut-tear-curl (CTC) maceration can operate over a wider range of moistures, 68 to 72% being preferred (Choudhury, 1970; Hampton, 1992). It is thought that excessive moisture in the green leaf will clog both the rotorvane and CTC rollers (Owuor et al., 1987). The orthodox method utilises leaf at 60 to 66% (Choudhury, 1970; Hampton, 1992) (although it is not clear whether the moisture loss refers to per cent moisture content on a wet basis or a percentage of the original leaf weight). This is to ensure that the leaves are sufficiently flaccid.
for the rollers to produce the desired twist in the leaf. The Legg cutter (Johnson, 1990) is not dependent on the leaf moisture for efficiency of cutting but seems to have a reputation for producing 'brassy' teas, although Trinick (1962) reported an improvement in quality. Some authors report the degree of wither as per cent moisture content and others as percentage wither. These are not the same; moisture content refers to the per cent of moisture in the leaf on a wet basis, whereas percentage wither refers to weight loss in relation to the fresh weight.

**Fermentation**

Excessive moisture in the dhool may hinder aeration and temperature control resulting in uneven fermentation (Sanderson & Graham, 1973). Excessive withering may concentrate the catechins to levels that inhibit polyphenol oxidase (PPO) activity and reduce the expression of the cell contents onto the surface of the macerated leaf (Robertson, 1992). Hence, a significant proportion of the fermentation may occur within the leaf particle under limiting oxygen conditions. Moisture loss during withering does not appear to alter the optimum fermentation time (Ullah et al., 1984; Owuor & Obanda, 1992a).

**Drying**

Dhool that is too wet has been reported to be difficult to dry evenly because it can form clumps, particularly in fluidised bed dryers (Owuor & Orchard, 1991, 1992).

**Withering processes occurring in the green leaf**

During withering, two processes occur in the green leaf. On the one hand, they are physical, leading to a loss in moisture and changes in cell membrane permeability (Sanderson, 1964) and, on the other, they are chemical, influencing the formation of the tea aroma, which is important for flavoury teas (Bhatia, 1962; Sanderson, 1964; Yamanishi et al., 1966; Saiko & Takeo, 1973; Selvendran et al., 1978; Wright & Fishwick, 1979; Dev Choudhury & Bajaj, 1980a, b Takeo, 1984a; Owuor et al., 1986; Robinson & Owuor, 1992).

In practice, several withering methods have been described. A normal wither refers to the traditional method of withering where air is blown through the leaf (12 to 24 h) until the desired moisture loss is reached. Moisture is lost during the wither along with biochemical changes in the leaf. Heat may be applied on wet and humid days to remove moisture from the leaf.

A physical wither refers to a loss in moisture and changes in cell membrane permeability which result in the leaf becoming flaccid. It is achieved by passing air (ambient or heated) through the leaf. The physical wither can take about 4 h when ambient air is used. Shorter times of 2 to 2.5 h are possible with heated air.

Chemical wither refers to natural biochemical changes that occur inside the leaf. It is achieved by blowing air either intermittently or continuously at low flow rates through the leaf to keep it cool without losing moisture for between 4 and 18 h.

Two-stage withers relate to a chemical wither, used to store or hold the leaf, followed by a physical wither to lose moisture. The depth of the leaf bed may be greater than that used in troughs; the term tank-withering has been used for the chemical stage. A nil wither is when the green leaf is manufactured fresh.

