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TECHNICAL NOTE

Changes in quality parameters of commercial black seedling tea due to the time of the year in the Eastern Highlands of Kenya

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Significant ($P \leq 0{\cdot}05$) changes in yields, rainfall and chemical quality parameters (except thearubigins) of black seedling tea with the time of the year were recorded in the Eastern Kenya Highlands. Larger variations were noted in the aroma and yields than in the plain tea quality parameters. However, the variations were less than those recorded in countries further away from the equator. The Group I volatile flavour compounds (VFC) and caffeine levels were inversely correlated ($P \leq 0{\cdot}05$) with each other, while flavour index and sensory evaluation had significant ($P \leq 0{\cdot}01$) correlations with rainfall. Sensory evaluation was also significantly correlated with flavour index ($P \leq 0{\cdot}001$) and inversely with caffeine ($P \leq 0{\cdot}05$) and Group I VFC ($P \leq 0{\cdot}01$). High yields and caffeine levels in black teas were realised in the warmer months.

INTRODUCTION

Unlike countries further away from the equator, the commercial production of black tea from young, tender shoots of *Camellia sinensis* (L.) O. Kuntze in Kenya, where tea farms/gardens are very close to the equator, is continuous throughout the year. In countries further away from the equator, changes in the climatic conditions make it impractical for production to continue throughout the year. Thus, in a country like Malawi, for example, 80% of the crop is produced between December and May (Cloughey, 1983). The large variations in climatic conditions have been observed to cause quality fluctuations in Malawi (Hilton & Palmer-Jones, 1973; Hilton *et al.*, 1973), Sri Lanka (Wickremasinghe, 1974; Feranando & Roberts, 1984) and Argentina (Malec & Vigo, 1988). Despite the more regular growing conditions, fluctuation in tea quality is suspected to occur in Kenya with time of the year. Generally, the depressions in black-tea prices follow peak crop seasons. Such depressions are normally attributed to improper manufacture, as it is claimed that factories cannot cope with the high crop. Attempts have not been made to quantify the contribution of fast growth conditions, which prompt the peak crop, to the quality of the produced black teas. However, in countries where large climatic variations occur within the year, changes in tea quality have been noted to follow tea-growing conditions. In Malawi, for example, it was observed, in a nine-month study, that quality deteriorated during fast growth conditions as measured by theaflavins (TF) (Hilton *et al.*, 1973). A similar observation was also made in Sri Lanka in a three-month study of the volatile flavour compounds (VFC) (Fernando & Roberts, 1984). However, it is not known how the noted changes in the growth pattern would affect the quality of the tea in the Eastern Kenya Highlands, where tea is grown along the equator.

In a recent study, Owuor *et al.* (1991) demonstrated that, despite the apparently regular growing patterns in Kenya, there were some variations in the monthly tea yields and that these were accompanied by changes in the quality of tea under conditions in Kericho in the Western Kenya Highlands, where rainfall is largely influenced by the close proximity of Lake Victoria (the largest lake in Africa). The rainfall in this region tends to be regular and is well distributed throughout the year. Although most of the Kenyan teas are produced west of the Rift Valley, some of the finest teas are produced east of the Rift Valley, especially in the Meru (Nyambei Hills) and Mount Kenya areas. The rainfall in Meru is of the relief type and bimodal with rains from March to May and October to December. In a preliminary note (Owuor, 1990), it was shown that there were some variations in quality parameters of black tea due to the time of the year in the Nyambeni Hills of the Meru District. However, the data were inconclusive, as two months of the year were not covered and the data on the climatic factors affecting growth and quality of tea were not recorded. In addition, attempts were not made to relate the quality fluctuations noted to the yields and/or weather patterns. Data covering the above aspects are reported in the present paper.

