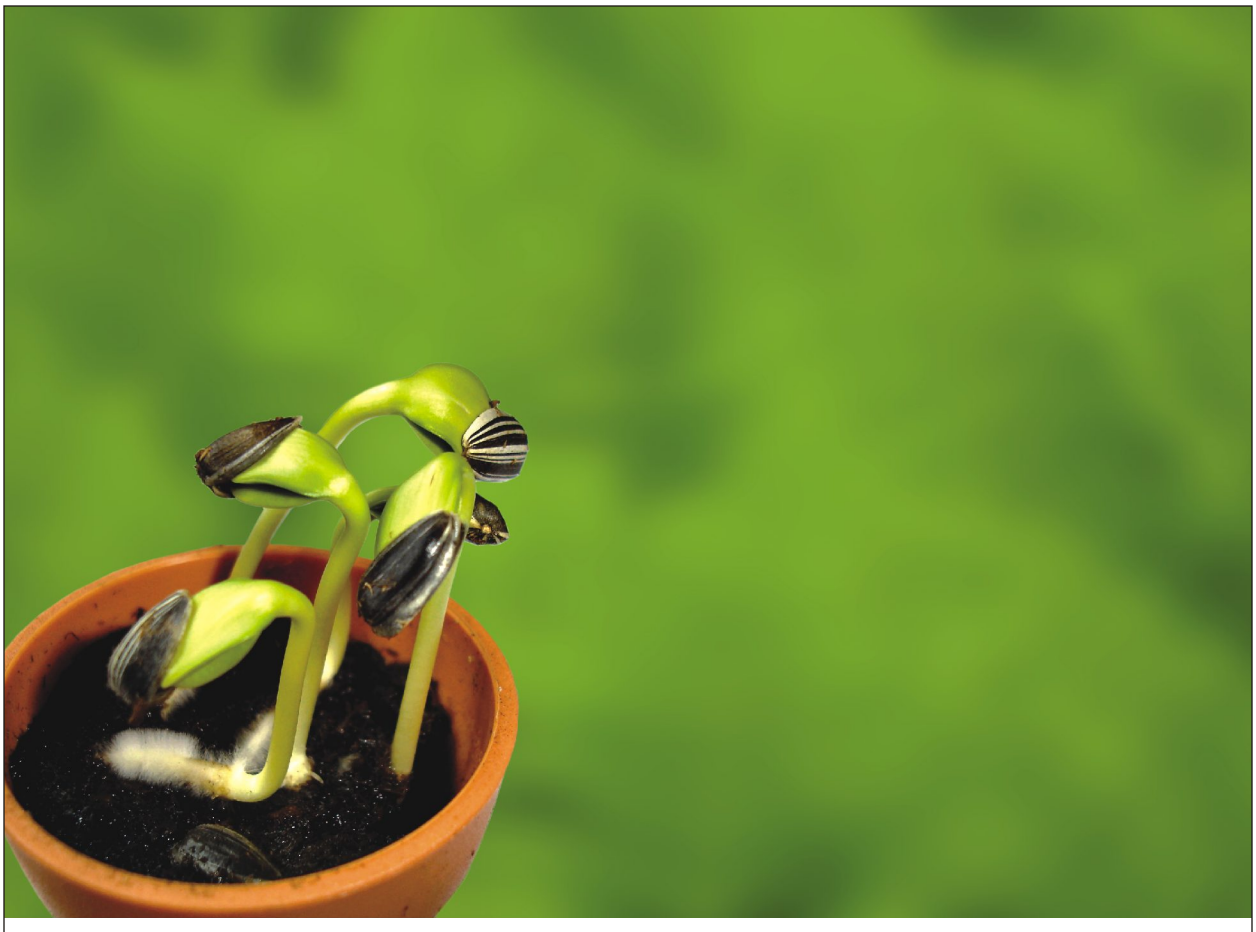

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Research Article
Agro-Morphological Characterization of Arabica Coffee Cultivars in Burundi

[1,2]Jonas Ndikumana, [1]Githiri Mwangi, [1]Cornelius Wainaina and [3]Taye Kufa Obso

[1]School of Agriculture and Environmental Sciences (SOAES), JKUAT, P.O. Box 62000-00200, Nairobi, Kenya
[2]Institute of Agronomic Sciences of Burundi (ISABU), P.O. Box 795, Bujumbura, Burundi
[3]International Institute of Tropical Agriculture, P.O. Box 1893, Bujumbura, Burundi

Abstract

Background and Objective: Arabica coffee is an important beverage crop in world trade. The crop is gaining increasing importance in Burundi as an export crop. This study aimed to evaluate diversity among coffee cultivars based on quantitative agro-morphological traits for developing superior cultivars in Burundi. **Materials and Methods:** Fifteen coffee accessions including five commercial cultivars) were used in the study. From each accession, data were collected from three randomly selected trees on 17 quantitative agro-morphological traits and subjected to various statistical analyses including, analysis of variance (ANOVA), PCA biplot and cluster analysis. **Results:** The analysis of variance showed significant differences ($p<0.05$) among the accessions for most of the quantitative traits studied. Considering the number of fruits per internode and percentage of fruit-bearing primary branches, the highest yielding accessions were SL28, Mysore and S795. PCA showed that four principal components namely, PC1(33.70), PC2(30.57), PC3(10.21) and PC4(9.15) explained about 83.63% of the total variation. Cluster and distance analysis of quantitative traits revealed the existence of three different groups. The number of accessions in each group was 3, 3 and 9 for clusters I, II and III respectively. The maximum distance was seen between clusters I and II (88) while the minimum was seen between I and III (23). **Conclusion:** The results show wide diversity among the 15 coffee genotypes grown in Burundi concerning most quantitative morphological traits studied. The genotypes were grouped into three clusters where, Cluster II and III contained genotypes with valuable quantitative agronomic traits, while most of the accessions in cluster I exhibited poor agronomic performance.

