Advances in the Development of Reliable Black Tea Quality Parameters and Use in Selection of Superior Quality Plants

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Abstract:
The definition of ‘superior quality’ in the tea trade is largely subjective as it is erroneously associated with price. But although the price of tea is thought to be related to quality, most of the time the actual price is influenced by supply and demand. In the 1960s to early 1980s, significant relationships were recorded between some Northeast Indian and Central African black teas theaflavins levels and prices or sensory evaluations, leading to the suggestion that theaflavin levels were the objective chemical black tea quality indicators. Such relationships were however non–existent for black teas from Sri Lanka and Kenya. Thus, the relationship was not applicable to some major black tea producers.

Further research in Kenya directed at defining the actual black tea chemical quality parameters. Aromatic black teas are valued for their delicate sweet floral smell. The black tea volatile components responsible for smell were characterized into those responsible for sweet floral smell and those producing undesirable green grassy smell. The ratio of the sum of gas chromatographic peak areas of those responsible for sweet floral smell (Group II volatile flavour compounds (VFC)) to the sum of peaks of those producing green grassy smell (Group 1 VFC) (Owuor’s flavour index) significantly correlated with sensory evaluations and prices of aromatic black teas. This ratio proved superior to those developed for the same purpose in the other major tea producing countries and is thus a reliable parameter for grading flavoury black teas.

Most Kenya black teas are classified as plain to medium flavoury teas. Such teas are valued for their taste and colour characteristics. These factors are attributed to the non-volatile components of tea. For plain black teas, it was recognized that the individual theaflavins (theaflavin-3, 3’-digallate, theafalvin-3-gallate, theaflavin-3’-gallate and theaflavin) have an astringency ratio 6.4:2.22:2.22:1, respectively. Thus the total theaflavins *per se* may not be the critical factor in the contribution to taste. A normalizing factor, theaflavins digallate equivalent was developed and this had superior relationship with sensory evaluation for the Kenyan, Southern and Central African black teas. Thus theaflavins digallate equivalent was shown to be a reliable and more universal parameter of assessing plain black tea quality.

Factors leading to production of high theaflavin digallate have been studied. It was demonstrated that green leaf with high epigallocatechin gallate (EGCG) and epicatechin gallate (ECG) usually produce superior plain black tea. Thus EGCG and ECG levels in green leaf are reliable indicators of black teas with high quality potential.

Introduction

Quality is sometimes an ambiguous terminology in black tea production and trade. This makes research into tea quality difficult. Generally in tea production and trade, quality is erroneously associated with pricing. However, a lot of times pricing is dictated by supply and demand and these factors usually have nothing to do with quality. The observation, however, does not imply lack of quality in black tea. Indeed there are low and high quality teas. Consequently, there has been need to identify objective and reliable chemical tea quality parameters. Such parameters will augment the current subjective organoleptic evaluation method in the assessment of value of tea. The establishment of the reliable quality parameter would help the tea trade in setting standards, creating objective price criteria and yard stick, ultimately improving the image of tea as a beverage of choice and thereby enhancing tea prices.

Total theaflavins levels

The chemistry of tea manufacture was dominated with the understanding of the role of the polyphenols in black tea processing[1]. By early 1960s Wood and Roberts had recognised the possible existence of a relationship between black tea theaflavins and sensory evaluation[2]. Simi1ar relationship was later observed for Northeast Indian tea[3] and Central African tea[4, 5, 6]. This led to the suggestion that theaflavins were the objective quality indicator in black tea[7, 8]. In an effort to improve both price and image of black tea, UNCTAD commissioned a consultant to draw 'Minimum Export Standard' for tea, who recommended that for black tea qualify for export the minimum level of theaflavins should be 8 µmoles/gm (dry weight), crude fibre content be 16% and moisture content 6%[8]. There was pressure from UNCTAD that the Minimum Export Standard be adopted for use to regulate black tea trade. It was hoped that adoption of the standard would remove low quality and sub-standard black teas from the market. This was targeted at improving the image of black tea as a beverage, thereby increasing consumption and ultimately helping to create an upward surge in black tea prices for the benefit of the producers.

