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## Yield Selection within *Coffea arabica* cv. Ruiru 11

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### Authors' contributions

*This work was carried out in collaboration between all authors. The research project was conducted by BMG, a PhD student at Jomo Kenyatta University of Agriculture and Technology. The contribution of the co-authors was as follows: EKG assisted greatly in the development of the concept note for this study and together with ABN provided technical advice on design and layout of experiment. GEM analyzed and interpreted the data and contributed greatly in the preparation of the manuscript assisted by BMG in consultation with EKG. All authors read and approved the final manuscript.*

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### ABSTRACT

**Aims:** This study was aimed at identifying high yielding Ruiru 11 sibs in varying growing conditions. The study also intended to measure the extent to which cherry yields of Ruiru 11 are affected by the environment.

**Study Design:** Randomized Complete Block Design with three replications.

**Place and Duration of Study:** 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 between November 2008 and September 2011.

**Methodology:** Thirty four (34) Ruiru 11 sibs, all of which are resistant to Coffee Berry Disease and Coffee Leaf Rust, were evaluated in this study alongside two entries of SL28, a cultivar susceptible to the two diseases. One entry of SL28 was sprayed with copper fungicides to control, while the other SL28 entry was not sprayed with any fungicides. Planted at a spacing of 2m by 2m, each entry had 12 trees per plot per rep, giving a total of 1296 plants per experiment per site. Cherry yield recording was done during the peak harvesting period of May to July at Mariene and July to September at Koru and Kisii. The data was subjected to Analysis of Variance (ANOVA) using XLSTAT version 2012 statistical software and effects declared significant at 5% level.

**Results:** Significant ( $P = .05$ ) yield differences among Ruiru 11 sibs were obtained in all

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years of evaluation at Koru but only in 2011 at Kisii and Mariene. There was a greater discrimination between sibs at Koru, followed by Kisii and then Mariene. Year effect was highly significant ( $P < .001$ ) and equally distinguished in all sites but year x sib interactions were significant ( $P = .05$ ) only at Kisii. Combined analysis for all environmental combinations showed highly significant ( $P < .001$ ) differences between sibs, environments and their interaction. Environments made a greater contribution (42.6%) to the variation compared to sibs (7%). The interaction term also made a significant contribution (18.7%). The best sibs per site and those adapted to contrasting environments were identified.

**Conclusion:** The expression of high yield variation among Ruiru 11 sibs is a sign of high potential of intra-selection within the cultivar for yield improvement. Identified sibs can be recommended to farmers and also exploited in future breeding programmes for improvement of Ruiru 11 productivity and agronomic adaptability. The occurrence of significant sib by environment (G x E) interactions was an indication that the best improvement strategy should be a multi-site selection.

*Keywords: Coffee; Ruiru 11; cherry yields; Kenya.*

## 1. INTRODUCTION

Behind oil, coffee is the second most traded commodity in the world. Its cultivation is mainly by smallholder farmers who hardly break even mainly due to low yields, high production cost and low world market prices. Increasing productivity, while reducing the cost of production is a main breeding objective of most producing countries [1]. New arabica cultivars with higher yield potential and resistance to Coffee Leaf Rust (CLR) and/or Coffee Berry Disease (CBD) have started to replace traditional varieties on a large scale in several countries [2]. 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 [3]. The cultivar was developed at the Coffee Research Station, Ruiru, Kenya, and released to growers in 1985. It combines resistance to CBD and CLR with high yield, fine quality and compact growth amenable to high density planting [3].

The economic value of Arabica coffee *Coffea arabica* L. is determined both by the yield potential and the bean quality [4]. Yields of 5 tons  $\text{ha}^{-1}$  and higher have been obtained in some close-spaced and unshaded Arabica coffee blocks e.g. in Brazil, Colombia and Kenya [5]. However, most smallholder Arabica coffee farms with no access to external inputs often produce less than 300 kg  $\text{ha}^{-1}$  year $^{-1}$  green coffee beans, while intensively managed plantations at conventional spacing may yield an average of 2 tons  $\text{ha}^{-1}$  annually [6]. Data from field trials at Coffee Research Foundation, in Kenya shows that Ruiru 11 cultivar planted at a density 3300 trees/ha produces between 2.5 and 3.0 tons  $\text{ha}^{-1}$  year $^{-1}$  [6]. Depending on conditions, coffee yields fluctuate from year to year and from location to location [7;8].

