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Full Length Research Paper

Selection within *Coffea arabica* cv. Ruiru 11 for high cup quality

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In recent years, consumer awareness about the quality of different coffees has increased and therefore production and supply of coffee with excellent quality attach more significance. As a result, many coffee producing countries include coffee quality assessment in their coffee variety development programmes. The present study was undertaken to evaluate the variation of cup quality traits and determine their associations with each other and with overall cup quality among the sibs of *Coffea arabica* L. cultivar Ruiru 11. In addition, the study targeted to select specific Ruiru 11 sibs with superior cup quality and wide adaptability based on assessment of 7 traits including fragrance, flavor, aftertaste, acidity, body, balance, preference and their total score. Thirty four full-sib families representing this hybrid cultivar grown in three different agro climatic zones of Kenya were used for the study. Rainfall amounts during various phases of berry development were used to explain the differences observed in the discriminating abilities of the locations for cup quality traits. The results showed that Ruiru 11 sibs were highly variable in all the cup quality traits except body. Site variations were also highly significant and the sibs were best differentiated in the sites where moderate moisture stress occurred during bean expansion and filling stages. Genotype by environment (G × E) interactions, were observed for all the traits except body. A highly significant positive correlation was registered between all traits. The study also demonstrated the existence of a high variation in cup quality among Ruiru 11 sibs. The most widely adapted Ruiru 11 sibs were identified to be R11-52, R11-117, R11-131, R11-107, R11-121, R11-11, R11-137 and R11-22.

Key words: Arabica coffee, Ruiru 11 sibs, site variations, correlation coefficients, Kenya.

INTRODUCTION

The cultivar Ruiru 11 is a composite of about 60 F1 hybrid sibs each derived from a cross between a specific female and male population (Omondi et al., 2001). The male parents are outstanding selections from a multiple cross programme involving Coffee Berry Disease (CBD) resistant donor parents such as Rume Sudan (R gene), Hibrido de Timor (T gene), K7 (k gene), and the high yielding, good quality but susceptible cultivars such as N39, SL28, SL34, Bourbon and SL4 (Omondi et al., 2000). The female parents are advanced generations (F3, F4 and F5) of the cultivar Catimor from Colombia, which has Hibrido de Timor clone 1343/269 as one parent (Omondi et al., 2000). The cultivar was developed at the Coffee Research Station, Ruiru, Kenya, and released to growers in 1985 (Gichimu and Omondi, 2010). It combines resistance to major diseases of coffee (Coffee Berry Disease and Coffee Leaf Rust) with high yield, fine quality and compact growth amenable to high density planting (Omondi et al., 2001).

Beverage quality, often referred to as liquor quality is an important attribute of coffee and acts as yardstick for price determination (Muschler, 2001; Agwanda et al., 2003; Kathurima et al., 2009). Production and supply of coffee with excellent quality is therefore important for coffee exporting countries (Abadiga, 2010). Moreover, success of a new variety of Arabica coffee depends to a great extent on its bean and beverage quality (Agwanda et al., 2003). Consequently, many coffee producing

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countries consider assessment of coffee quality as critical as disease resistance and productivity in their coffee variety development programmes (Abadiga, 2010). Assessment of organoleptic cup quality is therefore an important step in coffee trade.

Assessment of beverage quality is done by panels of experienced coffee tasters (Agwanda et al., 2003; Kathurima et al., 2009). This method is recommended as sufficiently reliable for use as a basis of selection in quality improvement programmes. Such formal sensory evaluation can be used successfully for screening breeding selections, and may provide more reliable data than the opinions of only one or two people (Hampson et al., 2000). Kenya produces coffee that is classified within the Colombian milds known for balanced acidity and body with pleasant distinctive aroma (Omondi, 2008). These three traits are known to determine to a large extent the beverage quality of coffee (Agwanda et al., 2003). Omondi (2008) reported that the reputable quality of Kenyan coffee is as a result of favourable climatic conditions, good agronomic practices, rigorous harvesting and post-harvest practices, appropriate processing and storage conditions and cultivation of varieties with proven genetic constitution.