Unfortunately for Kenya, which as at that time was the fourth leading exporter of black tea[9], there was no data to facilitate acceptance or rejection of the proposal. It therefore became necessary that studies be undertaken to find if a relationship existed between Kenya black tea total theaflavin levels and sensory evaluations and/or prices. These studies demonstrated lack of significant relationship between the total theaflavins levels and sensory evaluation and/or tea prices for Kenyan black tea (Table 1)[10, 11].

Table 1: Pooled correlation coefficients (r) for linear relationship between total theaflavins content and tasters' valuations on miniature manufactured Kenyan clonal black teas.

Taster	Number of experiments	Number of samples	Pooled r	Minimum r for significance (p=0.05)
A	0.41	492	0.12	0.09
B	18	216	0.13	0.12 (NS)
C	16	192	0.21	0.10
D	15	180	0.02	0.10 (NS)
E	15	180	0.08	0.10 (NS)
All	105	1280	0.02	0.06 (NS)

**Each Experiment has 12 samples, each from different clone*

Source: Owuor; Reeves & Wanyoko. *J. Sci. Food Agric.* **37**, 507-513 (1986)

It was further observed that the theaflavins levels in Kenya black tea were exceptionally high compared to the theaflavins levels in the Central Africa teas[9]. Consequently it was thought the levels were above thresh-hold limits making other quality parameters more dominant than theaflavins. However, further work showed that the total theaflavins levels were not the objective quality indicator for Kenya tea[12, 13]. Indeed, similar lack of relationship between the total theaflavins and prices and/or sensory evaluation had also been recorded for Sri Lankan[14] black teas.

One of the other problems of not accepting the use of theaflavins levels as objective quality indicator was the poor reproducibility of theaflavins analysis in various laboratories. Factors causing the poor reproducibility were examined and shown to include the varying boiling point of water at different altitudes, the size and shape of thermos flasks and the method of infusion[15]. After this exposition, the results were confirmed by independent analyst working in various laboratories[16]. These problems led to a search for other more reliable chemical quality parameters for Kenyan black teas.

Black tea aroma quality parameter

Studies on the Kenyan black tea aroma complex were initiated in 1986 when there was no existing reliable method of quantification of the aroma quality of black tea. Earlier, Wicremasinghe *et al*[17] had developed an aroma quantification parameter (Wicremasinghe Yamanishi ratio) based on the retention times of the gas chromatographic peaks of the black tea volatile flavour compounds. The compounds were separated into two groups: - I and II. In group I were volatile flavour compounds with gas chromatographic elution durations shorter than linalool and in group II were the volatile flavour compounds from linalool plus those with longer retention times. A ratio of the sum of the gas chromatographic peak areas of group I to group II was then developed to quantify the black tea aroma[17]. However, it was observed that most of the group I VFC were giving black tea inferior aroma while most of the group II were giving black tea sweet flowery aroma. Thus the parameter was an inverse of quality.

Secondly, the classification was based on arbitrary boundary of linalools retention time which had no bearing on the smell characteristic of the compounds. There were compounds in group I which had sweet flowery aroma and some in group II with greenish aroma. Thirdly, the retention sequence of the volatile compounds are bound to change with the type of packing material used in the column. Thus depending on the column used, some compounds could come before or after linalool which was used as the boundary hence the aroma classification would change, not because of the black tea but due to the packing material used. These made it necessary to develop a more realistic black tea aroma quantification parameter.