Success of a new variety depends to a great extent on its adaptability to a wide range of climatic and soil conditions [8]. Coffee can be cultivated on a wide range of soil types, provided these are at least 2 m deep, free-draining loams with a good water-holding capacity and a pH of 5–6, fertile and contain at least 2% organic matter. High-quality, acidic Arabica coffees are mostly produced on soils of volcanic origin [6]. Arabica coffee is grown in altitude ranges between 1400 and 1800 m above sea level [9]. The optimum mean annual temperature range for Arabica coffee is 18-21°C [10]. Rainfall requirements depend on the

retention properties of the soil, atmospheric humidity and cloud cover, as well as cultivation practices. The optimum annual rainfall range is 1200-1800 mm for Arabica coffee [10] with a maximum of 2500 mm [6]. Coffee plants grow and yield better if exposed to alternate cycles of wet and dry seasons [6]. Abundant rainfall throughout the year often results in scattered harvest and low yields [10]. The distribution of sunshine also has a strong influence on flowering, bean expansion and ripening. Shade decreases coffee tree productivity by about 20%, but reduces the alternate bearing pattern [11].

Knowledge of the effects of environment and genotype by environment (GxE) interaction is important to breeders in making decisions regarding the development, evaluation and release of new cultivars [7,8]. Identifying high yielding coffee genotypes is often time consuming and difficult to achieve due to the perennial nature of the crop, biennial bearing, and the large environmental component of variance for yield [1]. This study aimed at identifying high yielding Ruiru 11 sibs in varying growing conditions. The study also intended to measure the extent to which cherry yields of Ruiru 11 are affected by the environment.

## **2. MATERIALS AND METHODS**

### **2.1 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 mollic 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.

### **2.2 Plant Materials and Field Layout**

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 copper fungicides to control CBD and 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 2m by 2m, each entry had 12 trees per plot per rep, giving a total of 1296 plants per experiment per site. Cherry yield recording was done during the peak harvesting period of May to July at Mariene and July to September at Koru and Kisii. Rainfall was recorded in all the three sites for the three production seasons (years) at various berry development stages (Table 2).

**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 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, Cat. = Catimor, The numbers in the table are Ruiru 11 sibs e.g. 1 = Ruiru 11 sib 1 and so on

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

Kisii												
Stages	Flowering	Pinhead	Berry expansion				Filling		Ripening			Total rainfall
Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	
2008/09	153.4	82.6	111.2	661.3	188.3	231	297.4	152.3	63.2	197.2	160.3	2298.2
2009/10	151.7	305.5	49.8	99.6	203.4	233.7	406.8	202.4	79.6	204.3	292.1	2228.9
2010/11	109.1	188.5	97.5	42.5	138.5	237.2	267.8	91.6	100.5	233.6	225.3	1732.1
Koru												
Stages	Flowering	Pinhead	Berry expansion				Filling		Ripening			Total rainfall
Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	
2008/09	92.1	28.5	122.6	87.8	59.9	267.7	177.6	102.6	113.8	83.1	176.6	1312.3
2009/10	106.2	343	102.8	215.5	211.8	163.4	258.9	140.6	132	118.4	89	1881.6
2010/11	80	163.3	67.7	88	177.5	60.3	198.5	138.4	77.4	205.9	211.6	1468.6
Mariene												
Stages	Flowering	Pinhead	Berry expansion				Filling		Ripening			Total rainfall
Month	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	
2008/09	37.5	3.5	19	181.4	138.3	0.6	147	15.6	156.5	221.6	96	1017.0
2009/10	12.6	16.8	3	303.8	420.5	194.7	192.9	118.7	348.4	504.2	121.1	2236.7
2010/11	21.3	21	1.4	181.8	370.5	30.6	49	22.8	52.8	252.5	148.4	1152.1

### 2.3 Data Analysis

The data was 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 over the three production years. Least Significance Difference (LSD) was used to separate the means.

