The relationship between some chemical parameters and sensory evaluations for plain black tea (*Camellia sinensis*) produced in Kenya and comparison with similar teas from Malawi and South Africa

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Abstract

Reliable and accurately measurable chemical parameters that can be used to estimate black tea quality are desirable in trade, research and breeding programmes. Using plain Kenyan black tea from 11 cultivars, which gave some significant differences in their plain black tea quality parameters, the individual theaflavins composition, total theaflavins, thearubigins, theaflavin digallate equivalent, total colour and brightness were determined. The parameters were regressed against sensory evaluation scores of two tasters A and B. The theaflavin digallate equivalent (TDE) showed the strongest relationship ($r = 0.71$ ($P \leqslant 0.01$) and $r = 0.80$ ($P \leqslant 0.001$)) for A and B′, respectively. The simple (non gallated) theaflavin and thearubigins did not show significant relationships with sensory evaluation. Of the liquor characteristics, there were significant relationships between liquor brightness and sensory evaluation by A and B ($r = 0.58$ ($P \leqslant 0.06$) and $r = 0.59$ ($P \leqslant 0.05$)), respectively. In consequence, TDE and brightness can be used in tea breeding programmes as quality indicators or to estimate plain black tea quality potential in the tea trade. Optimising their levels can also help to produce good quality Kenyan black teas during processing. Comparison of these results with work published earlier indicates that, of the individual theaflavins, theaflavin-3,3′-digallate correlates best with tea taster scores for the 11 Kenyan cultivars, whereas the simple theaflavin correlates best with tea tasters' scores for 40 Malawian cultivars. However, the derived parameter, TDE correlates very well with tea tasters' scores for all of the above cultivars.
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1. Introduction

Tea beverages, processed from the young tender shoots of *Camellia sinensis* (L.) O. Kuntze are widely consumed in the world. Black tea dominates the tea beverages. Kenya is the fourth largest tea producer after China, India and Sri Lanka, accounting for about
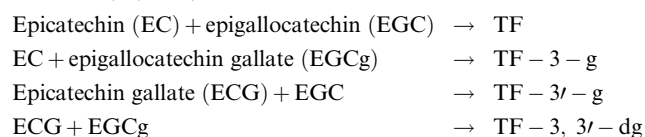
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8% of the total world tea production in 2000 (Anon, 2001), and produces mainly black teas. In 2000, Kenya was the third largest tea exporter after Sri Lanka and China, accounting for 16% of total world tea exports. Tea plays an important role in the country's economy, being the leading foreign exchange earner and a key industry for employment generation. It has similar role in many developing countries like Malawi. Most of the Kenyan black teas are classified as plain to medium plain in the tea trade (Owuor, 1996). Such teas are usually valued for their content of theaflavins and thearubigins (Biswas & Biswas, 1971; Biswas, Biswas, & Sarkar, 1971, 1973) responsible for colour, brightness and strength. Significant relationship had been demonstrated between total theaflavins and sensory evaluation or tea prices of Central African black teas (Hilton & Ellis, 1972; Hilton, Palmer-Jones, & Ellis, 1973). Although the relationships were positive for Kenyan black teas, the regressions were not significant (Owuor, Reeves, & Wanyoko, 1986). Consequently, the total theaflavins were not considered the critical quality parameters for Kenya teas (Owuor, Othieno, & Reeves, 1987). This necessitated further research for reliable Kenyan plain black tea quality parameters.

The theaflavins composition of black tea is dominated by four theaflavins: simple theaflavin (TF), theaflavin-3-gallate (TF-3-g), theaflavin-3′-gallate (TF-3′-g) and theaflavin-3.3′-digallate (TF-3,3′-dg) (Fig. 1), although there are also other minor theaflavins (Davies et al., 1992). The various theaflavins are produced by oxidative dimerisation of a simple (dihydroxy) catechin and a gallo (trihydroxy) catechin during the fermentation phase of black tea manufacture, catalysed by polyphenol oxidase (*O*-diphenol: O_2 oxido reductase, EC 1.10.33.1) (PPO) as follows:

Epicatechin (EC) + epigallocatechin (EGC) $\rightarrow$ TF
EC + epigallocatechin gallate (EGCg) $\rightarrow$ TF − 3 − g
Epicatechin gallate (ECG) + EGC $\rightarrow$ TF − 3′ − g
ECG + EGCg $\rightarrow$ TF − 3, 3′ − dg

The structures of the individual flavan-3-ols (catechins) are presented in Fig. 2.