Table 2: Flavour components composition[a] of black teas from different parts of the world

Source	1c	2c	3c	4c	5c	6c	7c	8d	9d
Hexanal	0.93	0.86	0.95	0.48	1.03	1.28	0.70	0.57	0.71
1-Penten-3-ol	0.21	0.47	0.45	0.32	0.46	0.32	0.64	0.31	0.32
Heptanal	0.06	0.05	0.06	0.02	0.03	0.10	0.04	0.02	0.03
(Z)-3-Hexenal	0.19	0.16	0.20	0.07	0.25	0.21	0.12	0.09	0.17
(E)-2-Hexenal	3.89	2.27	3.50	1.44	1.53	2.92	2.79	2.26	3.40
2-Pentylfuran	0.07	0.06	0.04	nil	0.06	Nil	nil	0.01	Nil
Pentanol	0.11	0.19	0.18	0.16	0.35	0.26	0.27	0.17	0.20
(Z)-2-Pentenol	0.14	0.35	0.31	0.29	0.31	0.12	0.47	0.25	0.13
Hexanol	0.11	0.17	0.17	0.17	0.46	0.16	0.16	0.06	0.05
(Z)-3-Hexenol	0.63	1.22	1.15	0.72	1.72	0.47	1.38	0.34	0.17
Nonanal	0.11	0.10	0.11	0.05	0.08	0.15	0.07	0.05	0.07
(E)-2-Hexenol	0.18	0.23	0.22	0.35	0.41	0.11	0.27	0.12	0.05
(E,Z)-2,4-Heptadienal	0.04	0.07	0.08	0.04	0.05	0.06	0.05	0.05	0.09
(E,E)-2,4-Heptadienal	0.06	0.19	0.18	0.04	0.08	0.06	0.11	0.10	0.12

Sum of Group I	**6.73**	**7.39**	**7.90**	**4.15**	**6.82**	**6.14**	**7.02**	**4.42**	**5.52**
Linalool oxide (Cis furanoid)	0.15	0.27	0.26	0.26	0.43	1.97	0.35	0.46	0.08
Linalool oxide (Trans furanoid)	0.44	0.91	0.88	1.21	3.58	0.97	1.42	1.20	0.25
Bezaldehyde	0.12	0.23	0.22	0.25	0.53	0.57	0.21	0.22	0.38
Linalool	1.30	2.43	2.44	2.19	3.16	1.02	2.90	2.87	0.46
3,7-Dimethly-1,5,7-octatrienol	0.03	0.09	0.08	0.08	0.13	0.08	0.07	0.08	0.09
ß-Cyclocitral	0.02	0.02	0.02	0.03	0.90	0.06	0.02	0.18	0.12
Phenyl acetaldehyde	0.60	0.29	0.34	1.03	0.57	0.92	0.33	1.14	1.41
(Z)-3-Hexenylhexanoate	0.08	0.16	0.16	0.10	0.18	0.15	0.16	0.01	0.08
-Terpineol	0.08	0.10	0.10	0.12	0.17	0.07	0.14	0.16	0.06
Linalool oxide (cis pyranoid)	0.01	0.02	0.03	0.02	0.,02	0.10	0.02	0.01	0.02
Nerylacetate	0.02	0.02	0.02	0.04	0.25	0.12	0.03	0.05	0.05
Methyl salicylate[b]	0.43	0.90	0.90	1.07	2.32	0.75	2.21	1.23	0.28
Nerol	0.06	0.13	0.13	0.08	0.15	0.10	0.07	0.09	0.05
ß-Ionone	0.04	0.06	0.04	0.09	0.13	0.02	0.12	0.06	0.12
Geraniol	0.51	1.10	1.08	0.12	4.22	3.81	0.37	0.76	0.05
Geranyl acetone	0.05	0.08	0.07	0.06	0.04	0.04	0.11	0.04	0.08
Benzyl alcohol	0.02	0.02	0.02	0.04	0.13	0.25	0.03	0.03	0.04
2-Phenyl ethanol	0.01	0.01	0.01	0.04	0.25	0.25	0.04	0.01	0.05
-Ionone	0.17	0.25	0.23	0.22	0.39	0.41	0.32	0.24	0.35
5,6-Epoxy- ß-ionone	0.03	0.07	0.06	0.05	0.07	0.01	0.09	0.03	0.06
Nerolidol	0.13	0.31	0.27	0.20	0.38	0.35	0.27	0.23	0.12
Cedrol	Nil	Nil	Nil	0.04	Trace	Trace	Nil	0.01	Nil
Bovolide	0.03	0.03	0.03	0.03	0.05	0.06	0.03	0.02	0.04
6,10,14-Trimethy-2-pentaoctanone	0.06	0.04	0.04	0.05	0.05	0.08	0.08	0.03	0.03
Nonanoic acid	0.02	0.06	0.05	0.04	0.08	0.19	0.10	0.06	0.07
Jasmine lactone	Trace	0.06	0.05	0.01	0.03	0.02	Trace	0.04	Trace
Methyl palmitate	0.04	0.09	0.08	0.01	0.07	0.02	0.06	0.04	0.05
Unknown I	0.13	0.10	0.11	0.01	0.04	0.11	Trace	0.01	0.01
(E)-Geranic acid	0.04	0.0-8	0.08	0.03	0.18	0.39	0.07	0.25	0.01
Indole	Nil	0.02	0.02	0.01	0.01	0.04	0.02	0.02	0.02
Sum of Group II	**4.61**	**7.95**	**7.82**	**7.75**	**20.05**	**11.28**	**9.72**	**9.49**	**4.47**
Flavour index	**0.68**	**1.08**	**0.99**	**1.87**	**2.94**	**1.84**	**1.38**	**2.15**	**0.81**