Key words: Arabica coffee, morphological diversity, principal component analysis, quantitative traits, agronomic performance

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Corresponding Author: Jonas Ndikumana, School of Agriculture and Environmental Sciences (SOAES), JKUAT, P.O. Box 62000-00200, Nairobi, Kenya

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Most of the commercial coffees produced in the world are classified as either Arabica (*Coffea arabica*) or Robusta (*Coffee canephora*) and they belong to the family Rubiaceae[1]. In Burundi, Arabica coffee is more important than Robusta coffee in terms of the land area allocated to the crop and quantity of beans produced. It is the most important export crop from the country[2]. Today, the crop is grown in most parts of the country and accounts for about 10% of cultivated land. Coffee produced in the country is exported mostly to Switzerland, the United Kingdom and Germany. It accounts for about 60-70% of the total value of exports. Over the last three decades, it has created an average of US $ 40-50 million per year of export incomes[2,3]. However, Coffee production in the country faces several constraints, including low yielding cultivars and declining soil fertility[4,5].

The Burundian government has in current years encouraged farmers to increase the land under coffee cultivation in a bid to boost production. But this approach has not been effective in regions with high population densities, since it has led to competition with food crops for available land. Moreover, land has become increasingly scarce as a result of a high population growth rate[5].

As the farmer acceptance of coffee as commercial undertaking increases, the need for information to assist its improvement has become more apparent. The existing strategy for coffee improvement in the country has been to introduce cultivars from various regions of the world, test them for adaptation and select the most adapted clones[4].

For an effective crop improvement program, the analysis of diversity is one of the useful tools and plays a fundamental role in the identification of suitable germplasm[6,7]. Moreover, better knowledge of diversity among the cultivars could help to achieve long-term selection gain[8-10]. As a traditional method, morphological traits have been used to assess genetic divergence and classify existing germplasm materials[11-13]. The commonly used morphological traits used for diversity studies have been leaf, stem, flower and fruit characteristics[14,15]. For example, in Ethiopia, Olika *et al.*[16] evaluated 49 coffee accessions and reported that they significantly differed for most of the traits evaluated, while Tounekti *et al.*[17], Muvunyi *et al.*[18] reported significant genetic variations for quantitative traits examined among germplasm cultivated in the South-western region of Saudi Arabia and Rwanda respectively. The coffee germplasm currently maintained in the fields of the Institute des Sciences Agronomics du Burundi (ISABU), on which this study was conducted, were introduced from diverse countries namely Kenya, Inde, Rwanda and Salvador[2,4]. The Burundian government is currently embarking on rehabilitation of the coffee sector through diverse approaches including breeding, agronomy, crop protection and marketing. The breeding approach calls for an understanding of the diversity present among coffee accessions in the country in a bid to identify suitable parental genotypes. However, the diversity among the accessions has not been previously quantified and hence, this study was proposed. The objective of this study was to quantify the extent of diversity among coffee accessions in Burundi as a basis for cultivar growth and germplasm management in the country.

MATERIALS AND METHODS

Description of the experimental site: The study was conducted in the 2019-2020 rainy season in Nyange Research Station of the Institut des Sciences Agronomiques du Burundi (ISABU). Nyange lies at 4°10'S latitude, 29°45'E longitude and an altitude of 1260 masl with a mean total annual rainfall of about 1250 mm received in two rainy seasons, long rains (January-May) and short rains (October-December). The average annual temperature is 21°C while the major soil type is ferrisols. The rainfall, temperature and relative humidity data recorded during the period of the current study showed that the highest monthly mean and the lowest monthly mean temperature were recorded in May and June (21.7°C) and December (19.7°C) respectively. The maximum monthly rainfall (365 mm) during the study period was recorded in April and the minimum monthly rainfall (0 mm) in June. The highest monthly relative humidity (89.39%) was recorded in April while the lowest relative humidity (61.35%) was recorded in October in Table 1.

Table 1: Total rainfall and mean monthly temperature and relative humidity recorded at Nyange, Burundi during the experimental period in 2019/2020

Months	Monthly rainfall (mm)	Mean temperature (°C)	Relative humidity (%)
October/2019	112	22.3	61.3567
November/2019	169	20.1	72.6786
December/2019	249	19.7	88.1267
January/2020	117	20.6	84.1453
February/2020	148	21.6	79.3892
March/2020	147	21.4	80.5906
April/2020	365	20.1	89.3957
May/2020	64	20.7	84.0628
June/2020	0	21.7	70.0423

Table 2: Origin and status of coffee arabica accessions evaluated in this study

Accession name	Abbreviation	Origin	Status
Jackson 2/1257	J2/1257	ISAR RWANDA	Commercial variety
Bourbon Mayaguez 71	B 71	ISAR RWANDA	Commercial variety
Bourbon Mayaguez139	B 139	ISAR RWANDA	Commercial variety
Mibirizi bouts Bruns	Mi TV	ISAR RWANDA	Germplasm accession
Mibirizi 49/1848	Mi 49/1848	ISAR RWANDA	Commercial variety
Mibirizi 68/1589	Mi 68/1589	ISAR RWANDA	Commercial variety
Mysore	Mysore	ISAR RWANDA	Germplasm accession
Ainamba-Babaca-Kaffa-ABK 5691	ABK 5691	Abyssinie via Rubona (RWANDA)	Germplasm accession
Ainamba-Babaca-Kaffa-ABK 5718	ABK 5718	Abyssinie via Rubona (RWANDA)	Germplasm accession
Blue Mountain	Blue Mountain	KENYA	Germplasm accession
Tekisic	Tekisic	San Salvador	Germplasm accession
K7	K7	KENYA	Germplasm accession
SL 28	SL 28	KENYA	Germplasm accession
S 288	S 288	INDE	Germplasm accession
S 795	S 795	INDE	Germplasm accession

