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Responses of clonal tea to location of production and plucking intervals

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ABSTRACT

Tea is cultivated in diverse environments causing yield and quality differences in its beverages. To maximise yields and quality, agronomic practices should be optimised. But agronomic recommendations are uniform in different environments in Kenya despite variations in the growth factors responsible for changes in yields and quality. Plucking is labour intensive and a costly agronomic input in tea production. Trials were conducted for ten years in five tea growing regions in Kenya to assess yields and quality responses of clone BBK 35 tea to location of production and harvesting intervals. There were different ($P \leqslant 0.05$) yields in the various locations, with significant ($P \leqslant 0.05$) interaction effects between locations and harvesting intervals. Yields declined in three out of five regions but increased in one location with longer plucking intervals. Yields in a geographical area of production can not be used to estimate its expected yields in other tea growing areas. Black tea theaflavins varied significantly ($P \leqslant 0.05$) with geographical area of production, but other plain tea quality parameters did not vary with location. It is therefore possible to make similar black teas with similar plain tea quality parameters except theaflavins from all tea growing regions of Kenya. Tea quality improved with short plucking rounds. One way to maximise tea quality is through shortening harvesting intervals. It is necessary to establish optimal harvesting rounds in the different tea growing regions in Kenya to maximise yields and quality.

1. Introduction

Tea, *Camellia sinensis* (L.) O. Kuntze is cultivated under diverse environments ranging from 49°N, outer Carpathians to 30°S, Natal, South Africa (Shoubo, 1989) and altitudes varying from sea level in Japan to above 2700 m above mean sea level (amsl) in Olenguruone, Kenya and Gisovu, Rwanda (Owuor, Obanda, Nyirenda, & Mandala, 2008a). In Kenya, it is grown on the foothills of Abardare ranges and Mount Kenya in the East of the Great Rift Valley and the Mau ranges, Nandi, Kisii and Kakamega Hills in the West of the Great Rift Valley of Kenya. The plant is widely adaptable to geographical areas with large differences in climate and physical features which affect rates of growth, leading to yields and quality variations. Such variations may require different management strategies to maximise yields and quality. Previous studies demonstrated wide responses in yields of tea genotypes to different environments (Wachira, Ng'etich, Omolo, & Mamati, 2002; Wickremaratne, 1981). Quality variations have also been recorded due to environmental factors (Gulati & Ravichranath, 1996) and geographical area of production (Borse, Rao, Nagalakshmi, & Krishnamurthy, 2002; Fernandez, Fernando, Martin, & Gonzalez, 2002; Li, Yu, Li, & Li, 2007; Moreda-Pineiro, Fisher, & Hill, 2003; Owuor et al., 2008a; Peterson et al., 2004). Where data has been generated in different countries, comparisons of the results have been confounded by the use of different genotypes. Despite the noted differences in yields and quality due to growth factors, agronomic recommendations are usually uniform within one country or region (Othieno, 1988). In some instances the agronomic recommendations have been used across borders without any modifications despite the variations in tea growth parameters.

One agronomic practice recommended across borders is plucking intervals. The process of harvesting the young tender shoots to make tea beverages is labour intensive and costly (Ellis & Grice, 1981). In India, for example, plucking constitutes up to 70% of the total costs of field operations (Sharma, 1987; Sharma, Harida, & Venkataram, 1981). Similar high costs are being recorded in other tea growing countries. Despite the high costs, the undertaking is indispensable, and if incorrectly practiced it reduces tea yields (Cloughley, 1983; Grice, 1982) and/or quality (Owuor & Othieno, 1996). The process needs to be optimised for realisation of high yields and quality. This paper evaluates the changes in yields and plain tea quality parameters of one clonal tea grown in different major tea growing areas in Kenya, due to plucking intervals.

Previous studies used to formulate plucking policies, especially intervals were conducted at single sites. It has been assumed that

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results from these single sites will be replicated in other tea growing regions within one country or even across borders. In a recent study, Wachira et al. (2002) demonstrated that yield responses of tea genotypes can vary widely within Kenya. The results suggested that the recommended production policies even within one country (Othieno, 1988) could be inaccurate for some tea growing areas. The recommended plucking interval in Kenya varies from 7 to 14 days (Othieno, 1988). Short plucking intervals remove the leaves when the pluckable shoots are still young and are mostly two leaves and a bud (Odhiambo, 1988; Owuor & Odhiambo, 1994), thus reduces "breaking-back" (Mwakha & Anyuka, 1984), a process that reduces yields, but improves quality (Owuor, Ng'etich, & Obanda, 2000). However, many commercial growers harvest all the available leaf to minimise yield losses. This study evaluated the variations in yields and plain tea quality parameters due to geographical area of production and harvesting intervals using one tea genotype under uniform management.

