SELECTION OF RUIRU 11 HYBRID SIBS ON RAW COFFEE QUALITY

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Abstract

The economic value of Arabica coffee (*Coffea arabica* L.) is determined mainly by the yield potential, the size and shape of raw beans and beverage quality. Bean quality reportedly differ depending on the variety, environmental conditions and management practices. This study aimed at genetically improving raw bean quality of *C. arabica* cultivar Ruiru 11 through selection within the cultivar. The study also intended to measure the extent to which raw bean quality of Ruiru 11 is affected by the environment. Thirty four Ruiru 11 full-sibs grown in three locations in Kenya exhibiting strong edaphic and climatic differences were used for the study. The three sites were Mariene in Meru, Kisii and Koru. Rainfall amounts during various phases of berry development were used to explain the differences observed in discriminating abilities of the locations for raw bean quality traits. The results showed that beans of desirable AA and AB grades were obtained from Mariene where moderate moisture supply was received during berry expansion and bean filling stages rather than in high rainfall conditions. The best overall Ruiru 11 sibs were identified as R11-121, R11-93, R11-142, R11-52 and R11-71.

Key Words: Coffee, Ruiru 11, Bean Grades, 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 (carrying the R gene), Hibrido de Timor (with the T gene), K7 (with the k gene) and the high yielding, good quality but susceptible cultivars such as N39, SL4, 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 was developed at the Coffee Research Station, Ruiru, Kenya, and released to growers in 1985. It combines resistance to CBD and Coffee Leaf Rust (CLR) with high yield, fine quality and compact growth amenable to high density planting (Gichimu and Omondi 2010a).

Success of a new variety of Arabica coffee depends to a great extent on its bean and beverage quality (Agwanda *et al*., 2003). Bean size, defined as grade from a commercial point of view, is an important factor since it determines the price with smaller beans attracting lower prices (Leroy *et al*., 2006). Production and supply of coffee with excellent bean quality is crucial for coffee exporting countries as physical characteristics of green coffee bean have been reported to affect beverage quality. Consequently, some countries consider assessment of coffee quality as important as disease resistance and productivity in their coffee variety development program (Abadiga, 2010). Bean size offers unified criteria for conducting coffee business on the international market and is of considerable interest to coffee roasters from a technological point of view (Agwanda *et al*., 2003). Assessment of coffee quality is therefore an important step in coffee trade. Quality of raw coffee beans is determined mechanically based on the size, shape and density of processed beans (Agwanda *et al*., 2003). On average, beans are 10 mm long, 6-7 mm wide, 3-4 mm thick and weigh between 0.15 and 0.20g.

The size and shape of the beans differ depending upon the variety, environmental conditions and management practices (Abadiga, 2010). Omondi (2008) reported that the reputable quality of Kenyan coffee is the result of favourable climatic conditions, good agronomic practices, rigorous selective harvesting and post-harvest practices, appropriate processing, proper storage conditions and cultivation of varieties with proven genetic constitution. Kathurima *et al*., 2009 demonstrated that the raw bean quality of the cultivar Ruiru 11 is virtually similar to that of traditional varieties. Omondi *et al*. (2008) reported significant variation in raw bean quality among various Ruiru 11 hybrid sibs. Considering these previous reports, further selection within Ruiru 11 cultivar for raw bean quality is therefore desirable.

Hue (2005) reported that genetic consistency within varieties is essential to quality assurance for any agricultural product. However, selection for quality traits in Arabica coffee is constrained by the prevalence of large genotype-by-environment (GxE) interactions in conjunction with the low genetic variability within the species (Agwanda *et al*., 2003). Omondi (2008) also reported that the growing environment has a strong effect on coffee quality. Majority of reported works on the improvement of coffee quality primarily concerns liquor quality leaving out the genetic improvement of bean sizes. This study aimed at genetically improving raw bean quality of the cultivar Ruiru 11 through selection within the cultivar. The study also targeted to assess the extent to which raw bean quality of Ruiru 11 is affected by the environment.

Materials and Methods

Description of Study Sites

The study was conducted in three different agro-ecological zones in Kenya namely Mariene in Meru, 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 found 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 established in April 1990 while Meru plot was established in April 1991. All the plots have undergone change of cycle twice and were therefore almost of the same status. Other agronomic practices were carried out as recommended. All the sites were laid out in a Randomized Complete Block Design (RCBD) with three replications.

