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# Influence of region of production on relative clonal plain tea quality parameters in Kenya

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ABSTRACT

Tea is grown in diverse regions with varying climates. Growers seek high-yielding and superior quality cultivars to improve profitability of the enterprise. A superior quality genotype in one location is assumed to replicate the same attributes when planted in different regions, especially when climatic variations are minimal. Assessment of 20 commercial genotypes under identical management in three locations within Kenya revealed significant ($p \leqslant 0.05$) plain tea quality differences, demonstrating the need to identify superior quality clones. There were significant ($p \leqslant 0.05$) differences in the plain tea quality parameters with location of production. It is therefore not possible to produce tea of the same quality even from the same cultivars when the production location is varied. Regression coefficients ($r^2$) of linear correlations of the same parameters at different sites revealed low values that cannot be used to predict quality. This suggests the extents of changes in the individual parameters were different for the same clone in different regions. There were no significant interactions between sites and genotypes in the different plain tea parameters assessed, further showing the changes were not systematic. The results demonstrate that a genotype selected in one site for high quality may not retain the relative quality over other genotypes in new areas. It is necessary to test genotypes in new areas of production to fully evaluate their relative quality potentials.

## 1. Introduction

Tea (*Camellia sinensis* (L.) O. Kuntze) plant is an important source of different beverages which are claimed to be the most widely consumed fluids after water. It is grown in many countries ranging from as far north as 49°N, outer Carpathians to as far as 30°S, Natal, South Africa (Shoubo, 1989) and from altitudes varying from sea level in Japan to 2700 m above mean sea level (amsl) in Olenguruone, Kenya and Gisovu, Rwanda (Owuor, Obanda, Nyirenda, & Mandala, 2008). The plant is widely adaptable to geographical areas with large variations in climate and physical features which affect rates of growth, yields and quality. Several studies have demonstrated wide response ranges in yield (Ng'etich, Stephens, & Othieno, 2001; Wachira, Ng'etich, Obaga, & Othieno, 1990; Wickremaratne, 1981), yield partitioning (Ng'etich et al., 2001), growth (Ng'etich & Stephens, 2001a, 2001b), shoot population density (Balasuriya, 1999) and dry matter partitioning (Ng'etich & Stephens, 2001b) of tea genotypes to different environments (Carr & Stephens, 1992, chap. 4; Wachira et al., 1990; Wachira, Ng'etich, Omolo, & Mamati, 2002) including water stress (Carr, 1997), temperature (Tanton, 1982) and altitude (Obaga, Othieno, & Lang'at, 1989; Squire, Obaga, & Othieno, 1993). Such variations occur even within a 10-km radius (Ng'etich & Stephens, 2001a, 2001b; Ng'etich et al., 2001; Obaga et al., 1989; Squire et al., 1993). In terms of the black tea quality, the black tea aroma (Aisaka, Kosuge, & Yamanishi, 1978; Owuor & Obanda, 1996), volatile flavour compounds composition (Horita & Owuor, 1987; Yamanishi et al., 1968), and black tea plain quality parameters (Owuor, Reeves, & Wanyoko, 1986; Owuor, Tsushida, Horita, & Murai, 1986) varied widely with geographical area of production. However, the sources of the teas used in these quality studies, particularly the genetic make-up of the plants were variable or unknown. The observed differences could therefore be due to several factors, including climate, genetic make-up, agronomic/cultural practices and processing techniques, which cause changes in the chemical composition and hence quality of resultant teas. In a recent study comparing the quality of CTC black tea from Malawi and Kenya, it was shown that even when the same clonal tea plants were used to make black tea, quality variations persisted (Owuor et al., 2008). These quality variations (Owuor et al., 2008) were attributed largely to climatic differences in the geographical areas of production and/or agronomic practices. The tea from Malawi was obtained from 650 m amsl, latitude 16°5′S, while the tea from

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Kenya was sourced from 2180 m amsl, 0°22′S. Although the plants were grown under recommended agronomic practices in the respective countries, these practices were not identical in the two countries. The observed differences, while largely due to the respective climates in the areas of growth, could also in part be due to the non-uniformity of agronomical practices.

Previous studies assumed that large differences in climate are necessary for significant quality differences to be observed. As a result many tea-growing countries have centralised their clonal selection/breeding programmes in single locations. It has been thought that a superior genotype selected in one location maintains its desirable attributes within the country. However, tea plants selected in one location and planted in other locations have usually not matched the performance at the site of selection (Wachira et al., 1990, 2002). One reason for such difference has been altitude, which affects rates of growth, even when other agronomic/cultural practices are similar. In Kenya, for example, yields declined (Ng'etich et al., 2001; Squire et al., 1993) and quality improved (Owuor, Obaga, & Othieno, 1990) in clonal tea with a rise in altitude. These yield variations were attributed to growth rate and shoot density differences (Ng'etich & Stephens, 2001a, 2001b; Obaga et al., 1989) and for every 100 m rise in altitude, there is a loss of 1 kg made tea $ha^{-1}$ (Othieno, Stephens, & Carr, 1992). Tea plants grown at high altitude had slower growth rates than tea plants at lower altitude (Balasuriya, 1999; Squire et al., 1993). Consequently quality improved with slow growth at high altitude (Mahanta, Baruah, Owuor, & Murai, 1988; Owuor et al., 1990). For the changes which were observed in Kenya (Ng'etich et al., 2001; Obaga et al., 1989; Owuor et al., 1990; Squire et al., 1993), the trials were conducted within a 10-km radius, making climatic variations minimal or nearly constant. From these results, it was assumed that the changes in yields and quality will change with the altitude in a predictable manner, though not necessarily at the same rates for different cultivars. Consequently, a genotype with desirable attributes shall maintain these attributes relative to other genotypes, wherever they are grown within the same country. However, there are tea genotypes which are more resistant to yield variations with location of production and *vice versa* (Wachira et al., 2002).

