VARIATION AND ASSOCIATION OF CUP QUALITY ATTRIBUTES AND RESISTANCE TO COFFEE BERRY DISEASE IN *Coffea arabica* L. COMPOSITE CULTIVAR, RUIRU 11

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Abstract

Majority of reported work on coffee breeding primarily concerns agronomic improvement that directly impinges on coffee quality. However, it is crucial that coffee breeding programmes for disease resistance also include coffee quality improvement since consumer awareness about the quality of different coffees has increased. The aim of this study was to determine the variation and associations of cup quality parameters and resistance against Coffee Berry Disease (CBD) in *Coffea arabica* L. cultivar Ruiru 11 hybrid sibs. The study also aimed at selecting specific Ruiru 11 sibs that combines good cup quality with high CBD resistance. Thirty four full-sib families representing this hybrid cultivar grown in three different agro climatic zones in Kenya were used for the study. Evaluation of CBD resistance was conducted through hypocotyl inoculation in a laboratory set-up. The study demonstrated existence of a high variation in cup quality and CBD resistance among Ruiru 11 sibs. A highly significant positive correlation was observed between all cup quality traits but there was either negative or no correlation between most cup quality traits and CBD resistance.

Key Words: Arabica Coffee, Ruiru 11 Sibs, Cup Quality, Coffee Berry Disease, Kenya.

Introduction

Although the genus *Coffea* is diverse and reported to comprise about 130 species (Davis *et al*., 2006), only two species namely arabica (*Coffea arabica* L.) and robusta (*Coffea canephora* Pierre) are under commercial cultivation (Lashermes *et al*., 1999; Anthony *et al*., 2002; Pearl *et al*., 2004). *C arabica*, the highland coffee, accounts for nearly 70% of global production, whereas *C. canephora* is more suitable for lowlands and contributes the remaining 30% (Herrera *et al*., 2004**)**. *C. arabica* is therefore the most important species of the *Coffea* genus, followed by *C. canephora* (Silveira *et al*., 2003). The production of Arabica coffee is fundamental for over 50 developing countries, for which it is the main foreign currency earner. Its production is however constrained by a number of major diseases, including Coffee Berry Disease (CBD) caused by *Colletotrichum kahawae* Waller and Bridge, Coffee Leaf Rust (CLR) caused by *Hemileia vastatrix* Berk. and Br., and Bacterial Blight of Coffee (BBC) caused by *Pseudomonas syringae* pv. *garcae* van Hall (Agwanda *et al*., 1997). CBD is the most important disease in Arabica coffee production in Kenya and other countries in Eastern Africa as it can cause crop losses of 50% and over if not controlled by an intensive programme of fungicide sprays aimed at continuously protecting the developing crop (van der Vossen *et al*., 1976).

New arabica cultivars with higher yield potential and resistance to diseases are increasingly replacing the traditional varieties on a large scale in several countries (Van der Vossen, 2001). A composite cultivar, Ruiru 11, developed at the Coffee Research Station, Ruiru, Kenya, and released to growers in 1985, is an example. 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 CBD resistant donor parents such as Rume Sudan (R gene), Hibrido de Timor (T gene), K7 (k gene), and SL4 and the high yielding, good quality but susceptible cultivars such as N39, SL28, SL34 and Bourbon. The female parents are advanced generations (F3, F4 and F5) of the cultivar Catimor, ex Colombia, which has Hibrido de Timor clone 1343/269 as one parent (Omondi *et al*., 2000). The cultivar combines resistance to major diseases of coffee (CBD and CLR) with high yield, fine quality and compact growth amenable to high density planting (Omondi *et al*., 2001).

Despite its various agronomic advantages, Ruiru 11 presents 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). Apart from its variability in cup quality, Omondi *et al*. (2001) reported that resistance to Coffee Berry Disease within the cultivar Ruiru 11 is fairly non-uniform. The varying parentage of Ruiru 11 hybrids is suspected of causing the reported variation in beverage quality and non-uniform resistance to CBD within the composite cultivar. 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 other source of disease resistance in Ruiru 11 comes from the wild accession Rume Sudan whose bean and cup quality is also poor (Omondi *et al*., 2001).

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. 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). It's 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 x 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 CBD resistance/susceptibility 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

Study Locations

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 0^0N, 37^0 35'E, at an elevation of 1524M 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 0^0 07'S, 35^0 16'E and has an elevation of

1554M 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 0^0 41'S, 34^0 47'E at 1700M 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 locations were laid out in a Randomized Complete Block Design (RCBD) with three replications. Planted at a spacing of 2M by 2M, each entry had 12 trees per plot per replication, 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 replication.