### 3. RESULTS

Cherry yield 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. Analysis of variance (ANOVA) obtained significant ( $P = .05$ ) yield differences among Ruiru 11 sibs in all the years at Koru but only in 2011 at Kisii and Mariene. This was an indication of some genetic variation between the sibs which are considered to be closely related. Examination of the F values at each location showed that there was a greater discrimination between sibs at Koru, followed by Kisii and then Mariene. The year effect was highly significant ( $P < .001$ ) and equally distinguished in all sites but year x sib interactions were significant ( $P = .05$ ) only at Kisii (Table 3).

**Table 3. Sib variations for cherry yield at the three sites over three years**

	Sib variations			Combined variations		
	2009	2010	2011	Year	Sibs	Year x Sib
Kisii	-	0.0941 <sup>ns</sup>	0.0038 <sup>**</sup>	0.0001 <sup>***</sup>	0.0027 <sup>**</sup>	0.0358
Koru	0.0387 <sup>*</sup>	0.0181 <sup>*</sup>	0.0062 <sup>**</sup>	0.0001 <sup>***</sup>	0.0001 <sup>***</sup>	0.9392 <sup>ns</sup>
Mariene	0.1554 <sup>ns</sup>	0.5341 <sup>ns</sup>	0.0149 <sup>*</sup>	0.0001 <sup>***</sup>	0.0003 <sup>***</sup>	0.8501 <sup>ns</sup>

Analysis of variance of the individual years with the locations combined revealed that the site effect was significant ( $P = .05$ ) in all the years. All the sites recorded their best yields in 2010. Mariene trial consistently recorded the lowest yields in all the years that were evaluated while Koru trial recorded moderate yields. Kisii and Koru recorded similar yields in 2010 but the former yielded highest in 2011 (Table 4).

**Table 4. Site variations in average (Av.) cherry yields (in grams) over the three years**

	2009		2010		2011	
	Av. yield	Variation	Av. yield	Variation	Av. yield	Variation
Kisii	-	-	11825.29	A	10018.58	A
Koru	8785.29	A	11091.30	A	7515.34	B
Mariene	4419.74	B	5033.40	B	4188.93	C
LSD	713.97		790.22		851.07	

NB: Means sharing the same letter along the column are not significantly different ( $P = .05$ )

Multi-site analysis for the 8 environmental combinations recorded significant differences between sibs, environments and their interaction (Table 5). Further scrutiny of their contribution to total sum of squares indicated that environments made a greater contribution (42.6%) to the variation compared to sibs (7%). The interaction term also made a significant contribution (18.7%).

**Table 5. Multi-site analysis of variance for cherry**

Source	DF	SS	MS	F	P
Blocks	2	25401139.7	12700570	1.40733	0.2456 ns
Environment	7	7030918459	1.00E+09	111.298	0.0000 ***
Sib	35	1152790161	32936862	3.64967	0.0000 ***
Environment x Sib	245	3077380387	12560736	1.39183	0.0008 ***
Error	574	5180123925	9024606.1<-		
Total	863	1.65E+10			

Key: *df* = degrees of freedom, *SS* = Sum of Squares, *MS* = Mean Squares, *F* = Fishers value, *P* = level of significance

Overall, Kisii and Koru in 2010 produced the highest yields. They were followed by Koru in 2011, Koru in 2009, Kisii in 2011 and Mariene 2010 in that order, all of which recorded cherry yields that were significantly ( $P = .05$ ) different from each other. The lowest yields were recorded at Mariene in 2011 and 2009 (Table 6).

**Table 6. Environmental effect on cherry yield of Ruiru 11 sibs**

Rank	Environment	Yields (g)	Variation
1	Kisii 2010	11825.287	A
2	Koru 2010	11091.305	A
3	Koru 2011	10018.583	B
4	Koru 2009	8785.288	C
5	Kisii 2011	7515.341	D
6	Mariene 2010	5033.398	E
7	Mariene 2009	4419.741	EF
8	Mariene 2011	4188.927	F
	LSD	802.938	

NB: Means sharing the same letter along the column are not significantly different ( $P = .05$ )