Plant materials: Fifteen coffee accessions were used in this study and are presented in Table 2. They included seven from ISAR Rwanda, two from Inde, three from Kenya, one from Salvador and two from Abyssinie via Rubona (RWANDA). Five of these cultivars namely, Burbon 139, Burbon 71, Mibirizi 49, Mibirizi 68 and Jackson 2 have already been released for commercial production in Burundi[4].

Experimental design and field management: Data for this study were collected from experimental plots established in 1986 and comprised of fifteen Arabica Coffee genotypes planted out in single rows using a Randomized Complete Block Design (RCBD) with four replications. Each plot comprised of ten coffee trees planted at spacings of 2 m by 2 m between rows and trees, respectively. The experimental plots were surrounded by one row of border trees to provide competition to peripheral plots and at the same time to protect the trees from wind and wildlife. All field management practices, such as weeding and spraying for pest control were applied as per the recommendations of the centre.

Data collection: Quantitative data were collected from three randomly selected coffee trees of each accession using the coffee descriptor produced by the international plant genetic research institute in 1996 as presented by Tounekti *et al.*[17], Muvunyi *et al.*[18]. The traits considered included plant height (m), stem girth (cm), number of primary branches, percentage of fruit-bearing primary branches (%), length of primary branches (cm), internode length of primary branches (cm), leaf length, leaf width, leaf area, weight of 100 cherries (g), fruit length (mm) and width (mm), the weight of 100 beans (g), bean length (mm), bean width (mm) and bean thickness (mm) as presented in Table 3.

Data analysis: The data collected were analyzed using GenStat (2012) Discovery,14th Edition Statistical software. VSN International, Hemel Hempstead and R version 3.5.1 (2018-07-02) software. Analysis of variance (ANOVA) was computed using the general linear model in GenStat, assuming accession effects were random. Means for each morphological traits assessed were separated by the Least Significant Difference (LSD) at p = 0.05 probability level.

Coefficients were computed to examine the degree of association among the traits. Cluster analysis was conducted to determine phenotypic variation among the cultivars. A dendrogram was constructed from the Euclidian distance matrix using an agglomerative, hierarchical cluster classification technique with an average linkage strategy.

Principal component analysis of the evaluated accessions was performed according to Mohammadi *et al.*[19]. The pair-wise comparison of morphological parameters was done to derive a multidimensional scatter plot of individuals. Genetic distances for phenotypic characteristics were estimated using Euclidean straight line method[19]. Genetic distance based on the morphological trait for all pair-wise comparisons of 15 coffee accessions was determined according to the average intracluster distance as stated by Bhandari *et al.*[20] in the following Eq:

$$D^2 = \sum \frac{D^2 i}{N}$$

where, D^2i is the sum of distances between all possible combinations of accessions included in a cluster, N is the all possible combinations.

Table 3: List of quantitative morphological traits evaluated in 15 Arabica coffee genotypes in Nyange, Burundi and the method of evaluation

Quantitative traits	Abbreviation	Method of evaluation
Growth traits		
Plant height (m)	PH	The length from the ground level to the top of the tree
Stem girth (cm)	GIRTH	Measured as the diameter of main stem 10 cm from the ground
Number of fruits per internode	NFN	Number of cherries per internodes on five primary branches, obtained by the ratio between the total number of cherries bearing node of primary branch and the number of node bearing per each primary branch
Number of primary branches per tree	NPB	Total number of primary branches counted per tree
Percentage of fruit-bearing primary branches per tree	PFBPB	Percent fruits bearing primary branches obtained by the ratio between the number of primary branches produced and the number of fruiting branches per tree
Length of primary branches	LPB	Average of Five primary branches at the middle of the stem, measured from point of attachment to the main stem to the apex of branch
Internode length of primary branches (cm)	ILB	Average of five primary branches at the middle of the stem per tree, calculated as the sum of all internodes length per branch
Leaf traits		
Leaf length (cm)	LL	Average of five normal leaves measured from petiole end to apex
Leaf width (cm)	LW	Average of five normal leaves measured at the widest part
Leaf area (cm^2)	LA	Average of five leaves Calculated as =(length*Width) *0.88 (Walyaro,1983).
Fruit and bean traits		
Fruit length (mm)	FL	Average of five normal and mature green fruits of each tree measured at the longest part
Fruit width (mm)	FW	Average of five normal and mature green fruits of each tree measured at the widest part
100 cherries weight (g)	100 CW	Hundreds of normal cherries of each coffee tree weigh using sensitive balance
Bean length (mm)	BL	Average of five normal beans of each tree measured at the longest part
Bean width (mm)	BW	Average of five normal beans of each tree measured at the widest part
Bean thickness (mm)	BT	Average of five normal beans of each tree measured at the thickest part
100 bean weight (gm)	100 BW	At 11% moisture (g)-calculated as: ("bean weight at 0% moisture content" X 100)/(Bean No X 0.89). The oven was used for drying of beans to make 0% moisture and weight recorded using sensitive balance

RESULTS

Analysis of variance: The mean square of quantitative characters for 15 genotypes are shown in Table 4. The highest significant ($p<0.01$) and significant ($p<0.05$) mean square were observed for plant height, number of primary branches, percentage of fruit-bearing primary branches, leaf length, leaf width, number of fruits per internode, hundred cherries weight, bean length, bean width, bean thickness and stem Girth, leaf area, fruit length respectively. No significant mean square was observed for length of primary branches, internode length per branch, hundred bean weight.

