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Quality and yields of black tea *camellia sinensis* L. O. Kuntze in responses to harvesting in Kenya: a review

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Abstract

Tea beverages, from tender shoots of *Camellia sinensis* L., are the most widely consumed fluids after water. The young tender shoots of the plant are harvested using various plucking methods. Incorrect plucking leads to yield and quality declines. It is therefore necessary that this process is optimised. Extensive research showed changes in the chemical composition, quality and yields of black tea due to plucking standards. Black tea quality deteriorates as the leaves become older and the rate of decline varies with crop varieties. A plucking standard of two leaves and a bud is recommended in most tea growing countries. However, due to rising harvesting costs, many tea producers are resorting to various mechanical harvesters. Mechanical harvesters or shears produce lower quality black tea compared to hand plucking. But this evens out after the plants are subjected to continuous/ long term mechanical harvesting. There is decline in quality with long plucking intervals even when the plucking standard of two leaves and a bud is maintained. Although a plucking standard of two leaves and a bud is a good compromise between yields and quality, there are tea varieties which can withstand coarse plucking standard without substantial quality losses. Quality of black tea declined with coarse plucking standards and long plucking intervals. With unselective plucking and long plucking intervals produced leaf with a high proportion of mature (coarse) leaf beyond two leaves and a bud which resulted in low quality black tea. Selective plucking standard of up to two leaves and a bud improved black tea quality even at long plucking intervals, but yields are reduced. Short and fine plucking standards ensure production of high quality black teas. Soft physically withered leaves produce superior plain black tea parameters and inferior aroma compared to hard physically withered leaves at all plucking standards. Irrespective of plucking standards shorter fermentation duration improved black tea quality.

INTRODUCTION

Tea beverages, processed from the young tender shoots of *Camellia sinensis* L. O. Kuntze, are claimed to be the most widely consumed fluids after water. The beverages are also gaining further popularity as important "health drinks" due to beneficial medicinal properties of tea polyphenols [1], which are natural antioxidants [2] and are responsible for their anticarcinogenic and antimutagenic properties of tea, as well as protective action against cardiovascular diseases [1, 3-5]. Tea production and quality of the varieties of tea are affected by many variables such as soil type, altitude and weather. Most premium quality teas grow at higher elevations [6, 7], where low temperatures allow the leaves and buds to develop and mature at a slower pace. The quality of tea is dependent on agronomic, cultural and processing practices.

Commercially, there are three major varieties of *Camellia sinensis*: the China type (*Camellia sinensis* var. *sinensis*), the Assam type (*Camellia sinensis* var. *assamica*), and the hybrid type (*Camellia sinensis* var. *assamica* ssp *lasiocalyx*) [8]. The common tea beverages processed from the *Camellia sinensis* varieties include white, green, oolong and black teas. The classification is based on the methods of processing which is also dependent on harvesting standards. White tea is processed from buds of the *Camellia sinensis* plant. It does not go through any oxidation at all and to prevent oxidation. There is no rolling, breaking, or bruising of any kind. The dried buds have a silver-like appearance because of the presence of the tiny white hairs of new growth so it is called 'silver needle' in the United States of America. Green tea is processed from the plucked leaves of the *Camellia sinensis* laid out to wither for between 8 and 24 hours. The leaves are steamed or pan fried to deactivate the oxidative enzymes, before being rolled up in various ways and tightness, and this is finally followed by the drying process. The quality of harvesting for green tea processing may not be critical [7]. Black teas are prepared from the leaves of *Camellia sinensis* which have been withered, rolled or macerated, fermented, and dried (fired). The leaves are transformed through a process known as fermentation (oxidation) after maceration into black tea. Generally, the plucking standard for black tea processing is variable but not as fine as that for white tea processing. Plucking standards vary from two leaves and a bud to four leaves and a bud. Oolong tea is intermediate between black and green teas. Plucked leaf for oolong tea has undergone short fermentation durations. While the leaves wither naturally, endogenous enzymes begin to oxidise polyphenols in the leaves after maceration. Processors interrupt the fermentation by stirring the leaves in heated pans, then rolling and followed by drying. The macerated leaf tea is fermented only partially to a point to obtain a product with characteristics between black and green teas.

The process of harvesting the young tender shoots is known as plucking and is very labour intensive and costly [9]. In India [10, 11] harvesting constitutes up to 70% of the total costs of field operations, while in Turkey long term plucking has been documented to be harmful to the pluckers [12]. Despite the high costs and health risks, the undertaking is indispensable, and if incorrectly practiced leads to farming losses as it reduces yield [13, 14] and/or quality [15]. That this process should be optimised for realisation of high yields and quality. This paper reviews efforts to optimise black tea quality and production through harvesting with particular reference to Kenya. Kenya is the world leading exporter of black tea and the third largest producer of the crop after China, and India [16].

