Chemistry Research to Improve Quality for Sustainable Development of the Kenya Tea Industry: tea processing

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Abstract

Kenya projects to be agloballycompetitive and prosperous country witha highqualityof lifeby2030 through the achievement of Vision 2030 objectives. The Vision aims attransforming Kenya into“anewly-industrializing,middleincomecountry providing ahigh quality of life to all its citizens in a clean and secure environment”.TheVision is anchored on three key pillars:Economic;Social;and Political Governance. The economic pillar aims to achieve an economic growth rate of 10%per annum and sustaining the same till 2030. Agriculture and manufacturing are among the six key sectorsexpected to deliverthe 10%economicgrowthrate perannumunderthe economicpillar. It is hoped an innovative,commercially-oriented,andmodern agriculturalsector shall be promoted. One way of achieving this is through increasing productivity (quantity and quality) of crops and crop products.Kenyaaimsto have a robust,diversified,and

competitivemanufacturing sector, achieved through there structuring key local industries that use local raw materials and exploiting opportunities in value addition to local agriculturalproduce, while maintaining a clean, secure and sustainable environment. In part chemists can contribute to the achievement of these objectives through upgrading quality and value of Kenyan industrial crops through chemistry. The major industrial crops that Kenya produces include tea, coffee, sugarcane, pyrethrum, coconut, oil crops (sunflower, cottonseed, soya, groundnuts, rapeseed, bambara nuts, castor, palm oil, sim-sim, linseed, nuts, grains, beans, seeds (e.g. sesame), maize germ, copra and olives), cashew nut, fibre crops (sisal and cotton) and tobacco. The value of these agricultural crops can be enhanced through proper processing techniques guided by chemical principles to improve quality. An over view of past efforts to improve the quality of black tea in Kenya during processing is presented.

Introduction

The Seasonal Paper on Science and Technology for Development(GOK, 1982). Science and Technology provides the knowledge with which to identify opportunities and to increase economic growth rates by making capital and labour more productive. The paper recommended that the Government of Kenya should deliberately expand research to cover all sectors of the economy, increase level of research and experimental development funding to 1% of GDP and build capacity for technological transformation. Several attempts have been made to actualize the recommendations with varying successes. More recently(GOK, 2007), the Government launched Vision 2030 as a blueprint to steer the country to a globally competitive and prosperous nation with high quality of life by the year 2030. This is hoped to be achieved through three pillars: - economic, social and political. Through the economic pillar it is hoped the country will maintain a sustained economic growth of 10% per annum over the next 25 years. Social pillar hopes to create a just and cohesive society enjoying equitable social development in clean and secure environment. The political pillar intends the country to be issue-based, people-centered, result-oriented and accountable democratic political systems. In the implementations of the Vision 2030, science, technology and innovation are pinned as the foundation to achieve the giant leap. Indeed the Research, Innovation and Technology Sector of the Government has a vision of "Excellence in creation and provision of technology, information and knowledge" and mission "to improve quality of life of Kenyans through research, innovations and technology". Research and innovation is therefore mandatory for Kenya to realize global economic competitiveness and for maintaining sustainable development and equity concerns. Transformation of Kenya into a middle income country as outlined in Vision 2030 can only be achieved through development of the necessary scientific infrastructure and development of technical and entrepreneurial skills.

The Industrial sector is best positioned as a growth driver as identified in Vision 2030 since it enjoys strong forward and backward linkages with other important economic sectors such as agriculture and services, offers high prospects for employment creation especially in labour intensive industries, acts as a catalyst for technology transfer and attraction of foreign direct investment (FDI), offers high prospects for deepening Kenya's drive to integrate further into the regional and global economy, and provides significant foreign exchange earnings to the Kenyan Economy. However, currently the growth of industrial sector such as agriculture, mining and quarring, construction and others is slow, in part due to low technical support from the research institutes and universities. The mandate of the universities is capacity building, generation of new knowledge and knowledge transfer, while the mandate of research and development (R&D) institutions is generation of new knowledge and knowledge transfer. When their mandates are achieved the overall output is technological development. Indeed, the direct product of research is knowledge that can be in the form of new technology, new product, new process or improvement in existing product, process or technology. Publications have been the traditional R&D output. However, the dissemination of knowledge through publications is not enough. R&D is only useful of its products can lead to economic development, industrialization, job creation and poverty reduction. A R&D institution can become relevant to society only through transfer of knowledge. Several factors inhibit the effectiveness of the R&D institutions. These include low funding of science and technology institutions, low use of intellectual property right, low level of commercialization of science technology institution findings, low level of use of reverse engineering, in adequate technology transfer policy, lack of entrepreneurial cultural, weak linkages between science and technology institutions and small and medium enterprises (SME's)/industries, weak marketing practices in STI and SME's/Industries, inadequate utilization of local knowledge, weak linkages and networks amongst STI institutions and inadequate utilization of cleaner production techniques.