Test Materials

Thirty four (34) 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 fungicides to control CBD and CLR while the other one was not sprayed at all.

Processing of the samples

Cherry samples were picked during the peak harvesting period of May – July 2010 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).

Table 1: The pedigree of 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

Data analysis

The data was subjected to Analysis of Variance (ANOVA) using COSTAT statistical software and effects declared significant at 5% level. Percentage data was transformed before analysis using square root and arc sine transformation depending on the type of data. 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. Linear correlation was done to compare the relationship between the bean grades. In order to identify the most closely related sibs based on raw bean quality, the data was organized into a matrix and subjected to cluster analysis using XLSTAT 2010 software and a dendrogram constructed using the unweighted pair-group method with arithmetic average [UPGMA]. Discriminant Function Analysis (DFA) was conducted using XLSTAT 2010 to test whether raw bean quality could be used to discriminate different Ruiru 11 sibs according to agro-ecological zone.

Results

Rainfall records at different berry development stages during the entire period of coffee production in all the three sites are shown in table 2.

Analysis of variance (ANOVA) showed that Ruiru 11 sibs were best differentiated at grades AA, C and T (Table 3). There was consistently no significant differences ($p>0.05$) between sibs for grade AB which is the second best grade of coffee after AA. There were also no significant differences ($p>0.05$) observed in less important traits such as 100 berry weight, 100 bean weight and the E grade. Lack of significant variation among sibs for most of the traits indicated low genetic variation between sibs. A combined ANOVA showed highly significant ($p<0.0001$) site differences for all the traits but site x sib (G x E) interactions were observed only for %Outturn, %AA, %C and %T. However, for the latter three traits which also happened to be raw bean grades, the G x E interactions were highly significant ($p<0.01$) as shown in table 3.

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

Stages	**Flowering**	**Pinhead**	**Berry Expansion**				**Filling**		**Ripening**		
Month	**Sept 2009**	**Oct 2009**	**Nov 2009**	**Dec 2009**	**Jan 2010**	**Feb 2010**	**Mar 2010**	**Apr 2010**	**May 2010**	**June 2010**	**July 2010**
Kisii	160.3	86.2	151.7	305.5	49.8	99.6	203.4	233.7	406.8	202.4	79.6
Koru	176.6	89.1	106.2	343	102.8	215.5	211.8	163.4	258.9	140.6	132
Mariene	0	556.4	330.1	194.7	76.8	163.9	112.5	168.6	129.1	84.7	60.3

Table 3: Multi-site analysis of variance for cherry and raw bean grades

Traits	Sib Variations				Site Variation	Site x Sib Interaction
	Mariene	Kisii	Koru	Combined		
100 Berry Weight	0.2717ns	0.5149ns	0.5542ns	0.3873ns	0.0001***	0.4459ns
%Pulp	0.4530ns	0.3000*	0.2944ns	0.1491ns	0.0000***	0.3816ns
%Outturn	0.0372*	0.0184*	0.1541ns	0.0525ns	0.0000***	0.0114*
%TT	0.0412*	0.6217ns	0.1861ns	0.0608ns	0.0000***	0.1291ns
%PB	0.2242ns	0.2509ns	0.0113*	0.0011**	0.0000***	0.1912ns
%E	0.3974ns	0.5870ns	0.5712ns	0.5079ns	0.0000***	0.6960ns
%AA	0.0004***	0.0000***	0.0024**	0.0000***	0.0000***	0.0027**
%AB	0.2448ns	0.2276ns	0.2016ns	0.0594ns	0.0000***	0.0594ns
%C	0.0000***	0.0002***	0.1068ns	0.0000***	0.0000***	0.0018**
%T	0.0024**	0.0002***	0.0305*	0.0000***	0.0000***	0.0061**
100 Bean Weight	0.7611ns	0.3853ns	0.0916ns	0.0092**	0.0000***	0.6335ns
Degrees of Freedom	35	35	35	35	2	70

*Significant at 5%, **Significant at 1%, ***Significant at 0.1%, ns = not significant

Low genetic variances among the genotypes were further demonstrated by the cluster dendrogram developed using raw coffee grades (Fig. 1). Five main classes (labelled 1, 2, 3, 4, 5 in the figure) were formed when the similarity index was considered for clustering. Except for class 3 which contained 34 individuals, the rest 4 classes contained only one independent individual. Within class diversity of 29.55% was recorded in class 3 alongside a between classes diversity of 70.45%. The highest between class diversity was observed between classes 2 and 5 while classes 2 and 3 were the most closely related. The parentage of these sibs did not appear to play a major role in modifying the genetic diversity.

