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Genetic Variability, Heritability and Genetic Advance for Yield and Yield Components of Limmu Coffee (*Coffea arabica* L.) Accessions in South Western Ethiopia

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Abstract: Coffee (*Coffea arabica* L.) belongs to the genus Coffea in the Rubiaceae family and is a self-fertile allotetraploid species. The experiment was conducted in south western Ethiopia; at Agaro Agricultural research Sub Center in cropping seasons from 2001 to 2012 with the objective of studying the extent of genetic divergence, heritability and genetic advance. Sixty two Arabica coffee accessions which represent Limmu Coffee type with two Coffee Berry Disease (CBD) resistance verities, F-59 and 744 as checks were planted in simple lattice design with two replications. Statistical Analysis Software (SAS) version 9.2 was used for statistical computation and estimation of differences among accessions.Mean yield data of the last six years of cropping seasons were used, while the other agronomic traits taken once throughout the experimental period. Accessions were shows significant difference at $P<0.01$ and $P<0.05$ for all of the traits. Number of main stem nodes revealed larger genotypic and phenotypic coefficient of variation, 20.07 and 23.46 respectively, while yield showed the large values for phenotypic coefficient of variation (24.15) but medium genotypic coefficient of variation (14.93). High broad sense heritability estimates coupled with high genetic advance in percentage of mean for number of main stem nodes; stem diameter and internodes length, suggesting a wide scope for improvement of accessions through selection of these traits.

Key words: *Coffea arabica* L. · Broad sense heritability · Genotypic coefficient of variation · Phenotypic coefficient of variation

INTRODUCTION

Coffee (*Coffea arabica* L.) belongs to the genus Coffea in the Rubiaceae family and is a self-fertile allotetraploid species that is mostly grown in the tropical and subtropical regions [2]. Of the 124 species in the genus *Coffea* [5], Arabica coffee (*Coffea arabica* L.) which is the only tetraploid species ($2n = 4x = 44$) and Robusta coffee (*Coffea canephora* P.) diploid ($2n = 2x = 22$) chromosomes are the two most important commercial species [12]. Coffee is not only one of the highly preferred international beverages, but also one of the important agricultural commodity in the world and approximately 25 million families in 51 countries make a living from it. Economically, it is the second most exported commodity after oil worldwide [10] and also one of the most important commodities in the international agricultural trade, representing a significant source of income to several Latin American, African and Asian countries [1].

Ethiopia is the largest producer of coffee in Sub-Saharan Africa and is the fifth largest coffee producer in the world next to Brazil, Vietnam, Colombia and Indonesia, contributing about 7 to 10% of total world coffee production [10]. The total area coverage of coffee in Ethiopia is estimated to be around 800,000 ha of which about 95% is produced by 4 million small scale farmers [2]. In Ethiopia, Coffee is the major agricultural export crop, providing 30 percent of Ethiopia's foreign exchange earnings [15]. Besides, Coffee production is important to the Ethiopian economy with about 15 million people directly or indirectly deriving their livelihoods from coffee [10].

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Ethiopia is the single known center of origin and genetic diversity for Arabica coffee (*C. arabica* L.) [26]. However, the country is not yet fully utilizing its coffee genetic resources in terms of improving coffee production and productivity. Despite the wealth of ecological and coffee diversities, the national average coffee yield level is low as compare to major coffee growing regions in the world [25]. Studies have showed that, the major production constraint to Arabica coffee in growing areas are lack of high yielder improved varieties, lack of resistant varieties to diseases and insect pests and poor agronomic practices [9] and [27].

Genetic diversity is an essential part of biodiversity, necessary for the reproduction of species and crucial for the adaptation of species to a dynamic environment [19]. Detecting and quantifying genetic variability in crop species is important for successful conservation of genetic resources and plant breeding. The availability of huge genetic variations provides immense possibilities for improvement of the crop for any desirable traits of interest.

An Ethiopian coffee type is known internationally by the names Limmu, Gimbi, Yirgacheffe, Harar and *etc*.; [24]. Limmu Coffee types is one of well known for its peculiar winy flavor and fetching very high price on the world market [20] and [11] have been conducted genetic variability study on 49 Limmu coffee accessions each and reported the presence of genetic variability among accessions for most of the traits considered. Other researchers also conducted on different coffee type at different time. For instance, [8] on 81 west Wellega coffee accessions; [28] on 16 North-West and South-West of Ethiopian coffee accessions and [17] on Harar Coffee accessions at pre-bearing stage reported genetic variability among the accessions for most of the characters studied. However, intensive study was lacking and information on the genetic diversity of Limmu Coffee typeis limited. Therefore, the objective of this study was to estimate the extent of genetic divergence, heritability and genetic advance of sixty two (62) Limmu coffee (*Coffea arabica* L.) accessions with two coffee berry disease varieties in south western Ethiopia.