The individual theaflavins have different astringencies (Sanderson, Ranadive, Eisenberg, & Coggon, 1976) and therefore do not contribute to quality, including taste of tea, in proportion to their micromolar amounts. TF-3,3′-dg is 6.4 times while TF-3-g and TF-3′-g are 2.22 times as astringent than TF (Sanderson et al., 1976). A normalising equation to correct for the differential contribution to taste and black tea quality was developed (Thanaraj & Seshadri, 1990) and later improved (Owuor & McDowell, 1994) for the estimation of the theaflavin contribution to quality. The improved equation was
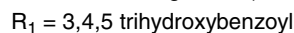
Theaflavin digallate equivalent (TDE) = TF/6.4 + (TF-3-g + TF-3′-g) × 2.22/6.4 + TF-3, 3′-dg.
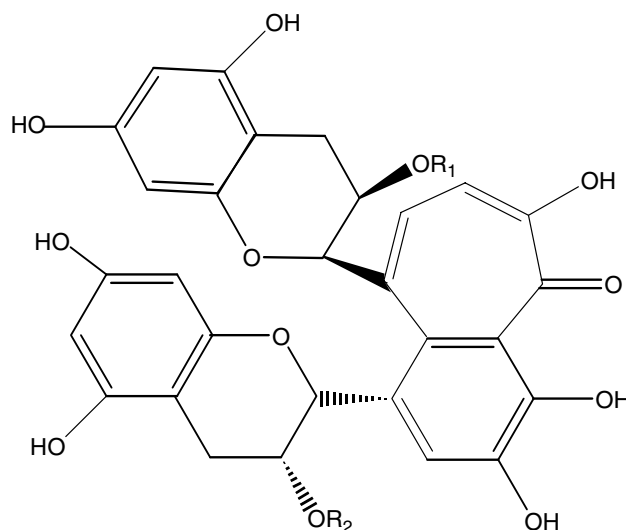
I   Simple theaflavin (TF)
      $R_1 = R_2 = H$

II   Theaflavin - 3 - gallate (TF - 3 - g)
      R_1 = 3,4,5 trihydroxybenzoyl
      R_2 = H

III   Theaflavin - 3' - gallate (TF - 3' - g)
      R_1 = H
      R_2 = 3,4,5 trihydroxybenzoyl

IV   Theaflavin - 3, 3' -digallate (TF - 3, 3' -dg)
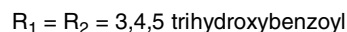 $R_1 = R_2$ = 3,4,5 trihydroxybenzoyl

Fig. 1. The Major theaflavins in black teas.

In a fermentation trial using clone 6/8 black tea, the improved normalising factor (Owuor & McDowell, 1994), TDE values regressed linearly and significantly with sensory evaluation and could thus be used to estimate the optimum fermentation duration in black tea processing. Although contribution of thearubigins as well as that of theaflavins to quality is acknowledged (Wood & Roberts, 1964), the relationship between thearubigin levels and quality remains obscure. The present study seeks to establish whether a relationship exists between the total theaflavins, individual theaflavins, TDE, thearubigins and liquor colour, brightness or sensory evaluation of different black teas.

The world tea production has continued to rise at a rate higher than the increase in consumption, thus causing price reductions over the last two decades (Anon, 2001). The stagnation and/or decline in price is occurring against a background of increasing cost of
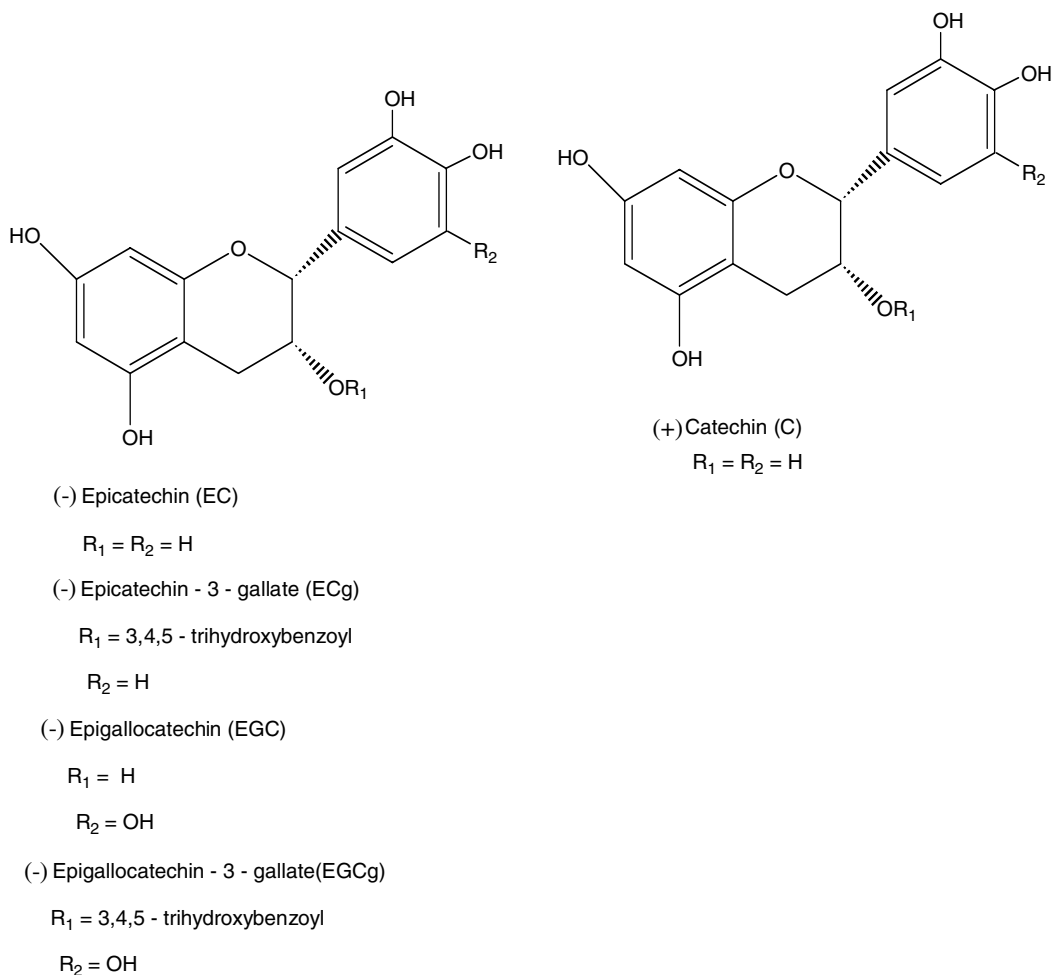
Fig. 2. The Major flavan-3-ols in fresh tea leaves.