Discriminant Factor Analysis grouped the genotypes according to the three locations based on the traits as shown in figure 2. Factor 1 explained 93.20% of the total variation while Factor 2 explained the remaining 6.80% variation. Based on the trait verses factor correlations, Kisii and Koru were plotted closely together at F1 coordinates of 3.233 and 1.77 respectively and F2 coordinates of 1.056 and -1.284 respectively (Fig. 2). Mariene was plotted separately on the left side at F1 and F2 coordinates of -5.003 and 0.228 respectively. This was because Mariene recorded relatively higher means for all the variables that least contributed to F1 axes namely Outturn, PB, AB and 100 Bean Weight. On the other hand, Kisii and Koru recorded higher means for all the variables that contributed principally to F1 axes namely %Pulp, %TT, %C and %T (Table 4).

The most important and highly valued grades of coffee are AA and AB. Variation in these grades is illustrated in figure 3 alongside grade TT which consists of light beans separated from the two grades on the basis of their density using a pneumatic separator. In this study, there was no significant difference ($p>0.05$) between the genotypes for grade AB unlike grade AA which varied significantly ($p<0.05$) among the sibs in all the three sites. Significant ($p<0.05$) variation in grade TT was observed only at Mariene. This demonstrated that the proportion of grades AA and AB can be increased by reducing the TT grade through the proper management of agronomic aspects. The average top price of Kenya's benchmark grade AA coffee in 2010/2011 was $8.66 per kg, 12% higher than grade AB which sold at an average of $7.71 per kg (Reuters, 2011). The prices were used to select the most promising sibs. The best performing ten sibs per location are shown in table 5 and the best overall sibs were R11-121, R11-93, R11-142, R11-52 and R11-71. The first recorded good results in all the sites while the rest four recorded good results in at least two of the three sites.

As expected, correlation coefficients registered a negative correlation between grade AA and TT as well as between AB and TT (Table 6). This was in support of the graphical presentation in figure 1 that the proportion of grades AA and AB can be increased by reducing the TT grade through the proper management of agronomic aspects. Likewise, a negative correlation was observed between grade AA and grades C and T. A positive correlation was observed between grade C and T. Other correlation coefficients are tabulated in Table 6.

