Agronomic Performance and Heritability of Some Yield Components of Robusta Coffee (*Coffea canephora* Pierre ex-Froehner) Clones

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Abstract

The present investigation evaluates the performance of newly identified clones in the major coffee growing zones of Kagera region, Tanzania. Five clones, namely MS1/95, MS2/95, MS3/95, MS5/95, MS6/95 selected from individual trees in farmers' fields and FS, a control variety, were grown in farmers fields in March 1998 at four locations representing 3 coffee growing zones of Kagera region. Each chosen farmer's field was a replicate. Plant girth and fruit set percentage differed significantly among the clones tested. MS2/95 had the thickest stems while MS3/95 gave the highest percentage of fruit set. Percent fruit set ranged from 13.5% - 31.4% for MS6/95 and MS3/95 respectively. Locations differed on yield, % bearing primary branches, canopy radius, plant girth and plant height. Kabirizi B gave the highest yield of 1853.8 kg/ha while Chanika gave the lowest yield of 358.8 kg/ha. The yield differences between locations were associated with performance of clones on plant height, plant girth, canopy radius, primary branches and % bearing primary branches. Plant height, girth, canopy radius, primary branches, % bearing primary branches and yield of clean coffee were positively correlated among themselves. Heritability estimates were high (50%) for plant girth, berries per node and fruit set percentage. Heritability ranged from negligible for yield to 125% for plant girth. Expected genetic gain varied with heritability, ranging from negligible to 36.5% for fruit set percentage. Yield of clean coffee had appreciable amounts of clone x location interaction and environmental variances in relation to the total phenotypic variance. It should be possible to realize substantial gain from selection and genetic improvement for plant girth, berries per node and fruit set percentage.

Keywords: Environmental variance, expected genetic gain, clone x location interaction, heritability, robusta coffee

Introduction

In Tanzania, coffee (*Coffea sp.*) is one of the top three crops in terms of monetary value, cotton and sisal being the other two forming the backbone of the country's domestic exports (Mbilinyi, 1976). Coffee contributes about 5% of the monetary Gross Domestic Product (GDP) in Tanzania. There are two types of coffee grown in Tanzania. These are arabica (*Coffea arabica*) and robusta (*Coffea canephora*). Coffee production in Kagera region contributes about one-quarter of the total coffee export earning of Tanzania, and this being mainly from robusta coffee (Marshall, 1983; Annon, 1994). In recent years, coffee production in Tanzania has been on the decline despite increased acreage (Eskes, 1997). Among other factors contributing to this decline, is lack of improved clones that withstand the prevailing environmental constraints. There is an urgent need of searching for improved clones in order to raise productivity. When robusta coffee was promoted to be planted in large scale on Kagera region, the only means farmers used in the initial development of the crop to rapidly multiply cof-

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fee was through use of seed. The coffee growers, having adopted the seed multiplication method, continued to select seeds from better trees, which they thought would raise good seedlings resembling their mother trees. However, this practice did not meet their expectations due to genetic segregation. Therefore, robusta coffee farmers in Kagera region are currently facing the problem of obtaining good robusta coffee planting materials. A selection programme of robusta coffee was initiated in 1957, by collecting robusta accessions from the region. More robusta materials were introduced from Kawanda Research Station in Uganda and the rest of the world. Although the programme started its activities satisfactorily, subsequent production of clones was not well sustained. So far, the Maruku Agricultural Research Institute (MARI) has selected clones MS1/95, MS2/95, MS3/95, MS5/95 and MS6/95 for further testing.

For plant breeders, information on the interaction between genotype x environment is important in developing and recommending cultivars to suitable environments for specific variables. Similarly, information on the amount of variation with respect to different factors in relation to the total variance on yield and its components is important to deduce the relative importance of the various factors in the expression of the variables of interest. The latter aids in proper planning of crop improvement and management practices for better productivity. Accurate estimates of components of variance provide a basis for critically evaluating breeding and testing procedures. Heritability and estimates of genetic advance help in designing appropriate improvement and selection procedure for improved clones. However, information on inheritance studies in robusta coffee, particularly under Tanzanian conditions is limited.