2. Materials and methods

Trials were laid out in five main tea growing regions of Kenya at Karirana (altitude 2260 m amsl, latitude 1° 6'S, longitude 36° 39'E), Timbilil (altitude 2180 m amsl, latitude 0° 22'S, longitude 35° 21'E), Changoi (altitude 1860 m amsl, latitude 0° 29'S, longitude 35° 14'E), Sotik Highlands (altitude 1800 m amsl, latitude 0° 35'S, longitude 35° 5'E) and Kipkebe (altitude 1800 m amsl, latitude 0° 41'S, longitude 35° 5'E). Clone BBK 35 plantations that had been uniformly managed and with known past cultivation histories, were selected from each site. The trials were laid out in a randomised complete block design with three plucking frequencies (7, 14 and 21 days round) replicated three times at each site. Each plot consisted of 60 tea bushes arranged in 6×10 bushes and each effective plot was surrounded by a line of tea bushes that served as a guard row and received 150 kg N per hectare^{-1} year^{-1} as NPKS 25:5:5:5 in November every year from 1997. The plots were uniformly managed in terms of harvesting and fertiliser application and were pruned every four years. Prior to the trials, all the plots were receiving 150 kg N hectare^{-1} year^{-1}. The experimental recording commenced in November 1997. Plucking was done in different plots as per the treatments, i.e. after every 7, 14 and 21 days depending on the plot. Green leaf produced per plot was converted to made tea (mt) per hectare (Othieno, 1988).

In 2007, one kilogram of leaf was plucked from each plot and processed by the miniature CTC method. The leaves were withered for 12–16 h and macerated four times on a miniature CTC machine followed by fermentation for 90 min at 26–28 °C before firing using a miniature tea dryer (TeaCraft). The unsorted black teas were subjected to plain tea quality parameters chemical analysis and sensory evaluations. The total theaflavins were analysed by the Flavognost method (Hilton, 1973), whilst thearubigins, brightness and total colour were determined by the methods of Roberts and Smith (1963). Sensory evaluations were done by two professional tea tasters at tea broking firms in Mombasa, Kenya, and were based on briskness, brightness, colour, thickness and infusion on scale of 0–20 and 0–10 for each item for Taster A and B, respectively.

Table 1
Effects of geographical area of production and plucking intervals on the yields of clone BBK 35 (1998–2002).

Year	Plucking round (days)	Site					Mean plucking round
		Kipkebe	Sotik Highlands	Karirana	Changoi	Timbilil	
1998	7	5394	5681	4371	4468	4801	4943
	14	5167	5110	4589	4793	4926	4917
	21	4853	6297	4354	4484	5405	5079
	Mean site	5138	5696	4438	4582	5044	
	CV (%)			9.36			
	LSD, ($P \leqslant 0.05$)			61-			NS
	Interactions			NS			
1999	7	3840	2828	3511	5053	4334	3913
	14	3487	2828	2881	5558	4080	3747
	21	3335	2399	2765	5078	4628	3641
	Mean site	3554	2652	3053	5230	4347	
	CV (%)			8.17			
	LSD, ($P \leqslant 0.05$)			403			NS
	Interactions			580			
2000	7	1821	5087	2614	5978	2705	3641
	14	2021	4302	2334	6125	2200	3397
	21	1992	4013	1824	7556	2564	3590
	Mean site	1944	4467	2257	6553	2490	
	CV (%)			11.47			
	LSD, ($P \leqslant 0.05$)			532			NS
	Interactions			765			
2001	7	4475	6410	2041	5347	2927	4240
	14	4336	5876	1656	6135	2402	4081
	21	4784	5882	1431	6885	2807	4358
	Mean site	4532	6056	1709	6122	2712	
	CV (%)			9.89			
	LSD, ($P \leqslant 0.05$)			547			NS
	Interactions			787			
2002	7	3682	4677	3975	4450	3438	4044
	14	4032	3829	3020	4900	3081	3773
	21	2928	3529	2587	4739	2402	3237
	Mean site	3547	4012	3194	4696	2974	
	CV (%)			8.66			
	LSD, ($P \leqslant 0.05$)			418			501
	Interactions			601			

Data were analysed using randomised complete block design in a factorial 2 arrangement, with sites as the main treatments and plucking intervals as sub treatments. MSTAC statistical package was used to do the analyses.