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

	Female Parent						
Male Parent	Cat.86	Cat.88	Cat.90	Cat.124	Cat.127	Cat.128	Cat.134
SL34 x [(SL34 x RS) HT]	-	-	-	135	-	137	-
SL28 x [(SL28 x RS) (B x HT)]	1,11,41	22,42	3,23	5	6	7	50
SL28 x [(N39 x HT) (SL4 x RS)]	71	72	-	-	-	-	80
SL28 x [(K7 x RS) (SL34 x HT)]	-	52	-	-	-	-	-
SL28 x [(SL34 x 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

Processing of the coffee cherry samples: Cherry samples were picked during the peak harvesting period of May to July at Mariene and September to November at Koru and Kisii. The data was obtained from two locations (Koru and Mariene) over three years and two years at Kisii making a total of 8 environmental combinations. The Kisii site was omitted in 2009 as it recorded very low yields as the trees were recovering from hailstorm damage. Coffee cherry samples were picked during the peak harvesting period of May – July both in 2010 and 2011 in all the three locations. The ripe cherries were weighed, bulked, pulped, fermented, washed and the wet parchment dried to final moisture content of 10.5 to 11% as determined by a moisture meter. 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 eight hours. The samples were weighed before and after roasting to determine the uniformity of roasting. The 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.

Laboratory Evaluation of CBD resistance

Evaluation of CBD resistance was conducted through hypocotyl inoculation using the method developed by Van der Vossen *et al*. (1976). The experiment was arranged in the laboratory in a completely randomized design with three replications. Each replicate was represented by 100 six-week old hypocotyl seedlings of the test materials. The susceptible cultivar SL28 was included in the experiment as a control. All the hypocotyl seedlings were inoculated on the same day with conidia suspensions from 10 day old cultures standardized to 2×10^6 conidia/ml. The seedlings were then scored individually on a scale of 1 to 12 as described by Van der Vossen *et al*. (1976). The experiment was conducted in July 2010 and reconfirmed in July 2011.

Data analysis

Both sensory and disease resistance data were subjected to Analysis of Variance (ANOVA) using XLSTAT Version 2012 statistical software and effects declared significant at 5% level. Separate as well as combined analysis of variance was performed on data from all locations. Least Significant Difference ($LSD_{5\%}$) was used to separate the means. Least significance difference ($LSD_{5\%}$) was used to separate the means. To determine the level of dissimilarity between sibs based on the sensory variables, cluster analysis was conducted and a dendrogram constructed using unweighted pair group method with arithmetic average (UPGMA). In order to determine the association between the quality traits and CBD resistance/susceptibility, Pearson correlation was done to compare their relationship with each other.

Results

Rainfall was recorded in all the three locations 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 x sib (G x E) interactions were highly significant ($p<0.001$) for all the traits except body (Table 3).

The highest cup quality was obtained in 2010 when adequate moisture supply was received especially during berry expansion and bean filling stages while the lowest quality was recorded in 2009 when moisture supply was relatively lower. All the sibs evaluated had an overall score of more than 82 points with some recording better quality than SL28 (Table 4). SL28 sprayed with fungicide

consistently recorded better quality than the unsprayed SL28 in absolute terms except at one instance at Kisii in 2011. There was no significant difference in overall cup quality between all genotypes at Koru in all seasons. At Kisii in 2010 season, the cup quality of 29 Ruiru 11 sibs was not significantly different ($p>0.05$) from that of sprayed SL28 while in 2011, 27 Ruiru 11 sibs recorded cup quality similar ($p>0.05$) to that of sprayed SL28. At Mariene, 8, 12 and 26 Ruiru 11 sibs recorded cup quality similar ($p>0.05$) to that of sprayed SL28 in 2009, 2010 and 2011 seasons respectively. A combined analysis of the data enabled selection of the best sibs per location as shown in Table 5.

Low genetic variances among the sibs were further demonstrated by the cluster dendrogram developed using the sensory variables (Fig. 1). Four main classes (labelled 1,2,3,4 in figure 1) were formed when the similarity index was considered for clustering. Class 1 contained two individuals (R11-52 and sprayed SL28) which consistently recorded high cup quality. Other individuals that recorded high cup quality were classified in class 2. Class 3 contained only one individual (R11-41) which was found to be highly unstable with its cup quality varying with locations and seasons. The rest of the genotypes which recorded relatively lower cup quality were classified in class 4. Within class diversity of 15.86% was recorded alongside a between classes diversity of 84.14%. The highest between class diversity was observed between classes 1 (best quality) and 4 (lowest quality) while classes 1 and 2 were the most closely related. The parentage of these sibs (Table 1) did not appear to play significant role in modifying the genetic diversity.

Significant ($p<0.05$) and positive correlation was observed between all traits (Table 6). Higher correlations were observed at Koru and Mariene than at Kisii. The traits acidity, flavor, aftertaste and balance in that order recorded the highest correlations with preference and total score.