The present investigation therefore aims at evaluating the newly identified clones of robusta coffee for agronomic performance and inheritance studies in the coffee growing zones of Kagera region. The information will facilitate identification of better clones for improved productivity and enable better planning of management and improvement programmes.

Materials and methods

Six clones of robust coffee were used in the evaluation trial that was carried out at four locations of variable agro ecological zones in Kagera region. The clones were MS1/95, formerly known as BK21, MS2/95 formerly known as BK 22, MS3/95 formerly known as BK 47; all being robusta trees selected in 1957 in Bukoba district. Others were MS5/95, formerly known as U.218/32, MS6/95 formerly known as U.224/37, which originated from Uganda and introduced into Tanzania in early 1960's; and FS (Farmers' Selection) robusta coffee plants raised by using seeds selected from farmers' fields. The locations used for the trial were Chanika and Bisheshe at higher altitudes that represent zones 9A and 9B respectively; Kabirizi A and Kabirizi B at lower altitudes which represent zone 8. According to Heemskerk and Mafuru (1998), zone 8 is a medium rainfall Bukoban system and zones 9A and 9B are medium rainfall Ankolean system although the latter two also differ in altitude and type of soils.

Trials were established in farmers' fields In March 1998 and three farmers were selected in each of the villages of Chanika and Bisheshe while at Kabirizi, six farmers were selected to conduct the trials. Each farmer planted five trees of each of the five Maruku selected clones, and five trees of the farmers' selected seedlings making a total of six treatments, 30 trees per farmer. Each chosen farmer's field or site was regarded as a replicate. The five plants for every selected clone/seedling were planted in one row at each site and this constituted a plot. The randomization of treatments was done within sites. Planting of the clones was done at a spacing of 3 m between rows and 2m between plants within a row. The dimensions of planting hole were 60 cm x 60 cm x 60 cm and for each hole, 20kg of farmyard manure from cattle kraal was incorporated with the top soil to fill a hole. Other management practices were based on guidelines developed by Marandu *et al.*, (1997) for robusta coffee. Data collection was carried out on already established robusta coffee plants. Data were collected for growth and yield variables during the 2000/2001 growing cycle. Growth variables viz. girth, plant height, canopy diameter and internode length were measured. The growth measurements were taken once and three plants were randomly selected out of the five plants of an accession in each replicate for the measurements. Girth of the main stem was measured at 5 cm from the ground level using vernier calipers. Plant height was measured from the ground level to the tallest stem terminal apical orthotropic bud on the plant. For each of the three selected coffee trees in a plot, the canopy cover was assessed by measuring the length (cm) of 5 primaries situated at the middle of the crown. The same 5 primaries were used to estimate the internodes length by dividing the total length of the 5 primary branches by the total number of nodes in the 5 primary branches.

The yield component variables, viz. bearing primary branches, number of flowers and fruit set were measured. Bearing and unbearing primary branches were counted and these were expressed in percentage of the total number of branches. Numbers of flowers were counted from a segment of five nodes of earlier selected five primary branches in the randomly selected tree in a plot. Total numbers of flowers were divided by the number of nodes to get the average number of flowers per node. The counted nodes were again labeled for further fruit set counting. From the labeled nodes, when coffee fruits were four months old, the numbers of fruits were again counted. The total numbers of fruits were divided by the number of nodes to get average fruits per node.

Yield was taken from fresh cherries that were harvested from each tree. Average yield per tree for each harvest in a plot was calculated. Yield per hectare was then calculated by multiplying yield per tree by the recommended number of trees per hectare (i.e. 1667 trees) to get yield of fresh cherries per hectare per harvest. The total yields of fresh cherries harvests per season were added up to get overall yield per hectare per season. To convert the yield of fresh cherries per hectare to clean coffee per hectare, the fresh cherries per hectare were multiplied by a conventional figure of 0.22 for robusta coffee (Wellman, 1961).

Recorded data were analyzed using an MSTATC software (Michigan State University, 1990). Correlation coefficient analysis was carried out among yield, components of yield and growth variables as a combined analysis. The phenotypic variance, δ^2ph, among clone means tested among locations was computed using the formula of Robinson *et al.*, (1949). Heritability (broad sense) was computed by using the estimates of phenotypic and genotypic variances using a formula proposed by Hanson *et al.*, (1956). The Expected Genetic Advance (EGA) was estimated by the formula proposed by Johnson et al., (1955).