New Arabica coffee cultivars with better quality, higher yield potential and resistance to diseases have started to replace the traditional varieties on a large scale in several countries (Van der Vossen, 2001). A good example of such cultivars is Ruiru 11. Despite its various agronomic advantages, Ruiru 11 present significant variability in terms of quality (Ojijo, 1993). Kathurima et al. (2010) also reported great variability in beverage quality among Ruiru 11 sibs although certain sibs presented beverage quality comparable to the standard cultivar, SL28. However, other scientists reported that the raw bean and liquor qualities of the cultivar Ruiru 11 is virtually similar to that of Kenyan traditional varieties (Owuor, 1988; Njoroge et al., 1990; Omondi, 2008). The major source of disease resistance in Ruiru 11 comes from *C. canephora* introgressed mainly through Timor Hybrid either directly or through Catimor (Omondi et al., 2001). Robusta coffee has relatively poor bean and beverage quality, and therefore its genome introgression is expected to affect beverage quality in Ruiru 11 and related families. The varying parentage of Ruiru 11 sibs is also suspected of contributing to the reported variation in quality.

It is important to note that genetic consistency within varieties is essential to quality assurance for any agricultural product (Hue, 2005). Further selection within Ruiru 11 cultivar for beverage quality is therefore desirable. However, selection for quality traits in Arabica coffee is constrained by the prevalence of large genotype by environment (G × E) interactions together with low genetic variability within the species (Agwanda et al., 2003). The aim of this study was to evaluate the variation of cup quality traits and determine their associations in a population of Ruiru 11 sibs. In addition, the study targeted to select specific Ruiru 11 sibs with superior cup quality. Besides the genetic differences, the growing environment has a strong effect on quality (Omondi, 2008), hence the need for multi-site studies.

MATERIALS AND METHODS

Description of study sites

The study was conducted in three different agro-ecological zones in Kenya namely Mariene in Meru County, Kisii near Kisii town in Kisii County and Koru in Kericho County. Mariene is located at 0° N, 37° 35′ E, at an elevation of 1524 m above sea level. The soils are ando-humic acrisols, friable clays, strongly acidic, very low in bases and moderate in organic matter. Koru is located at 0° 07′ S, 35° 16′ E and has an elevation of 1554 m above sea level. The soils are eutric nitosols, friable clays, and weakly acidic to neutral, rich in bases, available phosphorous and moderate inorganic matter. Kisii is located at 0° 41′ S, 34° 47′ E at 1700 m above sea level. The soils are molic nitosols, friable clays with acidic pH, low to moderate bases and are high in organic matter. The experimental plots in Koru and Kisii were previously established in April 1990, while the Meru plot was established in April 1991. All the plots have undergone change of cycle twice. Other agronomic practices including, weeding, pest and disease control, fertilizer application and pruning were carried out as recommended.

Test materials and field layout

Thirty four Ruiru 11 sibs (Table 1) were evaluated in this study alongside two entries of SL28 used as checks. One entry of SL28 was sprayed with copper fungicides to control Coffee Berry Disease (CBD) and Coffee Leaf Rust (CLR), while the other SL28 entry was not sprayed with any fungicides. All the sites were laid out in a Randomized Complete Block Design (RCBD) with three replications. Planted at a spacing of 2 m × 2 m, each entry had 12 trees per plot per rep, giving a total of 1296 plants per experiment per site. Samples were taken from all the twelve trees and bulked to give one sample per rep.

Processing of the coffee cherry samples

Coffee cherry samples were picked during the peak harvesting period of May to July both in 2010 and 2011 in all the three sites. The ripe cherries were weighed, bulked, pulped, fermented, washed and the wet parchment dried to final moisture content of 10.5 to 11%. The parchment was then hulled and graded to seven grades based on size, shape and density as follows: AA – Heavy beans retained by 7.15 mm screen; AB – Heavy beans retained by 5.95 mm screen; TT – Light beans separated from AA and AB using Pneumatic separator; PB – Beans retained by a piano wire screen with 4.43 mm spaces; C – Beans retained by a piano wire screen with 2.90 mm spaces; T – Very small beans and broken bits; E – Elephant beans which are the largest coffee beans resulting from two coffee seeds in one cherry joining together (a genetic defect). Only the premium grades (AA and AB) were used for cup quality evaluation.

Roasting and sensory evaluation

Roasting of the green coffee was done to attain a medium roast using a Probat laboratory roaster within 24 h of evaluation and allowed to rest for at least 8 h. The samples were weighed before and after roasting to determine the uniformity of roasting. The

Table 1. The pedigree of the 34 Ruiru 11 sibs evaluated.