3. Results and discussion

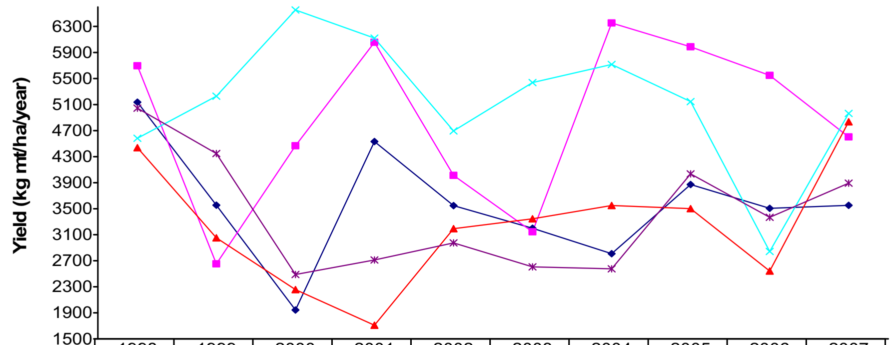
Clone BBK 35 is a popular commercial genotype widely cultivated in east African tea growing areas. The changes in clone BBK 35 yields at different sites from 1998 to 2007 due to plucking intervals of 7, 14 and 21 days are presented in Tables 1 and 2. The order of yield variations changed from year to year (Fig. 1), due to variations in environmental factors which control growth. Similar variations had been recorded in a 16 year study on seedling tea (Othieno, Stephens, & Carr, 1992) and an 18 year study on clonal tea (Owuor, Othieno, Kamau, Wanyoko, & Ng'etich, 2008b). Since there was no irrigation, environmental conditions governing growth including the amounts of rainfall, rainfall distribution and temperatures were not uniform at all sites (Othieno et al., 1992; Stephens, Othieno, & Carr, 1992). Despite the uniform management in terms of plucking and fertiliser applications, large variations were recorded from different sites and from year to year. The results demonstrate that production of tea in 1 year cannot be used to accurately estimate future production even at one site in a genotype under the same management.

One way of achieving high tea production is through growing cultivars with high yield potentials (Owuor et al., 2008b; Wachira et al., 2002). In most tea growing countries tea breeding and clonal selection programmes are usually concentrated at one site within a country and the results are assumed to be the same in other areas. A superior genotype at the selection site is expected to maintain its attributes within all tea growing areas especially when it is grown within one country where variations are considered minimal. The data presented here demonstrates that within Kenya, there are significant ($P \leqslant 0.05$) variations in yields even when one genotype is subjected to similar management in different regions. The yields at one site are not maintained or replicated in the other sites. High production genotypes should be tested in the intended areas of production before extensive plantation. This will identify geographical areas for which genotypes are most suited and help to produce high yields.

The yields varied ($P \leqslant 0.05$) with location of production in all the years of study. This was further reflected in the mean yield data (Table 3, Fig. 2). On average the order of yields was Changoi > Sotik Highlands > Kipkebe > Timbilil = Karirana. Yields at Karirana and Timbilil were lowest and not significantly different from each other. In one genotype grown within a radius of 10 km in Kenya, yield increased with a decrease in altitude (Obaga, Squire, & Lang'at, 1988; Squire, Obaga, & Othieno, 1993). The altitudes from which the yields were recorded in this study were in the order: Karirana > Timbilil > Changoi > Sotik Highlands = Kipkebe. Although there was a general trend of a decrease in yield with altitude, the yield from Changoi did not follow this trend. These results indicate that apart from altitude and temperature, other environmental factors also contribute to the yields. Although all the tea growing areas in Kenya receive adequate rainfall for tea

Table 2
Effects of geographical area of production and plucking intervals on the yields of clone BBK 35 (2003–2007).