production. This implies that only producers of high quality black teas are likely to survive in the global market. In countries where it is still attractive to expand tea production or to uproot old teas and replant with new cultivars, it is important that plants with high quality potential are used to ensure future production of high quality black teas. However, reliable selection criteria are not fully established, although earlier attempts to establish rapid reliable selection criteria, which would enable rapid screening of a large number of genotypes in green leaf to accurately, and efficiently predict their black tea quality potential have produced very promising results (Mphangwe & Nyirenda, 1997; Wright, Mphangwe, Nyirenda, & Apostolides, 2002). This study was done to establish the black tea chemical parameters that can be associated with the liquor characteristics of colour, brightness and sensory evaluations. The establishment of a quantifiable link between black tea chemical parameters and liquor characteristics would allow selection criteria to be set for tea breeding programmes to lead to future production of high quality teas. Similarly, establishment of appropriate quantifiable black

tea parameters would also allow these parameters to be enhanced by changing agronomic and/or processing technologies.

2. Experimental

2.1. Leaf

Leaf was obtained from 11 cultivars in Clonal Field Trials planted at the Tea Research Foundation of Kenya, Timbilil Estate, 2180 m a.m.s.l., latitude 0° 22′S and longitude 35° 21′E. Cultivars were selected which had shown good yields, but had either shown wide variation in the ratio of gallo to simple catechins in their leaves (Magoma, Wachira, Obanda, Imbuga, & Agong, 2000) or wide variations in the individual theaflavin distribution in their black teas (Owuor & Obanda, 1997). Except for cultivars 301/6 and 378/1 used in the study, all cultivars had been released to the industry and are being exploited commercially. Cultivar 301/6 is a *Camellia sinensis* var. *assamica* ssp. *lasiocalyx* under test, while

cultivar 378/1 is a *Camellia sinensis* var. *assamica* polyploid (triploid) plant. It was hoped the cultivars would have a wide genetic variation, such that criteria developed would be useful irrespective of the genetic base of the plants being evaluated or planted. The plants were grown under uniform agronomic practices, receiving fertilizer at 150 kg N ha^{-1} year^{-1} in one dose as NPKS 25:5:5:5. Plucking was done regularly at 10–14 day intervals, depending on leaf availability. One kilogram of leaf, comprising mostly of two leaves and a bud, was plucked from each cultivar. The harvesting and manufacture were done in four replicates.

In each manufacture, leaf was withered for 14–18 h to achieve 70% physical wither. The leaf was CTC miniature macerated, followed by fermentation for 90 min and termination in a bench-top fluid-bed dryer (Teacraft, UK). The unsorted black teas were subjected to chemical analyses and sensory evaluation as explained below.

2.2. Reagents

Isobutyl methyl ketone (IBMK), Flavognost reagent (diphenyl boric acid 2-amino ethyl ester) and HPLC grade acetonitrile were purchased from Aldrich Chemicals. The rest of the solvents and reagents were of analytical grade while the water was double distilled.

2.3. Sensory evaluation

Experienced professional tea tasters at two tea broking firms in Mombasa evaluated the black teas. The tasters have expert knowledge of black teas, which they auction regularly.

2.4. Chemical analysis

Total theaflavins were determined by the Flavognost method (Hilton, 1973), while the individual theaflavin ratios were determined by HPLC (Bailey, McDowell, & Nursten, 1990; McDowell, Feakes, & Gay, 1991; Steinhaus & Engelhardt, 1989). Liquors were prepared by adding 4 g of black tea to 195 ml deionised water that had just reached boiling and shaking was done for 10 min in a 475 ml capacity thermos flask. Clean liquor was obtained by filtration through cotton wool. The hot liquor was cooled to room temperature by placing the flask containing the liquor under a cold water tap (1–3 min). The liquor was diluted (1:1) with water prior to HPLC analysis. The liquor was analysed on a Cecil Series 1000 HPLC with a 20 μl sample loop and a Hypersil 5 μ ODS column (25 cm × 4.6 mm). The UV monitor was set at 365 nm and results were recorded and analysed using a JCL 6000 Cecil data system. Solvent A was 1% aqueous acetic acid and Solvent B was acetonitrile. A linear gradient from 8% to 31% Solvent B over 60 min with a flow rate of 1.5 ml per minute was used (Bailey et al., 1990; McDowell et al., 1991). The theaflavin ratios calculated from the HPLC data and the Flavognost (total) theaflavins data were used to calculate the amounts of the individual theaflavins, since the molar absorption coefficients of the four theaflavins are similar at 365 nm (Steinhaus & Engelhardt, 1989).