Male parent	Female parent						
	Cat.86	**Cat.88**	**Cat.90**	**Cat.124**	**Cat.127**	**Cat.128**	**Cat.134**
SL34 × [(SL34 × RS) HT]	-	-	-	135	-	137	-
SL28 × [(SL28 × RS) (B × HT)]	1, 11, 41	22, 42	3, 23	5	6	7	50
SL28 × [(N39 × HT) (SL4 × RS)]	71	72	-	-	-	-	80
SL28 × [(K7 × RS) (SL34 × HT)]	-	52	-	-	-	-	-
SL28 × [(SL34 × RS) HT]	91, 111, 121, 131	112,142	93, 103, 123, 143	105, 115, 125	106	107, 117	100

Key: RS = Rume sudan, HT = Hibrido de Timor, B = Bourbon.

samples were ground immediately after roasting using a laboratory grinder (Probat- Type 55 LM 1500). A rinsing quantity of every sample was run through the grinder before grinding the test sample. Each sib was ground individually and deposited into the cupping cups, ensuring that the whole and consistent quantity of sample gets deposited into each cup (five cups per sample). The ground samples were then infused in hot water using a predetermined ratio of 8.25 g per 150 ml of water prior to cupping. Sensory evaluation procedure described by Lingle (2001) was followed. Seven sensory variables namely: fragrance, flavour, aftertaste, acidity, body, balance and preference, were assessed by a trained panel of seven and rated on a 10-point scale as follows: 1 = very poor and 10 = outstanding for the attributes fragrance/aroma, flavor, aftertaste, balance and preference; 1 = very flat and 10 = very bright for acidity; and 1 = very thin and 10 = very heavy for body. An overall score (total score) was calculated as the sum of all the seven variables plus 30 points that are normally added to adjust the final score to a 100-point basis.

Data analysis

The sensory data were subjected to Analysis of Variance (ANOVA) using COSTAT statistical software and effects declared significant at 5% level. Separate as well as combined analysis of variance was performed on data from all sites. Student-Newman-Keuls ($SNK_{5\%}$) test was used to separate the means. In order to determine the association between the quality traits, linear correlation was done to compare their relationship with each other. Discriminant Function Analysis (DFA) was conducted using XLSTAT 2011 to test whether cup quality could be used to discriminate different Ruiru 11 sibs according to agro-ecological zone.

RESULTS

Rainfall was recorded in all the three sites for the two seasons at various berry development stages (Table 2). Analysis of variance (ANOVA) showed that Ruiru 11 sibs consistently recorded highly significant differences among them for all the traits except body (which consistently recorded non significant [$p > 0.05$] differences) and in a few instances, fragrance and aftertaste. This was an indication that the sibs were well differentiated at all sensory traits except body (Table 3). The presence of highly significant variations among sibs for most of the sensory traits indicated unexpectedly high genetic variation between sibs. Site variations were also highly significant ($p < 0.001$) except for fragrance and body in 2011 and aftertaste in 2010. Likewise, site × sib (G × E) interactions were highly significant ($p < 0.001$) for all the traits except body (Table 3).

Discriminant Factor Analysis (DFA) grouped the genotypes according to the three locations based on the traits as shown in Figure 1. Locational variations were more pronounced in 2010 than in 2011. Factor 1 explained 80.67 and 84.15% of the total variation while Factor 2 explained the remaining 19.33 and 15.85% variation in 2010 and 2011, respectively. In 2010, Mariene site recorded relatively lower means for all the variables that most contributed to F1 axes (Table 4) and was therefore plotted on the left side of the DFA plot while Koru site was plotted on the right side (Figure 1). Kisii site, on the other hand, was plotted at the middle but on the upper side of the DFA plot (Figure 1) because it recorded relatively higher means for all the variables that most contributed to both axes (Table 4). Kisii site therefore recorded the best cup quality in 2010, followed by Koru. In 2011, Kisii site was plotted almost at the same position as in 2010 (Figure 1). Mariene site emerged the best site in 2011 followed very closely by the Kisii site. The latter two sites were therefore plotted close together as they contributed almost equally to both axes (Table 4). Unlike the two, Koru (Figure 1) recorded relatively lower means for all the variables that most contributed to F1 axes (Table 4) hence it was plotted on the left side of the DFA plot.

All the sibs evaluated had an overall score of more than 82 points with some recording better quality than SL28 (Table 5). In all the three sites, SL28 sprayed with fungicide recorded better quality than the unsprayed SL28 in absolute terms. At Kisii site, the cup quality of 20 Ruiru 11 sibs was not significantly different ($p > 0.05$) from that of SL28 sprayed while 24 Ruiru 11 sibs recorded cup quality similar ($p > 0.05$) to that of SL28 unsprayed. At Koru site, R11-91 and R11-137 produced significantly ($p < 0.05$) better quality than SL28 sprayed whose quality was not significantly different from that of another 29 Ruiru 11 sibs. SL28 unsprayed recorded the lowest quality at Koru site on absolute terms though statistically similar ($p > 0.05$) to that of 12 Ruiru 11 sibs. At Mariene, SL28 sprayed gave the best cup quality which was not significantly different from that of SL28

Table 2. Rainfall in mm received at the three locations at different berry development stages.