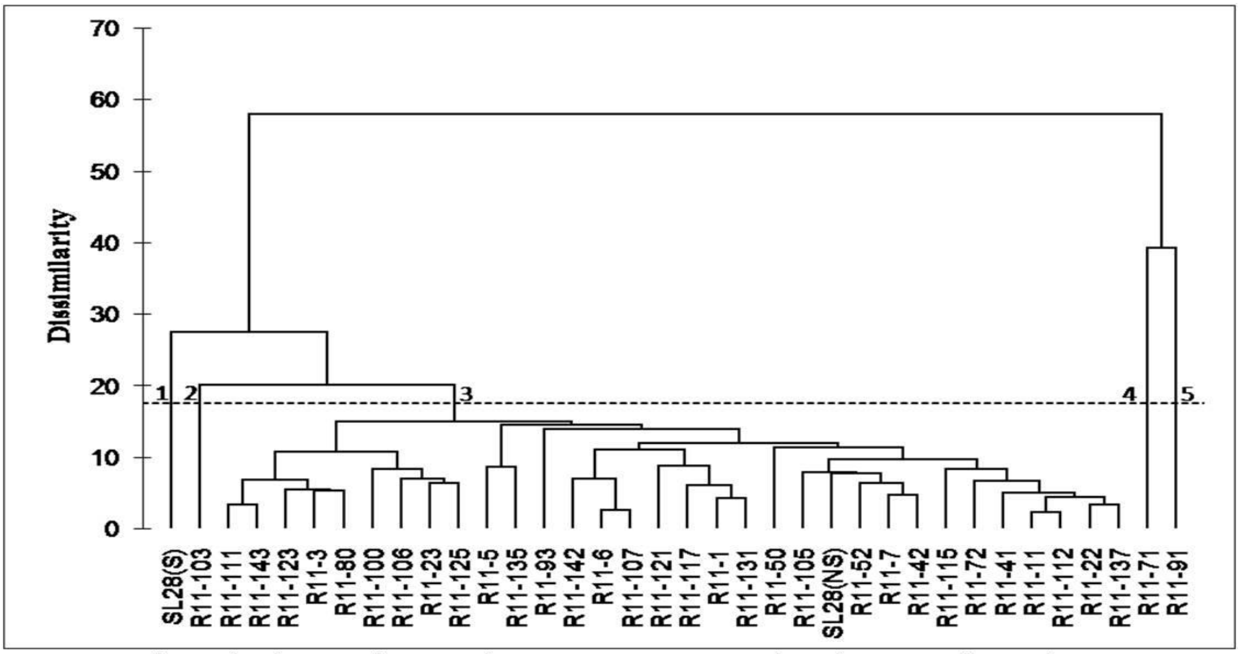

Figure 1: *Cluster dendrogram depicting diversity among genotypes based on raw coffee grades*

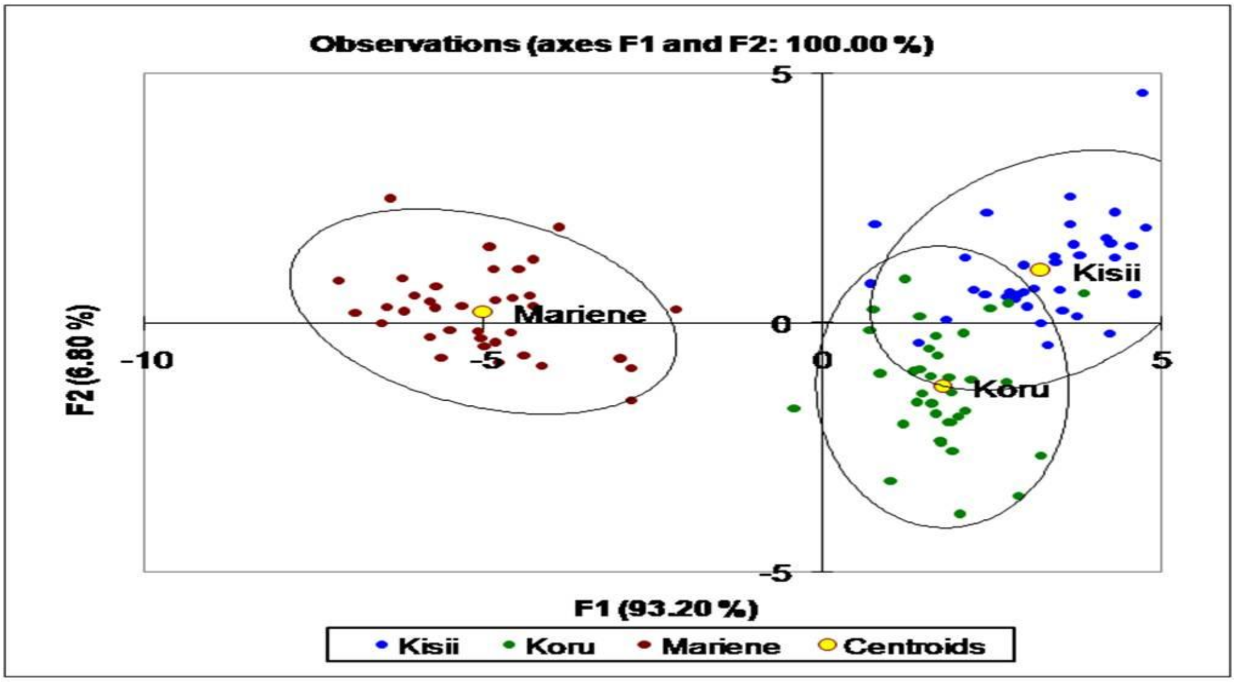

Figure 2: *Discriminant Factor Analysis (DFA) plot depicting location differences*

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

	Factor Coordinates		Average Proportions per Trait		
Traits	F1	F2	Mariene	Kisii	Koru
100 Berry Weight	0.270	0.420	140.6481	163.6142	141.5247
%Pulp	0.980	-0.023	43.16735	70.64707	66.22989
%Outturn	-0.751	0.090	17.84970	12.62921	13.09088
%TT	0.506	0.358	13.82862	26.30418	18.77908
%PB	-0.483	-0.385	9.597240	5.756425	8.244783
%E	0.154	-0.466	0.023980	0.049653	0.352603
%AA	0.173	-0.824	6.261801	5.470186	14.46544
%AB	-0.673	0.104	62.47113	46.49107	47.90195
%C	0.467	0.498	7.564134	13.84733	9.007854
%T	0.755	0.327	0.253098	2.081149	1.248297
100 Bean Weight	-0.048	-0.237	14.91199	14.27759	14.62930