The influence of the type of wither on made tea quality seems to differ between producing countries. For plain teas, such as those produced in Malawi and Kenya, tasters preferred teas that had been physically withered (Hilton, 1975; Owuor et al., 1989; Orchard, 1991; Owuor & Orchard, 1991, 1992). In Kenya, the duration of chemical wither (0 to 18 h) did not have any effect on quality. In other producing regions such as Assam (Ullah, 1988), the chemical wither was necessary for producing full and round liquors and the duration could be reduced to 6 to 8 h by holding the leaf at elevated temperatures between 30 and 37°C and passing air through at a rate of 0.6 m³ min⁻¹. It has been reported that the withering time was not critical for teas lacking quality but should be shorter for quality teas (Keegal, 1950). Some manufacturers practise a two-stage wither (Owuor & Orchard, 1989; Orchard, 1991) which starts with a chemical wither in which the leaf is stored, followed by a short physical wither to lose moisture. Other manufacturers follow a nil wither (Orchard, 1991), since reasonable quality teas can be produced by a chemical wither alone (Ullah, 1984a, b; Owuor et al., 1989).

**Changes occurring in the green leaf during the physical wither**

Immediately after plucking, the fresh leaf starts to lose water vapour. As withering progresses, the stomata of the lower leaf surface begin to close; two and a half times as much water is lost through the lower surface, which has stomata, compared to the upper surface which has no stomata (Orchard, 1991; Kramer & Kozlowski, 1979). The maximum initial drying rate is 0.075 kg of water per kg of green leaf per h (Johnson, 1990). As the degree of wither progresses, the permeability of the cell membranes in tea shoots increases. It has been noted that chilling of the leaf to 10°C or below increases cell permeability, whereas no change was recorded above 31°C (Sanderson, 1964). It has been estimated that, in addition to moisture loss, up to 4% of the dry matter in the leaf is lost as carbon dioxide through respiration (Roberts, 1948; Hampton, 1992).

To ensure good quality tea, an even wither is critical (Keegal, 1950). The rate of loss of moisture and temperature of the leaf during withering is related to surface moisture, humidity of the air, altitude, dry-bulb and wet-bulb temperature, air flow, packing density and whether heat is applied during withering (Johnson, 1987, 1990; Hampton, 1992). In compacted leaf,
temperature rises of 3°C per h can occur, but the effect on quality is not known, although regular turning of the leaf was recommended (Johnson, 1990).

**Biochemical changes in the green leaf during withering**

A large number of chemical changes occur during withering (Dev Choudhury & Bajaj, 1980a; Agarwal, 1989). At the time of plucking, numerous biochemical and physiological processes occur in the green leaf. During manufacture, many of these processes will be altered and new processes commence. The known biochemical changes involved are the breakdown of proteins into amino acids, a decrease in lipids and fatty acids, carotenoids and chlorophylls, an increase in caffeine content and changes in sugars, organic acids, PPO activity and aroma-volatile components.

**Proteins and amino acids**

Protein levels are reduced by approximately 1.2% during withering and the changes accompany increases in amino acids which are thought to be involved in aroma formation (Bhatia, 1962, 1965; Roberts & Sanderson, 1966; Perera & Wickremasinghe, 1972; Sajjo, 1973; Motoda, 1979; Dev Choudhury & Bajaj, 1980a). The increase in amino acids is thought to be because of the breakdown of protein by peptidase (Dev Choudhury & Bajaj, 1980b), although other routes may be involved since simple sugars formed during withering react with amino acids (Dev Choudhury & Bajaj, 1979). Some amino acids (glycine, alanine, valine, leucine, isoleucine and methionine) form the corresponding Strecker aldehydes (formaldehyde, acetaldehyde, isobutyraldehyde, isovaleraldehyde, 2-methylbutanal, methional) during fermentation (Sanderson & Graham, 1973). Such aldehydes can be further reduced to alcohols. These compounds are thought to cause poor flavour in tea (Owuor et al., 1987, 1989). Other amino acids, for example phenylalanine, increase during withering to form phenylacetaldehyde, which can also be reduced to alcohols (Sanderson & Graham, 1973). These compounds can improve the tea aroma (Owuor et al., 1987, 1989).