Key: 1 & 7: Uva, 2 Numara area, 3 Dimbula, 4 & 9: Assam, 5 Darjeeling, 6 Keemum, 8 Kenya

[a]as ratio of peak area due to the compound to that if internal standard; [b]containing minor amount of linalool oxide (trans pyranoid); [c]Orthodox, [d]CTC tea; [e]not detected, [f]less than 0.01

Source: Owuor, Horita, Tsushida, Murai, *Tea*, **7(2)**, 71-78 (1986)

Flavour chemists working at Tocklai developed an index based on the sum of gas chromatographic areas of terpenoid to non-terpenoids VFC[18] (Mahanta ratio). The ratio assumed all the terpenoids compounds were desirable while the non-terpenoids had undesirable contribution to black tea aroma. However, there are many non-terpenoid volatile flavour compounds in tea with desirable aroma.

Table 3: Comparison of different indices used to quantify black tea aroma using orthodox tea from different varieties

Variety	Clone/seedling stock	Mahanta ratio	Yamanishi-Botheju ratio	Wicremasinghe-Yamanishi ratio	Owuor's flavour index	Sensory evaluations
Assamica	31/8	0.89	1.35	0.75	2.13	127
	31/11	1.15	1.41	0.82	2.32	125
	S15/10	1.40	0.65	0.52	2.28	120
	6.8	1.17	1.07	0.55	2.21	138
	St 18	1.01	1.37	0.95	1.65	120
Sinensis	14/1	.58	0.31	1.18	1.02	72
	Seedling China	.56	0.25	1.44	0,85	60
Lasiocalyx (Shan tea)	301/4	.55	0.73	0.91	1.33	90
	301/5	.69	0.85	1.32	1.22	89
	301/6	1.08	1.37	0.95	1.75	120
R		0.83**	0.75*	-0.87***	0.95***	

r=Linear regression coefficient between different ratios and sensory evaluation.
*, **, *** Significant at $p \leq 0.05$, 0.01, 0.001, respectively
Source: Owuor, *J. Sci. Food Agric.* **59**, 189-192 (1992)

In 1986, we developed another ratio[19]. This ratio was based on the actual smell characteristic of the volatile flavour compound. To develop it, the first task was to correctly classify all the compounds, based on their smell characteristics. Fortunately when this work was starting most of the compounds had been sniffed and classified by other workers and what it required was only literature search to facilitate correct classification into the correct groups. The few compounds which had not been classified were sniffed and placed into either group I (i.e. those with undesirable, green grassy aroma) or group II (i.e. those with desirable sweet flowery aroma). This led to the development of a VFC quality quantifying index known as "Owuor's Flavour Index". This flavour index is the ratio of the sum of gas chromatographic peak areas of the volatile flavour compounds with desirable flowery aroma (Group II) to those with undesirable green grassy aroma (Group I)[20]. A typical classification and amounts of the volatile flavour compounds in black tea from different countries is presented in Table 2.