Some industries realized these weaknesses and have embraced R&D as a tool for development. In Kenya for example the tea industries has undergone a fast and competitive growth through use of research for development (Othieno, 1988; Othieno, 1991). The major industrial crops that Kenya produces include tea, coffee, sugarcane, pyrethrum, coconut, oil crops (sunflower, cottonseed, soya, groundnuts, rapeseed, bambara nuts, castor, palm oil, sim-sim, linseed, nuts, grains, beans, seeds (e.g. sesame), maize germ, copra and olives), cashew nut, fibre crops (sisal and cotton) and tobacco. The value of these agricultural crops can be enhanced through proper processing techniques guided by chemical principles to improve quality. Assessment of how quality of individual products can be enhanced can be a tall order in a short presentation. In this presentation, an over view of past efforts to improve the quality of black tea in Kenya during processing is presented.

Black tea making was considered an art, not a science, passed from one tea maker to another in a manner secret to competitors. However, black tea processing involves biochemical/chemical transformation of some metabolites under processing conditions that can be manipulated to enhance production of high levels of the desirable and low levels of undesirable chemical quality parameters. In practice, these chemical parameters have been assessed through sensory evaluations. However, sensory evaluation can be subjective and influenced by several factors including individual preferences. In Kenya, considerable efforts have been directed at developing reliable chemical quality parameters, that are measureable, reproduceable and not influenced by factors outside quality. Black tea theaflavins, thearubigins, caffeine, and volatile flavour compounds (VFC) were recorded to have immense influence on the pricing of black tea. As a result, most basic research has revolved around these parameters to assess their contribution to quality.

The chemistry of tea manufacture has been dominated with the understanding of the role of the polyphenols in black tea processing (Roberts, 1958). By early 1960s Wood and Roberts had recognised the possible existence of a relationship between black tea theaflavins and sensory evaluation (Roberts & Smith, 1961). Similar relationships were later observed for Northeast Indian tea (Deb & Ullah, 1968) and Central African tea (Ellis & Cloughley, 1981; Hilton & Ellis, 1972; Hilton & Palmer-Jones, 1973; Hilton & Palmer-Jones, 1975). This led to the suggestion that theaflavins were the objective quality indicator in black tea (Davies, 1983; Ellis et al., 1981). 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% (Ellis et al., 1981). UNCTAD put up pressure that the Minimum Export Standard be adopted for use to regulate black tea trade. It was urgued, thr adoption of the standard would remove low quality and sub-standard black teas from the market. This was would improve 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, Kenya, which at that time was the fourth leading exporter of black tea (ITC, 1981; ITC, 2011), and now the leading black tea exporter , had no data to facilitate acceptance or rejection of the proposal. It therefore became necessary that basic research be undertaken to establish if a relationship exists 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) (Owuor, 1983; Owuor, Reeves & Wanyoko, 1986d).

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 et al., 1986d)

But, it was observed that the theaflavins levels in Kenya black tea were exceptionally high compared to the theaflavins levels in the Central Africa teas (Owuor et al., 1986d) for which the relationship exists. It was then thought the levels were above thresh-hold limits making other quality parameters more dominant than theaflavins. However, further work confirmed that the total theaflavins levels were not the objective quality indicator for Kenya tea (Owuor, Othieno & Reeves, 1986b; Owuor, Othieno & Reeves, 1987b). Similar lack of relationship between the total theaflavins and prices and/or sensory evaluation were also recorded for Sri Lankan (Roberts & Fernando, 1981) black teas. The other problems of not accepting the use of theaflavins levels as objective quality indicator was the poor reproducibility of Flavognost 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 (Reeves, Gone & Owuor, 1985). These results were confirmed by independent analyst working in various laboratories (McDowell, Reeves, Owuor & Gone, 1985). These problems led to a search for other more reliable chemical quality parameters for Kenyan black teas.