Year	Plucking round (days)	Site					Mean plucking round
		Kipkebe	Sotik Highlands	Karirana	Changoi	Timbilil	
2003	7	3003	3222	3977	4793	2990	3597
	14	3161	3226	3372	5508	2263	3506
	21	3433	2985	2686	6011	2566	3536
	Mean site	3199	3144	3345	5438	2607	
	CV (%)			9.68			
	LSD, ($P \leqslant 0.05$)			449			NS
	Interactions			646			
2004	7	2475	6675	4322	5313	2677	4292
	14	2963	6509	3511	6337	2527	4370
	21	2991	5880	2817	5499	2526	3943
	Mean site	2810	6355	3550	5716	2577	
	CV (%)			7.95			
	LSD, ($P \leqslant 0.05$)			437			425
	Interactions			629			
2005	7	3807	6054	5083	4461	4241	4729
	14	4356	6316	3371	5376	4033	4690
	21	3454	5591	2049	5600	3827	4104
	Mean site	3872	5987	3501	5146	4034	
	CV (%)			12.68			
	LSD, ($P \leqslant 0.05$)			748			598
	Interactions			1076			
2006	7	3389	5475	2273	3089	2556	3557
	14	3708	5048	2804	2770	3192	3504
	21	3424	6122	2552	2673	2259	3626
	Mean site	3507	5548	2543	2844	3367	
	CV (%)			8.67			
	LSD, ($P \leqslant 0.05$)			404			NS
	Interactions			582			
2007	7	3460	5011	4759	4616	4646	4298
	14	3778	4527	4875	5150	3532	4372
	21	3421	4275	4870	5129	4499	4439
	Mean site	3553	4604	4835	4965	3892	
	CV (%)			7.22			
	LSD, ($P \leqslant 0.05$)			413			NS
	Interactions			594			



	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Kipkebe	5138	3554	1944	4532	3547	3199	2810	3872	3507	3553
Sotik Highlands	5696	2652	4467	6056	4012	3144	6355	5987	5548	4604
Karirana	4438	3053	2257	1709	3194	3345	3550	3501	2543	4835
Changoi	4582	5230	6553	6122	4696	5438	5716	5146	2844	4965
Timbili	5044	4347	2490	2712	2974	2607	2577	4034	3367	3892
LSD, (P < 0.05)	610	403	532	547	418	449	437	748	404	413

Fig. 1. Effects of geographical area of production on tea yields in different years.

Table 3
Effects of geographical area of production and plucking intervals on ten year (1998–2007) mean yields of clone BBK 35.

Plucking round (days)	Site					Mean plucking round
	Kipkebe	Sotik Highlands	Karirana	Changoi	Timbilil	
7	3534	5112	3693	4757	3532	4126
14	4033	4714	3241	5265	3223	4095
21	3465	4697	2793	5365	3462	3957
Mean site	3678	4841	3229	5129	3405	
CV (%)			7.21			
LSD, ($P \leqslant 0.05$)			383			NS
Interactions			511			

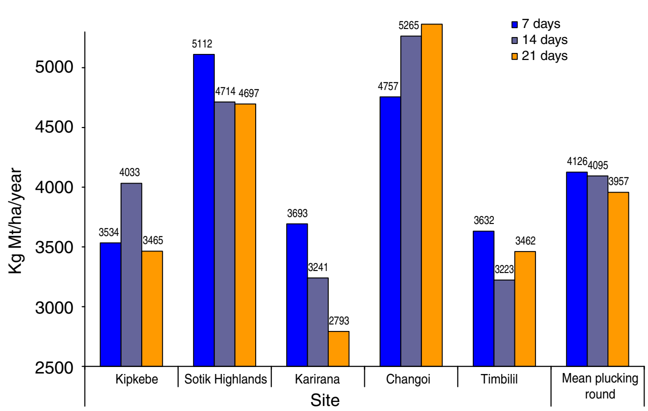


Fig. 2. Effects of area of production and plucking round on mean (1998–2006) yields of clone BB 35.

growing (Othieno, 1988), the amounts and distribution is usually not uniform (Othieno et al., 1992; Stephens et al., 1992). It is recognised that the rainfall distribution may be more critical than the total rainfall *per se* (Othieno, 1988). The rainfall amounts and distribution were not recorded in the present study but it is expected to vary from year to year and with locations as observed in the previous studies (Othieno et al., 1992; Stephens et al., 1992).