Results and discussion

The present investigation indicates generally low genetic variability among the tested clones in most of the variables studied (Tables 1 and 2). Future work should include more clones with wider genetic constitution in the study areas. Results however, suggest that higher yields can be realized if clones have higher fruit set percentages and thicker stems. In the present study, although clonal yield range of 617-1216.7 kg/ha was obtained, clones did not differ significantly from one another including the control farmer's selection (FS), which gave 629 kg/ha. The general low yields reported could be attributed to low genetic potential and variation in less favourable environmental conditions including poor distribution of rainfall (Table 7). It is suggested that concerted effort should be directed to seeking clones better adapted to the adverse conditions prevailing in the coffee growing Kagera zone of Tanzania. The coffee yields reported in this study are relatively low compared to potential yields in commercial farms. Yield levels of traditional coffee which is utilized by small growers range from 400-500 kg/ha (http://www.africa-atg.org/coffee.htm). Nevertheless, the yields of small scale farmers in Kagera is comparable or exceed those of small scale farmers in Ethiopia.

Table 1: Mean square values of components of yield in robusta coffee

Variable	Source of variation			
	Clone	Location	Clone x Location	Error
Yield	571465.8	5110046.6**	573072.8	446300.3
Fruit set %	692.8	346.3	124.7	220.2
Berries/node	25.9	69.5	15.2	28.1
%Bearing primary Branches	13.8	654.9**	54.2*	21.7
Flowers/node	40.9	167.1	75.6	65.1
Primary branches	1250.1	29.7**	40.6	34.7
Internodes length	0.1	0.4	0.1	0.2
Canopy radius	126.2	1098.9**	101.8	119.7
Plant girth	0.6	10.4**	0.2	0.3
Plant height	102.0	3494.7**	112.0	164.1

Table 2: Mean performance of six robusta clones on growth and yield variables over four locations during the 2000/2001 season.

Clone	Plant height (cm)	Plant girth (cm)	Canopy radius (cm)	Internode length (cm)	Primary branches (no)	Bearing primary branches (%)	Flowers/node (no)	Berries/node	Fruit set (%)	Yield of clean coffee (kg/ha)
MS1/95	106.1	3.8a	60.2	4.6	40.5	69.6	27.5	6.3	19.6ab	617.0
MS2/95	109.3	3.9a	61.9	4.4	44.5	69.0	25.0	7.5	23.5ab	1216.6
MS3/95	105.9	3.6ab	69.0	4.5	42.8	67.8	29.6	9.5	31.4a	1216.7
MS5/95	110.4	3.8a	68.6	4.5	45.0	70.1	29.6	9.0	29.6ab	993.6
MS6/95	101.8	3.2b	69.1	4.3	42.0	70.1	25.0	4.6	13.5b	912.8
FS	111.4	3.8a	63.7	4.6	40.5	66.9	25.1	6.5	24.5ab	629.0
Mean	107.5	3.7	65.4	4.5	42.5	68.9	27.0	7.2	23.7	931.0
SEx(±)	4.53	0.18	3.87	0.15	2.08	1.73	2.85	1.87	5.25	236.19
CV(%)	11.9	14.3	16.7	9.1	13.8	7.1	29.9	73.1	62.6	71.8

Means with same letter do not differ significantly according to DNMRT ($P \leq 0.05$).

Agronomic performance at Kabirizi A and Kabirizi B was better than at Bisheshe and Chanika (Table 3). Differential distribution of rainfall and soil variability between and within zones were among factors that accounted for differences in the performance of clones between locations. In the study sites, rainfall was not predictable and drought affected zones like Chanika where one site completely failed to set fruits. The rainfall across the four zones varied between 880 to 1185mm and the total rain days varied from 62 to 84 rain days (Table 7). According to Wrigley (1988), this amount of rainfall if well distributed, without a too long, hot and sunny dry season, is considered to be enough for coffee production.