Significant yield differences were observed among the sibs in all the locations. Evaluated sibs were found to produce average yields between 3 – 16 kgs (Table 7). The high yielding but susceptible SL28 cultivar was used as a check. In all the three sites, SL28 sprayed with fungicide recorded slightly higher yields than the unsprayed SL28 in absolute terms but statistically similar. Therefore, spraying SL28 against fungal diseases had no significant effect on yield. At Kisii site, the yields of SL28 (both sprayed and unsprayed) were highly comparable to those of most Ruiru 11 sibs. The yields of sprayed SL28 were not significantly different from those of the first 30 Ruiru 11 sibs (except 143, 107, 106 and 112) while the yields of unsprayed SL28 were statistically similar to those of all Ruiru 11 sibs except R11-112. At Koru, all Ruiru 11 sibs produced better yield than SL28 in absolute terms with 17 sibs recording significantly ( $P = .05$ ) higher yields than SL28. At Mariene, 8 Ruiru 11 sibs recorded significantly ( $P = .05$ ) higher yields than SL28 (Table 7).

The best performing sibs per location are shown in Table 8. The most suited sibs for Kisii site which recorded high yields in both seasons were found to be R11-131, R11-52, R11-7, R11-117, R11-6, R11-142, R11-1 and R11-41. The Koru site was found to be favourable for most of the sibs but best performing were R11-107, R11-91, R11-80, R11-117, R11-142, R11-52, R11-137, R11-11, R11-100 and R11-135.

**Table 7. Average performance of each sib per location**

Kisii				Koru				Mariene			
Rank	Sib	Mean yield	Variation	Rank	Sib	Mean yield	Variation	Rank	Sib	Mean yield	Variation
1.	R11-131	14115.97	a	1	R11-80	15995.37	a	1	R11-52	5976.15	a
2.	R11-52	12981.67	ab	2	R11-107	14223.80	ab	2	R11-1	5914.93	a
3.	R11-137	12671.94	abc	3	R11-137	13115.73	abc	3	R11-11	5890.04	ab
4.	R11-117	12437.08	abcd	4	R11-117	13038.19	abcd	4	R11-135	5640.22	abc
5.	R11-6	11747.50	abcde	5	R11-91	12886.57	abcde	5	R11-3	5580.67	abcd
6.	R11-7	11587.22	abcdef	6	R11-142	12423.47	bcdef	6	R11-22	5323.28	abcde
7.	R11-1	11545.28	abcdef	7	R11-52	12032.70	bcdefg	7	R11-117	5270.78	abcde
8.	SL28(S)	11208.06	abcdefg	8	R11-100	12016.00	bcdefg	8	R11-121	5173.85	abcdef
9.	R11-111	11015.00	abcdefg	9	R11-131	11765.36	bcdefgh	9	R11-7	4987.00	abcdefg
10.	R11-42	10817.64	abcdefgh	10	R11-11	11620.89	bcdefghi	10	R11-100	4827.81	abcdefgh
11.	R11-41	10655.86	abcdefghi	11	R11-135	11494.28	bcdefghij	11	R11-131	4823.04	abcdefgh
12.	R11-121	10604.86	abcdefghi	12	R11-115	11407.59	bcdefghij	12	R11-115	4822.93	abcdefgh
13.	R11-50	10587.08	abcdefghi	13	R11-125	10888.70	bcdefghijk	13	R11-143	4767.89	abcdefgh
14.	SL28(NS)	10317.94	abcdefghij	14	R11-105	10351.90	cdefghijk	14	R11-106	4663.63	abcdefgh
15.	R11-142	10238.75	abcdefghij	15	R11-123	10295.81	cdefghijk	15	R11-6	4654.26	abcdefgh
16.	R11-22	10142.78	bcdefghij	16	R11-7	10269.14	cdefghijk	16	R11-123	4551.48	bcdefghi
17.	R11-105	9948.75	bcdefghij	17	R11-121	9951.22	cdefghijk	17	R11-137	4531.41	cdefghi
18.	R11-72	9867.50	bcdefghij	18	R11-72	9677.07	cdefghijkl	18	R11-105	4525.30	cdefghi
19.	R11-5	9686.25	bcdefghij	19	R11-22	9569.67	defghijkl	19	R11-72	4518.41	cdefghi
20.	R11-23	9507.08	bcdefghij	20	R11-6	9384.40	efghijkl	20	R11-142	4484.33	cdefghi
21.	R11-91	9202.64	bcdefghijk	21	R11-42	9350.75	fghijkl	21	R11-80	4482.04	cdefghi
22.	R11-125	9198.75	bcdefghijk	22	R11-23	9125.94	fghijkl	22	R11-125	4410.22	cdefghi
23.	R11-115	8988.75	cdefghijk	23	R11-93	9040.70	fghijkl	23	R11-112	4335.44	cdefghi
24.	R11-11	8825.42	cdefghijk	24	R11-41	8880.03	ghijkl	24	R11-23	4270.07	defghi
25.	R11-103	8661.94	defghijk	25	R11-103	8731.01	ghijkl	25	R11-93	4187.93	efghi
26.	R11-100	8387.36	efghijk	26	R11-50	8370.11	hijkl	26	R11-5	4036.63	efghi
27.	R11-123	8261.67	efghijk	27	R11-143	8122.30	ijklm	27	R11-91	4000.74	efghi
28.	R11-80	8058.47	efghijk	28	R11-112	8033.38	jklm	28	R11-111	3891.11	fghi
29.	R11-135	7995.14	efghijk	29	R11-1	7865.91	klm	29	R11-42	3823.26	ghi
30.	R11-3	7841.11	fghijk	30	R11-111	7800.23	klm	30	R11-71	3788.44	ghi