Intensity of harvesting is an important parameter in the realisation of high yields in tea production (Mouli, Onsando, & Corley, 2007). One way of ensuring high plucking intensity in tea production is through the use of short plucking intervals. Conflicting reports on yield responses to plucking intervals have been reported. Yields decreased in Malawi (Palmer-Jones, 1977; Tanton, 1979), but increased in Kenya with short plucking intervals (Odhiambo, 1988; Owuor & Odhiambo, 1994). The observed difference in yield response could be partially due to differences in the varieties or geographical area of production at which the studies were conducted. The responses of one genotype to plucking frequencies in the five major tea growing environments in Kenya were assessed over a period of 10 years in this study. The yields due to plucking intervals varied from site to site (Tables 1 and 2, Fig. 3). However, in the ten years of study, significant ($P \leqslant 0.05$) differences due to plucking intervals were observed in only 3 years. Thus, the effect of geographical area of production was more dominant than that of plucking intervals. At every site, there were also year to year variations in the yield responses to plucking intervals. Thus depending on the site and the year of measurement, conflicting results could be obtained (Tables 1 and 2). The conflicting responses observed in the previous studies (Odhiambo, 1988; Owuor & Odhiambo, 1994; Palmer-Jones, 1977; Tanton, 1979) could in part be due to durations of recording since the yields were reported after short periods. However, tea is a perennial crop with a long life span. For such crops, recording of yields after short durations may not produce adequate data to draw any general conclusions from. The mean data for the ten years of experimentation is presented in Table 3 and Fig. 2. For the mean of the five sites, yields declined with long plucking intervals but this was not significant due to the conflicting responses as shown by the significant ($P \leqslant 0.05$) interaction effects between sites and plucking intervals (Table 3). Whereas there was yield increase with long plucking intervals in Changoi, in three sites (Sotik Highlands and Karirana) yields declined with short plucking intervals whilst in Kipkebe the order was 14 days > 7 days > 21 days. At Timbilil, there was also a general decline with short plucking intervals although the 14 days plucking intervals gave lowest yields. In a recent long term (18 years) trial (Owuor et al., in press) at one site in Kenya, the yields of clone S15/10 changed with plucking intervals in the order 7 days > 21 days > 14 days, as was observed in the Timbilil data. These results indicate that the present uniform blanket recommendation of plucking interval throughout Kenya (Othieno, 1988) may in part be subjecting some areas to low production. Optimal plucking rounds for realisation of high yields should be established for different tea growing regions in Kenya.

World tea production has been higher than world tea demand (Anon., 2007), whilst costs of production have continued to rise (Herath & Weersink, 2007). As a result only producers of high qual-

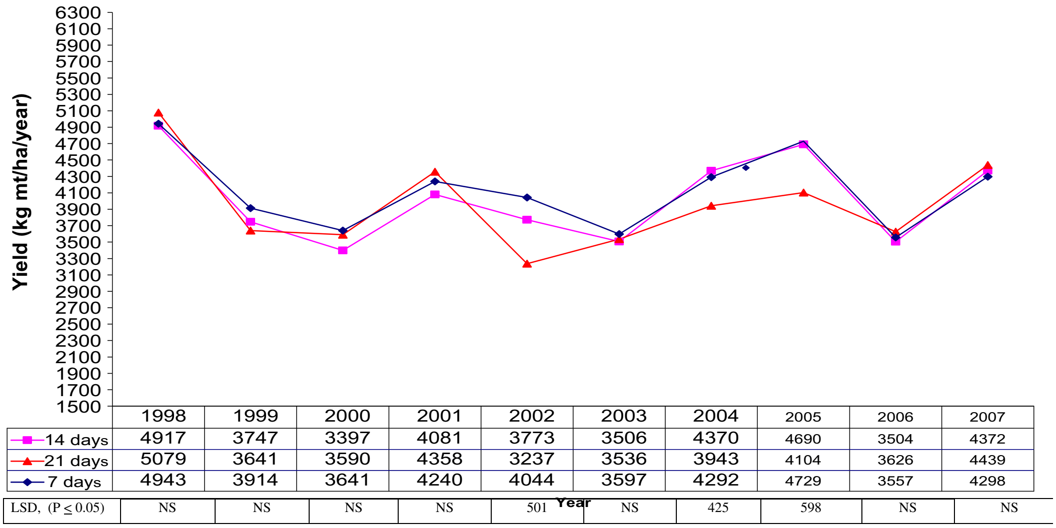


Fig. 3. Changes in yields due to plucking frequency.