World tea production has continued to increase at a rate higher than consumption (Anonymous, 2008). As a result tea prices have stagnated and in some cases declined (Anonymous, 2008) despite the increase in cost of production (Herath & Weersink, 2007). In situations of oversupply of commodities, only producers of premium quality products or those who drastically reduce cost of production can survive. Use of superior quality plants (Kamunya, 2003; Njuguna, 1984; Seurei, 1997) can improve the profitability of a tea enterprise, provided other agronomic practices are optimised (Owuor, Kamau, & Jondiko, 2009). With fast population rises in most tea-growing countries, land use pressure continues to increase. Many tea-growing countries have therefore run out of new lands for tea expansion. Indeed, some countries are converting tea lands into other uses. To sustain the supply of tea to the world, high-yielding and superior quality tea cultivars should be identified and cultivated.

As a result of the poor profits in tea enterprises, tea farmers, especially in Kenya, are searching for cultivars suited for their areas to enhance profits. Tea genotypes previously released to tea growers in Kenya were selected in Kericho. Although they are now widely grown in Africa, particularly in other tea-growing areas in Kenya, their quality performance in the new areas remains untested. It is not known if the selected clones are suitable for production of high quality black teas in all areas they are planted. This makes evaluation at many sites an expensive exercise. Tea farmers are therefore looking for stable cultivars whose yield and quality potentials do not change with environments. This study assesses the relative quality performance of clonal teas grown in different environments within Kenya.

In the tea trade, Kenyan black teas are classified as plain to medium flavour. The plain black teas are valued for their theaflavins content, which is responsible for their taste, brightness and also contributes to their colour, and for the thearubigins, which are responsible for thickness and colour of both the liquors and infusion (Biswas, Biswas, & Sarkar, 1971; Biswas, Sarkar, & Biswas, 1973). In terms of chemical analysis, apart from measuring the total theaflavins and thearubigins, methods of spectroscopic measurement of black tea brightness and colour have also been developed (Roberts & Smith, 1963). These chemical attributes are referred to as the plain tea quality parameters (Biswas et al., 1971, 1973). Indeed, theaflavins have become a critical parameter in estimating the quality of black teas (Lopez, Thomas, Pius, Kumar, & Muraleedharan, 2005; Owuor & Obanda, 2007; Owuor et al., 2006; Wright, Mphangwe, Nyirenda, & Apostolides, 2002). These parameters were used in this study to establish the possible quality variations in clones with geographical area of production.

## 2. Materials and methods

Twenty widely cultivated (commercial) genotypes of tea were planted in June 1991 in Kangaita Tea Farm (latitude 0°30′S, longitude 37°16′E, altitude 2100 m amsl) in the East of the Great Rift Valley, and Timbilil Estate, Kericho (latitude 0°22′S, longitude 35°21′E, altitude 2180 m amsl), and in June 1997 in Kipkebe Estate, Sotik (latitude 0°41′S longitude 35°5′, altitude 1800 m amsl), both in the west of the Great Rift Valley. The tea areas in the east of the Rift Valley have a weakly bimodal rainfall distribution with peaks in April/May and October/November, while areas in the west of the Rift valley have rains most of the year, except in the months of January and February when there is drought. At each site the plots were arranged in a randomised complete block design with three replicates (Wachira et al., 2002). The tea was planted using a 122 cm by 61 cm rectangular spacing (Anonymous, 2002).

Nitrogen, in the form of NPKS 25:5:5:5 compound fertiliser at a single dose of 120 kg N $ha^{-1}$, was applied during the year of planting and 300 kg N $ha^{-1}$ $year^{-1}$ in subsequent years. Plucking was done at 10–14 day intervals, depending on leaf availability. The plants were under uniform management and agronomic practices. One kilogram of leaf was plucked from each plot and processed by the miniature CTC method. The leaves were withered for 12–16 h and macerated four times on a miniature CTC machine, followed by fermentation for 90 min at 26–28 °C before firing using a miniature fluid bed dryer (Teacraft Ltd., Bedford, UK). The unsorted black teas were subjected to plain tea quality parameters chemical analysis and sensory evaluations. The total theaflavins were analysed by the Flavognost method (Hilton, 1973) while thearubigins brightness and total colour were determined by the method of Roberts and Smith (1963). Sensory evaluations were done by professional tea tasters at tea broking firms in Mombasa. The Mombasa Tea Auction Centre is now the second largest in the world after Colombo. The tasters have expert knowledge of black tea, especially teas of Kenyan origin, which they auction regularly.

The evaluations were based on briskness, brightness, colour, flavour, thickness, infusion and quality on scale of 0–20 for each item for Taster A and briskness, brightness, colour, thickness and infusion on a scale of 0–10 for Taster B (Since different score scales and parameters were used by Taster A and Taster B the importance is in the order of ranking). The manufacturing and evaluations were done on three different occasions. The mean data from the three analyses were used in the statistical analyses.

Data were analysed using randomised complete block design in a 2-factorial arrangement, with sites as the main treatments and plucking intervals as sub-treatments. MSTAT-C statistical package (Michigan State University, MI) was used for the analyses. The data for each attribute at each site was ranked to establish relative orders for the item in different cultivars. The means of the same parameters from different sites were correlated with each other to establish if their modes of change were the same.