Table 5: The best ten Ruiru 11 sibs per location

	Mariene		Kisii		Koru	
	Best Sibs	$ per Kg	Best Sibs	$ per Kg	Best Sibs	$ per Kg
1.	R11-52	6.59	R11-123	5.20	R11-93	6.16
2.	R11-117	6.47	R11-42	4.90	R11-107	5.82
3.	R11-131	6.28	R11-6	4.88	R11-142	5.69
4.	R11-121	6.25	R11-71	4.88	R11-112	5.67
5.	R11-93	6.17	R11-22	4.84	R11-5	5.65
6.	R11-142	6.13	R11-121	4.78	R11-105	5.61
7.	R11-103	6.13	R11-112	4.76	R11-121	5.60
8.	R11-1	6.06	R11-7	4.72	R11-71	5.50
9.	R11-50	5.82	R11-52	4.64	R11-103	5.46
10.	R11-105	5.70	R11-41	4.62	R11-80	5.43

Discussion

Low levels of genetic variation were observed among the test genotypes. Such low levels of genetic variation were expected due to the generally narrow genetic diversity associated with Arabica coffee (Agwanda *et al*., 2003; Gichimu and Omondi, 2010b). However, Mawardi and Hulip (1995) observed significant differences in bean characteristics among Arabica coffee genotypes. Similarly, Omondi *et al*. (2008) reported significant variation in raw bean quality among various Ruiru 11 hybrid sibs. Ruiru 11 sibs in the three locations were best differentiated at grades AA, C and T. The three sites did not therefore fulfill the condition of high genetic variances which is identified as one of the requirements for good selection and testing environment. Mariene and Kisii revealed higher differences between the sibs with respect to bean yield (outturn) and grades as compared to Koru. The latter could therefore be considered as a poor selection and testing environment for bean yield and quality. However, on the basis of average performance all the three sites qualified as good selection and testing environments but Kisii was the best as it consistently recorded lower means for outturn, 100 bean weight and high value grades (AA and AB) but higher means for low value grades (TT, C and T) and pulp.