ity tea sell at reasonable prices (Anon, 2007). It is necessary to balance benefits of quantity and quality in developing recommendations of agronomic practices. The agronomic practices that ensure high production should also produce black tea of good quality. The African black teas are classified as plain to medium flavoury. Such black teas' sell for their plain black tea quality parameters, i.e. theaflavins, thearubigins and caffeine. Theaflavins contribute to the astringency (briskness) and brightness whilst thearubigins contribute to the colour and thickness (mouth-feel) and caffeine is responsible for the stimulatory effects of black tea. Caffeine levels were not monitored in this study. The effects of the geographical area of production and plucking intervals on the plain black tea quality are presented in Table 4. Except for theaflavin levels, which significantly ($P \leqslant 0.05$) varied with geographical area of production, the other plain tea quality parameters did not significantly change. Thus it is possible to make black teas from BBK 35 with similar thearubigins, brightness and colour within tea growing regions of Kenya. Of the plain black tea quality parameters, the theaflavins have higher significance to quality since there are relationships between the theaflavins levels and quality (Owuor et al., 2006; Wright, Mphangwe, Nyirenda, & Apostolides, 2002). The theaflavins were in the order Changoi > Karirana > Timbilil > Kipkebe > Sotik Highlands. However, the most practical measure of black tea quality in tea trade is the use sensory evaluation technique. There were no significant variations in sensory evaluations (Table 4) due to geographical area of production which is

Table 4
Effects of geographical area of production and plucking intervals on the plain tea quality parameters of clone BBK 35 in 2007.

Parameter	Plucking round	Site					Mean plucking round
		Kipkebe	Sotik Highlands	Karirana	Changoi	Timbilil	
Theaflavin (umol/g)	7	23.31	21.11	24.83	25.62	23.69	23.71
	14	21.81	18.96	24.50	26.38	22.02	22.73
	21	21.04	17.54	21.92	23.75	20.55	20.96
	Mean site	22.06	19.20	23.75	25.25	22.09	
	CV (%)			5.69			
	LSD, ($P \leqslant 0.05$)			4.73			2.01
	Interactions			NS			
Thearubigins (%)	7	16.75	16.67	15.82	16.92	15.82	16.40
	14	18.31	17.91	17.54	16.19	17.43	17.47
	21	18.53	17.92	18.58	17.22	18.64	18.18
	Mean site	17.86	17.50	17.31	16.78	17.30	
	CV (%)			5.58			
	LSD, ($P \leqslant 0.05$)			NS			1.52
	Interactions			NS			
Total colour (Roberts) (%)	7	4.04	4.50	5.21	6.00	5.08	4.97
	14	4.44	4.71	5.52	5.57	5.40	5.13
	21	4.76	5.22	5.53	5.81	5.74	5.41
	Mean site	4.41	4.81	5.42	5.79	5.41	
	CV (%)			5.56			
	LSD, ($P \leqslant 0.05$)			NS			0.45
	Interactions			NS			
Brightness (%)	7	27.64	22.84	29.08	25.49	25.29	26.07
	14	25.51	21.63	27.24	26.40	24.23	25.00
	21	22.94	18.34	24.55	24.48	20.44	22.15
	Mean site	25.36	20.94	26.96	25.46	23.32	
	CV (%)			6.14			
	LSD, ($P \leqslant 0.05$)			NS			2.35
	Interactions			NS			

Table 5
Influence area of production and plucking intervals on sensory evaluation of clonal black tea in 2007.

Taster	Plucking round	Site					Mean plucking round
		Kipkebe	Sotik Highlands	Karirana	Changoi	Timbilil	
ATB	7	73	104	84	71	94	85
	14	62	73	78	69	63	69
	21	50	57	52	53	56	54
	Mean site	62	78	71	64	71	
	CV (%)			13.19			
	LSD, ($P \leqslant 0.05$)			NS			14
	Interactions			NS			
TBEA	7	21	20	21	19	20	20
	14	20	20	20	19	19	20
	21	18	17	18	18	18	18
	Mean site	19	19	20	19	19	
	CV (%)			4.31			
	LSD, ($P \leqslant 0.05$)			NS			1
	Interactions			NS			

similar to the results observed in thearubigins, brightness and total colour.

All plain tea quality parameters (Table 4) and sensory evaluations (Table 5) significantly ($P \leqslant 0.05$) varied due to plucking intervals. Long plucking intervals reduced the total theaflavins, brightness and sensory evaluations but increased black tea thearubigins and total colour levels at all major tea producing areas in Kenya similar to reports in earlier studies using one genotype at a single site (Owuor & Odhiambo, 1994; Owuor, Odhiambo, Robinson, & Taylor, 1990; Owuor, Othieno, Odhiambo, & Ng'etich, 1997; Owuor et al., 2000). The results demonstrate that short plucking intervals ensure production of high quality tea. Thus, despite the conflicting results obtained on yields (Tables 1 and 2), it is important to use short plucking intervals (Othieno, 1988) throughout Kenya to produce high quality plain black tea.