Black tea aroma quality parameter

Black tea contains more than 600 volatile flavor (aromatic) compounds (VFC) (Robinson & Owuor, 1992). Athough these volatiles constitute only approximately 0.2% dry tea weight, they have immense influence on the black tea quality (Yamanishi, 1999). 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, in Sri Lanka an index (Wicremasinghe, Wick & Yamanishi, 1973) had been developed as 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 (GC) peak areas of Group I to Group II was then developed to quantify the black tea aroma (Wicremasinghe *et al.*, 1973). 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.

Flavour chemists working at Tocklai Experimental Station, in Assam, India developed an index based on the sum of gas chromatographic areas of terpenoid to non-terpenoids VFC (Baruah, Hazarika, Mahanta, Horita & Murai, 1986) (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 and *vice versa*.

In 1986, we developed another ratio (Owuor, Tsushida, Horita & Murai, 1986e). 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 major VFC, based on their smell characteristics. Fortunately when this work was starting, most of the VFC 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) (Owuor, Tsushida, Horita & Murai, 1988). A typical classification and amounts of the volatile flavour compounds in black tea from different countries is presented in Table 2.

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	**6.7**	**7.**	**7.**	**4.**	**6.8**	**6.1**	**7.0**	**4.**	**5.5**

Group I	**3**	**39**	**90**	**15**	**2**	**4**	**2**	**42**	**2**
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-	0.08	0.03	0.18	0.39	0.07	0.25	0.01

		8							
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 et al., 1986e)

In 1989, Yamanishi and co-reseachers (Yamanishi, Botheju & De Silva, 1989) developed another ratio based on the ratio of the areas of linalool and 2-E-hexenal (Yamanishi Botheju ratio). These two metabolites dominate the VFC composition of black tea, especially tea from *Assamica variety* (Takeo). It is noted the ratio ignored all other volatile flavour compounds

A comparison of the performance (Table 3) of the different ratios on Kenya's clonal tea and teas of different varieties was done (Owuor, 1992). The Owuor's Flavour Index had superior relationship with sensory evaluation of Kenyan black tea (Owuor, 1992) than comparative aroma ratios developed by other researchers on black tea aroma (Baruah et al., 1986; Wicremasinghe et al., 1973; Yamanishi et al., 1989). Apart from use on Kenya tea, the ratio has become popular with other researchers and is currently being widely used in black tea research worldwide.

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 (Howard, 1978; Kobayashi, Kawamura, Yamamoto, Shimizu, Kubota & Yamanishi, 1988). Indeed, ethyl epijasmonate is about 500 more flavory that ethyl jasmonake (Kobayashi *et al.*, 1988). 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.

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≤0.05, 0.01, 0.001, respectively

Source: (Owuor, 1992)

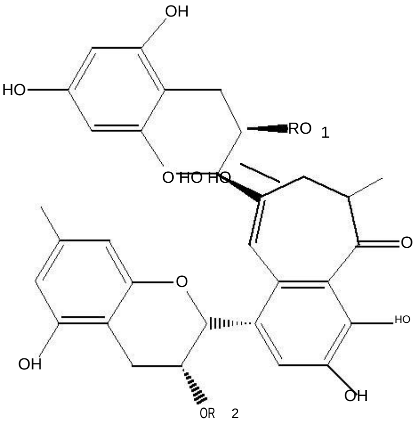
Plain black tea quality parameter

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 (Owuor, 1983; Owuor et al., 1986b; Owuor et al., 1987b; Owuor et al., 1986d), 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. The individual theaflavins have different astringency and thus contribute variably to the overall quality of plain black tea (Sanderson *et al.*, 1976). Theaflavin- 3,3'-digallate was 6.4 times while the theaflavin monogallates were 2.22 times more astringent than theaflavin. This observation was used in India to develop a normalization factor for the variations in the contribution of the different theaflavins to black tea astringency (Thanaraj & Seshadri, 1990).

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 (Thanaraj et al., 1990). Hence an improved equation:-

TFDG equivalent of total TF (umoles/g)= TF/6.4 + TFMG x 2.22/6.4 + TFDG was developed (Owuor & McDowell, 1994a).