The black tea thearubigins, liquor colour and brightness were determined as described by Roberts and Smith (1963).

2.5. Analysis of variance and regressions

The results were subjected to analysis of variance using MSTAT statistical package. The means were used to do linear regressions between individual theaflavins, total theaflavins, theaflavin digallate equivalents, thearubigins, total colour and brightness with total theaflavins, thearubigins, total colour, brightness and sensory evaluations.

3. Results and discussion

Although most of the cultivars used here had already been released to the industry as they had produced acceptable yields during clonal selection process, they exhibited significantly ($P \leqslant 0.05$) different plain black tea quality parameters (Table 1). Whereas most of the cultivars had also been assessed for quality by sensory evaluation, yield was the dominant factor in the decision for their release (Mamati, 2001). Since the cultivars had large genetic differences (Magoma et al., 2000), significant quality differences were expected. Within the set, there were high quality cultivars like cultivar 6/8, used as a quality standard (Mamati, 2001). Indeed even through sensory evaluations, the cultivars demonstrated significant ($P \leqslant 0.05$) differences (Table 1). The significant differences observed in the plain black tea quality parameters monitored and in the sensory evaluations indicate that the set provides a reasonable basis for the evaluation of possible relationship between the chemical parameters and liquor characteristics and/or sensory evaluations.

The quantification of the individual theaflavins in the different tea cultivars is presented in (Table 2). As expected from the large variations in the gallo to simple catechins (trihydroxy to dihydroxy flavan-3-ols) ratios in their green leaf (Magoma et al., 2000), the amounts and distributions of individual theaflavins varied widely between the different cultivars. There were significant ($P \leqslant 0.05$) differences in the levels of the individual theaflavins in the different cultivars, in keeping with the cultivars used in this study differing in genetic potential to make individual theaflavins. Recently

Table 1
Assessment of black tea quality parameters of different cultivars

Cultivar	Total theaflavins (Flavognost) (μmoles g^{-1})	Thearubigins (%)	Total colour (%)	Brightness (%)	Taster A′	Taster B′
6/8	26.38	18.62	5.43	31.29	51	20
S15/10	19.23	15.63	4.21	27.58	33	15
Ejulu	18.00	18.40	5.32	21.65	50	20
31/11	22.22	15.19	5.02	29.01	59	21
301/6	14.75	19.60	4.53	15.97	8	13
303/35	21.44	17.23	4.36	30.54	32	17
303/216	19.95	15.21	4.61	29.71	46	18
347/314	25.35	18.06	5.49	29.93	44	20
378/1	24.87	17.22	5.57	31.20	35	20
F7/346	22.60	16.68	4.92	29.16	41	21
PMC 61	22.66	16.03	4.70	28.44	38	19
C.V. (%)[a]	13.03	8.16	13.31	15.09	33.54	8.16
LSD ($P \leqslant 0.05$)[a]	4.06	2.01	0.95	6.03	19	2

[a] C.V., coefficient of variations; LSD, least significant difference.

Table 2
Assessment of individual theaflavins (μmol/g) levels of black tea from different cultivars

Cultivar	TF	TF-3-g	TF-3′-g	TF-3,3′-dg	TDE
6/8	12.47	6.86	4.16	2.64	8.42
S15/10	7.58	5.20	3.19	3.33	7.42
Ejulu	4.00	5.14	2.56	6.31	10.03
31/11	4.06	6.47	3.81	7.88	12.08
301/6	7.71	4.58	1.25	1.20	4.44
303/35	9.36	5.43	3.88	3.03	7.47
303/216	10.16	4.98	2.95	1.87	6.21
347/314	11.95	6.49	3.90	3.00	8.48
378/1	7.82	6.91	4.70	5.44	10.69
F7/346	8.94	5.93	3.72	3.77	8.60
PMC 61	7.27	6.71	4.01	4.10	9.54
C.V. (%)[a]	19.78	13.41	17.73	24.36	15.02
LSD ($P \leqslant 0.05$)[a]	2.37	1.16	0.89	1.36	2.01

[a] C.V., coefficient of variations; LSD, least significant difference.

(Wright et al., 2002), it was shown that in the Southern and Central African clonal black teas, simple theaflavin dominates among the theaflavins. A similar pattern is noted in many Kenya cultivars, especially where cultivar 6/8 is one of the parents. However, the data presented here show that, although in many cultivars simple theaflavin dominates, in cultivars Ejulu and 31/11, theaflavin digallate was the dominant theaflavin. This confirms the wide genetic base of the cultivars used in this study. In the present study, commercial estates developed some of the cultivars used, while others were bred at the Tea Research Foundation of Kenya and cultivar Ejulu was imported from Ambangulu in Southern Tanzania. Such cultivars are therefore unlikely to share the same parents. Indeed cultivar 301/6 is a *Camellia sinensis* variety *assamica* ssp. *lasiocalyx*, while cultivar 378/1 is a triploid *Camellia sinensis* variety *assamica*, whereas the rest are *Camellia sinensis* variety *assamica* diploids. At least part of the differences noted in the individual theaflavin composition can therefore attributed to genetic variations.