There were no significant interactions between the geographical area of production and plucking intervals in any of the quality parameters including sensory evaluations. This suggests that the pattern of the responses of the plain black tea quality parameters to plucking intervals were the same at all sites. Since plucking was unselective in the present study, the quality of the leaf obtained was dependent on the length of the harvesting intervals (Owuor et al., 2000; Owuor & Odhiambo, 1994). The decline of quality at all sites was therefore attributed to an increased maturity of the harvested leaf with long plucking intervals. However, better quality tea could still be obtained with long plucking intervals if plucking was selective (Owuor et al., 2000). This would lead to a yield reduction at longer plucking intervals than at shorter plucking intervals.

4. Conclusion

This study has demonstrated that although in one genotype the yield response patterns to plucking rounds vary from sites to site, quality declines with long plucking rounds irrespective of tea growing area in Kenya. Also despite using same plucking rounds, the yield of one genotype varied with geographical area of production. It is therefore necessary to evaluate optimal plucking intervals in different geographical areas of production that best balance yields and quality.

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References

Anon. (2007). International Tea Committee. Annual Bulletin of statistics.
Borse, B. B., Rao, L. J. M., Nagalakshmi, S., & Krishnamurthy, N. (2002). Fingerprint of black teas from India: Identification of the region-specific characteristics. *Food Chemistry, 79*, 419–424.
Cloughley, J. B. (1983). Effect of harvesting policy and nitrogen rates on the production of tea in Central Africa. I. Yield and crop distribution. *Experimental Agriculture, 19*, 35–46.
Ellis, R. T., & Grice, W. J. (1981). Fertilizer for 1981. *Tea Research Foundation of Central Africa, Quarterly Newsletter, 61*, 23.
Fernandez, P. L., Fernando, P., Martin, J., & Gonzalez, A. G. (2002). Study of catechin and xanthine tea profiles as geographical tracers. *Journal of Agricultural and Food Chemistry, 50*, 1833–1839.
Grice, W. J. (1982). The effect of plucking round length on yield, shoot size and standard break back and made tea. *Tea Research Foundation of Central Africa, Quarterly Newsletter, 65*, 10–41.
Gulati, A., & Ravichranath, S. D. (1996). Seasonal variations in quality of Kangra tea (*Camellia sinensis* (L.) O. Kuntze) in Himachal Pradesh. *Journal of the Science of Food Agriculture, 71*, 231–236.
Herath, D., & Weersink, A. (2007). Peasants and plantations in the Sri Lanka tea sector: Causes of change in their relative viability. *Australian Journal of Agricultural Resource Economics, 51*, 73–89.
Hilton, P. J. (1973). Tea. In F. D. Snell & L. S. Ettre (Eds.). *Encyclopedia of industrial chemical analysis* (Vol. 18, pp. 453–516). New York, USA: John Wiley.
Li, T., Yu, L. J., Li, M. T., & Li, W. (2007). Comparative studies on the qualities of green teas in Karst and non-Karst areas of Yichang, Hubei Province, PR China. *Food Chemistry, 103*, 71–74.
Moreda-Pineiro, A., Fisher, A., & Hill, S. J. (2003). The classification of tea according to region of origin using pattern recognition techniques and trace metal data. *Journal of Food Composition and Analysis, 16*, 195–211.
Mouli, M. R. C., Onsando, J. M., & Corley, R. H. V. (2007). Intensity of harvesting in tea. *Experimental Agriculture, 43*, 41–50.
Mwakha, E., & Anyuka, J. O. (1984). Effect of breaking-back and fertilizer on tea yields, plucking speed and table height. *Tea, 5*, 6–13.
Obaga, S. O., Squire, G. R., & Lang'at, J. K. (1988). Altitude temperature and growth of tea shoots. *Tea, 9*(1), 28–33.
Odhiambo, H. O. (1988). Nitrogen rates and plucking frequency on tea: The effect of plucking frequency and nitrogenous fertilizer rates on yields and yield components of tea (*Camellia sinensis*) in Kenya. *Tea, 10*, 90–96.
Othieno, C. O. (1988). Summary of recommendations and observations from TRFK. *Tea, 9*, 50–65.
Othieno, C. O., Stephens, W., & Carr, M. K. V. (1992). Yield variability at the Tea Research Foundation of Kenya. *Agriculture and Forestry Meteorology, 61*, 237–252.
Owuor, P. O., Ng'etich, W. K., & Obanda, M. (2000). Quality response of clonal black tea to nitrogen fertilisers, plucking intervals and standards. *Journal of the Science of Food Agriculture, 80*, 439–446.
Owuor, P. O., Obanda, M., Apostolides, Z., Wright, L. P., Nyirenda, H. E., & Mphangwe, N. I. K. (2006). The relationship between the chemical plain black tea quality parameters and black tea colour, brightness and sensory evaluation. *Food Chemistry, 97*, 644–653.
Owuor, P. O., Obanda, M., Nyirenda, H. E., & Mandala, W. L. (2008). Influence of region of production on clonal black tea chemical characteristics. *Food Chemistry, 108*, 271–363.
Owuor, P. O., & Odhiambo, H. O. (1994). Response of some black tea quality parameters to nitrogen fertiliser rates and plucking frequencies. *Journal of the Science of Food and Agriculture, 66*, 555–561.
Owuor, P. O., Odhiambo, H. O., Robinson, J. M., & Taylor, S. J. (1990). Chemical composition and quality of black tea *Camellia sinensis* (L.) variations due to plucking intervals. *Journal of the Science of Food and Agriculture, 52*, 63–69.