Phenotypic variation of Ruiru 11 sibs in resistance to CBD was also highly significant ($p<0.01$) with some sibs even recording varying results during the two screening experiments (Fig. 2). The cultivar SL28 which was used as a susceptible control fell in the highly susceptible class (score > 10) with an average infection score of 11.55 (Fig. 2) while resistance in Ruiru 11 sibs ranged from highly resistant to moderately resistant. The most resistant was sib 143 (with an average infection score of 3.32) which fell in the highly resistant class of 1-3. Sibs 3 and 107 also recorded good resistance with average infection scores of 3.83 and 3.90 respectively. The rest of Ruiru 11 sibs were in the range of 4-6 (Fig. 2) and were therefore rated as moderately resistant. These results concurred with the findings of Omondi *et al*. (2001) that although the composite cultivar, Ruiru 11 generally contains good resistance to CBD, this resistance is fairly non-uniform among the sibs.

Figure 3 shows the cup quality and CBD resistance/susceptibility levels in Ruiru 11. Although there was large variation in cup quality between sibs, all the sibs recorded an average overall cup quality of above 82 points. There was no correlation between any of the overall cup quality and CBD resistance/susceptibility (data not presented). Taking a CBD infection score of less than 6 and cup quality above 83 points, some promising sibs that appeared to combine good cup quality with high CBD resistance were identified (light coloured bars in Fig. 3) including R11-1, R11-105, R11-107, R11-11, R11-121, R11-135, R11-143, R11-22, R11-23, R11-3, R11-42, R11-5, R11-80, R11-93.

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

Kisii												
Stages	**Flowering and Pinhead Formation**		**Berry Expansion**				**Bean Filling**		**Ripening**			**Total Rainfall**
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	
2008/09	111.2	661.3	188.3	231.0	297.4	152.3	63.2	197.2	160.3	86.2	151.7	2300.1
2009/10	49.8	99.6	203.4	233.7	406.8	202.4	79.6	204.3	292.1	213.8	109.1	2094.6
2010/11	97.5	42.5	138.5	237.2	267.8	91.6	100.5	233.6	225.3	191.1	360.6	1986.2

Koru												
Stages	**Flowering and Pinhead Formation**		**Berry Expansion**				**Bean Filling**		**Ripening**			**Total Rainfall**
Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	
2008/09	122.6	87.8	59.9	267.7	177.6	102.6	113.8	83.1	176.6	89.1	106.2	1387.0
2009/10	102.8	215.5	211.8	163.4	258.9	140.6	132	118.4	89	170.5	80.0	1682.9
2010/11	67.7	88.0	177.5	60.3	198.5	138.4	77.4	205.9	211.6	163.6	270.2	1659.1

Mariene												
Stages	**Flowering and Pinhead Formation**		**Berry Expansion**				**Bean Filling**		**Ripening**			**Total Rainfall**
Month	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	
2008/09	19.0	181.4	138.3	0.6	147.0	15.6	156.5	221.6	96.0	5.6	12.6	994.2
2009/10	3.0	303.8	420.5	194.7	192.9	118.7	348.4	504.2	121.1	5.8	3.7	2216.8
2010/11	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: F values of multi-locational analysis of variance for cup quality traits within Ruiru 11 sibs

	Sib Variations											Location Variations			Location x Sib Interactions		
	Mariene				Koru				Kisii								
Traits	2009	2010	2011	Combined	2009	2010	2011	Combined	2010	2011	Combined	2009	2010	2011	2009	2010	2011
Fragrance	0.022^{*}	0.000^{***}	0.002^{**}	0.000^{***}	0.765^{ns}	0.003^{**}	0.216^{ns}	0.002^{**}	0.120^{ns}	0.012^{*}	0.004^{**}	0.525^{ns}	0.000^{***}	0.816^{ns}	0.324^{ns}	0.000^{***}	0.005^{**}
Flavor	0.193^{ns}	0.001^{***}	0.002^{**}	0.000^{***}	0.679^{ns}	0.777^{ns}	0.263^{ns}	0.068^{ns}	0.025^{*}	0.119^{ns}	0.007^{**}	0.927^{ns}	0.002^{**}	0.000^{***}	0.742^{ns}	0.215^{ns}	0.055^{ns}
Aftertaste	0.109^{ns}	0.109^{ns}	0.003^{**}	0.000^{***}	0.580^{ns}	0.497^{ns}	0.347^{ns}	0.055^{ns}	0.035^{*}	0.004^{**}	0.001^{***}	0.590^{ns}	0.672^{ns}	0.054^{ns}	0.586^{ns}	0.264^{ns}	0.010^{*}
Acidity	0.023^{*}	0.010^{*}	0.002^{**}	0.000^{***}	0.569^{ns}	0.155^{ns}	0.078^{ns}	0.004^{**}	0.061^{ns}	0.026^{*}	0.001^{***}	0.084^{ns}	0.006^{**}	0.000^{***}	0.336^{ns}	0.017^{*}	0.023^{*}
Body	0.029^{*}	0.000^{***}	0.036^{*}	0.000^{***}	0.687^{ns}	0.175^{ns}	0.124^{ns}	0.117^{ns}	0.027^{*}	0.041^{*}	0.005^{**}	0.020^{*}	0.000^{***}	0.070^{ns}	0.497^{ns}	0.002^{**}	0.025^{*}
Balance	0.295^{ns}	0.003^{**}	0.004^{**}	0.001^{***}	0.841^{ns}	0.133^{ns}	0.048^{*}	0.028^{*}	0.410^{ns}	0.072^{ns}	0.035^{*}	0.013^{*}	0.000^{***}	0.000^{***}	0.879^{ns}	0.224^{ns}	0.008^{**}
Preference	0.077^{ns}	0.045^{*}	0.023^{*}	0.000^{***}	0.736^{ns}	0.292^{ns}	0.017^{*}	0.005^{**}	0.049^{*}	0.014^{*}	0.000^{***}	0.117^{ns}	0.005^{**}	0.001^{**}	0.719^{ns}	0.079^{ns}	0.030^{*}
TotalScore	0.050^{*}	0.000^{***}	0.001^{**}	0.000^{***}	0.726^{ns}	0.218^{ns}	0.053^{ns}	0.011^{*}	0.016^{*}	0.011^{*}	0.000^{***}	0.171^{ns}	0.000^{***}	0.000^{***}	0.585^{ns}	0.026^{*}	0.005^{**}
DF	35	35	35	35	35	35	35	35	35	35	35	1	2	2	35	70	70