McDowell et al. (1991) had reported on the possibility of predicting black tea country of origin based on polyphenols composition. Their results suggested that geographical area of tea production may contribute to the pattern of individual theaflavin composition in black tea. The results presented here (Table 2 and Fig. 3) suggest that the use of the patterns on individual theaflavins in black tea liquors to assign country of origin can be misleading. The observations of McDowell et al. (1991) could be due to differences in cultivars used in their study. Indeed, there has been no study to establish the possible variations in the flavan-3-ols in green tea leaves or individual theaflavin composition of black tea from the same cultivar grown in different geographical regions. It is therefore not possible to differentiate the contribution of genetic and environmental effects on theaflavin composition.

The results of the regression analyses are shown in Table 3. The total theaflavins (Flavognost) were regressed against the individual theaflavins, theaflavin digallate, and theaflavin digallate equivalents. There
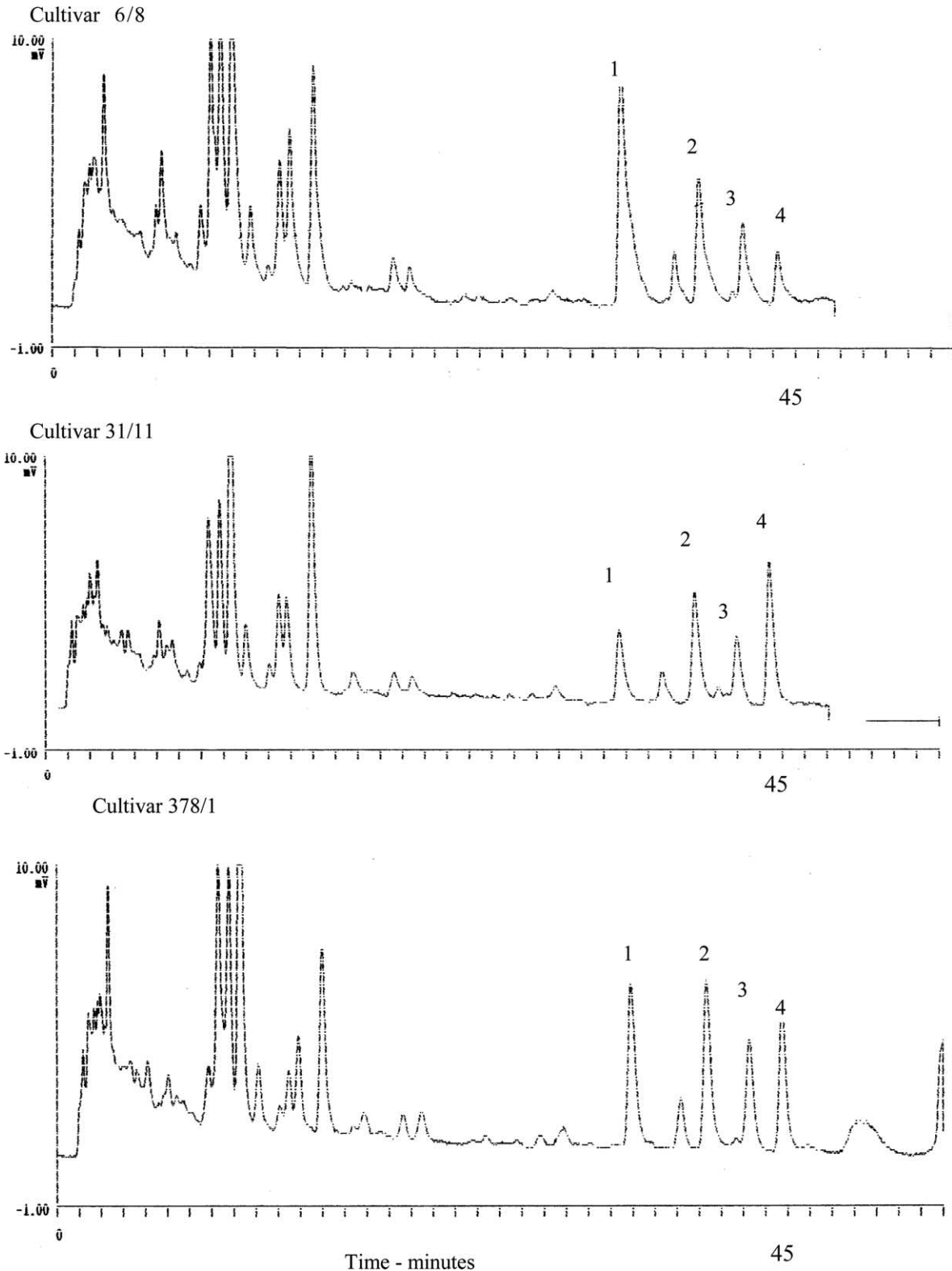
Fig. 3. The distribution of individual theaflavins in different clonal black teas 1, TF; 2, TF-3-g; 3, TF-3′-g; 4, TF-3,3′-dg.