MATERIALS AND METHODS

Yields of seedling tea were recorded from field 8 of the Michimukuru Tea Estate, Nyambeni Hills, Meru (1800 above mean sea level and latitude 0°10' N), between September 1989 and August 1990, at a plucking interval of 10–14 days, depending on the availability of crop and to conform with the normal commercial estate practice. The field was divided into three sections (plots), each of 0·82 ha; at every second plucking of each month, tea from each section of the field was manufactured separately. Half a kilogram of PF1-grade black tea was sampled for chemical analysis and sensory evaluation in triplicate as outlined earlier (Owuor *et al.*, 1986*a*, 1991). Each section of the field was used as a plot in analysis of variance. Rainfall and monthly mean maximum and minimum temperature data were also monitored. The monthly variations were recorded as the extent of change from the mean for each parameter (i.e. standard-deviation/mean ×100).

RESULTS AND DISCUSSION

Similar studies, in countries further away from the equator, on black tea quality variations with the time of the year covered only the main production periods of the year (Hilton & Palmer-Jones, 1973; Hilton *et al.*, 1973; Wickremasinghe, 1974; Fernando & Roberts, 1984; Malec & Vigo, 1988). In the present study, data covering a complete year are presented. Since it is impossible to replicate climatic conditions in successive years, data from one year or season are thought to be adequate to demonstrate whether changes do indeed occur in quality parameters of black tea with the time of the year. Again, the previous studies (above) did not cover all of the known black tea quality parameters. Thus, Fernando and Roberts (1984) assessed tea aroma, while workers in Malawi (Hilton & Palmer-Jones, 1973; Hilton *et al.*, 1973) and Argentina (Malec & Vigo, 1988) studied plain tea quality parameters. In the present study, data are presented on both plain tea and aroma quality parameters (Tables 1–3).

There were changes in the chemical quality parameters of black tea and yields (Tables 1–3) with the time of the year in the Eastern Kenya Highlands. Except for thearubigins (TR), significant changes (up to $P \leq 0·001$) were noted in all the chemical quality parameters measured. The extent of the variations in the different parameters noted are presented in Table 1. Fluctuations of 12, 7 and 6% were shown by TF, TR and caffeine, respectively (Table 1) with the time of the year. Such changes were slightly less than those observed for high-yielding clonal tea in the Western Kenya Highlands (Owuor *et al.*, 1991). However, the variations were much less than those observed in countries further away from the equator (Hilton & Palmer-Jones, 1973; Hilton *et al.*, 1973; Cloughley, 1983; Malec & Vigo, 1988). Despite the fluctuation noted, the TF levels noted here and earlier (Owuor *et al.*, 1991) remained higher than those in black tea grown further away from the equator (Hilton & Palmer-Jones, 1973; Hilton *et al.*, 1973; Cloughley, 1983; Malec & Vigo, 1988) throughout the year. Measured by TF, Kenyan black teas would be of higher quality than those grown further away from the equator. In a recent study, McDowell *et al.* (1990) demonstrated the presence of flavonol glycosides in the fractions used to determine the TR spectrophotometrically, as was done in the present study, resulting in an overestimation of these components; therefore, their values are slightly overstated. However, the method of analysis used by McDowell *et al.* (1990) is not used routinely, especially in the developing countries where tea is grown, since it is expensive and slow.

Table 1. Annual mean and coefficient of variation (CV) of monthly rainfall, temperatures, yields and black tea quality parameters in the Eastern Kenya Highlands

Parameter	Mean	CV (%)
Rainfall (mm/month)	213·7	115·16
Mean Max. temperature (°C)	23·4	2·99
Mean Min. temperature (°C)	11·8	5·08
Yields (kg made tea/ha per month)	315	29·52
TF (μmol/g)	22·77	11·55
TR (%)	13·61	7·42
Caffeine (%)	3·32	5·72
Total VFC[a]	5·92	30·23
Group I VFC[a]	3·07	41·37
Group II VFC[a]	2·84	22·89
Flavour index[a]	1·03	34·95
Sensory evaluation[b]	159	13·21

[a] See footnotes to Table 3.

[b] Sensory evaluation was based on brightness, briskness, colour, thickness, flavour and quality on an arbitrary scale of 0–20 for each component.