Harvesting policy also affects yields [13, 17] and black tea quality [18-20]. The plucking policy, particularly the frequency of plucking, and leaf standard are important parameters which affect the composition and levels of the important precursor chemicals

in green leaf and ultimately black tea quality [7, 21]. The recommended plucking standard in Kenya [22, 23] and other black tea producing countries is to pluck two leaves and a bud. This standard is difficult to achieve under commercial conditions [24], and usually leaf of different standards are plucked and the ratio of fine fraction (shoots up to two leaves and a bud) to coarse fraction (shoots above two leaves and a bud) determines the overall leaf quality. Where a plucking standard is preset, if plucking intervals are too long, pluckers harvest mostly two leaves and a bud then break-back to remove extra mature leaf left above the plucking table [25]. The "broken-back" leaves are discarded and are a loss to farmers.

Plucking standards

Two leaves and a bud plucking standard is considered the best compromise between yield and quality [8, 23]. However, some producers use less tender shoots to realise 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. Indeed, fine plucking standards of young shoots also improves yields [17]. The black tea caffeine [26, 27], theaflavins, total ash, and total water soluble solids contents declined while thearubigins [27-29], crude fibre [27, 30] and fluoride [31, 32] increased with coarse plucking standards. For black tea aroma, whereas the group I volatile flavour compounds (VFC), responsible for green grassy smell increased, the group II VFC, responsible for sweet, floral aroma declined with coarse plucking standards [7, 18, 27]. Also, lipoxygenase activities [33] and saturated fatty acids which breakdown to form group I VFC [34-37], increase with coarse plucking standard [33, 38]. As a result, the flavour index as a ratio of group II:I VFC, which is used to quantify black tea aroma declined with shoot maturation [7, 27]. Thus the quality of black tea declined with coarse plucking standard [7, 27] 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 [39, 40] making the plain quality parameters of the resultant tea beverages to drop as the leaves become older [18, 27]. Thus the catechins (flavan-3-ols) which are responsible for formation of the plain black tea quality parameters (theaflavins and thearubigins) decline [40, 41]. But chlorophyll whose high levels reduce black tea quality increased with maturation of the tea leaves [42, 43]. The group I VFC are dominated by C_6 alcohols and aldehydes [7, 27]. The C_6 alcohols and aldehydes are breakdown products of unsaturated fatty acids in green tea leaves [34-37]. There was increase in the unsaturated fatty acids with maturation of leaf or coarse plucking standards [38, 44, 84]. Yields also declined with coarse plucking standard [29].

Seasonal variations have been demonstrated in quality [28, 46, 47] and yields [47] of tea from leaf of the same plucking standard. Generally, cooler months produced tea leaves with higher catechins [46, 49] and carotenoid compounds [49]. These seasonal variations can be attributed to the influence of weather factors on development and growth of individual shoots [50, 51]. Similarly, changes in quality of tea vary with time from last pruning [52-54], suggesting that there is need to vary plucking standards or policies in different seasons and durations from pruning to maximise tea yields and quality, especially further away from the equator where seasonal variations are pronounced [54-57].

Plucking standards in different tea cultivars

A plucking standard of two leaves and a bud is recommended in most black tea producing countries [8, 22, 23] as a compromise between yields, plucker productivity and quality [8, 58]. This is practiced in all tea cultivars although clones differ significantly in the levels of the polyphenols in the shoots [59-63]. For example, clone 6/8 with higher green leaf polyphenol contents invariably make better quality black teas than clone S15/10 with low polyphenol content [64]. But clone S15/10 is probably the highest yielding tea in the world as it has yielded up to 10,995 kg made tea ha^{-1} $year^{-1}$ [65] and is therefore, widely established in many tea estates. Since black tea quality declines with rise in shoot maturity [27, 23, 31, 66], it was necessary to ascertain whether the quality of black tea from low polyphenol content clone S15/10 responded in the same manner as the high content clone 6/8. The black tea quality declined with coarse plucking standards in both cultivars [67]. However, clone 6/8 with high polyphenol content in green leaf had higher decline than clone S15/10 with low polyphenol content [68]. A clone like S15/10 can be plucked much more coarsely without serious quality deterioration. The same recommended plucking standard of two leaves and a bud may not be appropriate for all clones.

Effect of Blending

Due to large variations in yields and polyphenol contents of clones 6/8 and S15/10, these clones may have a symbiotic effect on each other. Blending clone S15/10 with 6/8 may improve its quality while a field on which both cultivars are planted may improve the yields due to the S15/10. Blending the different green leaf of the two clones prior to processing revealed that blending S15/10 leaf at 1 leaf and a bud to 6/8 leaf at 1 leaf and a bud to 5 leaves and a bud at 1:1 ration produced black teas with chemical quality parameters equivalent to 100% clone 6/8 only. Thus, the ability of clone 6/8 to form high quality black tea was not compromised by blending with finely plucked S15/10 leaf. Conversely, addition of clone 6/8 leaf at either 1 leaf and a bud or 5 leaves and a bud improved the quality S15/10 black tea [69].