Analysis of variance (ANOVA) for the seventeen quantitative traits showed that variances among the accessions were highly significant ($p<0.01$) and significant ($p<0.05$) for most of the traits except for three quantitative traits internode length per branch, length of primary branch and hundred beans weight) respectively which did not show any significant variation in Table 5.

As shown in Table 5, the length of primary branches ranged from 45.78-54.43 cm, averaging 50.9 cm. Over half (60%) of the accessions had a length between 51.42 and 54.43 cm. The internode length of primary branches averaged 52.1cm and ranged from 45.59-55.12 cm. Most of the accessions (86.6%) had 50.06-55.12 cm in length of primary branches. Leaf length ranged from 11.87-13.69 cm, averaging 12.97 cm. Over half of the accessions (60%) had 13.05-13.69 cm. Leaf width ranged from 4.77-5.62 cm, averaging 5.03 cm. The majority of accessions (73.3%) had below 5.2 cm. Leaf area averaged 42.71 cm^2 and ranged from 36.96-47.56 cm^2. Most of the accessions (93%) had 40.05-47.56 cm^2. Fruit length ranged from 15.44-16.74 mm, averaging 16.01 mm. The majority of the accessions (80%) had over 15.57 mm fruit length. Most of the accessions (66.6%) had 12.08-12.51 mm fruit width with an average of 12.15 mm and ranged from 11.73-12.51 mm. Hundreds of normal cherries weight ranged from 152.67-189.7 g, averaging 170.49 g. The greatest of accessions (80%) had 165.08-189.7 g. Stem girth ranged from 3.11-4.23 cm, averaging 3.90 cm. Over half of the accessions (54%) had 3.11-4.06 cm. Plant height averaged 2.85 m ranged from 2.28-3.18 m. Most of the accessions (73%) had 2.28-3.04 m of plant height.

The percentage of fruit-bearing primary branches ranged from 36.33-81.58, averaging 66. Most of the accessions (80%) had 62.5-81.58% of fruit-bearing primary branches. Several primary branches averaged 62.3, ranging from 37-75.83 primary branches. Over half of the accessions (80%) had 61.33-75.83 primary branches. The number of fruits per internode averaged 5.98, ranging from 4.41-8.12 per internode. Most of the accessions (80%) produced 5.22-8.12

Table 4: Mean squares and their significance levels from the analyses of variance for 17 quantitative morphological characters measured in 15 coffee accessions at Nyange in 2019/2020

Source of variation	Df	Girth (cm)	PH (m)	NPB	PFBPB	LPB (cm)	ILB (cm)	LL (cm)	LW (cm)	LA (cm^2)	NFN	FL (mm)	FW (mm)	100 CW (g)	BL (mm)	BW (mm)	BT (mm)	100 BW (g)
Accessions	14	0.36*	0.26**	501.13**	400.14**	23.40	26.50	0.70**	0.10**	26.26*	3.37**	0.64*	0.30**	407.22**	0.78**	0.49**	0.11**	4.95
Error	42	0.13	0.04	64.83	42.11	21.30	17.30	0.18	0.07	8.31	0.84	0.12	0.06	78.74	0.14	0.04	0.01	4.46
Total	56																	

*,**Significant at the 5 and 1% levels of probability, respectively. LPB: Length of primary branches, ILB: Internode length of primary branches, FL: Fruit length, FW: Fruit width, LL: Leaf length, LW: Leaf width, LA: Leaf area, 100CW: Hundred cherries weight, GIRTH: Stem girth, PH: Plant height, BL: Bean length, BW: Bean, BT: Bean thickness, NFN: Number of fruits per internode, PFBPB: Percentage of fruit-bearing primary branches per tree, NPB: Number of primary branches per tree, 100 BW: Hundred beans weight

Table 5: Mean values of 17 quantitative morphological characters recorded in 15 coffee accessions evaluated at Nyange in 2019-2020