Owuor, P. O., & Othieno, C. O. (1996). Optimising fertilizer application rates to different tea cultivars. *Tropical Science, 36*, 211–223.

Owuor, P. O., Othieno, C. O., Kamau, D. M., Wanyoko, J. K., & Ng'etich, W. K. (2008b). Effects of long term fertilizer use on a high yielding tea clone S15/10: Yields. *International Tea Journal, 2*, 19–31.

Owuor, P. O., Othieno, C. O., Odhiambo, H. O., & Ng'etich, W. K. (1997). Effect of fertiliser levels and plucking intervals of clonal tea (*Camellia sinensis* (L.) O. Kuntze). *Tropical Agriculture, (Trinidad), 74*, 184–191.

Palmer-Jones, R. W. (1977). Effect of plucking policies on the yield of tea in Malawi. *Experimental Agriculture, 13*, 43–49.

Peterson, J., Dwyer, J., Jacques, P., Rand, W., Prior, R., & Chui, K. (2004). Tea variety and brewing techniques influence flavonoid content of black tea. *Journal of Food Composition and Analysis, 17*, 397–405.

Roberts, E. A. H., & Smith, R. F. (1963). Phenolic substances of manufactured tea. II, Spectroscopic evaluation of tea liquors. *Journal of the Science of Food Agriculture, 14*, 889–900.

Sharma, V. S. (1987). Harvest in tea. *Planters Chronicle, 82*(8), 26l–266.

Sharma, V. S., Harida, P., & Venkataram, K. S. (1981). Mechanisation of harvesting in tea. *UPASI Tea Science Department, 37*, l06–110.

Shoubo, H. (1989). Meteorology of the tea plant in China. A review. *Agriculture and Forestry Meteorology, 47*, 19–30.

Squire, G. R., Obaga, S. M., & Othieno, C. O. (1993). Altitude, temperature and shoot production of tea in Kenyan highlands. *Experimental Agriculture, 29*, 107–120.

Stephens, W., Othieno, C. O., & Carr, M. K. V. (1992). Climate and weather variability at the Tea Research Foundation of Kenya. *Agriculture and Forestry Meteorology, 61*, 219–235.

Tanton, T. W. (1979). Some factors affecting the yield of tea. *Experimental Agriculture, 15*, 189–191.

Wachira, F. N., Ng'etich, W., Omolo, J., & Mamati, G. (2002). Genotype x environment interactions for tea yields. *Euphtica, 127*, 289–296.

Wickremaratne, M. T. (1981). Genotype-environment interactions in tea *Camellia sinensis* (L.) and their implications in tea breeding and selection. *Journal of Agriculture Science, 28*, 556–580.

Wright, L. P., Mphangwe, N. I. K., Nyirenda, H. E., & Apostolides, Z. (2002). Analysis of the theaflavin composition in black tea (*Camellia sinensis*) for predicting the quality of tea produced in Central and Southern Africa. *Journal of Science and Food Agriculture, 82*, 517–525.