Plucking intervals

For a pre-set plucking standard, correct plucking interval influences the quantity of available recommended leaf. Under commercial tea production, it is difficult to select leaf of one plucking standard exclusively, consequently varying proportions of leaf of different standards are found in the harvested crop. The choice of a plucking interval may control the shoot distribution and thus the quality and quantity of crop [24]. More frequent plucking result in higher yields as it causes enhanced rates of axillary bud development [13] since apical dominance is more frequently overcome through decapitation of apical shoots [24]. Some growers adopt long plucking intervals to increase yields per plucking round. Conflicting results have been obtained on the effects of plucking intervals on yields. In Malawi [39, 70, 71], yields increased with long plucking intervals while in Kenya [19, 24, 72, 73] long plucking intervals decreased yields. The increase in the total number of harvested shoots from frequent plucking outweighed the benefits from the increase in mean shoot weight from longer plucking round lengths. When all available leaf was harvested, fine shoots declined and coarse leaf increased as plucking rounds lengthened. However plucker productivity and man days required/round/ha increased with increasing plucking interval whereas total man days/ha and cost of plucking decreased. Average price of plucked leaves and gross and net income/ha decreased with increased plucking interval [74]. In

study conducted over a ten year period at different locations in Kenya using one tea cultivar, yield responses to plucking intervals varied with locality and in different years [75]. Yields declined in three out of five regions but increased in one location with longer plucking intervals. The total theaflavins, caffeine, group II VFC and flavour index declined while group I VFC and thearubigins increased with longer plucking rounds [21, 73, 76] leading to a decline in quality with long plucking intervals [28, 45, 75]. The decline was partially attributed to the increase in unsaturated fatty acids [77] leading to increase in group I VFC in black tea [38]. Thus short plucking intervals improves both crop yield and quality, hence the overall earnings from tea enterprises.

Use of mechanical harvesters

Usually, tea leaves are harvested by hand-plucking without causing mechanical injury and manufactured under optimal conditions in order to maintain quality [27, 39, 77, 78]. Due to the sharp rise in the labour costs and shortage of manpower, different mechanical harvesters and shears have been successfully utilized in tea production to reduce operations costs. Use of mechanical harvesters reduced yields [79-81] and quality [82, 83] compared to hand plucking. Where pluckers are available at the affordable costs, hand plucking should be the method of choice in harvesting. However, labour costs have continued to rise while tea prices have stagnated or declined with time [84]. This has made the use of leaf harvesting machines in tea agronomy a technology of choice. Thus some tea growers have found it more profitable to replace some human labour with machines. This trend is not likely to change, yields and quality reductions notwithstanding. It is necessary to have government policies which protect workers but also enables investors to stay in business. Possibly use of mechanical harvesters should be encouraged during high crop seasons, which coincide with times of the year when low quality teas are produced [82, 85].

Effects of plucking intervals at same nitrogen fertilizer rate on black tea quality

Growers pluck at different intervals due to many factors, including unavailability of adequate labour to remove the crop on time, belief that long plucking intervals increase yields, etc. Irrespective of plucking intervals, many farmers harvest the entire available crop, i.e. plucking unselectively. Unselective plucking, there is quality decline with long plucking intervals [19-21] due to the coarse plucking standards [73].

Although actual plucking standards vary from country to country or even in different tea producing concerns within one country, two leaves and a bud is considered the compromise between yields and quality [8]. Thus where there is over growth beyond two leaves and a bud, in normal tea production, only the two leaves and a bud is harvested for processing and the rest is broken-back and thrown away to maintain uniform plucking table height [25]. Many farmers are unwilling to follow the recommendation because the broken-back leaf is seen as waste or loss. But where the recommendation is strictly enforced or followed, despite the losses in yields in a plucking round there are net gains in quality [25]. When plucking intervals are optimised, there are no yield losses as broken back leaf is minimal. Black tea quality declined with increase in nitrogenous fertilizer rates when plucking frequency and standard were kept constant [76, 79], while black tea quality declined with long plucking intervals when nitrogen rate was constant [20, 27].