Accessions	PH (m)	GIRTH (cm)	NPB	PFBPB	LPB (cm)	ILB (cm)	LL (cm)	LW (cm)	LA (cm^2)	NFN	FL (mm)	FW (mm)	100 CW (g)	BL (mm)	BW (mm)	BT (mm)	100 BW (g)
Ainamba-Babaca-Kaffa-ABK 5691	2.28	3.58	37.00	36.33	50.32	53.33	11.87	5.18	40.58	5.59	15.55	12.34	161.50	12.01	7.73	4.52	20.92
Ainamba-Babaca-Kaffa-ABK 5718	2.35	3.62	45.17	40.42	49.89	52.73	11.94	5.16	40.64	5.33	15.44	11.93	157.58	12.14	7.74	4.40	19.07
Bourbon Mayaguez 71	3.07	4.06	63.42	62.75	53.29	54.21	13.34	4.84	42.64	5.73	15.65	12.22	174.92	12.91	8.11	4.68	19.25
Bourbon Mayaguez 139	3.04	3.88	67.17	62.5	53.49	52.99	13.71	4.86	43.96	5.75	16.52	12.24	173.42	13.45	7.88	4.60	17.42
Blue Mountain	3.17	4.19	62.33	66.92	51.77	51.40	13.66	4.78	43.14	4.86	16.05	12.22	169.42	12.79	7.96	4.57	17.83
Mibirizi bouts bruns	2.90	4.23	66.00	67.83	51.42	52.05	13.10	4.77	41.23	6.61	16.25	11.80	159.80	13.37	7.52	4.34	18.75
Jackson 2/1257	2.98	4.16	70.33	72.92	51.83	54.18	13.05	4.82	36.96	4.66	15.91	11.90	169.42	12.67	7.97	4.59	19.08
K 7	3.18	4.13	65.67	68.50	51.72	53.93	13.69	4.88	44.12	5.49	15.77	12.28	184.00	12.56	8.18	4.67	18.92
Mibirizi 68/1589	2.90	3.94	62.83	69.00	52.06	52.49	13.30	4.77	41.89	6.67	16.74	11.73	167.75	13.56	7.82	4.59	20.91
Mibirizi 49/1848	2.86	4.10	65.17	64.50	54.43	54.20	13.27	4.86	42.58	6.77	16.36	11.88	171.75	13.16	7.80	4.58	17.58
Mysore	2.82	4.07	75.83	81.58	47.78	50.06	12.79	5.51	46.53	8.12	15.99	12.41	184.08	12.84	8.03	4.65	20.25
S795	2.84	3.73	71.67	79.50	45.78	48.08	12.41	5.46	44.71	7.22	15.74	12.51	165.08	12.53	9.03	5.04	18.75
S 288	2.67	3.11	45.92	43.75	48.42	45.59	12.12	5.20	41.59	4.41	16.07	12.16	152.67	13.03	7.78	4.40	19.50
SL 28	2.85	3.82	74.83	76.00	48.46	51.05	12.83	5.62	47.56	7.31	16.53	12.70	189.75	13.08	8.28	4.79	19.83
Tekisic	2.88	3.94	61.33	67.83	52.89	55.12	13.49	4.78	42.57	5.22	15.57	12.08	166.17	12.96	8.19	4.54	20.50
Mean	2.85	3.90	62.31	64.02	50.90	52.10	12.97	5.03	42.71	5.98	16.01	12.15	170.49	12.87	8.00	4.59	19.24
LSD (0.05)	0.10	0.19	4.92	4.01	ns	ns	0.469	0.153	4.11	0.78	0.29	0.20	4.86	0.542	0.15	0.09	ns

LPB: Length of primary branches, ILB: Internode length of primary branches, FL: Fruit length, FW: Fruit width, LL: Leaf length, LW: Leaf width, LA: Leaf area, 100CW: Hundred cherries weight, GIRTH: Stem girth, PH: Plant height, BL: Bean length, BW: Bean, BT: Bean thickness, NFN: Number of fruits per internode, PFBPB: Percentage of fruit-bearing primary branches per tree, NPB: Number of primary branches per tree, 100 BW: Hundred beans weight

Table 6: Correlations among 17 quantitative morphological traits recorded in 15 coffee accessions evaluated at Nyange in 2019-2020

Traits	Girth (cm)	PH (m)	NPB	PFBPB	100 CW (g)	LL (cm)	LW (cm)	LA (cm^2)	NFN	FL (mm)	FW (mm)	ILB (cm)	LPB (cm)	100 BW (g)	BL (mm)	BW (mm)	BT (mm)
Girth	1																
PH	0.67**	1															
NPB	0.63**	0.61**	1														
PFB PB	0.55**	0.53**	0.91**	1													
100 CW	0.13	0.22	0.23	0.19	1												
LL	0.44**	0.68**	0.38**	0.27*	0.27*	1											
LW	-0.22	-0.31	0.06	0.18	0.21	-0.50	1										
LA	-0.05	0.09	0.22	0.25	0.32*	0.25	0.47**	1									
NFN	0.02	-0.20	-0.21	0.57*	-0.01	0.03	-0.11	-0.07	1								
FL	0.23	0.39**	0.34**	0.27*	0.15	0.31*	-0.05	0.17	0.19	1							
FW	-0.30	-0.09	-0.06	0.02	0.38**	-0.13	0.46**	0.36**	-0.20	-0.06	1						
ILB	0.13	0.01	-0.16	-0.18	0.26*	0.22	-0.26	-0.18	0.34**	-0.03	-0.04	1					
LPB	0.14	0.11	-0.11	-0.16	0.15	0.32*	-0.34	-0.17	0.31*	0.14	-0.18	0.85**	1				
100 BW	0.03	0.01	-0.01	0.07	0.06	-0.17	0.15	0.01	-0.06	0.05	0.54**	0.03	-0.06	1			
BL	0.22	0.41**	0.34**	0.23	0.10	0.50**	-0.22	0.27*	0.02	0.61**	-0.16	0.07	0.18	-0.02	1		
BW	-0.06	0.10	0.29*	0.34**	0.25*	0.06	0.34**	0.31*	-0.45	-0.18	0.32*	-0.19	-0.23	0.53**	-0.10	1	
BT	0.08	0.16	0.37**	0.40**	0.36**	0.20	0.36**	0.39**	0.27	0.08	0.33*	-0.09	-0.09	-0.07	0.11	0.83**	1