In 1989, Yamanishi et al[21] developed another ratio based on the ratio of the areas of linalool and 2-E-hexenal (Yamanishi Botheju ratio). It is noted the ratio ignored all other volatile flavour compounds

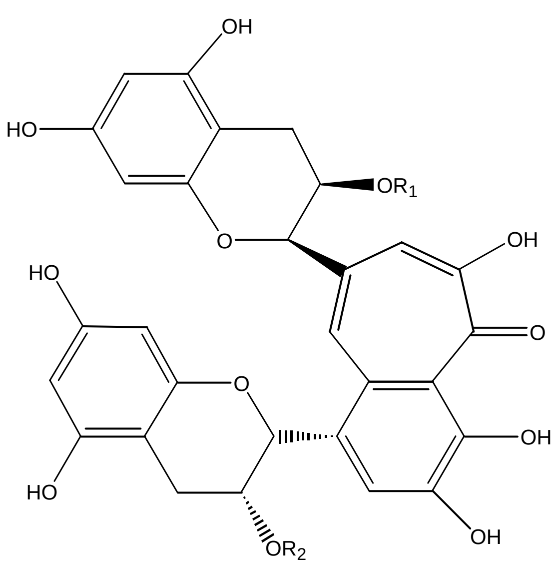
In a recent study, a comparison of the performance (Table 3) of the different ratios on Kenya's clonal tea and teas of different varieties was done[22]. The Owuor's Flavour Index was found to have superior relationship with sensory evaluation of Kenyan black tea[22] than comparative aroma ratios developed by other researchers on black tea aroma[17, 18, 21]. Apart from use on Kenya tea, the ratio has become popular with other researchers and is currently being widely used in black tea research.

Although the Owuor's Flavour Index seem to work reasonably well, the data must be used with caution. The indices should at best be treated as semi-quantitative since the olfactory perception limits of different VFC are variable. Some VFC may exist at low levels and affect aroma more than those occurring at higher levels[23, 24]. Again the contribution of each VFC to flavour is not proportional to gas chromatographic area. It is known that the relationship between stimulant concentration (represented by GC peak area) and neural response (perceived flavour intensity) is not linear. Progressive increases in stimulus give progressively smaller increases in neural response. Since for some VFC the range between minimum and maximum concentrations encountered may be considerable, better correlation with sensory evaluation might be obtained using logarithmic or power transformations of the peak area. This aspect will be addressed in the future studies.

The relative concentrations of volatile compounds as measured by GC after steam distillation do not necessarily represent the concentrations in the headspace of a tea brew. Thus the VFC composition presented in these studies could be different from those in tea brews. It is therefore necessary to develop an aroma extraction procedure which could more closely replicate the composition in the tea brew.

Plain black tea quality parameter

However a lot of Kenyan black teas are basically plain and for such teas aroma is less vital than astringency. Efforts have therefore been directed at developing other possible reliable quality parameters for plain black teas. Although there was no relationship between total theaflavins and prices and/or sensory evaluations[9, 10]], theaflavins play a significant role in plain black tea quality. Black teas contain varying amounts of the four individual major theaflavins: - theaflavin (TF), theaflavin-3-gallate (TFMG), theaflavin-3'-gallate (TFMG) and theaflavin-3,3'-digallate (TFDG) (figure 2). For example, the distribution of the individual theaflavins in some Kenya clones is presented in Table 4. Sanderson *et al*[25] had observed that the individual theaflavins have different astringency and thus contribute variably to the overall quality of plain black tea. Theaflavin- 3,3'-digallate was 6.4 times while the theaflavin monogallates were 2.22 times more astringent than theaflavin. This observation was used by Thanaraj and Seshadri[26] in India to develop a normalization factor for the variations in the contribution of the different theaflavins to black tea astringency.