The influence of withering on the amino acid composition varies with the duration, ambient temperature and moisture. Withers of short duration have little effect on amino acid composition, whereas longer withers allow for a build-up of amino acids. When moisture loss was prevented, amino acid formation was reduced. The formation of amino acids was reduced at temperatures below 18°C and accelerated as the temperature increased to 40°C; formation stopped after 6 h because of the death of the tissues (Roberts & Sanderson, 1966).

**Carbohydrates and simple sugars**


**Lipids and fatty acids**

Lipids are important in the development of aroma compounds in black tea. The levels of saturated fatty acids (FA) decrease during withering, but their influence on black tea flavour is not known (Selvendran et al., 1978; Wright & Fishwick, 1979). More is known about the role of unsaturated FA during withering and their influence on black tea quality. During withering, lipid degradation occurs and the unsaturated FA decrease to undergo regio- and enantio-selective oxidative cleavage to form aroma compounds (Wright & Fishwick, 1979; Hatanaka et al., 1984; Owuor et al., 1987, 1989). Aroma compounds formed from unsaturated FA breakdown are thought to have a negative effect on flavour. The strong grassy odour from the withering troughs is a result of aroma compounds produced from FA (Takao & Tsushida, 1980; Hatanaka et al., 1984). The breakdown of unsaturated FA during withering is catalysed by lipoxygenase which increases in activity during withering (Takao & Tsushida, 1980).

**Carotenoids**

The degradation of carotenoids during withering and fermentation leads to important flavour in high quality tea compounds (Trimanna & Wickremasinghe, 1965; Sanderson et al., 1971; Renold et al., 1974; Dev Choudhury & Bajaj, 1980b; Hazarika & Mahanta, 1983). Carotenoids and chlorophylls have been identified as important for quality in Kenyan teas and have been suggested as the basis of predicting quality (Taylor & McDowell, 1991; Taylor et al., 1992). Carotenoids (violoxanthin and neoxanthin) are significantly reduced during withering (Hazarika & Mahanta, 1983) whereas β-carotene and lutein only decline during fermentation. The decline in carotenoid concentration is most significant during physical (not chemical) wither.

**Chlorophyll**

Teas with high chlorophyll contents normally result in inferior liquors. It is thought that the conversion of chlorophylls to pheophytins during fermentation and firing contributes to black tea appearance (Dev Choudhury & Bajaj, 1980b; Taylor et al., 1992). During withering, the level of chlorophylls declines by 15%, forming chlorophyllides. It has been noted that green leaf high in chlorophyll produces tea with a grassy odour, but the cause of the grassy odour has not been identified (Nikolaishvili & Adeshvili, 1966; Wickremasinghe & Perera, 1966; Dev Choudhury & Bajaj, 1980b).

**Caffeine**

Teas with low levels of caffeine or those containing poorly fermented leaf particles lack the ability to cream (Roberts, 1963; Bhatia, 1964; Dev Choudhury & Bajaj,
The creaming properties of made tea are adversely affected by insufficient wither. Caffeine increases during withering (Bhatia, 1962; Sanderson & Graham, 1973; Dev Choudhury & Bajaj, 1980a; Owuor et al., 1986, 1989; Bhuyan & Mahanta, 1989) but is reduced when tea is withered at a higher temperature of 38°C (Dev Choudhury & Bajaj, 1980a). The increase in caffeine concentration appears to be related to amino acid metabolism (Roberts & Sanderson 1966). The method of withering may influence the caffeine concentration since, compared to normal withers, the level in physically withered teas was less (Owuor et al., 1987).