Table 4: Cup quality variations per location per season

Kisii				Koru						Mariene					
2010		2011		2009		2010		2011		2009		2010		2011	
Sibs	Variation	Sibs	Variation	Sibs	Variation	Sibs	Variation	Sibs	Variation	Sibs	Variation	Sibs	Variation	Sibs	Variation
R11-52	84.23 a	R11-52	84.37 a	SL28(S)	83.45	R11-91	84.40	R11-91	84.19	SL28(S)	84.22 a	R11-52	83.94 a	R11-1	85.21 a
R11-117	84.05 ab	R11-7	84.15 ab	R11-52	83.30	R11-137	84.12	R11-137	84.13	R11-52	83.57 ab	R11-22	83.93 a	SL28(S)	84.32 ab
R11-7	84.00 a-c	SL28(NS)	84.14 ab	R11-103	83.24	R11-125	84.02	R11-80	83.93	SL28(NS)	83.49 a-c	R11-3	83.88 ab	SL28(NS)	84.20 ab
R11-131	83.99 a-c	R11-1	84.11 a-c	R11-117	83.14	R11-107	83.92	R11-1	83.67	R11-117	83.37 a-d	SL28(S)	83.87 a-c	R11-123	83.95 bc
SL28(S)	83.93 a-c	R11-131	84.08 a-c	R11-137	83.12	R11-142	83.87	R11-123	83.62	R11-23	83.30 a-d	R11-6	83.65 a-d	R11-121	83.90 b-d
R11-121	83.86 a-d	R11-6	84.04 a-d	R11-91	83.01	R11-5	83.81	R11-142	83.57	R11-6	83.23 a-e	R11-135	83.64 a-d	R11-115	83.76 b-d
R11-5	83.83 a-e	SL28(S)	83.94 a-e	R11-42	82.64	SL28(S)	83.77	R11-135	83.51	R11-100	83.03 a-f	R11-117	83.58 a-e	R11-80	83.75 b-d
R11-125	83.82 a-e	R11-23	83.94 a-e	R11-22	82.62	R11-115	83.77	R11-11	83.50	R11-121	82.95 a-f	R11-121	83.51 a-f	R11-125	83.75 b-d
R11-11	83.77 a-e	R11-142	83.88 a-f	R11-105	82.57	R11-117	83.71	R11-115	83.47	R11-72	82.85 a-f	R11-72	83.49 a-g	R11-131	83.75 b-d
R11-6	83.77 a-e	R11-105	83.82 a-g	R11-7	82.51	R11-7	83.70	R11-107	83.40	R11-1	82.79 a-f	R11-100	83.39 a-g	R11-106	83.71 b-d
R11-100	83.75 a-e	R11-107	83.78 a-h	R11-72	82.49	R11-80	83.67	R11-52	83.39	R11-115	82.66 b-g	SL28(NS)	83.37 a-f	R11-52	83.71 b-d
R11-115	83.71 a-e	R11-22	83.68 a-i	R11-23	82.46	R11-131	83.67	R11-117	83.38	R11-143	82.63 b-g	R11-71	83.32 b-h	R11-100	83.71 b-d
R11-137	83.71 a-e	R11-41	83.67 a-i	R11-143	82.42	R11-52	83.64	SL28(S)	83.35	R11-106	82.62 b-g	R11-107	83.28 b-h	R11-11	83.69 b-d
R11-93	83.71 a-e	R11-117	83.63 a-j	R11-6	82.40	R11-106	83.64	R11-105	83.33	R11-107	82.58 b-g	R11-112	83.27 c-h	R11-135	83.68 b-d
R11-123	83.69 a-e	R11-72	83.62 a-j	R11-135	82.38	R11-42	83.63	R11-23	83.26	R11-142	82.58 b-g	R11-11	83.26 d-i	R11-91	83.64 b-e
R11-1	83.65 a-e	R11-137	83.60 a-j	R11-131	82.37	R11-135	83.61	R11-121	83.20	R11-112	82.51 b-g	R11-7	83.26 d-i	R11-22	83.62 b-e
R11-22	83.65 a-e	R11-111	83.57 a-j	R11-123	82.33	R11-100	83.60	R11-143	83.20	R11-11	82.50 b-g	R11-137	83.25 d-i	R11-3	83.62 b-e