Stages	Flowering	Pinhead	Berry expansion				Filling		Ripening			Total rainfall
Month	Sept 2009	Oct 2009	Nov 2009	Dec 2009	Jan 2010	Feb 2010	Mar 2010	Apr 2010	May 2010	Jun 2010	Jul 2010	
Kisii	160.3	86.2	151.7	305.5	49.8	99.6	203.4	233.7	406.8	202.4	79.6	1979.0
Koru	176.6	89.1	106.2	343.0	102.8	215.5	211.8	163.4	258.9	140.6	132.0	1939.9
Mariene	3.0	303.8	420.5	194.7	192.9	118.7	348.4	504.2	121.1	5.8	3.7	2216.8
Month	Sept 2010	Oct 2010	Nov 2010	Dec 2010	Jan 2011	Feb 2011	Mar 2011	Apr 2011	May 2011	Jun 2011	Jul 2011	Total rainfall
Kisii	292.1	213.8	109.1	188.5	97.5	42.5	138.5	237.2	267.8	91.6	100.5	1779.1
Koru	89.0	170.5	80.0	163.3	67.7	88.0	177.5	60.3	198.5	138.4	77.4	1310.6
Mariene	1.4	181.8	370.5	30.6	49.0	22.8	52.8	252.5	148.4	15.6	7.2	1132.6

Table 3. Multi-site analysis of variance for cup quality traits.

Traits	Sib variations								Site variations		Site × Sib interactions	
	Mariene		Koru		Kisii		Combined					
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Fragrance	0.000***	0.002**	0.000***	0.275ns	0.029*	0.014*	0.000***	0.002**	0.000***	0.837ns	0.000***	0.017*
Flavour	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
Aftertaste	0.072ns	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.520ns	0.000***	0.000***	0.000***
Acidity	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
Body	0.003**	0.081^{ns}	0.393^{ns}	0.131^{ns}	0.535^{ns}	0.596^{ns}	0.069^{ns}	0.096^{ns}	0.000***	0.122^{ns}	0.218^{ns}	0.221^{ns}
Balance	0.000***	0.000***	0.000***	0.001***	0.014*	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
Preference	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
Total Score	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***	0.000***
DF	35	35	35	35	35	35	35	35	2	2	70	70

unsprayed and 6 Ruiru 11 sibs. The quality of SL28 unsprayed at Mariene site was similar ($p > 0.05$) to that of 22 Ruiru 11 sibs (Table 5). In general, the cup quality of SL28 was therefore comparable to that of Ruiru 11.

The best performing sibs per location are shown in Table 6. The most suited sibs for Koru site which recorded excellent cup quality in both seasons were found to be R11-91, R11-137, R11-80, R11-142, R11-107, R11-115, R11-135 and R11-117. For Kisii, the best performing sibs were R11-52, R11-7, R11-131, R11-6, R11-1, R11-117 and R11-137. For Mariene, R11-52 was still the best overall followed by R11-22, R11-3, R11-121, R11-135, R11-100 and R11-11. Although R11-1 was the worst overall sib in 2010, it surprisingly recorded the best overall cup quality in 2011. However, the rest of the aforementioned sibs consistently recorded good cup quality with a total score of more than 83.