Table 3: Main effects of locations on growth and yield characters of robusta coffee clones

Location	Variable					
	Plant Height (sm)	Plant Girth (cm)	Canopy Radius (cm)	Primary branches (No)	Bearing primary branches (%)	Yield of Clean Coffee (kg/ha)
Chanika	87.0	2.5	52.8	30.0	58.1	358.8
Bisheshe	101.4	3.5	63.9	38.5	70.4	619.4
Kabirizi A	115.1	4.1	69.9	50.0	72.9	891.9
Kabirizi B	126.5	4.7	75.1	51.7	74.3	1853.8
Mean	107.5	3.7	65.4	42.5	68.9	931.0
SEx (±)	3.70	0.15	3.16	2.08	1.34	192.85
$LSD_{0.05}$	10.8	0.4	9.2	6.1	0.4	564.3

Table 4: Combination means of Genotype x Location interaction for % bearing primary branches in robusta coffee

Genotype	Location				
	Bisheshe	**Chanika**	**Kabirizi A**	**Kabirizi B**	**Mean ± 1.65**
MS 1/95	65.8(5)	65.8(1)	74.6(2)	72.3(5)	69.6
MS2/95	74.8(2)	52.1(5)	73.4(4)	75.5(2)	69.0
MS3/95	75.0(1)	48.1(6)	71.6(5)	76.4(1)	67.8
MS5/95	73.8(3)	56.7(4)	75.0(1)	74.9(4)	70.1
MS6/95	70.5(4)	65.7(2)	69.0(6)	75.4(3)	70.1
FS	62.5(6)	60.3(3)	73.6(3)	71.3(6)	66.9
Mean ± 1.73	70.4	58.1	72.9	74.3	

$LSD_{0.05}$ within table = ± 3.9
Clonal rank for each site in bracket

Rainfall in the study zones especially Chanika and Bishshe was not well distributed and was accompanied by a long, hot and sunny dry season that resulted into differences between locations on performance of the clones. Montagnon *et al.* (2000) working on studies of Genotype x Location interaction in Ivory Coast using 25 robusta coffee clones reported yield range of 890 to 2617 kg/ha as compared to the yield range of 617 to 1217 kg/ha in the current investigation. The locations in Ivory Coast had mean rainfall ranging 1300 to 2000 mm per year, well distributed on fields that were previously under fallow or forest. Exceptionally high levels of phosphorous at Chanika (197.9ppm P) (Table 8) compared to the other locations may cause nutrient imbalance and depress crop performance (Cambryony. 1992). Altitude across locations ranged from 1110 to 1620 m above sea level (Table 9). Wilson (1985) reported that for every increase of 180m of elevation, there is a 1°C drop in temperature. Since robusta coffee requires higer temperatures (24 to 30°C) than arabica coffee. the differences in altitude might have accounted for higher yields at the lower altitudes viz. Kabirizi and Kabirizi B compared to Chanika and Bisheshe (Table 3). Kabirizi A and Kabirizi B had altitude range of 1110 to 1330 m above sea level while Chanika and Bisheshe ranged between 1490 to 1620 m above sea level (Table 9).
above sea level (Table 9). Omondi and Owuor (1992) worked with interspecific crosses involv-

ing arabica and robusta coffee species in Kenya and found that plant height varied between locations. Since these trials are on farmers' fields, different management practices especially mulching also contributed to the within and across location variations. At Chanika (replication 2) and Bisheshe (replication 1) only one farmer/replicate in each of the two locations had their trial plots mulched while at Kabirizi A and Kabirizi B, all farmers had mulched their trial plots and the agronomic performances including height were correspondingly higher. In coffee, a mulch depth of 6 inches is usually applied at planting and stays for up to two seasons before the next application is done. However, due to the cost and unavailability of mulch in some areas like Chanika and Bisheshe, very few farmers apply mulch. Proper mulch of a coffee field has been found to increase berry yields by 120% (Marandu *et al.*, 1997).

The significant effects of location and clone x location interactions observed for the percentage bearing primary branches indicated that the contribution to the interaction in percentage bearing primary branches was due to location differences

Table 5: Simple correlation coefficients among yield and some growth and yield components of robusta coffee clones (n=48)

Variable	1	2	3	4	5	6
1. Plant height	-					
2. Plant girth	0.911**	-				
3. Canopy radius	0.769**	0.741**	-			
4. Primary branches	0.817**	0.868**	0.733**	-		
5. % bearing primary branches	0.658**	0.734**	0.580**	0.817**	-	
6. Yield of clean coffee	0.642**	0.590**	0.575**	0.510**	0.402**	-

** = Significant at 1% level.

Table 6: Variance components, heritability (broad sense) and expected genetic advance (EGA) of yield and some components of yield of six robusta coffee genotypes assessed at four locations in Kagera region during 2000/2001.