After determining the composition of individual theaflavins in black tea from various clones (Table 4) (Owuor, Orchard & McDowell, 1994d), it was demonstrated that a better relationship exists between the more astringent gallated theaflavins and sensory evaluation than simple theaflavins or total (Flavognost) theaflavins (Owuor, Obanda, Nyirenda, Mphangwe, Wright & Apostolides, 2006). With the use of the normalising equation for the various theaflavins (Owuor et al., 1994a) there exists an excellent relationship between the normalised factor "Theaflavin digallate equivalent" levels and sensory evaluation (Owuor, 1992; Owuor & Obanda, 1995a; Owuor et al., 2006) (Table 5) Thus although the relationship between total theaflavins and sensory evaluation were less successful (Owuor, 1983; Owuor et al., 1986b; Owuor et al., 1986d), the normalized theaflavin factor taking into account the variation in the individual theaflavin is more successful (Owuor et al., 1995a; Owuor et al., 2006). The lack of significant relationship noted between the high levels of total theaflavin of Kenyan tea and sensory evaluation earlier (Owuor, 1983; Owuor et al., 1986b; Owuor et al., 1987b; Owuor et al., 1986d) was partly due to this effect.



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)

$R_1 = H$

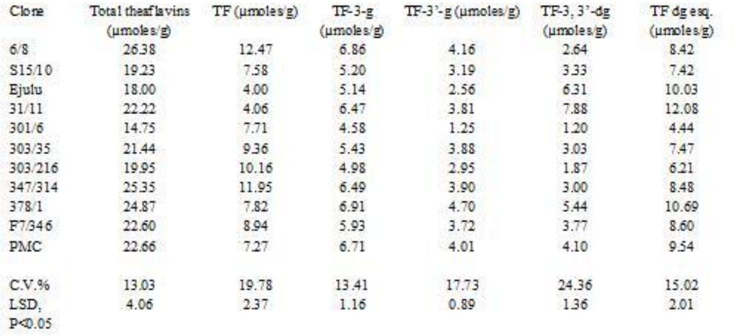
R_2 = 3,4,5-Trihydroxybenzoyl

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

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, $P<0.05$	4.06	2.37	1.16	0.89	1.36	2.01

Source: (Owuor & Obanda, 2007; Owuor et al., 2006)

Indeed, even for the Central Africa, for the newly developed clones with higher theaflavins levels, there was a better relationship between sensory evaluation and/or price with theaflavin digallate equivalent than total theaflavins *per se*(Owuor *et al.*, 2006). For 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 (Owuor *et al.*, 2006). 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 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 et al., 2006)

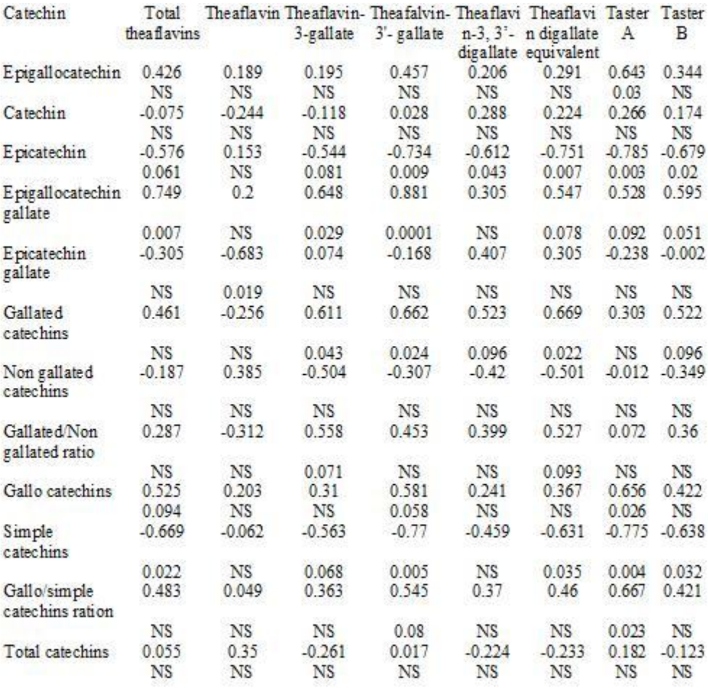
Some clones make higher levels of gallated theaflavins, especially theaflavin-3,3'-digallate than others (Table 4). Such clones make more astringent black teas (Owuor *et al.*, 2006). The level of individual flavan-3-ols in green leaf can be related to the theaflavins digallate equivalent (Table 7). 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 reliably tested for quality.