MATERIALS AND METHODS

Description of the Study Site: The experiment was conducted at Agaro agricultural research sub center of the Jimma Agricultural Research Center located at south-western part of Ethiopia. It is 45 km far from Jimma and 397 km from Addis Ababa. Agaro is located at latitudinal gradient of 7°50’35’’ – 7°51’00’’N and longitudinal gradient 36°35’30’’E with an altitude of 1650 meter above sea level. The mean annual rainfall of the area is 1616 mm with an average maximum and minimum air temperatures of 28.4°C and 12.4°C, respectively [6]. The major soil type is MollicNitisols with pH of 6.2, organic matter 7.07%, nitrogen 0.42%, phosphorus 11.9 ppm and CEC 39.40 cmol(+)/kg [30].

Plant Materials: Sixty two accessions with two released coffee berry disease (CBD) resistant varieties, F-59 and 744 as checks were used in this study (Table 1).

Experimental Design, Management and Season: The trial carried out from 2001 to 2012 cropping seasons in 8x8 simple lattice design with two replications. The plot consisted two rows with four trees per row and the planting space is 2mx2m between rows and plants. All field management practices were done properly and timely as per the recommendation of the area [7]. Mean yield data of the last six years of cropping seasons were used, while the other agronomic traits taken once throughout the experimental period.

Data and Data Management: Data were collected for the following quantitative traits like:

Yield (kg/ha): Fresh cherries were harvested and weighed in grams per tree basis and converted to kg/ha.

Height up to First Primary Branch (cm): The height from ground level up to first primary branch was measured using ruler.

Total Plant Height (cm): It was measured in centimeter from the ground level to tip of apical shoot using meter tape.

Number of First Primary Branches: Total number of primary branches was counted for each tree.

Main Stem Diameter (mm): The diameter of the main stem was measured at 5 cm above the ground level using digital caliper.

Canopy Diameter (cm): The diameter of the trees was measured in East-West and added to the South-North diameter and divided by two.

Table 1: Passport data of coffee accessions collected from Limu coffee growing areas in 2001

Collection districts	Farmers Association	Local name of accessions in the area	Altitude range of collection areas (m.a.s.l)	Collections number/s
Limu- Kossa	Weleke -sombo	Gajo	1550-1550	L01/2001, L03/2001, L04/2001
>>	Debello	>>	1720-1720	L06/2001,L07/2001
>>	Suntu	Dalecho	1530-1850	L12/2001, L13/2001, L14/2001, L15/2001,L16/2001, L17/2001, L18/2001, L19/2001, L20/2001, L23/2001
>>	Dambi -gabena	-	1725	L28/2001
>>	Chakawo	-	1720-1740	L29/2001, L30/2001
>>	Mecha -dire	-	1500	L32/2001, L33/2001, L34/2001
>>	Charake	Mi'aa	1650	L35/2001, L36/2001, L37/2001, L38/2001, L39/2001, L40/2001
>>	Tenabo	>>	1620	L41/2001
>>	Chime	Kerenso	1660	L43/2001, L44/2001, L45/2001
>>	Meto -Gundib	-	1725-1760	L46/2001, L47/2001, L48/2001, L49/2001, L50/2001
>>	Tenabo	-	1620	L51/2001
>>	Chime	-	1660	L52/2001
>>	Mecha- Dire	Mi'aa	1500	L53/2001
>>	Cheraki	>>		L54/2001, L55/2001
>>	Yedo	Gota		L56/2001
>>	Limu- Kossa	Dalecho	1540-1600	L65/2001, L66/2001, L67/2001, L68/2001, L69/2001, L70/2001
Limu-Seka	Gujil	-	1600-1620	L24/2001, L25/2001, L26/2001, L27/2001
>>	DegoJiru	>>	1550	L57/2001, L58/2001, L59/2001, L60/2001, L61/2001
>>	Gejib	Kerenso		L62/2001, L63/2001, L64/2001
-	-	-	-	744(Check)
-	-	-	-	F-59(Check)

Source: Extracted from passport data existing in JARC coffee breeding and genetics department

Internodes Length (cm): computed as $\frac{(TH-HFPB)}{(NN-1)}$ where, TH=total height, HFPB=height up to first primary branch, NN=number of nodes on main stem.

Numbers of Main Stem Nodes: Number of nodes on main stem counted.

Length of the 1st Primary Branch (cm): Length of first longest primary branch measured from main stem to the tip of the branch.

Statistical Analysis: SAS version 9.2 [21] statistical software were used for statistical computations and estimation of differences among genotypes for the traits.Phenotypic variance (σ^2p), genotypic variance (σ^2g) and environmental variance (σ^2e) were determined by formulas proposed by [22] and [13]. Genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were estimated by the formula suggested by [22].

Environmental Variance (σ^2e):

$\sigma^2e=MSe$

Phenotypic Variance (σ^2p):

$\sigma^2p=\sigma^2g+\sigma^2e$

where, σ^2g = genotypic variance and σ^2e= mean square of error (Environmental variance).