*,**Significant at the 5 and 1% levels of probability, respectively. LPB: Length of primary branches, ILB: Internode length of primary branches, FL: Fruit length, FW: Fruit width, LL: Leaf length, LW: Leaf width, LA: Leaf area, 100CW: Hundred cherries weight, GIRTH: Stem girth, PH: Plant height, BL: Bean length, BW: Bean, BT: Bean thickness, NFN: Number of fruits per internode, PFBPB: Percentage of fruit-bearing primary branches per tree, NPB: Number of primary branches per tree, 100BW: Hundred beans weight

fruits per internode. Hundred bean weight ranged from 17.42-20.91 g and averaged 19.24 g. Most of the accessions (65%) had 19.07-20.91 g hundred bean weights. Bean length ranged from 12.01-13.56 mm and averaged 12.87 mm. A large proportion of the accessions (66.6%) had 12.01-13.03 mm. Bean width ranged from 7.52-9.03 mm and averaged 8 mm. A large proportion of the accessions (60%) had 7.52-8 mm. Bean thickness averaged 4.59 mm, ranging from 4.34-5.04 mm. Most of the accessions (96%) had 4.4-4.79 mm. The coffee accessions Mysore, S795 and SL28 showed higher mean value for most of the measured quantitative traits.

A highly significant ($p<0.01$) positive correlation was recorded between the following pairs of parameters in Table 6: number of primary branches and percentage of fruit bearing primary branches (r = 0.91), length of primary branches and internode length of primary branches (r = 0.85), between number of fruit per internode and percentage of fruit bearing primary branches (r = 0.566),between bean width and bean thickness (r = 0.83), between leaf length and plant height (r = 0.68), between plant height and stem girth (r = 0.67), between number of primary branches and stem girth (r = 0.63), between number of primary branches and plant height (0.61), between number of fruit per internode and percentage of fruit bearing primary branches (r = 0.57), between percentage of fruit bearing primary branches and stem girth (r = 0.55), between hundred bean weight and fruit width (r = 0.54), between bean width and hundred bean weight (r = 0.53), between bean length and leaf length (r = 0.50), between leaf area and leaf width (r = 0.47), between fruit width and hundred cherries weight (r = 0.38).

Cluster analysis: The 15 coffee accessions were classified into three distinct groups in Table 7. Cluster III had the highest number of accessions with nine (60% of the total population), while each cluster I and II had 3 accessions (each had 20% of the total population). Cluster I includes accessions ABK5691 and ABK5718 from Abyssinie via Rubona (RWANDA) and S 288 from INDE. These accessions contributed to the lowest mean value of Plant height, leaf length, number of primary branches, Percentage of fruit-bearing primary branches, leaf length, leaf area, number of fruit per internode, hundred cherries weight, the moderate mean value of the length of primary branches, internode length, stem girth, fruit length, fruit width, bean length, bean thickness, bean width, hundred beans weight and high leaf width (Table 5). Cluster II includes accessions S 795 from INDE, Mysore from ISAR RWANDA and SL 28 from KENYA. These accessions were characterized by the highest mean value of the number of primary branches, leaf width, leaf area, percentage of fruit-bearing primary branches,

Table 7: Distribution of coffee accessions in three clusters based on diversity in quantitative morphological traits

Cluster	Members	Code	Abbreviation	Accession name	Origin
I	3	S2	S 288	S 288	INDE
		A1	ABK 5691	Ainamba-Babaca-Kaffa-ABK 5691	Abyssinie via Rubona (RWANDA)
		A2	ABK 5718	Ainamba-Babaca-Kaffa-ABK 5718	Abyssinie via Rubona (RWANDA)
II	3	S1	S 795	S 795	INDE
		M3	Mysore	Mysore	ISAR RWANDA
		S3	SL 28	SL 28	KENYA
III	9	B4	Mi TV	Mibirizi bouts bruns	ISAR RWANDA
		M1	Mi 68/1589	Mibirizi 68/1589	ISAR RWANDA
		M2	Mi 49/1848	Mibirizi 49/1848	ISAR RWANDA
		T	Tekisic	Tekisic	San Salvador
		J1	J 2/1257	Jackson 2/1257	ISAR RWANDA
		B1	B 71	Bourbon Mayaguez 71	ISAR RWANDA
		K	K 7	K 7	KENYA
		B2	B 139	Bourbon Mayaguez 139	ISAR RWANDA
		B3	Blue Mountain	Blue Mountain	KENYA

Table 8: Eigenvalue, factor scores and contribution of the first three principal component axes to variation in 15 coffee accessions evaluated in Nyange, in 2019/2020

Characters	PC1	PC2	PC3	PC 4
PH	0.70	0.56	0.03	-0.33
GIRTH	0.48	0.69	0.33	0.13
NPB	0.90	0.23	-0.08	0.02
PFBPB	0.88	0.02	-0.07	-0.01
LPB	-0.17	0.90	0.20	0.04
ILB	-0.07	0.66	0.62	0.33
LL	0.54	0.78	0.09	-0.10
LW	0.26	-0.88	-0.16	0.30
LA	0.71	-0.31	-0.20	0.36
NFN	-0.34	0.42	-0.12	0.68
FL	0.35	0.38	-0.75	0.16
FW	0.54	-0.68	0.16	0.11
100 CW	0.69	0.01	0.27	0.56
BL	0.35	0.57	-0.68	-0.01
BW	0.67	-0.49	0.30	-0.29
BT	0.78	-0.39	0.23	-0.10
100 BW	-0.20	-0.37	0.06	0.43
Eigenvalue	5.45	5.20	1.91	1.56
Variance (%)	33.70	30.57	10.21	9.15
Cumulative (%)	33.70	64.27	74.48	83.63