Table 6: Linear regression coefficients between theaflavins and sensory evaluation or/and cash valuatio
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 et al., 2006)

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

*Numbers in bracket are significant levels, limit set at P = 0.10

Source: (Owuor et al., 2007)

It is however noted that, Kenya black teas have high amounts of residual catechins (Obanda, Owuor & Taylor, 1996). These catechins are relatively astringent (Sanderson *et al.*, 1976) and contribute to the astringency of black teas. Favanol glycosides in black tea are weakly astringent and are major contributors to black tea quality (Scharbert & Hofmann, 2005; Scharbert, Holzmann &

Hofmann, 2004). Further studies are necessary to incorporate the contribution of the catechins and other polyphenols in black tea whose astringency may also be contributing to black tea quality.

These quality parameters developed through basic research have been progressed to applied research to improve black tea quality.

Use of black tea quality research to improve the Kenya tea industry

(i) Guiding principles

Due to the favourable tea growing environmental conditions and the research development of suitable agronomic practices (Othieno, 1981; Othieno, 1991), Kenya has seen unmatched increase in tea productivity. In both the estate and smallholder tea sector tea production per unit area has been on the upward trend (Figure 4). Indeed, through these research outputs, Kenya has produced up to 10,995 kg made tea per hectare under commercial estate practices (Oyamo, 1992). This arguably is the highest recorded yield under commercial production in the world. The impressive productivity recorded implied that Kenya has/had the potential to be a leading world tea producer. Indeed, today, Kenya is the third leading largest producer of tea and the leading exported of black tea (ITC, 2011). The prospects to increase and improve production continues and quality can be enhanced through using research proven processing technologies.

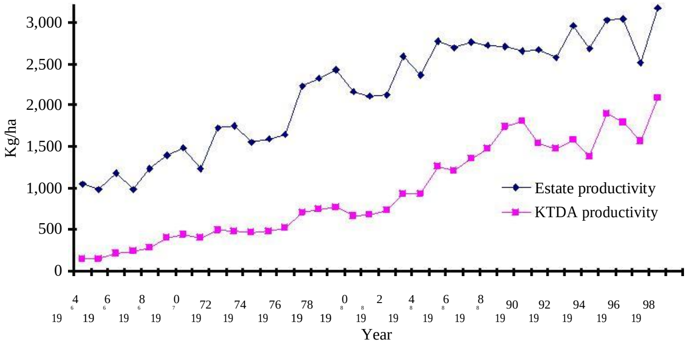


Figure 4: Tea production per hectare in different sectors
Source: Tea Board of Kenya Statistics.

Concurrent with the development of the reliable black tea quality parameters was the realisation that tea prices were either stagnant or reducing (Figure 5) while costs of production were escalating. Tea business was becoming unattractive venture particularly at a time the Kenyan tea industry, especially the smallholder sector was committing more land to tea (Figure 6) while the country annual production was also rising (Figure 7). The uncertain prices and continued low prices of tea implied only producers of high quality tea could survive. This suggested that the Kenya tea industry had to diversify and produce other more competitive products and/or reduce costs of production without sacrificing the existing quality. The black tea quality research in Kenya therefore, embarked on the development of tea technologies aimed at addressing the need to improving the product quality or reducing the costs of production without quality impairment.

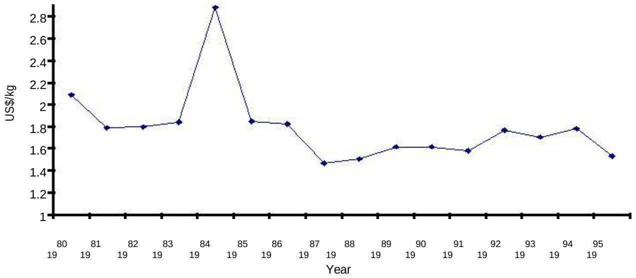


Figure 5: Annual mean prices of Kenya tea.
Source: International Tea Committee, Annual Bulletin of Statistics.