were significant relationships between total theaflavins and theaflavin-3-gallate ($r = 0.91$, $P \leqslant 0.001$), theaflavin-3′-gallate ($r = 0.92$, $P \leqslant 0.001$) and theaflavin digallate equivalent ($r = 0.53$, $P \leqslant 0.09$). Although simple theaflavin was dominant in many cultivars, the relationship between its level and total theaflavin was weak and

Table 3
Linear regression coefficients and significant levels between plain black tea quality parameters and individual theaflavins of different cultivars

	Total theaflavins	Thearubigins	Total colour	Brightness	Taster A′	Taster B′
Simple theaflavin	0.50 (NS)[a]	0.23 (NS)	0.12 (NS)	0.44 (NS)	0.08 (NS)	−0.02 (NS)
Theaflavin-3-gallate	0.91 (0.001)	−0.11 (NS)	0.65 (0.03)	0.67 (0.02)	0.48 (NS)	0.71 (0.01)
Theaflavin-3′-gallate	0.92 (0.001)	−0.36 (NS)	0.43 (NS)	0.92 (0.001)	0.53 (0.09)	0.69 (0.02)
Theaflavin digallate	0.19 (NS)	−0.32 (NS)	0.40 (NS)	0.16 (NS)	0.60 (0.05)	0.62 (0.04)
Theaflavin digallate equivalents	0.53 (0.09)	−0.33 (NS)	0.57 (0.07)	0.44 (NS)	0.71 (0.01)	0.80 (0.001)
Total theaflavins (Flavognost)		−0.13 (NS)	0.61 (0.04)	0.86 (0.001)	0.55 (0.08)	0.72 (0.01)
Thearubigins			0.36 (NS)	−0.52 (0.10)	−0.42 (NS)	−0.22 (NS)
Total colour				0.24 (NS)	0.48 (NS)	0.73 (0.01)
Brightness					0.58 (0.06)	0.59 (0.05)

[a] Numbers in bracket are significance levels; limit set at $P = 0.10$.

not significant. Similarly, the relationship between total theaflavin and theaflavin digallate was weak and not significant. These results suggest that the Kenyan tea cultivars producing black teas with higher levels of total theaflavins are likely to have high levels of the theaflavin monogallates.

The relationship between thearubigins and the individual theaflavins were mostly negative, except for simple theaflavin, and not significant. However, the thearubigins ($r = -0.52$, $P \leqslant 0.10$) reduced black tea brightness. These spectrophotometric brightness results reaffirm the recent results of Obanda, Owuor, Mang'oka, and Kavoi (2004) that black tea liquor brightness as assessed by sensory evaluation is reduced by high thearubigins levels. In the production of bright black teas, cultivars need to be selected with potential of leading to low total thearubigins.

The total colour of the black teas was significantly and linearly correlated with theaflavin-3-gallate ($r = 0.65$, $P \leqslant 0.03$), total theaflavins ($r = 0.61$, $P \leqslant 0.04$) and theaflavin digallate equivalent ($r = 0.57$, $P \leqslant 0.07$). These parameters are therefore crucial in the production of colour black teas. Although the total colour is normally attributed to the thearubigin levels, the regression between the two parameters was not significant ($r = 0.36$, $P = NS$). This result is surprising and needs further study to confirm.

The liquor brightness was more closely associated with theaflavin-3′-gallate ($r = 0.92$, $P \leqslant 0.001$), total theaflavin ($r = 0.86$, $P \leqslant 0.001$) and theaflavin-3-gallate ($r = 0.67$, $P \leqslant 0.02$). In most studies, the spectrophotometric brightness of tea has been associated with total theaflavins. The present results reaffirm these associations. Again, it is noteworthy that the theaflavin monogallates were more closely related to the brightness of black teas than the theaflavin digallate, theaflavin digallate equivalent and simple theaflavin.

There were no significant relationships between sensory evaluations and simple theaflavin and thearubigins. Indeed the thearubigins tended to lower the sensory evaluation of black teas. For taster A significant relationships were observed with theaflavin digallate

equivalent ($r = 0.71$, $P \leqslant 0.01$), theaflavin digallate ($r = 0.60$, $P \leqslant 0.05$), liquor brightness ($r = 0.58$, $P \leqslant 0.06$), total theaflavin ($r = 0.55$, $P \leqslant 0.08$), and theaflavin-3′-gallate ($r = 0.53$, $P \leqslant 0.09$). For taster B, there were significant correlations with theaflavin digallate equivalent ($r = 0.80$, $P \leqslant 0.001$), total colour ($r = 0.73$, $P \leqslant 0.01$), total theaflavins ($r = 0.72$, $P \leqslant 0.01$), theaflavin-3-gallate ($r = 0.71$, $P \leqslant 0.01$), theaflavin-3′-gallate ($r = 0.69$, $P \leqslant 0.02$), theaflavin digallate ($r = 0.62$, $P \leqslant 0.04$), and brightness ($r = 0.59$, $P \leqslant 0.05$). Both tasters agreed on the importance of liquor brightness to sensory evaluation. This demonstrates that in tea breeding for quality, there is a need for a background of chemical data for liquor brightness, as it is an important quality parameter to be optimised. Taster B was alone in liking black teas with strong colour ($r = 0.73$, $P \leqslant 0.01$).