## 3. Results and discussion

The clones used here were commercial clones, most of which were initially selected at the Timbilil site. Their selections were based on yield, not chemical quality parameters. There were significant ($p \leqslant 0.05$) changes in the plain tea quality parameters, due to genotypes and sites (Tables 1–6). However, there were no significant site and genotype interactions in any of the parameters analysed. Earlier, Wachira et al. (2002) had shown that although these clones had been selected for their yields, when grown in Timbilil and Kangaita, they exhibited significant yield differences and did not change in any predictable pattern. Similar variations in composition of some chemical constituents of tea from the same country had been observed in other studies. In China, the fluoride and aluminium (Shu, Zhang, Lan, & Wong, 2003) and copper (Jin, Du, Zhang, & Lin, 2008) contents of tea from different farms within

**Table 1**
Clonal black tea total theaflavins (μmol/g) and relative ranking based on theaflavins levels to growing environment.

| Clone | Theaflavins (μ mol/g) | | | | Ranking | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | | | Mean clones | Site | | | Mean clones |
| | Timbilil | Kipkebe | Kangaita | | Timbilil | Kipkebe | Kangaita | |
| TRFK 6/8 | 24.03 | 26.33 | 30.14 | 26.83 | 7 | 4 | 1 | 4 |
| TRFK 31/8 | 21.75 | 25.71 | 23.44 | 23.64 | 14 | 7 | 16 | 12 |
| AHP S15/10 | 18.06 | 22.48 | 21.19 | 20.58 | 19 | 16 | 18 | 18 |
| EPK TN 14-3 | 28.02 | 25.46 | 29.32 | 27.60 | 1 | 9 | 4 | 1 |
| BBK 35 | 24.49 | 25.14 | 27.34 | 25.66 | 5 | 10 | 8 | 9 |
| TRFK 54/40 | 24.15 | 27.15 | 29.37 | 26.85 | 6 | 2 | 3 | 3 |
| TRFK 12/12 | 23.77 | 24.97 | 29.89 | 26.21 | 8 | 11 | 2 | 5 |
| TRFK 12/19 | 19.58 | 20.89 | 23.50 | 21.32 | 16 | 18 | 15 | 17 |
| TRFK 31/27 | 18.50 | 19.01 | 21.17 | 19.56 | 17 | 20 | 19 | 19 |
| TRFK 11/26 | 23.05 | 25.48 | 28.97 | 25.84 | 10 | 8 | 6 | 8 |
| TRFK 57/15 | 25.62 | 26.17 | 25.92 | 25.90 | 2 | 5 | 10 | 7 |
| TRFK 7/3 | 22.97 | 22.78 | 23.06 | 22.94 | 11 | 15 | 17 | 14 |
| TRFK 7/9 | 21.96 | 24.64 | 24.69 | 23.76 | 13 | 13 | 11 | 11 |
| TRFK 56/89 | 17.58 | 20.52 | 18.63 | 18.91 | 20 | 19 | 20 | 20 |
| STCK 5/3 | 19.76 | 22.98 | 23.58 | 22.10 | 15 | 14 | 13 | 16 |
| TRFK 303/259 | 18.48 | 27.30 | 24.15 | 23.31 | 18 | 1 | 12 | 13 |
| TRFK 303/577 | 25.29 | 24.97 | 28.23 | 26.16 | 3 | 11 | 7 | 6 |
| TRFK 303/999 | 24.86 | 26.84 | 29.05 | 26.92 | 4 | 3 | 5 | 2 |
| TRFK 303/1199 | 23.49 | 25.80 | 26.74 | 25.34 | 8 | 6 | 9 | 10 |
| TRFK 2XI/4 | 22.07 | 22.20 | 23.54 | 22.60 | 12 | 17 | 14 | 15 |
| Mean site | 22.38 | 24.34 | 25.59 | | | | | |
| CV (%) | | 13.27 | | | | | | |
| LSD, $p \leqslant 0.05$) | | 1.16 | | 2.99 | | | | |

**Table 2**
Clonal black tea total thearubigins (%) content and their relative ranking in different growing environments.

| Clone | Thearubigins (%) | | | | Ranking | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | | | Mean clones | Site | | | Mean clones |
| | Timbilil | Kipkebe | Kangaita | | Timbilil | Kipkebe | Kangaita | |
| TRFK 6/8 | 16.44 | 17.27 | 18.86 | 17.52 | 9 | 8 | 3 | 5 |
| TRFK 31/8 | 15.12 | 14.72 | 16.78 | 15.54 | 17 | 19 | 14 | 16 |
| AHP S15/10 | 15.74 | 14.78 | 19.43 | 16.65 | 12 | 18 | 1 | 14 |
| EPK TN 14-3 | 17.78 | 18.24 | 17.86 | 17.96 | 2 | 2 | 9 | 2 |
| BBK 35 | 15.59 | 17.28 | 17.10 | 16.66 | 13 | 7 | 12 | 13 |
| TRFK 54/40 | 14.32 | 15.43 | 15.96 | 15.24 | 20 | 16 | 17 | 18 |
| TRFK 12/12 | 16.05 | 18.31 | 18.04 | 17.47 | 10 | 1 | 7 | 6 |
| TRFK 12/19 | 14.46 | 14.97 | 15.68 | 15.04 | 19 | 17 | 20 | 20 |
| TRFK 31/27 | 15.21 | 14.48 | 15.71 | 15.14 | 16 | 20 | 19 | 19 |
| TRFK 11/26 | 15.32 | 16.41 | 19.22 | 16.99 | 15 | 13 | 2 | 9 |
| TRFK 57/15 | 16.45 | 16.98 | 16.68 | 16.70 | 8 | 9 | 16 | 12 |
| TRFK 7/3 | 17.26 | 15.69 | 18.18 | 17.05 | 4 | 15 | 6 | 8 |
| TRFK 7/9 | 16.56 | 17.70 | 18.00 | 17.42 | 7 | 5 | 8 | 7 |
| TRFK 56/89 | 14.54 | 15.95 | 15.80 | 15.43 | 18 | 14 | 18 | 17 |
| STCK 5/3 | 16.02 | 16.84 | 17.72 | 16.86 | 11 | 11 | 10 | 11 |
| TRFK 303/259 | 15.45 | 16.62 | 16.72 | 16.26 | 14 | 12 | 15 | 15 |
| TRFK 303/577 | 18.28 | 17.59 | 17.42 | 17.76 | 1 | 6 | 11 | 3 |
| TRFK 303/999 | 17.64 | 17.80 | 18.82 | 18.09 | 3 | 4 | 4 | 1 |
| TRFK 303/1199 | 16.75 | 17.84 | 18.70 | 17.76 | 6 | 3 | 5 | 3 |
| TRFK 2XI/4 | 17.02 | 16.85 | 16.96 | 16.95 | 5 | 10 | 13 | 10 |
| Mean site | 16.10 | 16.59 | 17.48 | | | | | |
| CV (%) | | 8.67 | | | | | | |
| LSD, $p \leqslant 0.05$) | | 0.52 | | 1.35 | | | | |