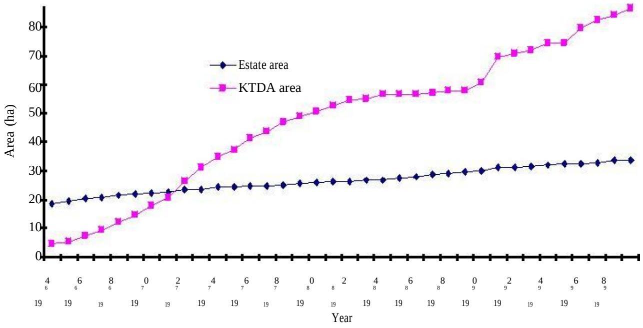


Figure 6: Area under tea in different sectors of Kenya
Source: Tea Board of Kenya Statistics.

The world tea was also faced with a problem of over production. At the international tea trade level, production was rising faster than consumption (Figure 8). The Kenya tea trade was therefore threatened both at home and in the international market. Both factors called for research interventions to ensure the future of the industry was sustainable. Tea quality research projects were initiated aimed at understanding how existing processing and agronomic technologies affected the resultant quality of tea or improving/optimising the technologies to improve product quality and/or reduce costs of the operations. The research was also intended to ensure teas of consistent standards were availed to international trade. It was also aimed at development of new technologies in tea production and processing.

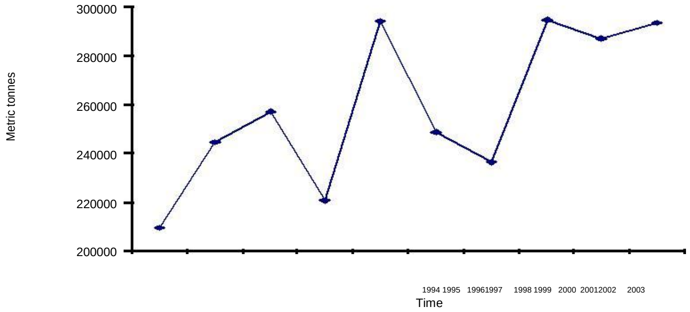


Figure 7: Kenya tea production trends
Source: Tea Board of Kenya Statistics.

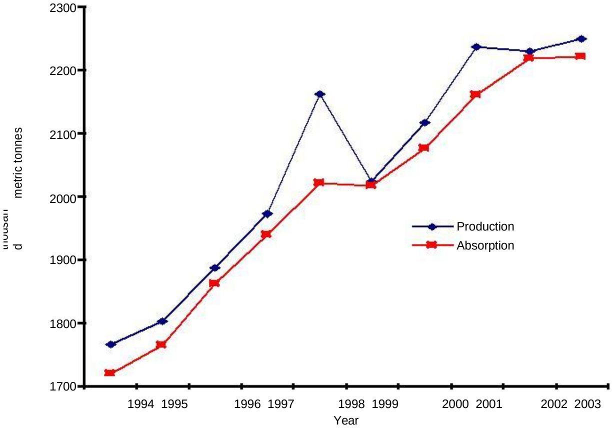


Fig. 8: World supply and absorption of tea.
Source: International Tea Committee, Annual Bulletin of Statistics.

The research on quality in Kenya was given direction all the times by the stakeholders. Through the Tea Research Foundation of Kenya, Research Advisory Committee and regular, but mandatory visits, the farmers defined their research problems. This led to the evaluation of whether the problem had an existing technology to address it or if it needed development of new technologies. For existing technologies, it became important to understand reasons for their not reaching the farmers. Over 90% of Kenya tea is exported. This made it mandatory to develop technologies to make tea meet the market demands. Through the interactions, the policies, processing technologies, agronomic technologies obstacles facing the Kenya tea industry were identified and research agenda developed for the improvement of tea quality. The government and other regulatory bodies were the other stakeholders in tea business. These stakeholders required that the industry produces competitive teas that conform to any new/proposed national and international black tea standards.

The tea quality research recognised the prices of black tea are dictated by supply and demand, factors that usually have nothing to do with quality. Usually, when supply is lower than demand all teas are bought with less choice and prices tend to be higher than usual. But when supply is higher than demand all tea is bought on basis of quality as defined by some chemical composition. When supply and demand is balanced, the situation becomes 50-50. But generally, some teas are always dearer than the other, due to their quality as defined by make, taste, aroma, and appearance. The taste and aroma are closely linked to chemical composition. Tea quality research was therefore geared towards enhancing the desirable quality attributes (Owuor, 1990). Herein, few examples of the applied research efforts to improve tea quality or reduce costs of production in Kenya are reviewed.