Table 2. Changes in rainfall, yields and black tea quality parameters with the time of the year in the Eastern Kenya Highlands

Parameter	1989				1990								CV (%)	LSD[a]		
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.		$P \leq 0·05$	$P \leq 0·01$	$P \leq 0·001$
Rainfall (mm)	70·8	668·7	493·5	95	38·3	75·9	368·7	593·4	115·0	20·6	8·3	16·0	—	—	—	—
Yields (kg made tea/ha)	313	411	393	235	444	331	330	276	438	224	179	200	8·35	85	98	111
TF (μmol/g)	26·51	24·64	25·25	21·15	22·93	25·32	21·75	17·64	22·09	22·85	24·09	19·03	6·74	2·60	3·53	4·75
TR (%)	13·93	13·33	16·30	14·21	12·94	13·97	13·39	13·87	12·32	13·06	13·08	12·86	16·27	NS	NS	NS
Caffeine (%)	3·22	3·43	3·62	3·25	3·43	3·41	3·45	3·48	3·42	3·02	2·98	3·18	2·65	0·15	0·20	0·27
Total VFC[b]	8·69	9·52	5·34	4·56	4·35	5·47	5·69	6·35	7·69	4·36	4·38	4·61	4·51	0·45	0·61	0·83
Group I VFC[b]	4·70	5·60	2·91	2·70	1·86	2·64	2·96	4·07	4·11	1·86	1·75	1·72	4·05	0·21	0·29	0·39
Group II VFC[b]	3·99	3·86	2·43	1·85	2·49	2·83	2·71	2·29	3·58	2·51	2·63	2·89	6·01	0·29	0·39	0·52
Flavour index[b]	0·85	0·68	0·83	0·69	1·34	1·07	0·92	0·56	0·87	1·35	1·49	1·68	5·33	0·09	0·13	0·17
Sensory evaluation[c]	157	135	144	137	185	160	156	132	154	167	189	190	5·11	15	20	27

[a] Least significance difference.

[b] See footnotes to Table 3.

[c] Sensory evaluation as Table 1.

Therefore, most studies continue to use the spectrophotometric method (Hilton & Palmer-Jones, 1973; Hilton *et al.*, 1973; Cloughley, 1983; Malec & Vigo, 1988; Owuor *et al.*, 1991). The present data, and that of an earlier report (Owuor *et al.*, 1991), demonstrate that, in terms of plain tea quality parameters, the Kenyan black teas undergo less fluctuation with the time of the year, provided that correct agronomic and manufacturing practices are observed, than tea produced further away from the equator.

Changes in the individual VFC with the time of the year are presented in Table 3. The VFC composition showed the largest variation with the time of the year (Table 1). Indeed, the total VFC, the Group I VFC (which impart the deleterious aroma to black tea), the Group II VFC (responsible for the sweet, flowery aroma) and the flavour index all significantly changed with the time of the year (Table 2). The fluctuations in these parameters with the time of the year were higher than those noted in the plain tea quality parameters (Table 1). Therefore, the quality changes in black tea, under Kenyan conditions, are noted here and earlier (Owuor *et al.*, 1991) to be mainly attributable to the aroma of black tea. Fernando and Roberts (1984) had earlier observed some changes in VFC for three months in Sri Lanka. However, the study was conducted for a very short period and the extent of variation was not quantified. Changes were also observed in the tasters' evaluation of the black tea with the time of the year (Tables 1 and 2). Therefore, the data presented in the present paper have confirmed that, even in Kenya, where tea is grown very close to the equator and production continues throughout the year, fluctuations in quality parameters exist.

Yields varied ($P \leq 0·001$) with the time of the year (Table 2) by up to 30% (Table 1). It is noted that, although tea production continues throughout the year in Kenya, the crop distribution is not uniform. However, the yield variations were less than those observed in high-yielding clonal tea in the Western Kenya Highlands (Owuor *et al.*, 1991) and were also far less than those observed in countries further away from the equator (Cloughley, 1983).