The most widely adapted sibs which performed

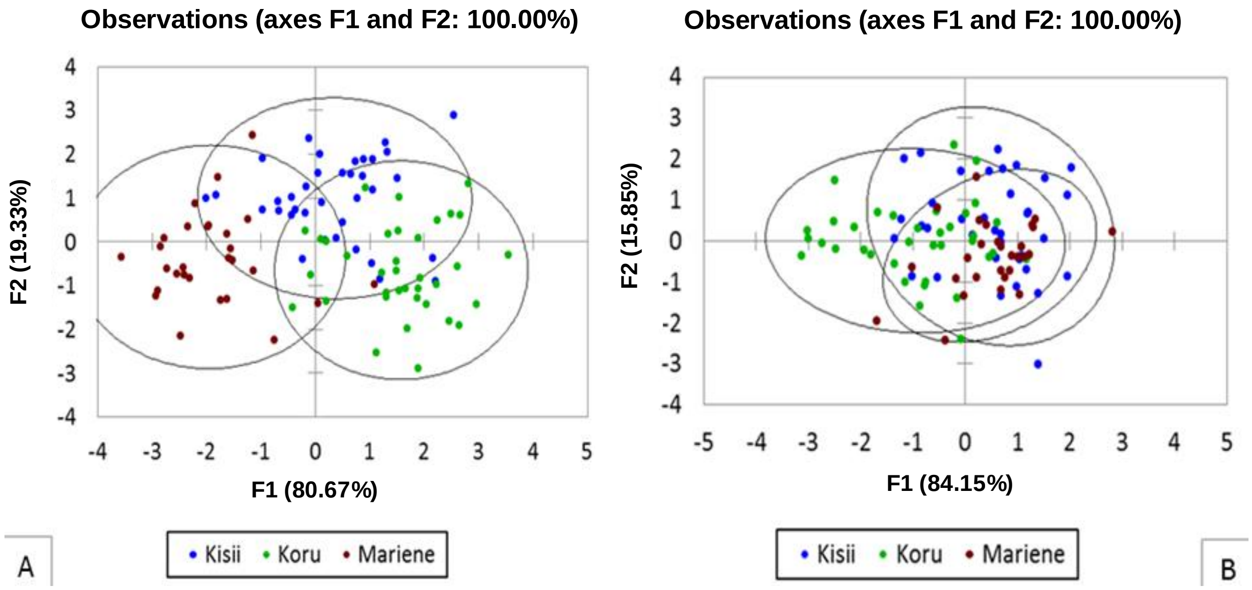

Figure 1. Discriminant factor analysis (DFA) plot depicting location differences. A = 2010 Season; B = 2011 Season.

Table 4. Trait's contribution to F1 and F2 coordinates.

Traits	Variables/factor correlations				Average proportions per Trait					
	2010		2011		2010			2011		
	F1	F2	F1	F2	Kisii	Koru	Mariene	Kisii	Koru	Mariene
Fragrance	0.59	0.03	0.08	0.02	7.60	7.63	7.55	7.58	7.57	7.57
Flavor	-0.06	0.50	0.56	-0.22	7.65	7.60	7.61	7.67	7.61	7.69
Aftertaste	0.04	0.12	0.28	-0.25	7.63	7.62	7.62	7.58	7.56	7.60
Acidity	0.05	0.42	0.57	-0.33	7.75	7.71	7.71	7.68	7.62	7.71
Body	0.71	0.60	0.32	-0.05	7.71	7.69	7.62	7.62	7.60	7.62
Balance	0.46	0.01	0.61	-0.16	7.57	7.58	7.54	7.65	7.60	7.66
Preference	0.29	0.19	0.43	-0.43	7.65	7.65	7.61	7.64	7.60	7.67
Total Score	0.33	0.33	0.48	-0.26	83.56	83.47	83.25	83.42	83.15	83.51

better in varying climatic conditions are shown in Table 7. R11-52 was the best sib overall, consistently recording high quality in all sites and in both seasons. R11-117 recorded high quality in all sites in 2010 and at Koru and Kisii in 2011. R11-131 recorded high quality at Koru and Mariene in 2010 and at Kisii and Mariene in 2011 while R11-107 recorded high quality at Kisii and Mariene in 2010 and Koru and Kisii in 2011. Other sibs that consistently recorded high quality in more than one site and season are R11-121 and R11-11 at Kisii and Mariene in 2010 and Koru and Mariene in 2011. R11-137 was found to be best suited for only Koru and Kisii while R11-22 was best suited for Koru and Mariene only.

A highly significant ($p < 0.0001$) positive correlation was registered between all traits (Table 8). Higher correlations were observed in 2011 than in 2010. The traits flavor, acidity, aftertaste and balance in that order recorded the highest correlations with preference and total score.

DISCUSSION

Ruiru 11 sibs evaluated were found to differ significantly in all the sensory traits except body and in a few instances, fragrance and aftertaste. This was an indication of high genetic variation between Ruiru 11 sibs and concurred with Ojijo (1993) who reported that the composite Ruiru 11 cultivar present significant variability in terms of quality. This finding also partly agreed with Kathurima et al. (2010) who reported significant differences in fragrance, flavor, aftertaste, acidity and body among ten Ruiru 11 sibs. The three sites therefore fulfilled the condition of high genetic variances (except for body), high mean performance and high heritability which is one of the requirements for good selection and testing environment (Agwanda et al., 2003). However, on the basis of average performance, Mariene and Koru were the best selection sites in 2010 and 2011, respectively,

Table 5. Average performance of each sib per location.