Improvement of Kenya tea quality through chemical and biochemical; research Processing

Withering

Withering is one of the most expensive steps in black tea processing. It takes largest factory space and highest energy. It is the part of processing that is most poorly understood. During withering, the leaf loses moisture and becomes flaccid making maceration easier. This is the most noticeable aspect and most factory personnel assume the purpose of withering is barely to reduce the leaf moisture content and make maceration easier. However, during withering there are physiological and biochemical transformation that also occur which ultimately affect black tea quality (Owuor, 2013). Research on withering demonstrated that fresh leaf makes inferior black tea compared to withered leaf and forcing moisture reduction in fresh leaf to attain physical wither reduces quality (Owuor, Mutea, Obanda & Reeves, 1986a). Indeed the aroma of black tea is much improved by allowing leaf to wither for at least 12 hours (Owuor, Tsushida, Horita & Murai, 1987c). These early studies demonstrated that there was need to understand the biochemical basis of withering and that withering can be separated into physical and chemical aspects. It became important to establish how to optimally achieve both chemical and physical wither (Owuor, Wanyiera, Njeru, Munavu & Bhatt, 1989). Achieving physical wither ahead of chemical wither and using warm air to achieve physical wither reduce black tea quality. Indeed use of warm air during withering is detrimental to tea quality ((Owuor & Obanda, 1996; Owuor, Orchard & Miyumo, 1992c).

The rate of tea production in Kenya continued to out strip the rates of factory expansion programmes. The part of tea processing that this affect most is withering due to its large space requirements. Innovative technologies were therefore developed to cope with the high production (Owuor, 2001; Owuor & Obanda, 1997). Two-stage withering in which chemical wither is achieved ahead of physical wither proved very useful in helping factories to use some of their withering troughs as holding spaces to achieve chemical wither since the troughs could be over loaded and later separated in several troughs to achieve physical wither (Owuor & Orchard, 1991). Tank withering was developed as an effective method of withering plain teas (Obanda & Owuor, 1992) and two stage withering process for both plain and aromatic teas (Owuor & Orchard, 1992b). These studies also demonstrated that the extent of moisture loss in a two stage withering affected quality. Soft withers (high moisture content) produced better quality black teas while floury black teas emanated from hard physical withers (low moisture content) (Obanda, Owuor & Bore, 1997; Owuor & Orchard, 1989; Owuor & Orchard, 1990a; Owuor & Orchard, 1990b). In a commercial factory, over time black tea processed using the tank withering techniques had better auction prices than normal wither in which leaf achieved chemical and physical withers concurrently (Owuor, Obanda, Edmonds & Rono, 1995b).

Due to the state of roads in the smallholder tea sector, some times leaf takes long before arriving in the factory. This occasions long withering duration. Withering beyond 20 hours reduced plain black tea quality, but black tea aroma improved with longer withering duration (Owuor, Orchard, Robinson & Taylor, 1990c). Indeed, withering duration was established to be an important parameter in making high quality black tea (Obanda et al., 1992; Obanda, Owuor & Kamanu, 1998). For plain teas, withering duration could be as short as 8 hours (Owuor et al., 1992c).

Also some agronomic practices influenced withering. Hard plucked leaf were more difficult to wither and their quality did not change much due to degree of physical wither (Obanda & Owuor, 1994). Withering procedures were also developed for the optimisation of processing anti-hypertensive CTC black teas with high amounts on gamma amino butyric acid (Gabaron tea) (Omori, Kato, Tamura, Takada, Owuor & Obanda, 1998).