**Catechins and enzyme activity**

The total catechin content decreases during withering (Hilton, 1975; Bokuchava & Skobeleva, 1980). Epigallocatechin (EGC), galloylecatechin (GC), epigalloxyate gallate (EGCG) and epicatechin gallate (ECG) decrease in amount during withering, whilst epicatechin (EC) increases. Catechins produce theaflavin (TF) and low molecular weight, chromatographically-resolved thearubigin (TR) in the presence of PPO (Opie et al., 1990; Robertson, 1992). In the presence of peroxidases (PO), unresolved, high molecular weight TRs are formed (Finger, 1994). The activity of PPO has been reported to decrease during withering (Hilton, 1975; Ullah & Roy, 1982; Ullah, 1984a,b; Ullah et al., 1984; Robertson, 1992) as a result of moisture loss. In India, the activity of withering appeared to have little effect on either PPO or PO activity (Mahanta et al., 1993). The activity of PPO was restored when the withered leaf was rehydrated (Ullah & Roy, 1982). The activity of the enzyme is also reduced by increased temperature (Cloughley, 1979). Losses in activity of 70% were noted at temperatures of 35°C which varied greatly between clones.

Non-enzymic chemical oxidation of the catechins may occur during the fermentation stage (Bailey et al., 1993) and is thought to produce pigments similar to TR in black tea. The occurrence and influence of non-enzymic changes during withering is not known.

**Influence of withering on the fermentation process**

Withering can influence the formation of black tea phenolics and volatile compounds during fermentation.

**Black tea phenolics**

Unwithered leaf is associated with teas that are bright, brisk, but thin; correspondingly, the teas were higher in TF but lower in TR (Ullah et al., 1984; Owuor & Orchard, 1989; Orchard, 1991). Harder withers produced teas with less brightness and briskness, but improved body; the TFs were lower and the TRs higher (Perera & Wickremasinghe, 1972; Ullah, 1984a,b; Owuor et al., 1986, 1987, 1989). Leaf withered to different moisture levels in Malawi (Mashingaidze, 1995) showed that TF levels declined by 16% as the moisture in the leaf decreased from 72.5 to 64.8%. There was no difference in the tasters’ market evaluation. It is thought that high leaf-moisture contents are associated with high PPO activity, which enhances the formation of TFs and hinders the formation of TRs (Hazarika et al., 1984).

A biphasic production of TFs during withering has been noted and is thought to be the result of different phases in enzyme activity (Obanda & Owuor, 1991; Kumsinda, 1993; Madanhire, 1993). Teas manufactured during the initial rise in TF concentration were bright but thin compared to those manufactured after the second increase in TF.

**Volatile compounds**

Withering is thought to improve the aroma of tea (Yamanishi et al., 1966; Saijo & Takeo, 1973; Saijo, 1977; Takeo & Mahanta, 1983; Takeo, 1984; Owuor et al., 1987; Mahanta & Boruah, 1989; Owuor et al., 1989) and affect the volatile composition (Takeo, 1984a). Studies in India (Mahanta & Boruah, 1989) indicate that withering influences the development of terpenoids, improving the flavour of tea. Flavour compounds that are important to quality (linalool, geraniol, methylsalsicylate) have been reported to increase during withering, while compounds (E-2-hexenal) detrimental to quality are highest in unwithered teas (Yamanishi, 1967; Howard, 1978). Groups I and II volatile flavour compounds (VFC) impart an inferior, grassy aroma and a sweet flowery aroma to black tea, respectively (Owuor & Orchard, 1992). During chemical withering, both groups I and II declined in Kenya teas, although group I declined faster, resulting in an improvement in quality.

For oolong teas (Takeo, 1984a), it has been noted that volatile compounds increased in warm withered leaves at near 40°C during the first stage of withering. Furthermore, the production of aroma compounds was accelerated by soft hand-rolling every half hour during the withering process. Withering under direct sunlight or artificial light also improved the aroma.

**Leaf handling from the field to the factory**

The green leaf starts the withering process from the moment it is plucked from the tea bush. However, little has been published on the effect that handling of the leaf, from the time it is plucked to the time that it arrives at the factory, has on market value or subsequent stages in manufacture. Initial work in Malawi (Hilton, 1975) suggested that handling of clonal leaf (SFS204) did not adversely affect quality, which was still of a better quality than Indian hybrid seedling tea. Overheating of the leaf was thought to cause more quality loss than physical leaf damage (bending, bruising and tearing).