R11-112	83.58 a-f	R11-80	83.51 a-k	R11-142	82.32	R11-105	83.60	R11-71	83.19	R11-131	82.50 b-g	R11-143	83.24 d-i	R11-117	83.54 b-e
R11-72	83.55 a-f	R11-3	83.44 a-k	R11-11	82.32	R11-11	83.49	R11-100	83.14	R11-71	82.44 b-h	R11-80	83.23 d-i	R11-93	83.54 b-e
R11-91	83.55 a-f	R11-42	83.43 a-k	R11-93	82.23	R11-72	83.48	R11-131	83.13	R11-50	82.43 b-h	R11-5	83.18 d-j	R11-112	83.51 b-e
R11-42	83.54 a-f	R11-112	83.37 a-k	R11-71	82.21	R11-6	83.46	R11-111	83.06	R11-80	82.37 b-h	R11-131	83.17 d-j	R11-7	83.51 b-e
R11-41	83.51 b-f	R11-11	83.37 a-k	R11-112	82.12	R11-103	83.45	R11-125	83.01	R11-22	82.35 b-h	R11-142	83.14 d-j	R11-6	83.46 b-e
R11-50	83.44 b-g	R11-121	83.35 a-k	R11-107	82.12	R11-121	83.45	R11-6	83.00	R11-7	82.28 b-h	R11-105	83.12 d-j	R11-23	83.45 b-e
R11-105	83.43 b-g	R11-71	83.13 b-k	R11-115	82.07	R11-111	83.43	R11-3	83.00	R11-3	82.23 b-h	R11-42	83.11 d-j	R11-143	83.44 b-e
R11-3	83.40 b-g	R11-125	83.02 c-k	R11-106	82.05	R11-23	83.33	R11-42	83.00	R11-5	82.22 b-h	R11-115	83.06 d-j	R11-50	83.43 b-e
SL28(NS)	83.40 b-g	R11-5	82.96 d-k	R11-41	82.00	R11-22	83.30	R11-7	82.95	R11-137	82.16 b-h	R11-123	83.04 e-j	R11-137	83.40 b-e
R11-111	83.39 b-g	R11-100	82.93 e-k	R11-1	81.95	R11-143	83.27	R11-93	82.90	R11-103	82.07 c-h	R11-103	83.01 e-j	R11-142	83.40 b-e
R11-142	83.39 b-g	R11-123	82.87 e-k	R11-50	81.90	R11-93	83.26	R11-41	82.89	R11-125	82.07 c-h	R11-125	82.99 e-j	R11-105	83.39 b-e
R11-23	83.34 b-g	R11-143	82.87 e-k	SL28(NS)	81.89	R11-112	83.24	R11-22	82.81	R11-42	82.00 d-h	R11-23	82.99 e-j	R11-107	83.18 c-e
R11-103	83.33 c-g	R11-50	82.82 f-k	R11-111	81.80	R11-123	83.15	R11-50	82.80	R11-135	82.00 d-h	R11-41	82.98 f-j	R11-72	83.15 c-e
R11-143	83.31 c-g	R11-115	82.76 g-k	R11-5	81.65	R11-50	83.08	R11-72	82.73	R11-111	81.98 d-h	R11-111	82.96 f-j	R11-5	83.08 c-e
R11-106	83.17 d-g	R11-103	82.74 g-k	R11-80	81.61	R11-71	82.96	R11-103	82.67	R11-41	81.78 e-h	R11-50	82.91 g-j	R11-103	82.86 de
R11-107	83.14 e-g	R11-91	82.73 h-k	R11-100	81.61	R11-41	82.89	R11-112	82.62	R11-91	81.67 f-h	R11-93	82.89 g-j	R11-42	82.82 de
R11-135	82.89 fg	R11-135	82.69 i-k	R11-121	81.48	SL28(NS)	82.70	SL28(NS)	82.35	R11-105	81.45 f-h	R11-1	82.73 h-j	R11-111	82.79 de
R11-80	82.75 g	R11-106	82.57 jk	R11-3	81.12	R11-3	82.61	R11-5	82.19	R11-123	81.33 gh	R11-91	82.67 ij	R11-71	82.65 ef
R11-71	82.75 g	R11-93	82.43 k	R11-125	80.87	R11-1	82.19	R11-106	81.99	R11-93	81.00 h	R11-106	82.58 j	R11-41	81.71 f
LSD(5%)	0.7138	LSD(5%)	1.092	LSD(5%)	NS	LSD(5%)	NS	LSD(5%)	NS	LSD(5%)	1.8049	LSD(5%)	0.5939	LSD(5%)	1.0258