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

Figure1: The major individual theaflavins in black teas

The equation :-TFDG equivalent of total TF% = A/6.4 + B x B/2.22 + C)/100, where A, B, C denote percent TF, TFMGs and TFDG respectively was thus developed. However, it was noted that TFMG converts to TFDG equivalent as TFMG x 2.22/6.4 not as TFMG/2.22 as suggested by Thanaraj and Seshadri[26]. Hence an improved equation:-

TFDG equivalent of total TF (umoles/g)= TF/6.4 + TFMG x 2.22/6.4 + TFDG was developed[27].

After determining the composition of individual theaflavins in black tea from various clones (Table 4)[28], it was demonstrated that a better relationship exists between the more astringent gallated theaflavins and sensory evaluation than simple theaflavins or total (Flavognost) theaflavins[29]. With the use of the normalising equation for the various theaflavins[27] there exists an excellent relationship between the normalised factor "Theaflavin digallate equivalent" levels and sensory evaluation[22, 29, 30] (Table 5) Thus although the relationship between total theaflavins and sensory evaluation were less successful, the normalized theaflavin factor taking into account the variation in the individual theaflavin is more successful[29, 30]. The lack of significant relationship noted between the high levels of total theaflavin of Kenyan tea and sensory evaluation earlier[10, 11, 12, 13] was partly due to this effect[29].

Table 4: *The distribution of individual theaflavins* (µmol/g) *levels of black tea from different cultivars*

Clone	**Total theaflavins (µmoles/g)**	**TF (µmoles/g)**	**TF-3-g (µmoles/g)**	**TF-3'-g (µmoles/g)**	**TF-3, 3'-dg (µmoles/g)**	**TF dg esq. (µmoles/g)**
6/8	26.38	12.47	6.86	4.16	2.64	8.42
S15/10	19.23	7.58	5.20	3.19	3.33	7.42
Ejulu	18.00	4.00	5.14	2.56	6.31	10.03
31/11	22.22	4.06	6.47	3.81	7.88	12.08
301/6	14.75	7.71	4.58	1.25	1.20	4.44
303/35	21.44	9.36	5.43	3.88	3.03	7.47
303/216	19.95	10.16	4.98	2.95	1.87	6.21
347/314	25.35	11.95	6.49	3.90	3.00	8.48
378/1	24.87	7.82	6.91	4.70	5.44	10.69
F7/346	22.60	8.94	5.93	3.72	3.77	8.60
PMC	22.66	7.27	6.71	4.01	4.10	9.54
C.V.%	13.03	19.78	13.41	17.73	24.36	15.02
LSD, $P \leq 0.05$	4.06	2.37	1.16	0.89	1.36	2.01

Source: Owuor and Obanda, Food Chem 2005, in press and Owuor, Obanda, Nyirenda, Mphangwe, Wright, and Apostolides, Food Chem, 2005, In press

Table 5: *Linear regression coefficients and significant levels between plain black tea quality parameters and individual theaflavins of different cultivars*

	Taster A'	Taster B'
Simple theaflavin	0.08, (NS)	-0.02, (NS)
Theaflavin-3-gallate	0.48, (NS)	0.71, (0.01)
Theaflavin-3'-gallate	0.53, (0.09)	0.69, (0.02)
Theaflavin digallate	0.60, (0.05)	0.62, (0.04)
Theaflavin digallate equivalents	0.71, (0.01)	0.80, (0.001)
Total theaflavins (Flavognost)	0.55, (0.08)	0.72, (0.01)
Thearubigins	-0.42, (NS)	-0.22, (NS)
Total colour	0.48, (NS)	0.73, (0.01)
Brightness	0.58, (0.06)	0.59, (0.05)

*Numbers in bracket are significance levels; limit set at P = 0.10

Source: Owuor, Obanda, Nyirenda, Mphangwe, Wright, and Apostolides, Food Chem, 2005, In press

*Table 6: 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)

Source: Owuor, Obanda, Nyirenda, Mphangwe, Wright, and Apostolides, Food Chem, 2005, In press

Indeed, even in Central Africa, for the newly developed clones with higher theaflavins levels, a better relationship with sensory evaluation or price has been developed with the use of Theaflavin digallate equivalent than total theaflavins *per se*[30]. In a recent study, both Kenyan and Malawi (Tables 5 and 6), black teas were shown to exhibit good relationship between theaflavin digallate equivalent and sensory evaluations and/or prices[30]. These studies have shown that theaflavins are indeed useful black tea quality parameters which, when used properly, can give objective estimate of plain black tea quality irrespective of geographical area of production.