The changes in monthly mean maximum and mean minimum temperatures were minimal (Table 1), and this made it impractical to clearly separate the time of the year into distinct seasons based on temperatures. However, the yields were significantly correlated with temperature (Table 4). Rainfall distribution showed large monthly variations (Table 1). The pattern could easily be separated into wet seasons, October–November and March–April, and relatively dry seasons between the next two wet seasons. An attempt was made to determine the interrelationship between yields, rainfall, monthly temperatures and different black tea quality parameters, as the time of the year changed, using a linear regression analysis. The correlation coefficients of the analyses are presented in Table 4. Rainfall significantly correlated with caffeine ($P \leq 0·01$), Group I VFC ($P \leq 0·05$), flavour index ($P \leq 0·01$) and sensory evaluation ($P \leq 0·01$). Thus, high rainfall reduced black tea quality parameters by increasing the sum of Group I VFC while reducing flavour index and sensory evaluation. Therefore, rainfall is an important factor affecting the quality of black tea in the Eastern Kenya Highlands. Temperatures were significantly correlated with yields ($P \leq 0·05$) and caffeine levels ($P \leq 0·01$). Therefore, the low temperatures are one of the factors that limit yields in the Eastern Kenya Highlands. Warmer conditions led to higher caffeine levels (Table 4). However, the monthly mean temperatures were not significantly correlated with the other quality parameters of black tea. Yields were also significantly correlated with caffeine levels. Therefore, fast growth conditions were accompanied by higher rates of caffeine biosynthesis.

Table 3. Changes in the major VFC compositions due to the time of the year[a]