31.	R11-71	7588.33	ghijk	31	R11-3	7624.22	klm	31	R11-41	3773.70	ghi
32.	R11-93	7503.33	ghijk	32	R11-106	7574.63	klm	32	R11-107	3711.15	ghi
33.	R11-143	7012.78	hijk	33	R11-5	7456.94	klm	33	SL28(S)	3652.52	ghi
34.	R11-107	6886.67	ijk	34	R11-71	7451.14	klm	34	SL28(NS)	3585.78	hi
35.	R11-106	6461.39	jk	35	SL28(S)	6169.75	lm	35	R11-50	3583.89	hi
36.	R11-112	5573.33	k	36	SL28(NS)	4737.24	m	36	R11-103	3244.48	i

Table 8. The best 15 Ruiru 11 sibs for the Koru, Kisii and Mariene sites

Kisii		Koru						Mariene							
2010	2011	2009		2010		2011		2009		2010		2011			
Sib	Mean yields (g/tree)	Sib	Mean yields (g/tree)	Sib	Mean yields (g/tree)	Sib	Mean yields (g/tree)	Sib	Mean yields (g/tree)	Sib	Mean yields (g/tree)	Sib	Mean yields (g/tree)		
R11-131	15937.8	R11-137	14248.3	R11-107	16241.7	R11-80	18608.3	R11-80	16933.3	R11-1	6443.7	R11-3	6906.3	R11-106	6122.2
R11-52	14820.0	R11-131	12294.2	R11-91	14348.6	R11-117	15797.9	R11-137	14975.0	R11-135	6223.0	R11-22	6636.7	R11-52	5596.1
R11-50	14000.0	R11-117	11584.2	R11-80	12444.4	R11-131	14638.0	R11-115	13350.0	R11-11	5909.3	R11-52	6489.0	R11-11	5539.4
R11-72	13546.7	R11-111	11443.3	R11-117	11758.3	R11-100	14445.2	R11-107	13250.0	R11-52	5843.3	R11-121	6314.3	R11-1	5477.8
R11-11	13455.6	R11-52	11143.3	R11-142	11394.4	R11-142	14242.6	R11-91	12634.0	R11-121	5793.3	R11-11	6221.3	R11-7	5388.3
R11-7	13381.1	R11-105	11093.1	R11-52	11361.1	R11-121	14187.0	R11-131	12433.3	R11-117	5671.7	R11-123	5949.3	R11-135	5271.7
R11-117	13290.0	R11-42	10867.5	R11-137	10584.7	R11-137	13787.5	R11-11	12075.0	R11-3	5617.3	R11-117	5865.7	R11-42	5062.8
R11-6	12826.7	R11-6	10668.3	R11-11	10440.3	R11-107	13179.7	R11-135	11925.0	R11-22	5374.0	R11-1	5823.3	R11-5	4867.2
R11-142	12746.7	R11-1	10585.0	R11-125	10175.0	R11-52	13095.3	R11-100	11666.7	R11-6	5211.7	R11-100	5600.0	R11-93	4804.4
R11-22	12737.8	R11-121	9856.4	R11-115	9991.7	R11-135	12874.5	R11-52	11641.7	R11-100	5187.3	R11-6	5470.0	R11-105	4643.9
R11-1	12505.6	R11-7	9793.3	R11-100	9936.1	R11-125	12866.1	R11-142	11633.3	R11-80	4928.0	R11-115	5432.0	R11-41	4569.4
R11-5	12290.0	R11-41	9163.6	R11-135	9683.3	R11-11	12347.4	R11-123	11616.7	R11-123	4857.3	R11-135	5426.0	R11-91	4555.6
R11-93	12286.7	R11-125	8541.9	R11-121	9058.3	R11-72	11988.2	R11-117	11558.3	R11-131	4844.0	R11-131	5360.7	R11-115	4514.4
R11-41	12148.1	R11-115	8384.2	R11-42	8987.5	R11-7	11910.2	R11-6	11250.0	R11-7	4722.0	R11-143	5312.0	R11-137	4415.6
R11-3	11922.2	R11-142	7730.8	R11-105	8970.8	R11-91	11677.1	R11-22	11175.0	R11-142	4720.7	R11-112	5062.7	R11-143	4400.0