LPB: Length of primary branches, ILB: Internode length of primary branches, FL: Fruit length, FW: Fruit width, LL: Leaf length, LW: Leaf width, LA: Leaf area, 100 CW: Hundred cherries weight, GIRTH: Stem girth, PH: Plant height, BL: Bean length, BW: Bean, BT: Bean thickness, NFN: Number of fruits per internode, PFBPB: Percentage of fruit-bearing primary branches per tree, NPB: Number of primary branches per tree, 100 BW: Hundred beans weight

number of fruits per internode, fruit width, beans width and thickness, hundred cherries weight, the moderate mean value of fruit length, stem girth, plant height, leaf length, bean length and the lowest mean value of the length of primary branches and internode length per branch. Cluster III comprises accessions J2/1257, B71, B139, Mi TV, Mi49/1848, Mi68/1589 all from ISAR RWANDA, Blue mountain and K7 from KENYA and Tekisic from San Salvador. This cluster grouped accessions with the high mean value of traits like Plant height, fruit length, stem girth, length of primary branches, internode length of primary branches, leaf length, hundred cherries weight, bean length, the moderate mean value of the number of primary branches, percentage of fruit-bearing primary branches, leaf area, hundred bean weight, bean thickness and lowest fruit width, bean width and leaf width (Table 5).

Principal component analysis: The presence of phenotypic dissimilarity among the accessions was further described by different groups across the PCA biplot in Table 8. The PCA clustered the genotypes into four clades centred on their comparisons and variances in terms of the quantitative traits. The results showed that 4 PCs accounted for 83.63% of the total variation in the population. The selective control of the PCA as revealed by the Eigenvalues was high in PC1 (5.45) and lower in PC4 (1.56). The first component (PC1) accounted for 33.70% of the total disparity. The highest contributors to the variations were NPB (0.9), PFBPB (0.88), BT (0.78%), LA (0.71) and PH (0.7), followed by 100 CW (0.69), BW (0.67%). However, NFN (-0.34), LPB (-0.17), ILB (-0.07) and 100 BW (-0.2) contributed negatively in the PC1. All other characters contributed a little to the PC1 (Table 8). The PC2 contributed 30.57% of the total variation. Characters that contributed to this component were LPB (0.9), LL (0.78), GIRTH (0.69), PH (0.56) and BL (0.57), NFN (0.42) and FL (0.38). However, LW (-0.88), FW (-0.68), BW (-0.49), BT (-0.39) and 100BW (-0.37) contributed the highest negative donations to the PC2. The PC3 accounted for 10.21% of the total variation. The traits FL (-0.75), BL (-0.68) contributed negatively to the PC3. The trait ILB (0.66), GIRTH (0.33), contributed the highest donation followed by BW (0.3). The PC4 contributed 9.15% of the total variation, most of the characters of PC4 had a low contribution to the variation except NFN (0.68),100CW (0.56) and 100 BW (0.42). Thus, these traits were the key source of the distinction in all accessions studied. The accessions which continued

Table 9: Estimates of genetic distance based on quantitative morphological characters for all pair-wise comparisons of 15 coffee accessions evaluated in Nyange in 2019/2020

Distance	A1	A2	B1	B2	B3	B4	J1	K	M1	M2	M3	S1	S2	S3	T
A1	0.00														
A2	3.46	0.00													
B1	6.19	6.13	0.00												
B2	7.73	7.25	3.31	0.00											
B3	7.15	6.84	2.62	2.78	0.00										
B4	7.22	5.84	4.30	3.95	3.96	0.00									
J1	6.67	6.41	3.36	4.72	3.51	4.09	0.00								
K	6.91	7.02	1.86	3.67	2.53	5.14	3.94	0.00							
M1	7.30	6.78	4.40	4.19	4.86	3.20	4.69	5.19	0.00						
M2	7.20	6.12	3.27	2.44	3.48	2.91	4.14	4.03	3.64	0.00					
M3	7.16	7.28	4.98	5.68	5.27	6.06	5.99	4.45	5.79	5.94	0.00				
S1	8.31	8.58	6.71	7.57	6.61	8.65	7.15	6.40	8.37	8.23	5.26	0.00			
S2	5.51	5.52	6.96	6.91	6.55	6.48	6.96	7.64	6.78	7.32	7.19	7.32	0.00		
S3	7.87	8.55	5.68	5.64	5.88	7.37	6.97	5.07	6.55	6.61	2.70	5.07	7.61	0.00	
T	5.90	5.93	2.14	4.33	3.57	4.30	3.38	3.21	4.15	4.15	5.40	7.01	6.58	6.31	0.00

S2: S288, A1: ABK5691, A2: ABK5718, S1: S795, M3: Mysore, S3: SL28, B4: Mi TV, M1: Mi 68/1589, M2: Mi 49/1848, T: Tekisic, J1: J2/1257, B1: B71, K: K7, B2: B139, B3: Blue mountain

Table 10: Distance between clusters of the coffee germplasm accessions

Cluster	1	2	3
1		88.40	25.06
2	88.40		23.71
3	25.06	23.71	

discrete had larger genetic variability for the traits studied, while accessions which, are less scattered in the principal component axes had considerable comparisons in the traits assessed. The pair-wise genetic distances founded on the phenotypic traits presented varying genetic distances for the 15 coffee accessions in Table 9.