Kisii				Koru				Mariene			
Rank	**Sibs**	**Overall**	**Variation**	**Rank**	**Sibs**	**Overall**	**Variation**	**Rank**	**Sibs**	**Overall**	**Variation**
1	R11-52	84.30	a	1	R11-91	84.30	a	1	SL28(S)	84.10	a
2	R11-7	84.08	ab	2	R11-137	84.13	b	2	R11-1	83.97	ab
3	R11-131	84.04	abc	3	R11-80	83.80	bc	3	R11-52	83.83	abc
4	SL28(S)	83.93	abcd	4	R11-142	83.72	bcd	4	SL28(NS)	83.79	abcd
5	R11-6	83.90	bcde	5	R11-107	83.66	cde	5	R11-22	83.77	abcd
6	R11-1	83.88	bcde	6	R11-115	83.63	cdef	6	R11-3	83.75	abcde
7	R11-117	83.84	bcdef	7	R11-135	83.56	cdefg	7	R11-121	83.71	abcde
8	SL28(NS)	83.77	bcdefg	8	SL28(S)	83.56	cdefg	8	R11-135	83.66	abcdef
9	R11-22	83.67	bcdefgh	9	R11-117	83.55	cdefg	9	R11-6	83.56	bcdef
10	R11-137	83.65	bcdefgh	10	R11-52	83.52	cdefgh	10	R11-117	83.56	bcdef
11	R11-23	83.64	bcdefgh	11	R11-125	83.52	cdefgh	11	R11-100	83.55	bcdef
12	R11-142	83.64	bcdefgh	12	R11-11	83.49	cdefgh	12	R11-123	83.49	bcdefg
13	R11-105	83.63	bcdefghi	13	R11-105	83.46	cdefgh	13	R11-80	83.49	bcdefg
14	R11-121	83.60	bcdefghi	14	R11-131	83.40	cdefghi	14	R11-11	83.48	bcdefg
15	R11-41	83.60	bcdefghi	15	R11-123	83.39	cdefghi	15	R11-131	83.46	cdefgh
16	R11-72	83.59	cdefghi	16	R11-100	83.37	cdefghi	16	R11-115	83.41	cdefgh
17	R11-11	83.57	cdefghij	17	R11-121	83.33	cdefghi	17	R11-112	83.39	cdefghi
18	R11-42	83.48	defghijk	18	R11-7	83.33	cdefghi	18	R11-7	83.39	cdefghi
19	R11-111	83.48	defghijk	19	R11-42	83.32	cdefghi	19	R11-125	83.37	cdefghi
20	R11-112	83.48	defghijk	20	R11-23	83.30	cdefghi	20	R11-143	83.34	cdefghi
21	R11-107	83.46	defghijk	21	R11-111	83.24	cdefghi	21	R11-137	83.33	cdefghi
22	R11-3	83.42	efghijk	22	R11-143	83.24	cdefghi	22	R11-72	83.32	cdefghi
23	R11-125	83.42	efghijk	23	R11-6	83.23	cdefghi	23	R11-142	83.27	defghi
24	R11-5	83.40	efghijkl	24	R11-72	83.10	defghij	24	R11-105	83.26	defghi
25	R11-100	83.34	fghijkl	25	R11-93	83.08	efghij	25	R11-107	83.23	efghi
26	R11-123	83.28	ghijklm	26	R11-71	83.08	efghij	26	R11-23	83.22	efghi
27	R11-115	83.24	hijklmn	27	R11-103	83.06	efghij	27	R11-93	83.21	efghi
28	R11-91	83.14	ijklmn	28	R11-22	83.05	efghij	28	R11-50	83.17	fghi
29	R11-50	83.13	ijklmn	29	R11-5	83.00	fghij	29	R11-91	83.15	fghi
30	R11-80	83.13	ijklmn	30	R11-50	82.94	ghij	30	R11-106	83.15	fghi
31	R11-143	83.09	jklmn	31	R11-112	82.93	ghij	31	R11-5	83.13	fghi
32	R11-93	83.07	klmn	32	R11-1	82.93	ghij	32	R11-71	82.99	ghi
33	R11-103	83.04	klmn	33	R11-41	82.89	hij	33	R11-42	82.96	ghi
34	R11-71	82.94	lmn	34	R11-106	82.82	ij	34	R11-103	82.93	hi
35	R11-106	82.87	mn	35	R11-3	82.80	ij	35	R11-111	82.88	i
36	R11-135	82.79	n	36	SL28(NS)	82.52	j	36	R11-41	82.35	j

as they consistently recorded the lowest means for all traits.