Table 7: Linear regression coefficients and significant levels between plain black tea quality parameters and catechins or catechin ratios of different clones

Catechin	Total theaflavins	Theaflavin	Theaflavin-3-gallate	Theafalvin-3'- gallate	Theaflavin-3, 3'-digallate	Theaflavin digallate equivalent	Taster A	Taster B
Epigallocatechin	0.426	0.189	0.195	0.457	0.206	0.291	0.643	0.344
	NS	NS	NS	NS	NS	NS	0.03	NS
Catechin	-0.075	-0.244	-0.118	0.028	0.288	0.224	0.266	0.174
	NS	NS	NS	NS	NS	NS	NS	NS
Epicatechin	-0.576	0.153	-0.544	-0.734	-0.612	-0.751	-0.785	-0.679
	0.061	NS	0.081	0.009	0.043	0.007	0.003	0.02
Epigallocatechin gallate	0.749	0.2	0.648	0.881	0.305	0.547	0.528	0.595
	0.007	NS	0.029	0.0001	NS	0.078	0.092	0.051
Epicatechin gallate	-0.305	-0.683	0.074	-0.168	0.407	0.305	-0.238	-0.002
	NS	0.019	NS	NS	NS	NS	NS	NS
Gallated catechins	0.461	-0.256	0.611	0.662	0.523	0.669	0.303	0.522
	NS	NS	0.043	0.024	0.096	0.022	NS	0.096
Non gallated catechins	-0.187	0.385	-0.504	-0.307	-0.42	-0.501	-0.012	-0.349
	NS	NS	NS	NS	NS	NS	NS	NS
Gallated/Non gallated ratio	0.287	-0.312	0.558	0.453	0.399	0.527	0.072	0.36
	NS	NS	0.071	NS	NS	0.093	NS	NS
Gallo catechins	0.525	0.203	0.31	0.581	0.241	0.367	0.656	0.422
	0.094	NS	NS	0.058	NS	NS	0.026	NS
Simple catechins	-0.669	-0.062	-0.563	-0.77	-0.459	-0.631	-0.775	-0.638
	0.022	NS	0.068	0.005	NS	0.035	0.004	0.032
Gallo/simple catechins ration	0.483	0.049	0.363	0.545	0.37	0.46	0.667	0.421
	NS	NS	NS	0.08	NS	NS	0.023	NS
Total catechins	0.055	0.35	-0.261	0.017	-0.224	-0.233	0.182	-0.123
	NS	NS	NS	NS	NS	NS	NS	NS

*Numbers in bracket are significant levels, limit set at P = 0.10
Source: Owuor and Obanda, Food Chem 2005, in press

In a recent studies, we demonstrated that some clones make higher levels of gallated theaflavins, especially theaflavin-3,3'-digallate than others [Table 4]. Such clones make more astringent black teas[29]. We have also demonstrated that the level of individual flavanols in green leaf can be related to the theaflavins digallate equivalent [Table 7]. Thus, it is possible to predict the quality potential of clonal leaf at a single bush level. This is facilitates faster and early selection of clones for quality. Before this study, it took between 4 to 16 years before clones being developed could be tested for quality.

It is however noted that, Kenya black teas have high amounts of residual catechins[32]. These catechins are relatively astringent[25] and contribute to the astringency of black teas. Scharbert *et al*[33] recently showed that flavanol glycosides in black tea are also weakly astringent. It is not known if some other polyphenols in black tea are also astringent. Further studies are necessary to incorporate the contribution of the catechins and other polyphenols in black tea whose astringency also contribute to black tea quality.

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