Means followed by the same letter(s) are not significantly different at alpha=0.05

Table 5: The best Ruiru 11 sibs per location

Rank	Kisii		Koru		Mariene	
1	R11-52	84.30	R11-91	83.87	R11-52	83.74
2	R11-7	84.08	R11-137	83.79	R11-1	83.58
3	R11-131	84.04	R11-52	83.44	R11-117	83.50
4	R11-6	83.90	R11-117	83.39	R11-121	83.45
5	R11-1	83.88	R11-142	83.25	R11-6	83.45
6	R11-117	83.84	R11-105	83.17	R11-100	83.38
7	R11-22	83.67	R11-135	83.17	R11-22	83.30
8	R11-137	83.66	R11-42	83.15	R11-23	83.25
9	R11-23	83.64	R11-107	83.15	R11-3	83.24
10	R11-142	83.64	R11-103	83.12	R11-72	83.16

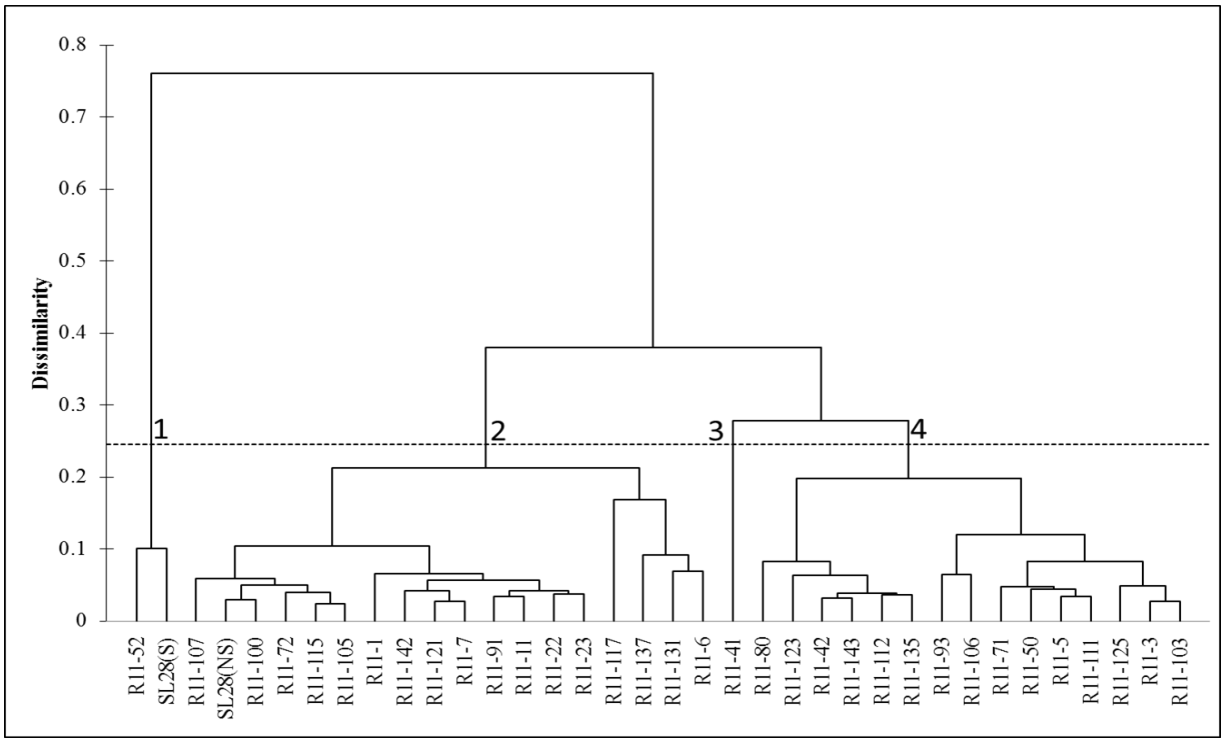

Fig. 1: Cluster dendrogram depicting diversity among genotypes based on cup quality

Table 6: Pearson correlation matrix between cup quality traits on the three locations