Maceration

Maceration is an important step in black tea processing. During the process, leaf cell wall matrix is destroyed thus enabling the tea enzymes to mix with biochemicals that transform to black tea quality parameters. Although many volatile flavour compounds are formed after maceration, polyphenols oxidation dominates reactions following maceration. The degree of cell wall destruction in this stage determines the extent of mixing of the chemicals and hence quality. The black teas made from orthodox manufacture are therefore low in plain tea quality parameters but high in aroma, while CTC maceration ensures production of black tea with high plain black tea parameters but low flavour (Owuor, Othieno & Takeo, 1989). The method that individual processor follows should therefore be dictated by the demands of the tea markets. Although CTC and LTP macerations make the same quality black teas, LTP maceration requires softer withers (Owuor & Njuguna, 1993a; Owuor

& Obanda, 1994c). Some tea cultivars especially *var. sinensis* clones make more aromatic black teas while *var. assamica* and *var. assamica spp Lasiocalyx* make higher quality plain teas (Owuor et al., 1993a).

Fermentation

The most noticeable changes during black tea processing occur during fermentation stage of tea processing. Many attempts had been made to optimize the process as it has been imagined quality is made or destroyed at this stage (Obanda & Owuor, 1997). In Malawi, an in-line theaflavins method (ILTF) of analysis as away of determining optimal fermentation duration was developed (Cloughley, 1979). A comparison was done between the ILTF, and theaflavins in made tea (TFMT) for optimising fermentation time (Owuor & Reeves, 1986c; Owuor & Reeves, 1988). These results revealed that ILTF was always predicting an earlier optimal fermentation time. TFMT and sensory evaluations were established as the more accurate methods of estimating optimal fermentation duration (Owuor, 1987). A closer look at the rates of formation of the individual theaflavins revealed that they formed at different rates, causing variations in black tea astringency as fermentation proceeds (Owuor et al., 1994d).

However, fermentation is influenced by many factors. There are tea varieties that ferment faster than the others (Owuor & Obanda, 2001; Owuor, Obanda, McLean & Kisinyo, 1999). Rate of fermentation varies with plucking standards, where coarsely plucked leaf ferments faster than fine plucked leaf (Owuor & Obanda, 1998a). Adequate aeration is necessary for fermentation. Although supplying oxygen speeds up the fermentation process, it does not improve plain black tea quality (Owuor & Obanda, 1998c) but it reduces black tea aroma quality (Owuor & Obanda, 1998b). Use of ambient air is adequate in supplying necessary oxygen for the fermentation process (Owuor et al., 1998b; Owuor et al., 1998c) provided particles are adequately exposed to air through regular forking (Obanda *et al.*, 1998) or change of maceration fermentation sequences (Owuor & Obanda, 1994b). Hard physically withered leaf ferment much more slowly than soft withered leaf (Owuor et al., 1990b). However, the rates of such slow fermentation due to hard wither can be altered by increasing fermenting chamber humidity (Obanda, Owuor, Mang'oka & Kavoi, 2004; Owuor & Obanda, 1992a). Temperature regulation is mandatory during black tea fermentation. High fermentation temperatures reduce black tea quality (Owuor & Obanda, 1993b). However, there are tea varieties that can withstand slightly higher fermentation temperatures without much quality decline (Obanda, Owuor & Mang'oka, 2001; Owuor et al., 1993b). The preferred fermentation temperature should be between 20 and 25^{o}C.

Dryers, Grading/sorting, Storage a

The fermentation process is terminated through deactivation of tea enzymes using dryers. There are two types of dryers that are commonly used, the conventional and fluid bed dryers, although various manufacturers have different versions of the dryers. A comparison of the two dryer revealed that while fluid bed dryers make good plain black tea, conventional dryers make slightly superior aromatic black teas (Obanda et al., 1992; Owuor, Obanda & Wanyiera, 1987a). Generally the large grades black teas have better aroma than the fine dust grades, although dust grades infuse better and have higher plain tea quality parameters than the large particle size grades (Owuor *et al.*, 1987a). Processed black tea deteriorates during storage especially if it moisture can absorb moisture. Storage under dry conditions enhances the useful life span of tea and such enhancement increases if tea is stored under anaerobic conditions (Obanda & Owuor, 1995; Owuor & Obanda, 2000).

Factors contributing to research output

For a commodity crop like tea, successful scientific contribution in the improvement of the crop can be achieved with the support and interest of the industry. Financial support from the industry through Tea Board of Kenya that provided research facilities, equipment, good financial reward, incentives for researchers, and adequate exposure and training made the attainment of these results a reality. This was accompanied by enabling working environment free of political and partisan interests interference. Teamwork and networking by highly trained scientific staff, recruited on the basis of competence and good management made the scientific output possible.

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