Poorly-handled leaf, that has undergone senescence, will turn red. This is thought to occur when green-coloured chloroplasts are transformed into red-coloured...
chromoplasts. Studies in Kenya (Melican & Mallows, 1992) indicated that red leaf formation occurred in 30 min when buds were exposed to a temperature of 45°C. For the first and second leaves, red leaf occurred after 40 and 165 min, respectively. Tea made from the red leaf was found to have lower TFs but higher TRs than a control sample. Tasters scored tea made from red leaf as too poor to rate. In Papua, New Guinea, an inclusion of 10% red leaf resulted in a perceivable reduction in quality (Melican & Mallows, 1992).

Field withering in Malawi and its influence on market value of made tea

Recently, a study was carried out in Malawi (Burton, 1995) which, although not done in depth, was wide-ranging. It indicated that up to 25% of the value of tea could be lost before the leaf arrived at the factory. The study comprised a field survey, monitoring green-leaf temperature, duration of storage in sacks, packing density, sack design and green-leaf condition, and their effects on made tea quality.

Field survey

A field survey indicated that leaf took up to 10 h to reach the factory and, in that time, became heated to temperatures between 25 and 49°C. The method of transport could affect the time that the leaf remained in the field, open trailers being easier to load and unload than pew-type trailers. The design of shelters may also have an effect on leaf temperature, permanent bamboo-type shelters recording lower average maximum ambient temperatures of 29°C compared with those of portable hessian bag shelters at 35°C.

Temperature, time and tea variety

The rise in leaf temperature in the field varied with the variety of leaf and the ambient temperature. Most (70%) of the rise in temperature occurred under the shelters. The temperature of clonal leaf appeared to rise more rapidly than Indian hybrid. Most of the increase in temperature occurred in the first 6 h, particularly when the ambient temperature was above 30°C. For clonal leaf, there were signs of red leaf at temperatures at or above 35°C when stored for more than 6 h. The highest leaf temperature recorded was 52°C. The loss in value and TF accelerated with increasing temperature. A 23% loss in valuation was noted when the leaf temperature reached 45°C after 9 h.

A study in Kenya (Owuor & Obanda, 1992a,b) on the influence of temperature on chemical withering also showed that holding the leaf at higher temperatures lowers black tea quality, reduces TF and increases TR.

Weight of green leaf (packing density) in sacks and sack design

The weight of green leaf (SFS204) stuffed into sacks influenced the rise in temperature. Although initially the rise in temperature was the same, regardless of packing density, after 2 h, the greater the weight of green leaf, the higher was the rise in temperature, which reached a maximum of 51°C. The tasters’ evaluations indicated that packing a sack with 8 kg gave the highest score followed by open leaf, and packing at 12 kg came last. The design of the bag can also influence the quality of the leaf. Net bags, allowing more air to flow between the leaves, gave lower leaf temperatures and made-tea evaluations. The influence of bag design was both density- and time-related; for short storage periods, the design of the bag was less important, but for longer storage times the loss in quality for leaf stored in hessian bags was greater.

Leaf condition and made tea quality

Physical damage of the leaf can perhaps have the largest effect on made-tea quality. Brokers’ evaluations showed that, after 9 h, tea manufactured from damaged green leaf (SFS204) was rated as dull and flat: scoring zero for briskness, one for brightness, and two for colour of infusion on a zero to ten scale. The market value of the damaged leaf was between 11 and 16% less than undamaged leaf. In other studies (Saijo, 1977), aliphatic, aromatic and terpenoid alcohols increased in damaged leaf during withering. In particular, linalool oxide and geraniol, which enhance tea flavour, increased markedly before a slight decrease. However, the effect on quality as determined by tasters was not reported.