Location	Variables	Fragrance	Flavor	Aftertaste	Acidity	Body	Balance	Preference
Kisii	Flavor	0.656						
Koru	Flavour	0.666						
Mariene	Flavor	0.754						
Kisii	Aftertaste	0.709	0.749					
Koru	Aftertaste	0.734	0.880					
Mariene	Aftertaste	0.746	0.879					
Kisii	Acidity	0.708	0.804	0.822				
Koru	Acidity	0.723	0.855	0.857				
Mariene	Acidity	0.723	0.866	0.865				
Kisii	Body	0.531	0.322	0.513	0.538			
Koru	Body	0.770	0.697	0.770	0.794			
Mariene	Body	0.699	0.703	0.720	0.750			
Kisii	Balance	0.482	0.786	0.618	0.608	0.093		
Koru	Balance	0.773	0.882	0.873	0.849	0.775		
Mariene	Balance	0.675	0.857	0.780	0.757	0.667		
Kisii	Preference	0.629	0.821	0.786	0.869	0.467	0.748	
Koru	Preference	0.739	0.899	0.890	0.932	0.798	0.886	
Mariene	Preference	0.725	0.898	0.859	0.874	0.727	0.853	
Kisii	Total Score	0.783	0.904	0.898	0.934	0.552	0.769	0.932
Koru	Total Score	0.830	0.921	0.939	0.943	0.864	0.936	0.962
Mariene	Total Score	0.837	0.952	0.933	0.932	0.814	0.885	0.946

All values are different from 0 with a significance level alpha=0.05

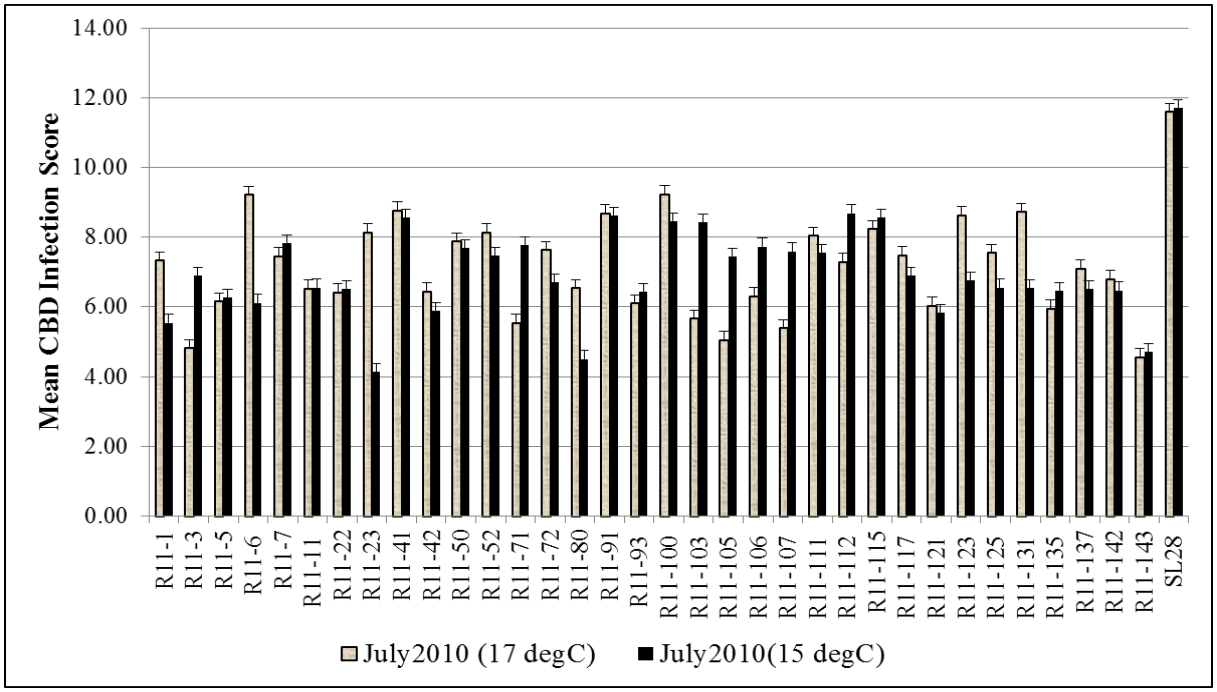

Fig. 2: CBD infection reaction in Ruiru 11 hybrid sibs with SL28 as a susceptible control