	1989				1990							
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
2-Methylbutanal	0·05	0·05	0·02	0·03	0·01	0·03	0·04	0·05	0·04	0·02	0·01	0·01
Pentanal	0·08	0·07	0·04	0·04	0·02	0·04	0·07	0·14	0·16	0·03	0·03	0·02
Hexanal	0·51	0·59	0·28	0·30	0·16	0·23	0·32	0·40	0·31	0·18	0·18	0·13
1-Penten-3-ol	0·21	0·28	0·13	0·12	0·08	0·14	0·15	0·17	0·24	0·10	0·10	0·08
n-Heptenal	0·04	0·04	0·03	0·02	0·02	0·02	0·03	0·04	0·04	0·03	0·03	0·02
Z-3-Hexenal	0·13	0·16	0·09	0·09	0·14	0·08	0·11	0·13	0·10	0·05	0·04	0·04
E-2-Hexenal	2·81	3·53	1·90	1·75	1·06	1·65	1·78	2·60	2·62	1·14	1·00	1·11
n-Pentanol	0·03	0·03	0·03	0·02	0·01	0·01	0·01	0·02	0·01	0·01	0·01	0·01
Z-2-Penten-1-ol	0·24	0·27	0·14	0·11	0·10	0·16	0·15	0·17	0·23	0·10	0·09	0·09
n-Hexanol	0·04	0·04	0·03	0·02	0·02	0·02	0·02	0·04	0·03	0·02	0·02	0·02
Z-3-Hexenol	0·27	0·26	0·10	0·08	0·10	0·12	0·13	0·14	0·17	0·12	0·09	0·09
n-Nonanal	0·05	0·07	0·03	0·03	0·05	0·03	0·04	0·05	0·05	0·02	0·04	0·03
E-2-Hexenol	0·07	0·07	0·05	0·03	0·04	0·04	0·05	0·06	0·05	0·02	0·04	0·03
E,*Z*-2,4-Heptadienal	0·02	0·08	0·03	0·03	0·03	0·03	0·03	0·03	0·03	0·02	0·03	0·02
E,*E*-2,4-Heptadienal	0·10	0·12	0·03	0·03	0·02	0·04	0·03	0·03	0·03	0·01	0·04	0·02
Sum of Group I VFC	4·65	5·66	2·93	2·70	1·86	2·64	2·96	4·07	4·11	1·87	1·75	1·72
Linalool oxide (*cis*-furanoid)	0·16	0·17	0·09	0·06	0·08	0·08	0·08	0·09	0·14	0·08	0·09	0·11
Linalool oxide (*trans*-furanoid)	0·45	0·53	0·33	0·31	0·23	0·27	0·27	0·28	0·52	0·30	0·29	0·39
Benzaldehyde	0·15	0·14	0·06	0·05	0·04	0·05	0·05	0·05	0·05	0·01	0·03	0·03
Linalool	1·40	1·22	0·76	0·55	0·53	0·57	0·70	0·81	1·27	1·03	0·91	1·08
α-Cedrene	0·05	0·10	0·01	0·01	0·04	0·03	0·02	0·02	0·01	0·01	0·03	0·03
β-Cedrene	0·01	0·02	0·01	0·01	0·02	0·01	0·01	0·01	0·01	0·01	0·01	0·01
3,7-Dimethyl-1,5-7-octatrien-3-ol	0·02	0·05	0·01	0·02	0·03	0·01	0·01	0·01	0·01	0·01	0·02	0·05
a-Cyclocitral	0·03	0·03	0·02	0·02	0·02	0·02	0·02	0·02	0·03	0·01	0·02	0·03
Phenyl-acetaldehyde	0·36	0·52	0·49	0·44	0·94	1·05	1·03	0·50	0·60	0·16	0·25	0·23
Neral	0·07	0·11	0·01	0·01	0·01	0·01	0·01	0·01	0·03	0·02	0·02	0·02
α-Terpineol	0·06	0·05	0·04	0·03	0·07	0·03	0·04	0·04	0·06	0·05	0·06	0·05
Linalool oxide (*cis*-pyranoid)	0·01	0·01	0·01	0·02	0·02	0·01	0·02	0·02	0·02	0·01	0·01	0·01
Methylsalicylate	0·34	0·32	0·19	0·09	0·14	0·28	0·16	0·15	0·26	0·23	0·15	0·25
Nerol	0·05	0·04	0·03	0·02	0·02	0·02	0·02	0·02	0·03	0·02	0·03	0·03
Geraniol	0·48	0·19	0·15	0·10	0·10	0·25	0·12	0·09	0·24	0·29	0·42	0·26
Benzyl alcohol	0·02	0·05	0·01	0·02	0·02	0·01	0·01	0·01	0·01	0·01	0·01	0·02
2-Phenylethanol	0·05	0·03	0·02	0·01	0·01	0·01	0·01	0·01	0·03	0·01	0·05	0·07
β-ionone	0·07	0·07	0·06	0·06	0·06	0·03	0·03	0·04	0·02	0·04	0·04	0·05
5,6-Epoxy-*β*-ionone	0·05	0·04	0·05	0·04	0·03	0·02	0·02	0·02	0·03	0·03	0·03	0·04
Nerolidol	0·05	0·05	0·03	0·02	0·02	0·02	0·02	0·02	0·04	0·03	0·04	0·05
Cedrol	0·02	0·02	0·01	0·01	0·01	0·01	0·01	0·01	0·05	0·03	0·01	0·01
Bovolide	0·01	0·01	0·01	0·01	0·01	0·01	0·01	0·01	0·08	0·01	0·02	0·01
Methylpalmitate	trace	0·03	0·01	0·01	0·01	0·01	0·01	0·01	trace	0·02	0·01	0·01
6,10,14-Trimethyl-pentadecan-2-one	0·03	0·05	0·02	0·02	0·02	0·01	0·02	0·02	0·04	0·05	0·01	0·01
E-Geranic acid	0·05	0·01	0·01	0·01	0·02	0·01	0·01	0·01	trace	0·04	0·06	0·03
Sum of Group II VFC	3·99	3·86	2·44	1·95	2·50	2·83	2·71	2·29	3·58	2·51	2·62	2·88
Flavour index[b]	0·86	0·68	0·83	0·72	1·34	1·07	0·92	0·56	0·87	1·34	1·50	1·67

[a] The ratio of the gas-chromatographic area of the compound to that of the internal standard.

[b] $\frac{\text{Sum of Group II VFC}}{\text{Sum of Group I VFC}}$.