Sichuan Province varied. In Turkey, iron and manganese content of tea from different growing regions were significantly different (Sahin, Nas, & Gökalp, 1991). However, there has been no study linking these chemical constituents to tea quality. Again, the genetic makeup of the teas used in these studies was not indicated. The noted differences could be in part due to genotypes. However, quality of plain tea is mainly due to polyphenolic compounds. The polyphenolic compounds varied in tea of undeclared genetic makeup across regions of production both in India (Borse, Rao, Nagalakshmi, & Krishnamurthy, 2002) and Australia (Yao et al., 2004). The variations of the individual taste attributes did not vary much for Taster B. Indeed even the total variations for Taster B had small ranges of 14–19, 15–20 and 18–19 for Timbilil, Kipkebe and Kangaita black teas, respectively (Table 5). This led to a very narrow margin of 16–19 for the mean in sensory evaluations. In part, this is due to the fact that Taster A made scores out of 20 instead of 10 used by taster B for the various evaluation components. Consequently, the ranges for Taster A were larger (Table 6). Despite the large differences, Taster A did not observe significant differences in the cultivars. The data presented here demonstrate in part the subjective nature of sensory evaluations. As noted in all the black tea parameters (Tables 1–6), the ranking of the clones widely

**Table 3**
Clonal black tea liquor total colour (%) and their relative ranking in different growing environments.

| Clone | Total colour (%) | | | | Ranking | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | | | Mean clones | Site | | | Mean clones |
| | Timbilil | Kipkebe | Kangaita | | Timbilil | Kipkebe | Kangaita | |
| TRFK 6/8 | 4.63 | 5.05 | 5.69 | 5.12 | 6 | 7 | 4 | 6 |
| TRFK 31/8 | 4.23 | 4.56 | 4.90 | 4.56 | 12 | 14 | 17 | 16 |
| AHP S15/10 | 3.90 | 3.90 | 5.11 | 4.30 | 18 | 20 | 11 | 18 |
| EPK TN 14-3 | 5.17 | 5.25 | 5.68 | 5.36 | 1 | 3 | 5 | 2 |
| BBK 35 | 4.75 | 5.46 | 5.71 | 5.30 | 4 | 2 | 3 | 3 |
| TRFK 54/40 | 4.20 | 4.99 | 5.34 | 4.84 | 14 | 8 | 9 | 8 |
| TRFK 12/12 | 4.79 | 5.66 | 5.89 | 5.45 | 3 | 1 | 2 | 1 |
| TRFK 12/19 | 3.94 | 4.20 | 4.70 | 4.28 | 17 | 18 | 19 | 19 |
| TRFK 31/27 | 4.01 | 4.17 | 4.60 | 4.26 | 16 | 19 | 20 | 20 |
| TRFK 11/26 | 4.28 | 5.12 | 5.98 | 5.13 | 10 | 5 | 1 | 5 |
| TRFK 57/15 | 4.48 | 4.81 | 5.10 | 4.80 | 8 | 11 | 13 | 10 |
| TRFK 7/3 | 4.60 | 4.35 | 5.35 | 4.77 | 7 | 17 | 8 | 11 |
| TRFK 7/9 | 4.22 | 4.93 | 5.37 | 4.84 | 13 | 9 | 7 | 8 |
| TRFK 56/89 | 4.16 | 4.77 | 4.96 | 4.63 | 15 | 13 | 15 | 13 |
| STCK 5/3 | 3.88 | 4.46 | 4.91 | 4.42 | 19 | 16 | 16 | 17 |
| TRFK 303/259 | 3.80 | 5.07 | 4.98 | 4.62 | 20 | 6 | 14 | 14 |
| TRFK 303/577 | 4.80 | 4.87 | 5.11 | 4.93 | 2 | 10 | 11 | 7 |
| TRFK 303/999 | 4.73 | 5.20 | 5.59 | 5.17 | 5 | 4 | 6 | 4 |
| TRFK 303/1199 | 4.25 | 4.80 | 5.18 | 4.74 | 11 | 12 | 10 | 12 |
| TRFK 2XI/4 | 4.45 | 4.50 | 4.78 | 4.58 | 9 | 15 | 18 | 15 |
| Mean site | 4.36 | 4.81 | 5.25 | | | | | |
| CV (%) | | 9.53 | | | | | | |
| LSD, $p \leqslant 0.05$) | | 0.17 | | 0.43 | | | | |

**Table 4**
Response of clonal black tea liquor brightness (%) and their relative ranking in different growing environments.