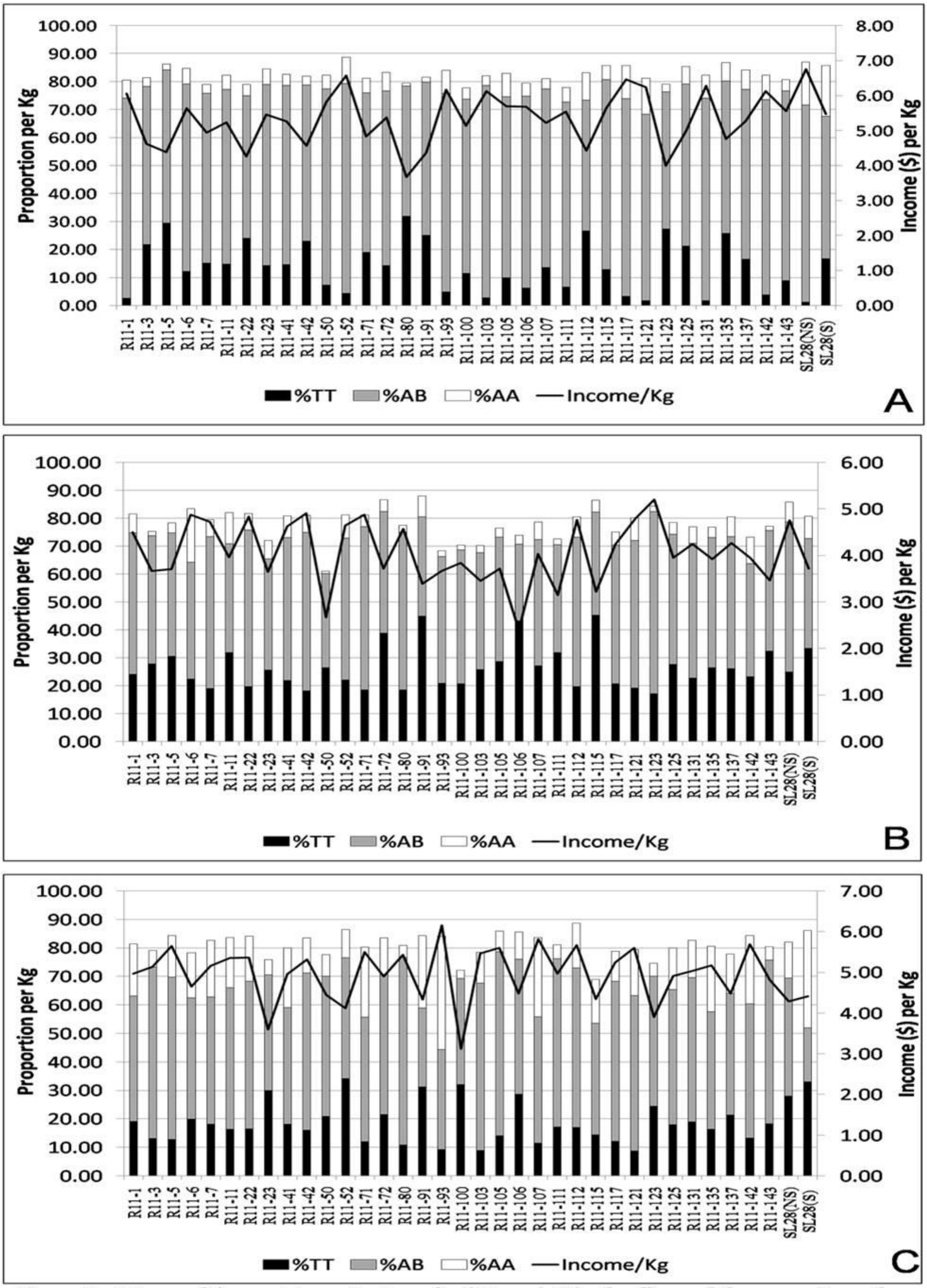

Figure 3: *Means of the most important grades (AA and AB) of coffee and the proportion of light beans (TT) separated from them. A = Mariene, B = Kisii, C = Koru*

Table 6: Pearson Correlation Matrix

Site	Variables	100 BerryWt	%Pulp	%Outturn	%TT	%PB	%E	%AA	%AB	%C	%T
Kisii	%Pulp	**0.293**									
Koru	%Pulp	-0.077									
Mariene	%Pulp	**-0.310**									
Kisii	%Outturn	-0.042	**-0.511**								
Koru	%Outturn	-0.014	-0.169								
Mariene	%Outturn	0.000	**0.483**								
Kisii	%TT	-0.076	-0.032	-0.113							
Koru	%TT	0.007	-0.012	-0.063							
Mariene	%TT	0.082	-0.094	-0.080							
Kisii	%PB	0.034	-0.144	0.131	-0.076						
Koru	%PB	0.132	-0.126	**0.436**	-0.037						
Mariene	%PB	0.119	0.133	0.153	-0.099						
Kisii	%E	-0.049	-0.090	-0.044	-0.053	0.069					
Koru	%E	-0.059	-0.041	-0.140	0.042	-0.122					
Mariene	%E	-0.017	0.093	0.061	0.188	-0.001					
Kisii	%AA	-0.003	**-0.220**	0.094	**-0.194**	0.119	0.091				
Koru	%AA	0.167	-0.089	0.140	**-0.239**	0.101	**0.293**				
Mariene	%AA	0.046	0.185	-0.037	**-0.259**	**0.422**	-0.001				
Kisii	%AB	0.079	0.070	0.155	**-0.837**	-0.179	0.084	-0.030			
Koru	%AB	-0.062	0.036	-0.081	**-0.597**	-0.185	**-0.276**	**-0.517**			
Mariene	%AB	-0.089	0.008	0.038	**-0.925**	-0.174	-0.167	-0.038			
Kisii	%C	-0.030	0.175	**-0.211**	**-0.213**	**-0.301**	-0.166	**-0.376**	-0.057		
Koru	%C	**-0.260**	0.181	**-0.196**	0.007	**-0.291**	-0.131	**-0.430**	-0.005		
Mariene	%C	-0.156	-0.048	0.081	0.091	**-0.446**	-0.117	**-0.639**	-0.009		
Kisii	%T	0.038	**0.243**	**-0.229**	-0.069	**-0.283**	**-0.198**	**-0.283**	-0.135	**0.699**	
Koru	%T	-0.097	0.152	**-0.207**	0.074	**-0.224**	-0.034	**-0.276**	0.001	**0.408**	
Mariene	%T	-0.056	-0.021	-0.006	-0.015	**-0.412**	0.012	-0.171	0.073	**0.341**	
Kisii	100BnWt	0.032	-0.145	0.089	-0.091	-0.015	-0.065	0.058	0.122	-0.063	-0.126
Koru	100BnWt	0.081	0.022	0.043	-0.105	**0.229**	0.052	**0.251**	-0.133	-0.139	-0.112
Mariene	100BnWt	0.016	-0.158	-0.167	0.071	-0.072	-0.109	0.086	-0.097	0.043	0.072