**Table 9. Most widely adapted sibs**

2009			2010		2011	
No.	Sib	Most adapted at	Sib	Most adapted at	Sibs	Most adapted at
1	R11-117	Koru and Mariene	R11-131	All Sites	R11-137	All Sites
2	R11-80	Koru and Mariene	R11-117	All Sites	R11-131	All Sites
3	R11-52	Koru and Mariene	R11-52	All Sites	R11-52	All Sites
4	R11-11	Koru and Mariene	R11-11	All Sites	R11-117	All Sites
5	R11-142	Koru and Mariene	R11-121	Koru and Mariene	R11-105	All Sites
6	R11-135	Koru and Mariene	R11-100	Koru and Mariene	R11-115	All Sites
7	R11-100	Koru and Mariene	R11-142	Koru and Kisii	R11-41	All Sites
8	R11-121	Koru and Mariene	R11-22	Kisii and Mariene	R11-7	Kisii and Mariene
9	R11-105	Koru and Mariene	R11-72	Koru and Kisii	R11-6	Kisii and Koru
10	R11-7	Koru and Mariene	R11-7	Koru and Kisii	R11-91	Koru and Mariene

The above mentioned sibs for both Kisii and Koru sites consistently recorded high yields in varying environmental conditions. For Mariene, the best performing sibs were R11-1, R11-135, R11-11 and R11-52. The four were the only ones that yielded consistently better under all conditions and were regarded to be highly stable in terms of yields. The sibs were best discriminated at Mariene and the site was considered the best for yield selection followed by Kisii.

The most widely adapted sibs which performed better in varying climatic conditions are shown in Table 8. R11-52 and R11-117 were the best sibs overall, consistently recording high yields in all the environments. Other sibs that consistently recorded high yields in varying environments are R11-131, R11-11, R11-105, R11-142, R11-7, R11-100 and R11-121. In addition, R11-80, R11-135, R11-22, R11-72, R11-137, R11-115, R11-6 and R11-91 consistently recorded high yields in more than one environment (Table 9).

#### 4. DISCUSSION

Although some studies have been carried out to assess variation of Ruiru 11 sibs in quality [4;12;13;14] and disease resistance [3], there is little information about their variation in yield. Ruiru 11 sibs evaluated were found to differ significantly in yields. This was an indication of high genetic variation between Ruiru 11 sibs. Similar results were obtained by Wamatu *et al.* [8] when evaluating related coffee clones some of which have been utilized as Ruiru 11 male parents. In Brazil, Carvalho *et al.* [15] observed large variability in cherry yields among F1 generation plants obtained by crossing selected coffee trees and among bourbon coffee progenies that have been harvested for 12 to 15 consecutive years. When assessing cup quality of Ruiru 11, Ojijo [12], Agwanda *et al.* [4], Omondi [13], Kathurima *et al.* [14], also reported significant variability within the cultivar.