The observed variations in quality traits at different sites indicated that the growing environment has a strong effect on the expression of quality parameters. The differences were attributed to differences in edaphic and climatic conditions of the three locations. Similar results were obtained by Omondi (2008). In our study, rainfall was taken as the first most important limiting factor and thus used to explain the observed site differences. Similar approach was also applied by Agwanda et al. (2003). In the 2010 season, all the sites received adequate rainfall during berry expansion and filling but Kisii produced the best cup quality because it experienced a two month period of reduced moisture. Adequate rainfall intercepted with short periods of moisture stress during berry expansion and bean filling (the period between 6 to 24 weeks after blossoming) has been found to be favorable for cup quality. Such conditions favour the production of biochemical compounds which determine the cup quality (Agwanda et al., 2003; Van der Vossen, 2009). The scenario was totally different in 2011 when all the sites experienced reduced rainfall. This adversely affected cup quality especially at

Table 6. The best 15 Ruiru 11 sibs for the Koru, Kisii and Mariene sites.

Koru				Kisii				Mariene			
2010		2011		2010		2011		2010		2011	
Sib	Total score	Sib	Total score	Sib	Total score	Sib	Total score	Sib	Total score	Sib	Total score
R11-91	84.40	R11-91	84.19	R11-52	84.23	R11-52	84.37	R11-52	83.94	R11-1	85.21
R11-137	84.12	R11-137	84.13	R11-117	84.05	R11-7	84.15	R11-22	83.93	R11-123	83.95
R11-125	84.02	R11-80	83.93	R11-7	84.00	R11-1	84.11	R11-3	83.88	R11-121	83.90
R11-107	83.92	R11-1	83.67	R11-131	83.99	R11-131	84.08	R11-6	83.65	R11-115	83.76
R11-142	83.87	R11-123	83.62	R11-121	83.86	R11-6	84.04	R11-135	83.64	R11-125	83.75
R11-5	83.81	R11-142	83.57	R11-5	83.83	R11-23	83.94	R11-117	83.58	R11-131	83.75
R11-115	83.77	R11-135	83.51	R11-125	83.82	R11-142	83.88	R11-121	83.51	R11-80	83.75
R11-117	83.71	R11-11	83.50	R11-6	83.77	R11-105	83.82	R11-72	83.49	R11-100	83.71
R11-7	83.70	R11-115	83.48	R11-11	83.77	R11-107	83.79	R11-100	83.39	R11-106	83.71
R11-80	83.67	R11-107	83.40	R11-100	83.75	R11-22	83.68	R11-71	83.32	R11-52	83.71
R11-131	83.67	R11-52	83.39	R11-137	83.71	R11-41	83.68	R11-107	83.29	R11-11	83.69
R11-106	83.64	R11-117	83.38	R11-115	83.71	R11-117	83.63	R11-112	83.27	R11-135	83.68
R11-52	83.64	R11-105	83.33	R11-93	83.71	R11-72	83.62	R11-11	83.26	R11-91	83.64
R11-42	83.63	R11-23	83.26	R11-123	83.69	R11-137	83.60	R11-7	83.26	R11-22	83.62
R11-135	83.61	R11-121	83.20	R11-1	83.65	R11-111	83.57	R11-137	83.25	R11-3	83.62

Koru which is normally a high rainfall zone. Mariene and Kisii, however, recorded close to normal rainfall thus they produced better cup quality than Koru in the 2011 season.

G × E is a measure of stability and adaptability of genotypes in varying environments. In this study, significant G × E interactions was observed in all the cup quality traits indicating that different Ruiru 11 sibs responded differently to different environments. This also concurred with the observations made by Omondi (2008), Kathurima et al. (2010) and Agwanda et al. (2003). High G × E interactions for both bean and liquor traits have been reported as a major setback in achieving faster progress in selection (Agwanda et al., 2003). These significant interactions might be to a large extent attributable to the low precision in balancing the growing conditions in the multi-site trials and may also be partly explained by trial characteristics. Apart from cup quality traits, significant G × E interactions have also been reported on other quality related traits in Arabica coffee. For example, on coffee yields, Wamatu et al. (2003) reported G × E interactions of significant magnitude. Mawardi and Hulip (1995) and Agwanda et al. (2003) observed highly significant G × E interactions in bean characteristics of Arabica coffee.

Coffees graded according to SCAA's Green Coffee Classification Chart should receive the following scores: Class I – Specialty grade, 90 to 100+ points; Class 2 – Premium grade, 80 to 89 points; Class 3 – Exchange grade, 70 to 79 points; Class 4 – Below Standard Grade, 60 to 69 points; and Class 5 – Off grade, 50 to 59 points. All the sibs evaluated had an overall score of more than 82 points. The cup quality of Ruiru 11 is therefore of premium grade. Other previous studies had reported that the cultivar Ruiru 11 is virtually similar to the traditional varieties in terms of cup quality (Owuor, 1988; Njoroge et al., 1990). The study further identified several sibs that are best suited for each of the three locations. These sibs should be recommended to farmers in these agronomic locations for production of high quality Ruiru 11 coffee. Besides, the study identified the most widely adapted Ruiru 11 sibs with a potential of producing high quality coffee in varying climatic conditions. These include R11-52, R11-117, R11-131, R11 107, R11-121, R11-11, R11-137 and R11-22. These consistently recorded good quality

Table 7. Widely adapted sibs.