Effects of nitrogen fertilizer rates and plucking intervals on yields, shoot distribution, mean shoot weight and quality

Yield benefits to nitrogenous fertilizer application, is widely documented in the literature [80, 81]. However, high rates of nitrogen fertilizer reduce quality of black tea [14, 20, 82, 83]. Yield increased with increases in the rates of applied NPKS 25:5:5:5 fertilizers but decreased with long plucking intervals [73]. At every plucking interval, the weighted mean annual yield data responses to nitrogenous fertilizer rates were quadratic ($P<0.05$) with a calculated maximum responses rates at 466, 487 and 491 kg N ha^{-1} $year^{-1}$ for 7, 14 and 21 days plucking intervals, respectively. However, significant yield responses were obtained by applying only up to 200 kg N ha^{-1} $year^{-1}$. Application of the fertilizer above this rate did not produce significant yield improvement. In Kenya short plucking intervals produce higher yields, unlike in Malawi where there was yield increase with long plucking intervals [39, 70, 71]. The variations in the results obtained in Kenya and Malawi may be due to the annual crop distribution patterns. Whereas the tea production in Kenya is almost uniform throughout the year, in Malawi 80% of tea is produced in five months, between December and April [14].

The number of shoots per square meter increased with increasing nitrogen rates and long plucking intervals [73]. However, the total number of harvested shoots declined with long plucking intervals due to the fewer times plucking was done. The mean fresh mass of two leaves and a bud shoots marginally increased with high rates of nitrogenous fertilizer and short plucking intervals. The shoot extension rates increased with increasing rates of nitrogenous fertilizer but were not affected by plucking intervals [73]. The distribution of plucked leaf into fine (two leaves and a bud) and course (above two leaves and a bud) was not affected by the increasing rates of nitrogenous fertilizers. However, the percent plucked good leaf of two leaves and a bud was highest at short plucking intervals and declined with longer plucking intervals.

Effects of varying nitrogen fertilizer rates, plucking intervals and standards on black tea quality

In a study where leaf from different plucking intervals were further separated into unselective harvesting in which all harvested shoots were processed irrespective of plucking standard and selective harvesting where only leaf up to two leaves and a bud was processed, there was decline in the quality with unselective (coarse) plucking standards at different nitrogen fertilizer rates [75]. Thus coarse plucking standards led to quality decline irrespective of nitrogen fertilizer rate being applied. The interactions between nitrogen fertilizer rates and plucking standards were insignificant, further demonstrating that the patterns of quality decline with plucking standard was the same at different nitrogen fertilizer rates. Poor black tea quality due to coarse plucking standards can therefore not be corrected by varying the nitrogen fertilizer rates and *vice versa*. In a study where leaf from different plucking intervals were further separated into unselective harvesting in which all harvested shoots were processed irrespective of plucking standard and selective harvesting where only leaf up to two leaves and a bud was processed, there was decline in the quality with unselective (coarse) plucking standards at different nitrogen fertilizer rates [75]. But even when the plucking standard was constant, long plucking intervals [73] increased levels of unsaturated fatty acids leading to group I VFC increase even at the same rate of nitrogen fertiliser [45], thus reducing quality of resultant black teas.

Optimising plucking for improved yields and quality

An agronomic undertaking is economically justifiable only if it leads to extra crop, improves tea quality, reduces costs of production or makes agriculture sustainable. Although coarse plucking standard improved biomass per plucking round, it reduced black tea quality. Fine plucking standard can be achieved by shortening plucking rounds which also increases yields over extended periods. Thus short plucking interval is one agronomic practice that enhances both yields and quality leading to higher profits and faster economic growth.

Plucking standards and withering

Withering is an important aspect in black tea processing as it influences the chemical components of green leaf that contribute to black tea quality [86-89]. At the same time total catechins [90], and polyphenols oxidase activity decline, with net change in the polyphenols oxidase isoenzymes composition [66, 91] leading to reduction in black tea quality as plucking becomes coarse [7, 18, 27]. The interactions between withering and plucking standards have been ill defined. Consequently withering practices in factories are standardised irrespective of plucking practices. In a study to understand the possible interactions [40], black tea quality declined with coarse plucking standard as had been observed in the previous studies. This occurred irrespective of the degree of physical wither. Similarly soft physically withered black tea had superior plain black tea parameters and inferior aroma compared to hard physically withered black tea at all plucking standards. On the contrary, hard physically withered black teas produced more aromatic black tea at all plucking standards. The differences in quality, particularly the plain black tea parameters were larger due to withering at coarse plucking standards.

Plucking standards and fermentation

Black tea quality declines with coarse plucking standards [7, 18, 27, 38] due to decline in catechins levels [90] and changes in polyphenols oxidase isoenzyme activity [40, 66, 92]. Unsaturated fatty acids levels increase with coarse plucking standards [21] leading to production of less aromatic black teas [7, 18, 37, 37]. Despite the knowledge of the changes in the green leaf components which are transformed into black tea quality parameters during black tea fermentation process, black tea processors normally set same fermentation time. Although there was a general decline in quality with plucking standards, better aromatic teas were observed from short fermentation duration [92]. There was a general decline in the black tea brightness and rise in thearubigins and total colour with long fermentation durations at all plucking standards [91]. The results suggest that irrespective of plucking standards shorter fermentation duration improved black tea quality.

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