The observed site differences indicated that the environment has a strong effect on the expression of yield potential. We attribute differences in yield to the particular edaphic and climatic conditions of each site. Wamatu *et al.* [8] and Anim-Kwapong and Adomako [1] also reported large environmental component of variance for yield in coffee. The three sites partly fulfilled the conditions of good selection and testing environment which include high genetic variances, high mean performance and high heritability [4]. On the basis of average performance, Koru could be the best selection site followed by Kisii as they consistently recorded the highest means which better portrayed the potential of the sibs. There was also greater discrimination between sibs at Koru, followed by Kisii and then Mariene. However, Mariene could also be a good selection site to discriminate the sibs under less favourable conditions while Koru could be the best selection site based on high genetic variances.

In our study, rainfall was taken as the first most important limiting factor and thus used to explain the observed site differences. A similar approach was also applied by Agwanda *et al.* [4] when selecting for cup quality. The observed seasonal (year) effects can be partly explained by varying quantity and distribution of rainfall and partly by the biennial bearing nature of coffee. All the sites recorded their best yields in 2010. This was because the sites received adequate rainfall which was well distributed in 2009/2010 production year thus resulting in high yields. In 2008/2009 production year, the Koru trial experienced reduced rainfall especially in the early stages of berry development which resulted in reduced yields. A similar effect was observed in 2008/2009 production year at Mariene and also in 2010/2011 production year at both Mariene and Kisii. Seasonal (year) x sib interactions were not significant except at Kisii and this effect was attributed to biennial bearing.

Genotype by Environment (G x E) interactions is a measure of stability and adaptability of genotypes in varying environments. In this study, significant G x E interactions was observed indicating that different Ruiru 11 sibs responded differently to different environments. When evaluating related coffee clones some of which have been utilized as Ruiru 11 male parents, Wamatu *et al.* [8] also observed significant G x E interactions. Apart from yields, significant G x E interactions has also been reported on other desirable traits in Ruiru 11 and other types of Arabica coffee. For example, on coffee quality of Ruiru 11, Agwanda *et al.* [4], Omondi [13] and Kathurima *et al.* [14] reported G x E interactions of significant magnitude. Mawardi and Hulip [16] and Agwanda *et al.* [4] observed highly significant G x E interactions in bean characteristics of Arabica coffee. High G x E interactions for desirable traits have been reported as a major setback in achieving faster progress in selection [4]. 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.

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 high yielding potential in varying climatic conditions. These included R11-52, R11-117, R11-131, R11-11, R11-105, R11-142, R11-7, R11-100 and R11-121. These consistently recorded high yields in highly varying environments. Others that consistently recorded high yields in more than one environment include R11-80, R11-135, R11-22, R11-72, R11-137, R11-115, R11-6 and R11-91. Some of these sibs including R11-52, R11-117, R11-131, R11-107, R11-121, R11-11, R11-137 and R11-22 have also been found to have high bean and cup quality with good climatic stability [17]. Kathurima *et al.* [14] also recorded high cup quality from R11-41, R11-11, R11-91 and R11-131 in a multi-site study involving ten Ruiru 11 sibs. Such sibs can be recommended to farmers and also be exploited in future breeding programmes for improvement of Ruiru 11 yield agronomic adaptability.

## 5. CONCLUSION

The study demonstrated the existence of a high yield variation among Ruiru 11 sibs. There is therefore high potential of intra-selection within the cultivar for yield improvement. The most widely adapted Ruiru 11 sibs as well as the best sibs for the studied coffee growing areas on the basis of cherry yield were identified. These will be recommended to farmers and also be exploited in future breeding programmes for improvement of Ruiru 11 yield agronomic adaptability. The growing environment was found to have a strong effect on the expression of yield potential as portrayed by high site variations. The occurrence of significant G x E interactions was an indication that the best improvement strategy should be a multi-site selection. Future studies should therefore include many locations with more variable climatic conditions ranging from marginal to suitable coffee growing areas. Rainfall intensity and distribution especially during the early stages of berry development was also found to be critical as the highest yields were where rainfall was adequate and well distributed.

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## COMPETING INTERESTS

Authors declared that no competing interests exist.

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