Variable	σ2g	σ2I	σ2gI	σ2e	σ2ph	h2	EGA (% of means)	Mean	Range%	CV (%)
Yield (kg/ha)	-200.87	3868.52	105756.37	361560.00	71433.23	-	-	931.0	617.0-1216.7	71.8
Plant girth (cm)	0.05	0.74	-0.07	0.10	0.04	125.0	13.5	3.7	3.2-3.9	14.3
Canopy radius (cm)	3.05	46.06	-12.16	60.32	7.55	40.4	2.4	65.4	60.2-69.1	16.7
Barries per node (no)	0.06	-0.03	0.27	0.36	0.11	54.5	11.2	7.2	4.6-9.5	73.1
Fruits set (%)	27.69	-23.42	17.90	88.93	43.28	64.0	36.5	23.7	13.5-31.4	62.6

Key: σ^2g: variance due to genetic differences among clones
σ^2I: variance due to location differences
σ^2gI: variance due to the interaction between genotypes and locations
σ^2e: variance due to environmental factors
σ^2ph: variance due to differences between phenotypes
H^2: heritability in the broad sense
EGA: Expected Genetic Advance

rather than genotypic differences (Table 1). In the present investigation. MS3/95 gave the highest percent of bearing primary branches at Kabirizi B (76.4%) and Bisheshe (75.0%) but ranked the least at Chanika (48.1%) (Table 4). Walyaro (1983) working with arabica coffee plants in Kenya obtained significant effects on bearing primaries for genotype x location interaction. Thus. recommendations on the performance on percentage bearing primaries should be environment specific.

Knowledge of interrelationships between yield and its major components is important for selecting two or more concurrent complex variables contributing to yield. In this study. simple correlations were studied to find the associations of growth and yield attributes to the final yield. Since all the components tested showed significant and positive correlations with yield and among themselves (Table 5). selection for high yielding clones is possible by indirectly selecting for taller plants. wider stems and canopy and more primary branches without the risk of yield reduction through component compensation effects (Adams. 1967). It can be concluded therefore. that a number of plant variables. in particular plant height, plant girth. canopy radius. primary branches and percent bearing primary branches are worth improving in robusta coffee breeding programmes for improvement of yield. However. in breeding for higher yield through improved height. care needs to be taken in order to have genotypes that can easily bend for hand picking.

Srinivasan (1980) while working on arabica coffee reported a non-significant relationship between numbers of primaries with yield of coffee.

Table 7: Eleven months of rainfall records in mm and rain days per month of the st udy locations during the 2000/2001 season

Site	Sept	Oct	Nov	Dec	Jan	Feb	Mar.	Apr	May	Jun	Jul	Total	Mean
Kabirizi	36	71	79	125	224	32	86	146	102	34	145	1080	98.2
A	(3)	(7)	(9)	(9)	(11)	(4)	(12)	(11)	(8)	(5)	(5)	(84)	(8)
Kabirizi	33	46	72	102	193	26	47	132	83	21	125	880	80.0
B	(3)	(6)	(9)	(8)	(13)	(5)	(7)	(10)	(7)	(3)	(2)	(73)	(7)
Bisheshe	27	57	64	109	115	96	253	112	176	67	109	1185	108.7
	(2)	(5)	(7)	(7)	(5)	(6)	(8)	(6)	(11)	(2)	(3)	(62)	(6)
Chanika	25	59	61	102	104	90	183	49	100	57	102	932	84 7
	(3)	(5)	(6)	(7)	(5)	(6)	(8)	(6)	(11)	(2)	(4)	(63)	(6)

Rain days per month in brackets,
Source: Maruku Meteorological Station. Bukoba. Tanzania