S/N	2010		2011	
	Sib	**Most adapted at**	**Sibs**	**Most adapted at**
1	R11-52	All Sites	R11-1	All Sites
2	R11-117	All Sites	R11-52	All Sites
3	R11-7	All Sites	R11-80	Koru and Mariene
4	R11-137	Koru and Kisii	R11-137	Koru and Kisii
5	R11-6	Kisii and Mariene	R11-131	Kisii and Mariene
6	R11-125	Koru and Kisii	R11-142	Koru and Kisii
7	R11-131	Koru and Kisii	R11-23	Koru and Kisii
8	R11-121	Kisii and Mariene	R11-91	Koru and Mariene
9	R11-5	Koru and Kisii	R11-11	Koru and Mariene
10	R11-100	Kisii and Mariene	R11-105	Koru and Kisii
11	R11-115	Koru and Kisii	R11-117	Koru and Kisii
12	R11-11	Kisii and Mariene	R11-121	Koru and Mariene
13	R11-107	Koru and Mariene	R11-123	Koru and Mariene
14	R11-135	Koru and Mariene	R11-107	Koru and Kisii
15	R11-22	Kisii and Mariene	R11-22	Kisii and Mariene

Table 8. Pearson correlation matrix.

Date	Variables	2010							
		Fragrance	**Flavour**	**Aftertaste**	**Acidity**	**Body**	**Balance**	**Preference**	**Total score**
2011	Fragrance		0.512	0.486	0.598	0.506	0.589	0.571	0.727
	Flavour	0.689		0.682	0.782	0.450	0.669	0.750	0.859
	Aftertaste	0.702	0.880		0.695	0.403	0.662	0.686	0.811
	Acidity	0.682	0.896	0.861		0.517	0.699	0.839	0.915
	Body	0.590	0.614	0.596	0.596		0.551	0.572	0.667
	Balance	0.685	0.883	0.865	0.872	0.627		0.745	0.841
	Preference	0.723	0.892	0.871	0.908	0.654	0.868		0.907
	Total score	0.777	0.949	0.933	0.947	0.706	0.930	0.955	

All the values are different from 0 with a significance level alpha = 0.0001.

in more than one site and season. Such sibs can be used in future improvement of Ruiru 11 and its derivatives to expand their agronomic adaptability. Kathurima et al. (2010) also recorded high cup quality from R11-41, R11-11, R11-91 and R11-131 in a multi locational study involving ten Ruiru 11 sibs.

Correlation coefficients portrayed very close positive associations between the cup quality traits. This was an indication that any one sensory trait is an important component of cup quality. However, flavor, acidity, aftertaste and balance in that order showed the highest correlations with preference and total score. Although all the seven sensory traits contribute to total score, preference is the overall perception of the coffee taster as guided by other traits and should therefore mirror the total score. Kathurima et al. (2009) observed that aftertaste, acidity and flavor in that order recorded the highest correlation with preference. Agwanda (1999) also reported high correlation between flavour and preference and recommended flavour as the best selection criterion for genetic improvement of cup quality in Arabica coffee. This also partly agrees with Omondi (2008) that Kenya produces coffee that is known for balanced acidity and body with pleasant distinctive aroma.

Conclusion

The study demonstrated the existence of a high variation in cup quality among Ruiru 11 sibs although the quality of most of the sibs is highly comparable to that of SL28. There is therefore high potential of intra-selection within the cultivar for further improvement of its cup quality. The most widely adapted Ruiru 11 sibs on the basis of cup quality were identified as R11-52, R11-117, R11-131, R11 107, R11-121, R11-11, R11-137 and R11-22. The growing environment was found to have a strong effect on the expression of quality parameters as portrayed by high site variations. The occurrence of significant G × E interactions in most of the studied traits was an indication that the best improvement strategy should be a multi-site selection. Rainfall intensity and distribution during berry expansion and bean filling stages was also found to be critical. The highest bean yields of desirable grades were obtained in the site where moderate moisture supply was received during berry expansion and bean filling stages rather than in high rainfall conditions. Future studies should therefore include many locations with more variable climatic conditions ranging from marginal to suitable coffee growing areas.

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