| Clone | Brightness (%) | | | | Ranking | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | | | Mean clones | Site | | | Mean clones |
| | Timbilil | Kipkebe | Kangaita | | Timbilil | Kipkebe | Kangaita | |
| TRFK 6/8 | 29.50 | 30.75 | 34.03 | 31.43 | 3 | 3 | 1 | 2 |
| TRFK 31/8 | 26.48 | 32.93 | 27.71 | 29.04 | 12 | 1 | 17 | 7 |
| AHP S15/10 | 23.21 | 25.66 | 25.36 | 24.74 | 20 | 14 | 18 | 19 |
| EPK TN 14-3 | 29.17 | 25.44 | 31.83 | 28.81 | 5 | 16 | 6 | 8 |
| BBK 35 | 29.05 | 25.82 | 30.38 | 28.41 | 6 | 13 | 11 | 11 |
| TRFK 54/40 | 32.17 | 32.03 | 31.21 | 31.80 | 1 | 2 | 8 | 1 |
| TRFK 12/12 | 27.42 | 25.47 | 31.01 | 27.97 | 11 | 15 | 10 | 12 |
| TRFK 12/19 | 24.21 | 23.49 | 31.24 | 26.31 | 18 | 18 | 7 | 17 |
| TRFK 31/27 | 25.03 | 27.94 | 28.20 | 27.06 | 16 | 4 | 16 | 13 |
| TRFK 11/26 | 29.47 | 27.21 | 29.64 | 28.77 | 4 | 10 | 12 | 9 |
| TRFK 57/15 | 28.70 | 27.76 | 32.57 | 29.68 | 8 | 7 | 5 | 5 |
| TRFK 7/3 | 26.22 | 27.87 | 26.06 | 26.72 | 14 | 5 | 18 | 15 |
| TRFK 7/9 | 28.74 | 26.10 | 31.21 | 28.68 | 7 | 12 | 8 | 10 |
| TRFK 56/89 | 24.86 | 22.74 | 25.20 | 24.27 | 17 | 19 | 20 | 20 |
| STCK 5/3 | 26.44 | 24.60 | 28.98 | 26.67 | 13 | 17 | 14 | 16 |
| TRFK 303/259 | 23.99 | 27.80 | 29.23 | 27.00 | 19 | 6 | 13 | 14 |
| TRFK 303/577 | 28.39 | 27.25 | 33.40 | 29.68 | 10 | 9 | 2 | 4 |
| TRFK 303/999 | 28.47 | 27.03 | 32.61 | 29.37 | 9 | 11 | 4 | 6 |
| TRFK 303/1199 | 30.75 | 27.68 | 32.64 | 30.36 | 2 | 8 | 3 | 3 |
| TRFK 2XI/4 | 25.11 | 21.87 | 28.54 | 25.17 | 15 | 20 | 15 | 18 |
| Mean site | 27.37 | 26.87 | 30.05 | | | | | |
| CV (%) | | 11.70 | | | | | | |
| LSD, $p \leqslant 0.05$) | | 1.19 | | 1.48 | | | | |

varied at different sites. Thus a genotype with high quality potential in one site does not necessarily maintain the relative quality at a different site.

The results have significant implications for tea quality. In many tea countries, growers seek new tea varieties for planting to boost the quality of their teas. It had been assumed that relative and/or absolute quality of the cultivars in the areas of selection would be maintained in any new area of planting. The results presented here demonstrate that there are variations in both relative and absolute black tea quality of genotypes, due to planting in different geographical areas, even within one country where climatic variations are considered minimal. Thus cultivars for new areas should undergo further quality evaluation for confirmation of quality.

In early studies, using the same clones, it was demonstrated that within a 10-km radius yields (Obaga et al., 1989; Squire et al., 1993) declined and quality (Owuor et al., 1990) improved linearly with rise in altitude. These results suggested that the changes in quality with environmental growth conditions may be occurring in a predictable way. In this study, the individual parameters were regressed using data from different sites. The regression coefficients ($r^2$) of the linear correlations are presented in Table 7. There were poor relationships between the individual attributes

**Table 5**
Response of clonal black tea to Taster B sensory evaluation and their relative ranking in different growing environments.

| Clone | Taster B sensory evaluation | | | | Ranking | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | | | Mean clones | Site | | | Mean clones |
| | Timbilil | Kipkebe | Kangaita | | Timbilil | Kipkebe | Kangaita | |
| TRFK 6/8 | 18.0 | 20..3 | 19.3 | 19.2 | 4 | 1 | 7 | 2 |
| TRFK 31/8 | 17.7 | 16.3 | 19.0 | 17.7 | 7 | 15 | 12 | 14 |
| AHP S15/10 | 15.3 | 16.3 | 17.7 | 16.4 | 19 | 15 | 19 | 19 |
| EPK TN 14-3 | 17.7 | 15.7 | 19.0 | 17.4 | 7 | 18 | 12 | 16 |
| BBK 35 | 17.7 | 19.0 | 19.7 | 18.8 | 7 | 3 | 4 | 5 |
| TRFK 54/40 | 17.0 | 18.3 | 19.3 | 18.2 | 17 | 8 | 7 | 10 |
| TRFK 12/12 | 18.7 | 19.7 | 19.7 | 19.3 | 2 | 2 | 4 | 1 |
| TRFK 12/19 | 17.3 | 17.0 | 19.3 | 17.9 | 12 | 14 | 7 | 13 |
| TRFK 31/27 | 14.3 | 15.3 | 18.3 | 16.0 | 20 | 20 | 17 | 20 |
| TRFK 11/26 | 17.3 | 18.0 | 19.3 | 18.2 | 12 | 10 | 7 | 10 |
| TRFK 57/15 | 19.3 | 17.3 | 19.3 | 18.7 | 1 | 11 | 7 | 7 |
| TRFK 7/3 | 18.7 | 18.7 | 18.7 | 18.7 | 2 | 6 | 16 | 7 |
| TRFK 7/9 | 17.3 | 16.3 | 18.0 | 17.2 | 12 | 15 | 18 | 17 |
| TRFK 56/89 | 17.3 | 15.7 | 17.7 | 16.9 | 12 | 18 | 19 | 18 |
| STCK 5/3 | 16.7 | 17.3 | 19.0 | 17.7 | 18 | 11 | 12 | 14 |
| TRFK 303/259 | 18.0 | 19.0 | 20.3 | 19.1 | 4 | 3 | 2 | 3 |
| TRFK 303/577 | 17.7 | 18.7 | 20.0 | 18.8 | 7 | 6 | 3 | 5 |
| TRFK 303/999 | 18.0 | 18.3 | 19.0 | 18.4 | 4 | 8 | 12 | 9 |
| TRFK 303/1199 | 17.3 | 19.0 | 21.0 | 19.1 | 12 | 3 | 1 | 3 |
| TRFK 2XI/4 | 17.7 | 17.3 | 19.7 | 18.2 | 7 | 11 | 4 | 10 |
| Mean site | 17.5 | 17.7 | 19.2 | | | | | |
| CV (%) | | 11.77 | | | | | | |
| LSD, $p \leqslant 0.05$) | | 1 | | 2 | | | | |