The relationships between sensory evaluations and TDE were much closer than relationship with any other factor. These results demonstrate that theaflavin digallate equivalent is a superior parameter for evaluating Kenyan plain black tea quality. However, some of the results presented here were in contrast to those observed in Central and Southern African clonal black teas (Wright et al., 2002). For both Kenyan clonal black teas and Central and Southern African clonal black teas, there were significant relationships between the theaflavins monogallates, especially theaflavin-3-gallate, and sensory evaluation. The results show that the theaflavin monogallates are key quality parameters in both teas. However, whereas there were significant relationships between the simple theaflavin levels in Central and Southern African clonal black teas and sensory evaluation, there was no such relationship for the Kenyan clonal black teas. Similarly, whereas the relationship between sensory evaluation and theaflavin digallate was significant for Kenyan clonal black teas, for Central and Southern African clonal black teas, the relationship was weak. The results show that either simple theaflavin or theaflavin digallate alone cannot be used as universal parameters for predicting black tea quality. Differences in the significance of the regressions between total theaflavins and sensory

evaluations in Kenyan and Central African black teas had been observed before (Hilton & Ellis, 1972; Hilton et al., 1973; Owuor et al., 1986, 1987). Indeed McDowell et al. (1991) noted that the compositions of phenolic compounds of teas from the two countries are different. The differences noted here are possibly due to variations observed in the distribution of the theaflavins between Kenyan black teas and the Central and Southern African black teas (Wright et al., 2002). It is likely that different individual theaflavins dominate the quality of black teas from different countries. Thus, the use of a single theaflavin to predict black tea quality may vary with geographical areas of production. It is therefore not too surprising that, whereas the simple theaflavin (TF) has dominant quality role in Central and Southern African black teas (Wright et al., 2002), for Kenyan black teas, the gallated theaflavins, especially theaflavin digallate, dominate. However, these variations underscore the need to develop a single chemical parameter that can be used as a quality indicator irrespective of geographical area of production.

The relationship between theaflavin digallate equivalent and sensory evaluation, had not been determined for the teas from the Central and Southern African clonal black teas (Wright et al., 2002). Using the data presented (Wright et al., 2002), TDE was calculated (Table 4) and regressed against sensory evaluation of their Tasters A and B and price evaluation (Table 5). The regression coefficients for TDE were $r = 0.758$ ($P \leqslant 0.001$) (for Taster A), $r = 0.430$ ($P \leqslant 0.007$) (for Taster B) and $r = 0.755$ ($P \leqslant 0.001$) for price evaluations.

Table 4
The theaflavins, sensory evaluation and valuations of Central and Southern African clonal teas[a]

Cultivar	TF	TF-3- g	TF-3′- g	TF-3,3′-dg	TF-dg eq.	SIT	Total TFs (Flavognost)	Taster A	Taster B	Valuation (US cents)
SFS204	5.3	3.2	1.6	2.8	5.29	13	11.8	23.6	70	130
PC1	14	4.4	2	1.4	5.81	21	17.2	22.1	54	117.2
88/79-2	4.5	3.7	1.5	2.7	5.21	12	7.72	18.2	58	109.4
PC117	12	5.6	2.3	2	6.62	22	13	24	74	147.7
PC213	15	4.7	1.9	1.5	6.13	23	12.1	21.7	74	140.6
PC190	9.2	4.9	2.2	3.5	7.4	20	15.2	20	64	151
PC108	16	5.8	2.7	2.1	7.55	27	17.7	25.1	72	150.5
15M-58	12	4.6	1.7	1.3	5.36	20	8.75	22.1	68	128.5
15M-39	9.6	3.1	1.3	0.9	3.93	15	9.11	20.6	74	121.5
88/3-3	6.3	4.7	1.5	2	5.14	14	6.56	21.2	64	123.3
15M-1	10	4.4	1.7	1.7	5.38	18	17.3	21.9	64	118.7
88/5-2	7.6	3.5	1.7	1.6	4.59	14	12.8	21.7	78	123.8
PC200	13	5.5	2.2	1.8	6.5	22	9.33	21.9	64	141.3
PC192	13	5.4	2.4	1.9	6.64	22	15.7	22.1	74	153
PC119	17	4.9	2.9	1.8	7.16	26	15.6	24.1	64	152.1
PC168	11	6.3	2.8	3.7	8.58	24	6.65	25	54	140.3
33/10-47	14	4.5	2.3	1.8	6.35	22	13.8	25.2	76	137.3
PC104	13	5.6	2.7	2.8	7.71	24	18.4	30.1	64	150.2
88/50-5	7.6	3.6	1.4	1.6	4.52	14	8.44	19.8	52	116.2
PC206	6.1	3.5	1.7	2.2	4.96	14	12.3	16.2	52	98.8
NKW30	5	2.8	1.2	1.7	3.87	11	5.22	17.4	45	113.2
88/60-9	12	4.3	1.9	1.6	5.63	19	8.39	17.7	50	108.8
NKW20	3.8	2.2	0.8	1.4	3.03	8.2	4.82	14.7	40	107.6
NKW44	3.9	2.6	0.9	1.5	3.32	8.9	8.39	14.5	50	106.7
88/79-1	6.9	3.6	1.6	1.9	4.78	14	6.12	17	45	114.8
88/54-11	8.6	3.2	1.5	1.2	4.17	15	10.4	18.4	52	110
PC169	7.3	5	2	3.1	6.67	17	7.59	19.3	50	113
PC186	7	3.8	1.8	2.1	5.14	15	12.2	18.3	50	135
11M-3	8.4	3.1	1	0.9	3.64	13	9.02	17.6	45	102.8
PC211	9.1	3.6	1.5	1.2	4.39	15	7.46	16.4	45	125.5
88/61-11	3	2.2	0.7	1.4	2.88	7.3	6.03	14.4	40	88.6
88/119-1	7.1	4.3	1.7	2.2	5.39	15	10.7	18.1	53	112
88/54-14	9.8	4.7	2.2	2.2	6.13	19	7.72	17.4	52	108.8
15M-18	11	3.6	1.5	1.1	4.59	17	8.65	20.1	50	116.1
PC194	7.9	3.8	1.8	2	5.18	16	10.1	18.8	50	142
88/110-4	3.4	2.8	1	2.7	4.55	10	6.38	16	45	102.4
SFS42	6.5	4.1	2	2.9	6.03	16	10.8		45	
CL12	6	4.8	2.5	4.3	7.77	18	12.2		50	
PC76	15	6.3	3.5	3	8.74	28				
PC79	14	6.7	3.5	4.3	10.03	29				