Influence of other factors

The standard of plucking can have an effect on withering. How the leaf is withered can influence the quality of made tea during storage and its packing density.

Plucking standards and factory withering

A study in Kenya of the influence of plucking standards on withering (Obanda & Owuor, 1994) showed that quality, as perceived by tasters, declined with coarser plucking standards and that the decline was least when a chemical wither was employed. Biochemical analysis showed that TRs increased with a coarse plucking standard and that the increase was greatest for normal withers. TRs decreased with coarser plucking standards, but the decline was least with chemical withering. PPO activity was highest with the chemical wither. The flavour index declined with plucking standard.

Storage of made tea

Made tea manufactured in Malawi from leaf that had been withered for more than 10 h had improved keeping properties with respect to TF composition (Cloughley, 1981). Tea manufactured from shorter withers had the highest initial TF values but deteriorated more rapidly. A study in Kenya (Owuor & Obanda, 1992c) found similar results.
Packing density of made tea

Studies in Kenya have shown that chemical withers tend to produce teas of lower density, but acceptable quality (Orchard, 1991). However, the lower density leads to higher storage and transportation costs (Owuor & Obanda, 1993).

Mechanisation of leaf handling and withering

In factory withering, the green leaf is usually transferred to jats or withering troughs manually. This is labour-intensive and can increase the handling of the leaf. Withering has been mechanised in a factory in Kenya (Wemyss, 1973) and one in Assam (Boruah, 1988). Such systems are reported to reduce labour costs and improve quality through reduced handling of the green leaf.

A machine has been developed to remove water adhering to leaves before plucking (Watanbe et al., 1983). It uses a fan and rotary sponge brushes to remove excess water. With an air speed of 40 m s\(^{-1}\) for the fan, most of the adhering water was removed and the remainder evaporated within 10 min. No injury to the leaf was observed, but the influence on quality was not reported.

CONCLUSIONS

While much has been reported on changes occurring in the leaf whilst withering in the factory, until recently little was known about the importance of changes that occur in the field and how these might influence subsequent stages in the manufacturing process. For plain teas, such as those manufactured in Malawi, it is now clear that much of the potential value of the tea can be lost before the leaf has arrived at the factory. Also, little is known about the influence of poor leaf handling on the quality of plain and flavoury teas manufactured in other producing regions, or how it might affect the withering and fermentation of tea. For example, should leaf that has been in the field for 10 h and attained temperatures in excess of 40°C be treated in the factory in the same way as fresh leaf?

Withering involves both physical and chemical changes in the green leaf. The physical changes, such as the rate of moisture loss, might be easily determined if the moisture content, mass of the fresh leaf, altitude and humidity are known and the air flow and any applied heat during withering can be closely controlled. Where space is important, costs may be reduced by utilising a two-stage withering system. While much is known about the biochemical changes that occur in the green leaf during withering, the tea manufacturers are still very dependent on tea tasters to assess quality. Rapid objective methods need to be devised to measure green leaf moisture content and when the desired chemical wither is attained.

Withering practices differ with country and the type of tea being manufactured. For plain teas such as those from southern Africa, moisture loss by a physical wither appears to be the most important for quality as perceived by tasters. For more flavoury teas, a chemical wither is considered important.

When comparing the literature on withering methods, it was noted that the conditions of experimentation were not reported consistently or were omitted. For example, the per cent wither might refer to the moisture content of the withered leaf on a wet or dry weight basis or the proportion of weight lost in relation to the original weight of fresh leaf. In this review, the moisture contents are reported as per cent moisture on a wet weight basis when this is known. Other parameters which should be reported to allow proper comparisons of withering methods to be made are the condition of the leaf, altitude, ambient air temperatures, humidity, air-flow rate, including whether this was intermittent or continuous, when and how much heated air was applied, green-leaf bed loading on the withering trough (kg of green leaf per square metre), depth of leaf and how frequently the leaf was turned.

REFERENCES