**Table 6**
Response of clonal black tea to Taster A sensory evaluation and their relative ranking in different growing environments.

| Clone | Taster A sensory evaluation | | | | Ranking | | | |
|---|---|---|---|---|---|---|---|---|
| | Site | | | Mean clones | Site | | | Mean clones |
| | Timbilil | Kipkebe | Kangaita | | Timbilil | Kipkebe | Kangaita | |
| TRFK 6/8 | 96.7 | 61.0 | 62.3 | 73.3 | 5 | 8 | 6 | 6 |
| TRFK 31/8 | 78.0 | 57.7 | 79.7 | 71.8 | 11 | 10 | 3 | 7 |
| AHP S15/10 | 74.3 | 37.7 | 40.3 | 50.8 | 12 | 19 | 15 | 18 |
| EPK TN 14-3 | 93.7 | 58.3 | 47.0 | 66.3 | 7 | 9 | 13 | 8 |
| BBK 35 | 92.0 | 75.0 | 56.7 | 74.6 | 8 | 2 | 7 | 5 |
| TRFK 54/40 | 113.7 | 48.7 | 72.3 | 78.2 | 2 | 15 | 4 | 4 |
| TRFK 12/12 | 110.3 | 51.7 | 87.7 | 83.2 | 3 | 13 | 1 | 2 |
| TRFK 12/19 | 60.1 | 47.0 | 48.3 | 51.8 | 17 | 17 | 11 | 16 |
| TRFK 31/27 | 53.3 | 45.7 | 38.0 | 45.7 | 19 | 18 | 17 | 20 |
| TRFK 11/26 | 49.3 | 51.7 | 52.3 | 51.1 | 20 | 13 | 8 | 17 |
| TRFK 57/15 | 120.3 | 71.7 | 69.3 | 87.1 | 1 | 3 | 5 | 1 |
| TRFK 7/3 | 68.7 | 53.7 | 47.3 | 56.6 | 15 | 11 | 12 | 13 |
| TRFK 7/9 | 59.0 | 62.0 | 38.7 | 53.1 | 18 | 7 | 16 | 15 |
| TRFK 56/89 | 79.7 | 53.0 | 19.0 | 50.6 | 9 | 12 | 20 | 19 |
| STCK 5/3 | 73.3 | 36.7 | 50.7 | 53.6 | 13 | 20 | 9 | 14 |
| TRFK 303/259 | 66.7 | 68.7 | 36.7 | 57.3 | 16 | 4 | 18 | 12 |
| TRFK 303/577 | 96.3 | 65.7 | 87.7 | 83.1 | 6 | 6 | 1 | 3 |
| TRFK 303/999 | 71.3 | 81.7 | 43.0 | 65.3 | 14 | 1 | 14 | 9 |
| TRFK 303/1199 | 98.3 | 66.7 | 30.7 | 65.2 | 4 | 5 | 19 | 10 |
| TRFK 2XI/4 | 79.0 | 47.7 | 49.3 | 58.7 | 10 | 16 | 10 | 11 |
| Mean site | 81.7 | 57.1 | 53.9 | | | | | |
| CV (%) | | 58.36 | | | | | | |
| LSD, $p \leqslant 0.05$) | | 29.3 | | NS | | | | |