Table 8: Average values for soil data at the trial sites

Location	% Sand	% silt	% clay	pH	% Organic matter	% Total nitrogen	C N ratio	Avail P (ppm)	Conductivity ms cm	Ex.Cations (meq 100g soil) K	Ca	Mg	Meq 100g soil (CEC)
Kabirizi A	41	23.3	35.7	5.6	2.3	0.13	10 3	10 0	0.025	58	10.1	1 28	8 6
Kabirizi B	25.7	28 7	45.7	5.6	3.9	0.19	12.0	8.6	0 029	40	10.2	0.70	10.8
Chanika	16.3	37.3	46.3	6.2	6.5	0.32	11.7	197 9	0.057	.90	14.9	1.89	22.6
Bisheshe	30.0	20.0	50.0	6.0	4.0	0.23	10.5	7 4	0 036	.26	13.6	0.57	15 3

However, he found a significant and positive correlation between stem girth with yield of coffee similar to the results of this study. It seems that the relationship of yield with number of primary branches may depend on type, genotype or environment but that with stem girth tends to be stable. Plant girth therefore seems to be an important variable to consider in coffee improvement. Plant characters such as stem girth and width of canopy have as well been reported to positively influence yield in arabica coffee, according to observations of Srinivasan and Vishveshwara (1973). Similarly, Singh (1968) found that circumference of main stem, width of canopy and plant height contributed to increased yield of arabica coffee varieties grown on multiple stem.

In this study, growth and yield variables investigated show that the genetic variances were smaller than their respective phenotypic variances except for plant girth, which had higher genetic variance (Table 6). Thus, the variables are highly influenced by environmental factors than genetic differences among them. Heritability estimates for yield of clean coffee was negligible as shown by the negative value of genetic variance. Heritability of yield *per se* is generally reported to be low in most crop plants. Srinivasan *et al.*, (1979) reported low to moderate heritability of yield in arabica coffee grown on topped single stem under shade. On the other hand, Walyaro, and Van der Vossen (1979) found high heritability of yield in arabica coffee grown on multiple stems without shade in Kenya. The present study on robusta coffee was under unshaded environment of double and untopped stems. Contrasting findings could be attributed to different clones, environments and systems of training coffee (Srinivasan, 1982).

Table 9: Altitudes of the trial sites

Location	Replication	Altitude (masl)
Kabirizi A	1	1330
	2	1330
	3	1230
Kabirizi B	1	1170
	2	1190
	3	1110
Chanika	1	1530
	2	1490
	3	1540
Bisheshe	1	1620
	2	1550
	3	1580

Plant girth, number of berries per node and fruit set percentage had high heritability while plant canopy had medium heritability. The high heritability values for plant girth, berries per node and fruit set percentage were also associated with high expected genetic advances and thus selection for these variables may start from early generations of breeding. Plant girth was more influenced by its genetic makeup than by its environmental factor as also reflected by the very high heritability value (125%). The present findings agree with earlier studies of Walyaro and Van der Vossen (1979) on multiple stem, unshaded arabica coffee in Kenya. However, Srinivasan and Vishveshwara (1973) reported low heritability for stem girth in studies of topped arabica coffee of single stem under mixed shade. Canopy radius had low expected genetic advance of 2.4% of population mean and medium heritability indicating that this variable can be selected during late stages of a breeding programme. Yield and berries per node had higher variances due to the interaction of clone and location than both their genetic and phenotypic variances indicating that the relative importance of clones on yield and production of berries per node is not consistent in different environments. Thus, quantitative genes may be responsible in the control of yield and berries per node of the tested robusta coffee clones. However, for plant girth and canopy radius, the variance of the interaction between clone and location was not important since those variables seem to be consistent across environments. It is therefore appropriate to recommend clones based on their performance on plant girth and canopy radius across environments while for yield and berries per node, blanket recommendations may be risky and misleading.

Conclusion

The present study reveals that greater emphasis should be given for taller plants, wider stems and canopies with more primary branches that bear more berries for increased yield of robusta coffee. Plant girth, berries per node, and fruit set percentage will realize high-expected gains from selection due to high heritability. Similarly, clones can be blanket recommended for the aforementioned traits as a result of low genotype x location interaction. On the contrary, selection for yield should be done in later generations and production recommendation should be location specific. More effort should be geared towards widening of the genetic base of robusta coffee clones in Kagera region for higher productivity and in improvement programmes.

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