Table 4. Correlation coefficients between the different parameters measured

	Yields	Max. temperature	Min. temperature	TF	TR	Caffeine	Total VFC	Group I VFC	Group II VFC	Flavour index	Sensory evaluation
Max. temperature	0·62[a]										
Min. temperature	0·29	0·37									
TF	0·33	−0·32	−0·22								
TR	0·33	0·04	0·28	0·31							
Caffeine	0·77[b]	0·78[b]	0·61[a]	0·01	0·46						
Total VFC	0·49	0·05	0·29	0·31	−0·05	0·32					
Group I VFC	0·48	0·17	0·37	0·20	0·08	0·43	0·96[c]				
Group II VFC	0·39	−0·20	0·06	0·46	−0·30	0·03	0·85[c]	0·67[a]			
Flavour index	−0·41	−0·44	−0·38	−0·03	−0·43	−0·61[a]	−0·60[a]	−0·78[b]	0·10		
Sensory evaluation	−0·30	−0·43	−0·32	0·04	−0·47	−0·56[a]	−0·53	−0·72[b]	−0·03	0·96[c]	
Rainfall	0·37	0·39	0·66[a]	−0·11	0·09	0·67[a]	0·50	0·64[a]	0·09	−0·70[b]	−0·74

[a–c] Significant at $P \le$ 0·05, 0·01 and 0·001, respectively.

Although sensory evaluation has always been criticised as being subjective and influenced by many factors outside tea quality, it still remains the fastest and the most practical method of quality control and assessment in the production and trade of black tea. The relationships between the sensory evaluation and different black tea quality parameters, as the time of the year changed, are presented in Table 4. Only caffeine, the sum of Group I VFC and the flavour index were significantly correlated ($P \le$ 0·05, 0·01 and 0·001, respectively) with tasters' evaluation. High levels of caffeine and Group I VFC reduced sensory evaluation, while black teas with a superior flavour index had a high sensory evaluation. In the study, low caffeine levels, low sum of Group I VFC and high flavour index were noted as the critical chemical parameters for high quality in black tea from the Eastern Highlands of Kenya.

The observation that quality variations in the Eastern Highlands of Kenya were mainly due to VFC and the significant correlation between sensory evaluation and the flavour index, explain in part the inconsistent results concerning TF as a quality indicator for Kenyan black teas (Owuor *et al.*, 1986*a*). A significant relationship has been demonstrated (Owuor *et al.*, 1988) between the flavour index and sensory evaluation. In the present study the relationship between sensory evaluation and TF was insignificant. Thus, for black teas of the Eastern Highlands of Kenya, VFC is a more reliable quality indicator than TF.

Among the chemical quality parameters, no significant relationship was noted between TF or TR and any other parameter. Therefore, the changes in the precursors of these components were not significantly changed by the prevailing weather factors in the Eastern Kenya Highlands. However, caffeine was inversely correlated ($P \le$ 0·05) with the flavour index. Environmental conditions suitable for high caffeine productions seemed to depress the flavour index. Total VFC were significantly correlated ($P \le$ 0·001) with both Group I and Group II VFC and were inversely correlated ($P \le$ 0·05) with the flavour index. Group I VFC and Group II VFC were linearly correlated ($P \le$ 0·01). Increase in total VFC is due to the increases in both Group I and Group II VFC. However, large amounts of VFC depressed quality as assessed by the flavour index. Group I VFC and the flavour index were inversely correlated ($P \le$ 0·001) as expected (Owour *et al.*, 1986*b*, 1988, 1991).

The low variations in the levels of quality parameters noted in black tea for the Eastern Kenya Highlands, compared to those countries further away from the equator (Hilton & Palmer-Jones, 1973; Hilton *et al.*, 1973; Wickremasinghe, 1974; Cloughley *et al.*, 1982; Cloughley, 1983; Fernando & Roberts, 1984; Malec & Vigo, 1988), are mainly attributable to the minimal temperature fluctuations noted here. The Kenyan black teas are shown here and in an earlier report (Owuor *et al.*, 1991) to undergo less quality fluctuation with the time of the year than black teas produced further away from the equator (Hilton & Palmer-Jones, 1973; Hilton *et al.*, 1973; Cloughley, 1983; Fernando and Roberts, 1984; Malec & Vigo, 1988). Therefore the Kenyan black teas are likely to be of a more consistent quality, provided correct agronomic and manufacturing practices are observed throughout the year.

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