**Table 7**
Regression coefficients ($r^2$) of linear regression analyses between same parameters in different regions.

| Item | Timbilil | Kipkebe | Kangaita |
|---|---|---|---|
| *Theaflavins* | | | |
| Timbilil | – | | |
| Kipkebe | 0.3149 | – | |
| Kangaita | 0.5250 | 0.5665 | – |
| Mean | 0.6864 | 0.7261 | 0.9180 |
| *Thearubigins* | | | |
| Timbilil | – | | |
| Kipkebe | 0.4340 | – | |
| Kangaita | 0.2329 | 0.1303 | – |
| Mean | 0.7537 | 0.7074 | 0.5383 |
| *Total colour* | | | |
| Timbilil | – | | |
| Kipkebe | 0.3768 | – | |
| Kangaita | 0.3996 | 0.5863 | – |
| Mean | 0.6928 | 0.8292 | 0.8203 |
| *Chemical brightness* | | | |
| Timbilil | – | | |
| Kipkebe | 0.2126 | – | |
| Kangaita | 0.4668 | 0.0562 | – |
| Mean | 0.7760 | 0.5281 | 0.6247 |
| *Tasters B evaluation* | | | |
| Timbilil | – | | |
| Kipkebe | 0.3425 | – | |
| Kangaita | 0.2563 | 0.4886 | – |
| Mean | 0.6272 | 0.7341 | 0.5905 |
| *Tasters A evaluation* | | | |
| Timbilil | – | | |
| Kipkebe | 0.0120 | – | |
| Kangaita | 0.3002 | 0.0009 | – |
| Mean | 0.6964 | 0.1234 | 0.7001 |
| *Tasters A briskness* | | | |
| Timbilil | – | | |
| Kipkebe | 0.0230 | – | |
| Kangaita | 0.2458 | 0.0043 | – |
| Mean | 0.6375 | 0.2207 | 0.6660 |
| *Tasters A brightness* | | | |
| Timbilil | – | | |
| Kipkebe | 0.0523 | – | |
| Kangaita | 0.2230 | 0.0006 | – |
| Mean | 0.6838 | 0.2003 | 0.6190 |
| *Tasters A colour* | | | |
| Timbilil | – | | |
| Kipkebe | 0.0004 | – | |
| Kangaita | 0.2360 | 0.0045 | – |
| Mean | 0.5429 | 0.2494 | 0.5586 |
| *Tasters A thickness* | | | |
| Timbilil | – | | |
| Kipkebe | 0.005 | – | |
| Kangaita | 0.2405 | 0.0063 | – |
| Mean | 0.5289 | 0.2912 | 0.6057 |
| *Tasters A infusion* | | | |
| Timbilil | – | | |
| Kipkebe | 0.0001 | – | |
| Kangaita | 0.3001 | 0.0199 | – |
| Mean | 0.6659 | 0.0883 | 0.6683 |

correlated from different sites. The results demonstrate that the parameters were not closely related and were not changing in the same way within the different genotypes at various sites. Indeed, for the lack of significant interactions observed earlier between sites and genotypes, the variations of the parameters in different genotypes with sites appeared sporadic. This suggests that although there were changes in the individual parameters at different locations, the pattern of the changes varied with genotypes. Thus extent of changes in one genotype cannot be used to predict how the other genotypes will react to different environments. Similar results were recently obtained due to the effects of the environment on plucking intervals (Owuor et al., 2009). This study demonstrates that re-evaluation of plants in new locations of intended release, although costly and time-consuming is the only sure method of ensuring production of high quality black teas.

The results presented herein are not surprising since tea responds differently to different growing environments (Balasuriya, 1999; Ng'etich et al., 2001; Wachira et al., 2002; Wickremaratne, 1981) due to several factors, including soil types, soil fertility (Bonheure & Willson, 1992, chap. 9), temperatures (Tanton, 1982), rainfall and rainfall distribution (Othieno et al., 1992) and altitudes (Squire et al., 1993). Again, the tea-growing areas in Kenya normally suffer from sporadic hail damage (Ng'etich & Stephens, 2001a, 2001b; Ng'etich et al., 2001; Othieno et al., 1992; Stephens, Othieno, & Carr, 1992). The modes and extents of variations in response to these factors vary with cultivars. The tea cultivars received similar equal amounts of fertilisers thus reducing possible soil fertility differences. The other factors were not monitored in this study, but they are usually variable and uncontrollable, and might have been responsible for the variations observed herein.

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## References

Aisaka, H., Kosuge, M., & Yamanishi, T. (1978). Comparison of Chinese "Keemum" black tea and Ceylon black tea. *Agriculture and Biological Chemistry, 44*, 2157–2159.

Anonymous (2002). *Tea growers handbook* (5th ed.). Tea Research Foundation of Kenya.

Anonymous (2008). *Annual Bulletin of Statistics*. International Tea Committee.

Balasuriya, J. (1999). Shoot population density and shoot weight of clonal tea (*Camellia sinensis*) at different altitudes in Sri Lanka. *European Journal of Agronomy, 11*, 123–130.

Biswas, A. K., Biswas, A. K., & Sarkar, A. R. (1971). Biological and chemical factors affecting the evaluations of North East India plain teas. II. Statistical evaluation of the biochemical constituents and their effects on briskness, quality and cash valuation of black teas. *Journal of the Science and Food Agriculture, 22*, 191–198.

Biswas, A. K., Sarkar, A. R., & Biswas, A. K. (1973). Biological and chemical factors affecting the valuations of North East India planters. III. Statistical evaluation of the biochemical constituents and their effects on colour, brightness, and strength of black teas. *Journal of the Science and Food Agriculture, 24*, 1457–1477.

Bonheure, D., & Willson, K. C. (1992). Mineral nutrition and fertilisers. In K. C. Willson & M. N. Clifford (Eds.), *Tea: Cultivation to consumption* (pp. 269–329). USA: Chapman and Hall.

Borse, B. B., Rao, L. J. M., Nagalakshmi, S., & Krishnamurthy, N. (2002). Fingerprint of black teas from India: Identification of the regio-specific characteristics. *Food Chemistry, 79*, 419–424.

Carr, M. K. V. (1997). Response of seedling tea bushes and their clones to water stress. *Experimental Agriculture, 13*, 317–324.

Carr, M. K. V., & Stephens, W. (1992). Climate, weather and yield of tea. In K. C. Willson & M. N. Clifford (Eds.), *Tea: Cultivation to Consumption* (pp. 87–115). London: Chapman & Hall.

Herath, D., & Weersink, A. (2007). Peasants and plantations in the Sri Lanka tea sector: Causes of change in their relative viability. *Australian Journal of Agricultural Resource Economics, 51*, 73–89.

Hilton, P. J. (1973). Tea. In F. D. Snell & L. S. Ettre (Eds.). *Encyclopedia of Industrial Chemical Analysis* (Vol. 18, pp. 453–516). New York, USA: John Wiley.