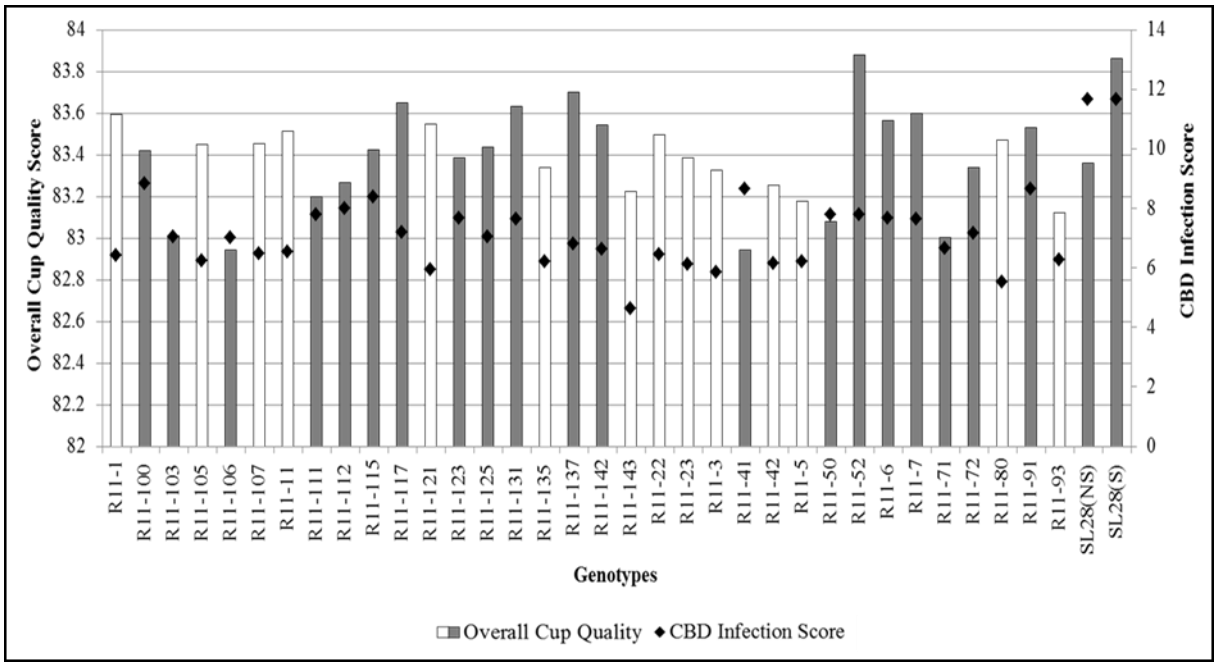

Fig. 3: Cup quality and CBD resistance/susceptibility levels. The light coloured bars represent the most promising sibs that appeared to combine good cup quality with high CBD resistance.

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 locations 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 locations in 2010 and 2011 respectively as they consistently recorded the lowest means for all traits.

The observed variations in quality traits at different locations indicated that the growing environment has a strong effect on cup quality. 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 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 locations 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 influence the cup quality (Agwanda *et al*. 2003; Van der Vossen, 2009). The scenario was totally different in 2011 when all the locations experienced reduced rainfall. This adversely affected cup quality especially at 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.

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. 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 different cup quality traits. This was an indication that any one sensory trait is an important component of cup quality. However, acidity, flavor, aftertaste and balance in that order recorded 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.

Reaction of Ruiru 11 sibs to CBD inoculation in the laboratory ranged from highly resistant to moderately resistant. A similar reaction can be experienced in the field when the conditions are similarly conducive. This finding concurred with the report of Silva *et al*. (2006) that differences in resistance of coffee trees to CBD are frequently observed under field and laboratory conditions. It also corroborates the report by Omondi *et al*. (2001) who reported that resistance to CBD within the cultivar Ruiru 11 is fairly non-uniform. These differences in CBD resistance in Ruiru 11 were attributed to differences in the pedigree (parentage) of the different Ruiru 11 sibs. There was no correlation observed between any of the cup quality traits and CBD resistance/susceptibility. This was an indication that there is a possibility of combining good cup quality with high CBD resistance in one coffee cultivar. It can also be deduced that cup quality is not a major concern in Ruiru 11 as compared to CBD resistance since most Ruiru 11 sibs (except 2) recorded overall quality of above 82 points (premium grade).

Conclusion

The study demonstrated the existence of a high variation in cup quality and CBD resistance among Ruiru 11 sibs. However, the cup quality of most of the sibs was highly comparable to that of SL28 while none of the sibs was comparable to SL28 in terms of susceptibility to CBD. There is therefore high potential of intra-selection within the cultivar for further improvement of its cup quality and CBD resistance. The study identified the most suited Ruiru 11 sibs for each location. The growing environment was found to have a strong effect on the expression of quality parameters as portrayed by high locational variations. Rainfall intensity and distribution during berry expansion and bean filling stages was also found to be critical in determining cup quality. The highest cup quality was obtained in 2010 when adequate moisture supply was received especially during berry expansion and bean filling stages. Future studies should therefore include many locations with more variable climatic conditions ranging from marginal to suitable coffee growing areas. Lack of correlation between any of the cup

quality traits and CBD resistance/susceptibility was an indication that there is a possibility of combining good cup quality with high CBD resistance in one coffee cultivar.

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