[a] Data taken from Wright et al. (2002); SIT, sum of individual theaflavins.

Table 5
Linear regression coefficients between theaflavins and sensory evaluation or/and cash valuations of Central and Southern African black teas[*]

Theaflavins	Taster A	Taster B	Valuation
Simple theaflavin	0.722 (0.001)	0.592 (0.001)	0.695 (0.001)
Theaflavin-3-gallate	0.747 (0.001)	0.508 (0.001)	0.737 (0.001)
Theaflavin-3′-gallate	0.779 (0.001)	0.482 (0.002)	0.789 (0.001)
Theaflavin-3,3′-digallate	0.284 (0.093)	−0.026 (NS)	0.303 (0.072)
Theaflavin-3,3′-digallate equivalents	0.758 (0.001)	0.430 (0.007)	0.755 (0.001)
Sum of individual theaflavins	0.799 (0.001)	0.584 (0.001)	0.788 (0.001)
Total theaflavins (Flavognost)	0.669 (0.001)	0.589 (0.001)	0.607 (0.001)

[*] Raw data for analysis obtained from Wright et al. (2002).

These regression coefficients were higher than those obtained for the total theaflavins (Flavognost) for Taster A ($r = 0.669$, $P \leqslant 0.001$), Taster B ($r = 0.589$, $P \leqslant 0.001$) and valuation ($r = 0.607$, $P \leqslant 0.001$). However, the sum of individual theaflavins had higher regression coefficients for Taster A ($r = 0.799$, $P \leqslant 0.001$), Taster B ($r = 0.584$, $P \leqslant 0.001$) and valuation ($r = 0.788$, $P \leqslant 0.001$), and these were highly significant (Table 5). Thus, TDE is a better and universal chemical quality parameter for estimating quality of both Kenyan, Central and Southern African black teas. The correlation between TDE and taster scores cannot be assumed to apply to plain black teas from other regions, e.g., Argentina, India and Sri Lanka, until tested. Again the relationship is also not expected to apply to black teas where aroma has a large influence on sensory evaluation (Horita & Owuor, 1987; Owuor, Tsushida, Horita, & Murai, 1988).

In conclusion, these results demonstrate that for Kenyan black teas the liquor parameter of brightness is associated with quality. Of the chemical quality parameters, theaflavin digallate equivalent is a superior and objective tool for assessing the quality of black teas, irrespective of geographical area of production, within the East, Central and Southern Africa.

The differences observed in the distribution of the individual theaflavins presented here and those from Central African black teas (Wright et al., 2002) are large. These could be due to the differences in geographical area of production (McDowell et al., 1991) or the genetic differences (Magoma et al., 2000) in the cultivars used in the studies. The results of McDowell et al. (1991) suggested that the growing environment largely influences the phenolic compound distribution in black tea. The results presented here and earlier (Owuor & Obanda, 1997) show that genetic variations in the plants may be an important factor in the distribution of black tea theaflavins. Indeed, it is not known if the pattern of the theaflavins distribution is genetically controlled and is stable to the environment/growing conditions. This needs to be clarified in a study using the same cultivars grown in different regions. If flavan-3-ols composition in green tea leaves is determined by the environment or growing conditions, then high quality tea cultivars developed in a particular environment may not replicate this high quality when grown in a different region. It is thus necessary to investigate the effect of environment on the flavan-3-ols composition in green tea leaves of cultivars used for production of black tea.

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