Horita, H., & Owuor, P. O. (1987). Comparison and characterisation of volatile components of Kenyan clonal black teas and various black teas from other producing areas of the world. *Bulletin of the National Research Institute of Vegetables, Ornamental Plants and Tea, (Japan), 1*(B), 55–65.

Jin, C. W., Du, S. T., Zhang, K., & Lin, X. Y. (2008). Factors determining copper concentration in tea leaves produced at Yuyao County, China. *Food and Chemical Toxicology, 46*, 2054–2061.

Kamunya, S. M. (2003). Tea improvement: Strides, constraints and opportunities. *Tea, 24*, 38–47.

Lopez, S. J., Thomas, J., Pius, P. K., Kumar, R. R., & Muraleedharan, N. (2005). A reliable technique to identify superior quality clones from tea germplasm. *Food Chemistry, 91*, 771–778.

Mahanta, P. K., Baruah, S., Owuor, P. O., & Murai, T. (1988). Flavour volatiles of Assam CTC Black Teas manufactured from different plucking standards and orthodox teas manufactured from different altitudes of Darjeeling. *Journal of the Science and Food Agriculture, 45*, 317–324.

Ng'etich, W. K., & Stephens, W. (2001a). Responses of tea to environment in Kenya. 1. Genotype 6 environment interactions for total dry matter production and yield. *Experimental Agriculture, 37*, 333–342.

Ng'etich, W. K., & Stephens, W. (2001b). Responses of tea to environment in Kenya. 2. Dry matter production and partitioning. *Experimental Agriculture, 37*, 343–360.

Ng'etich, W. K., Stephens, W., & Othieno, C. O. (2001). Responses of tea to environment in Kenya. 3. Yield and yield distribution. *Experimental Agriculture, 37*, 361–372.

Njuguna, C. K. (1984). Advances in tea breeding in some of the major tea producing countries – A review. *Tea, 5*(2), 18–27.

Obaga, S. O., Othieno, C. O., & Lang'at, J. K. (1989). Observations on the effect of altitude on yield attributes of some tea clones – Growth and density of shoots. *Tea, 10*, 73–79.

Othieno, C. O., Stephens, W., & Carr, M. K. V. (1992). Yield variability at the Tea Research Foundation of Kenya. *Agricultural and Forest Meteorology, 61*, 237–252.

Owuor, P. O., Kamau, D. M., & Jondiko, E. O. (2009). Response of clonal tea to location of production and plucking intervals. *Food Chemistry, 115*, 290–296.

Owuor, P. O., Obaga, S. O., & Othieno, C. O. (1990). Effects of altitude on the chemical composition of black tea. *Journal of the Science of Food and Agriculture, 50*, 9–17.

Owuor, P. O., & Obanda, M. (1996). Comparing the aroma quality of some Kenyan clonal black tea with black teas from various parts of the world. *Journal of Food Agriculture and Technology in Africa, 1*, 12–15.

Owuor, P. O., & Obanda, M. (2007). The use of green tea (*Camellia sinensis*) leaf flavan-3-ol composition in predicting plain black tea quality potential. *Food Chemistry, 100*, 873–884.

Owuor, P. O., Obanda, M., Apostolides, Z., Wright, L. P., Nyirenda, H. E., & Mphangwe, N. I. K. (2006). The relationship between the chemical plain black tea quality parameters and black tea colour, brightness and sensory evaluation. *Food Chemistry, 97*, 644–653.

Owuor, P. O., Obanda, M., Nyirenda, H. E., & Mandala, W. L. (2008). Influence of region of production on clonal black tea chemical characteristics. *Food Chemistry, 108*, 263–271.

Owuor, P. O., Reeves, S. G., & Wanyoko, J. K. (1986). Correlation of theaflavins content and valuation of Kenya black teas. *Journal of the Science of Food and Agriculture, 37*, 507–513.

Owuor, P. O., Tsushida, T., Horita, H., & Murai, T. (1986). Comparison of the chemical composition of black teas from main tea producing parts of the world. *Tea, 7*, 71–78.

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

Sahin, Y., Nas, S., & Gökalp, H. Y. (1991). Effect of shooting period, region of growth and processing method on the Fe and Mn content of tea determined by X-ray fluorescence. *International Journal of Food Science and Technology, 26*, 485–492.

Seurei, P. (1997). Tea Improvement in Kenya: Progress, constraints and prospects. *Tea, 18*, 87–100.

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

Shu, W. S., Zhang, Z. Q., Lan, C. Y., & Wong, M. H. (2003). Fluoride and aluminium concentrations of tea plants and tea products from Sichuan Province, PR China. *Chemosphere, 52*, 1475–1482.

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

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

Tanton, T. W. (1982). Environmental factors affecting yield of tea (*Camellia sinensis* L.): Effects of air temperature. *Experimental Agriculture, 18*, 47–52.

Wachira, F. N., Ng'etich, S. M. O., Obaga, S. M. O., & Othieno, C. O. (1990). Genotype × environment interactions and genotypic stability in tea. A preliminary indication. *Tea, 11*, 51–57.

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

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

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

Yao, L., Jiang, Y., Datta, N., Singanusong, R., Liu, X., Duan, J., et al. (2004). HPLC analyses of flavanols and phenolic acids in the fresh young shoots of tea (*Camellia sinensis)* grown in Australia. *Food Chemistry, 84*, 253–263.

Yamanishi, T., Kobayashi, A., Nakamura, H., Uchida, A., Mori, S., Ohsawa, K., et al. (1968). Flavour of black tea. V. Comparison of various black teas. *Agriculture and Biological Chemistry, 32*, 379–386.