Genetic distances ranging from 1.86-8.65 were recorded in the pair-wise combinations. The shortest genetic distance of 1.86 was noted between the K7 and B71 accessions, followed by 2.14, 2.44,2.7 and 2.78 which were noted between B71 and Tekisic, Mi49 and B139, SL28 and Mysore, B139 and Blue Mountain respectively while the highest genetic distance of 8.65 was noted between S795 and Mi TV followed by 8.58 which was noted between S795 and ABK5718 accessions. The accession S795 showed the highest genetic distance with most of the accessions and B71 showed the shortest genetic distance with most of the accession (Table 9). The highest cluster distance was 88 and was recorded between cluster I and II, followed by II and III clusters (25) and the lowest was between clusters I and III (23) in Table 10.

DISCUSSION

Agro-morphological description of cultivars is an important step towards actual exploitation of diversity in a crop species[20]. This study was carried out to quantify the extent of diversity among coffee accessions in Burundi based on quantitative morphological traits. Arabica coffee genotypes in this study showed significant variation in morphological characters evaluated. The results were similar to the findings of Atinafu *et al.*[21] and Gichimu and Omondi[22] who detected a wide range of phenotypic variation among Arabica coffee accessions in Ethiopia and Kenya respectively.

The results further showed that most of the quantitative traits studied were variable concerning multivariate analyses conducted such as cluster analysis and PCA. Such variability in several important traits clearly showed that there is a huge potential for improvement of coffee growth, fruits and beans characteristics through selection and crossing[23]. Variability between coffee accessions may be attributed either to the evolutionary developments or to the normal mutation happening to the population[23]. The presence of broad morphological variation among Arabica Coffee accessions was also reported by many authors who showed considerable morphological and agronomic variability among coffee germplasm accessions[20,21]. This dissimilarity among C. Arabica accessions may be attributed to the outcrossing present in the species[22]. Correlations recorded among quantitative characters could be used to classify important traits that are favoured by coffee breeders[24]. Significantly positive correlation coefficients were recorded between several combinations of traits in this study. Positive correlation indicated that both characters could be improved concurrently and can be utilized for indirect selection. Significantly negative correlations were also recorded between some combinations of traits. Traits with negative correlations need careful selection considerations since an improvement of one trait leads to a deterioration of the other trait[15,24].

Cluster analysis based on significant coffee quantitative traits grouped the coffee genotypes into three different clusters in this study. Cluster I included accessions ABK5691, ABK5718 and S 288. Cluster II included accessions S 795, Mysore and SL 28 while Cluster III included accessions J2/1257, B71, B139, Mi TV, Mi49/1848, Mi68/1589, Blue Mountain, K7 and Tekisic. These results showed that numerous coffee accessions were grouped despite them coming from diverse countries (sometimes very far from each other). For example, accessions from diverse locality like ISAR RWANDA, INDE and KENYA were grouped in cluster II. Further, the results showed that accessions from Abyssinie via Rubona(RWANDA) were all clustered in the same group, cluster I. In addition, most of the accessions cluster III were from RWANDA. In terms of performance, the accessions in cluster II were the most interesting followed by the accessions grouped under cluster III. However, most of the accessions in cluster I displayed poor agronomic performance, thus, an enhancement program should target upgrading these accessions. These results are in agreement with those of Muvunyi *et al.*[18] who showed that Arabica coffee accessions show variations for several morphological traits. The distance between the clusters of the 15 coffee accessions based on 17 quantitative traits showed that the shortest distance was between cluster I and III (23) flowed by cluster II and III (25). The highest distance was recorded between cluster I and II (88). These results showed that Coffee accessions in this study were diverse from each other. A high cluster distance showed that there is a high chance of obtaining desirable segregants and/or exploiting heterosis if crosses are made between accessions belonging to different clusters[7,17].

The PCA indicated that number of primary branches per tree, percentage of fruits bearing primary branches per tree, Leaf area, hundred cherries weight, plant height, stem girth, blanch length, leaf length, number of fruits per internodes and internode length was the main source of variations in the 15 coffee germplasm. The first 2 principal components PC1 and PC2 with values of 33.7 and 30.5%, respectively contributed extra to total variations among coffee germplasm accessions. According to Yan and Rajcan[25], characters with the largest absolute values closer to the unity within the first principal components influence the clustering of genotypes that are superior for some traits. So, morphological chiefly those contributed to the PC1 and PC2 played a key role in categorizing coffee accessions into diverse clusters and should be used in selecting diverse parents, in the crossing program. The key traits reported in this study concur with those of Atinafu *et al.*[21] and Olika *et al.*[16], who reported various morphological traits such as leaf length and leaf width, hundred bean weight and bean length as the greatest contributors to the variation among coffee accessions. The pair-wise genetic distances based on the phenotypic traits also indicated that there is a huge potential of exploiting heterosis from crosses among the genotypes from different clusters which could allow extension of the range of variability in segregating generations, as has been reported in several studies[19,26].

CONCLUSION

The study has shown that the 15 Arabica coffee genotypes in this study were highly variable concerning all quantitative morphological traits studied. Cluster analysis grouped the genotypes into three clusters where, Cluster II and III contained genotypes with valuable quantitative agronomic traits such as number of primary branches, percentage of fruit-bearing primary branches, number of fruits per internode, leaf area, leaf length, fruit length, hundred cherries weight, hundred beans weight while most of the accessions in cluster I exhibited poor agronomic performance. The genotypes in this study could be utilized directly as varieties or could be utilized in a crop improvement program to develop new varieties.

SIGNIFICANCE STATEMENT

This study has demonstrated that the Arabica coffee genotypes in Burundi are highly variable and could be utilized in a breeding program. The results will help the coffee researchers to identify suitable parents for use in crosses to develop new and improved coffee varieties that will be beneficial to the Burundian coffee growers in increasing their income.

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