NB: Values in bold are different from 0 at p = 0.05. Bn = Bean, Wt = Weight

The site differences were very pronounced an effect which was attributed to differences in edaphic and climatic conditions of the three locations. Wamatu *et al*. (2003) also reported that within the coffee growing regions, crop yields fluctuate from location to location. In our study, rainfall was taken as the first most limiting factor and thus used to explain the observed site differences. Similar approach was also applied by Agwanda *et al*. 2003 who reported that good bean grades can only be realized under favourable berry expansion and bean filling conditions. Berry expansion and bean filling stages are known to occur between 6-16 and 17-24 weeks after flowering (Agwanda *et al*., 2003). Rainfall requirements for arabica coffee production are at least 1200 mm per year with a maximum of 2500 mm (Van der Vossen, 2009).

Kisii experienced some moisture stress during the later stages of berry expansion (Table 1). As a result, the site produced the lowest proportion of AA and AB grades and the highest proportion of TT and T (Table 4). These results could also be attributed to reduced photosynthetic activities during the filling stage when most of the days were rainy and cloudy (Kanechi *et al*., 1995). This, however, contradicts with Van der Vossen

(2009) who reported that lower temperatures induce slower growth and more uniform ripening of the berries resulting in larger and denser beans. Rainfall patterns at Koru fully supported both phases of berry expansion and bean filling resulting in the highest proportion of AA grade. However, compared to other sites, Koru site recorded a relatively higher proportion of TT at the expense of AB grades (Table 4). Mariene experienced relatively lower rainfall which was evenly distributed throughout the berry expansion and filling period. These conditions apparently reduced the proportion of TT and T grades but favoured the production of AB grades compared to other sites (Table 4). Good distribution of rainfall during these two phases could also be of significance as demonstrated in Koru and Mariene. However, too much rainfall may lead to high proportion of pulp at the expense of bean outturn as experienced at Koru and Kisii.

G x E is a measure of stability and adaptability of genotypes in varying environments. In this study, significant G x E interactions were observed only in four (outturn, AA, C and T) out of eleven traits studied. These significant interactions might be to a large extent attributable to the low precision in balancing the growing conditions in the multi-site trials. Other researchers have obtained similar or contrasting G x E interaction results. Using 22 Ruiru 11 sibs in a similar study, Agwanda *et al*. (2003) found significant G x E interactions in all the bean grades except TT and C. Similarly, Mawardi and Hulip (1995) observed highly significant G x E interactions in bean characteristics of Arabica coffee. Wamatu *et al*., 2003 also reported that G x E interactions for coffee yield were of significant magnitude. On the other hand, Walyaro (1983) found that these interactions were far less important than genotypic effects. Gichimu and Omondi (2010a) did not find any significant G x E interactions in growth and yield parameters among five newly developed lines of Arabica coffee in Kenya. These contrasting results by different researchers may be explained by trial characteristics and variations with genotypes used.

Conclusion

The study demonstrated the existence of a high potential of intra-selection within the hybrid cultivar, Ruiru 11 and a possibility of further improvement of bean quality. The best overall sibs were identified as R11-121, R11-93, R11-142, R11-52 and R11-71. Although the study exhibited highly significant G x E interactions in four raw bean traits (outturn, AA, C and T), these interactions were not as heavy as reported by some previous authors. This was because the entire three sites lie in suitable coffee growing areas thus provided favourable conditions for coffee production without exposing the genotypes to harsh environmental conditions which would provide better grounds for selection. However, the occurrence of significant G x E interactions in some of the studied traits was an indication that the best improvement strategy should be a multi-site selection. Rainfall intensity and distribution was also found to be critical during berry expansion and bean filling stages. 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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