Genotypic Variance (σ^2g):

$\sigma^2g= (MSg -MSe)/r$

where, r = number of replication, σ^2g = mean square of Accessions and MS*e* = mean square of error (Environmental variance).

Genotypic Coefficient of Variation (GCV):

$$GCV = \frac{\sqrt{\sigma^2 g}}{\bar{X}} * 100$$

where, σ^2g= genotypic variance
$\bar{x}$ = mean of the character.

Phenotypic Coefficient of Variance (PCV):

$$PCV = \frac{\sqrt{\sigma^2 P}}{\bar{X}} * 100$$

where, σ^2p = phenotypic variance
$\bar{x}$ = mean of the accessions

Broad Sense Heritability (H^2b) and Genetic Advance (GA): Heritability in the broad sense and genetic advance as percentage of mean for quantitative traits was computed usingthe formula suggested by [13] and [16] respectively as follows.

$$H^2b = \frac{\sigma^2g}{\sigma^2P} \times 100$$

where, H^2b = heritability in the broad sense, σ^2g= genotypic variance and σ^2p= phenotypic variance.

$GA = K * \sigma p * H^2b$,

where, GA= Genetic advance, H^2b = heritability in the broad sense, σp = phenotypic standard deviation on mean basis and K=the selection differential.

The Genetic Advance as Percent of Mean (GAM) Was Computed As:

$$GAM = \frac{GA}{\bar{x}} * 100$$

where, GAM = genetic advance as percent of mean, GA= genetic advance under selection and $\bar{x}$ = mean of the population in which selection was employed.

RESULT AND DISCUSSION

Simple lattice design was more efficient over RCBD almost for all traits (Table 2). Therefore, the use of simple lattice design was important. Accessions showed significant difference at P<0.01 and P<0.05 for all traits (Table 2). This indicates the presence of diversity among accessions. In addition, significant variability among accessions creates immense opportunity for effective selection and hybridization programme to obtain wide spectrum of variation among the segregants. [20] and [11] also reported the presence of significant difference between Arabica Coffee accessions for different traits.

Estimation of Genotypic and Phenotypic Coefficients of variation: In this study, the phenotypic coefficients of variation (PCV) were comparatively higher than genotypic coefficients of variation (GCV) for all the traits studied (Table 3). Among the studied traits, the larger differences between PCV and GCV were revealed for yield, length of first primary branch and total plant height. This large difference, *i.e.*, higher values for PCV than that of GCV reflects the high environmental influence on expression of the studied traits. [8]; and [20] also revealed the higher values of PCV than GCV in most of the traits they studied. However, in this study, the slightly differences between PCV and GCV were revealed for inter nodes length and number of main stem nodes.

According to [4], PCV and GCV values > 20% regarded as high, between 10 and 20% medium and <10% low. Accordingly,number of main stems nodes revealed larger genotypic and phenotypic coefficient of variation 20%, while yield showed the large values for phenotypic coefficient of variation but medium genotypic coefficient of variation (Table 3). Besides, these traits could be used as selection for Arabica coffee improvement. The low genotypic coefficient of variation was revealed for all the remained traits. Among the studied traits, only canopy diameter and internodes length was revealed the low phenotypic coefficient of variation. As the traits PCV and

Table 2: Analysis of variances (Mean Square) and Relative efficiency for different morphological traits of sixty four Arabica Coffee Accessions

	Treatment				Error			
Traits	Replication	Adjusted	Unadjusted	Blocks within rep(adj)	Intra block	RCBD	CV%	RE
Degree of freedom	1	63	63	14	49	63		
Number of 1st primary branch	190.37*	63.63**	80.09	59.71	21.21	29.76	8.84	122.75
Canopy diameter	17555.87**	282.98**	309.85	262.99	126.03	156.47	6.73	111.27
Internodes length	0.97**	0.46**	0.55	0.22	0.13	0.15	5.71	105.55
Number of main stem nodes	88.44**	16.86**	21.27	15.34	4.19	6.67	7.55	136.97
Length of 1st primary branch	104.53ns	148.14*	161.26	70.18	78.31	76.5	10.29	97.70
Height up to 1st primary branch	21.70ns	32.72**	39.27	24.68	12.94	15.55	10.48	108.68
Stem diameter	0.06ns	0.26**	0.35	0.23	0.08	0.11	7.23	123.71
Total plant height	7658.76**	762.48*	1168.90	1050.21	400.99	545.26	9.62	119.55
Yield	619634.95ns	265669.46**	293666	195330	118739	135760	18.99	105.17

*, **, ns indicates significance at 0.05, 0.01 probability levels and none significance respectively, CV=Coefficient of variations, RCBD=Randomized complete block design and RE= Relative efficiency

Table 3: Range, mean, variance, genotypic and phenotypic coefficient of variation, broad sense heritability genetic advance as percent of mean for traits of Limmu Coffee accessions

Traits	Range	Mean	σ^2e	σ^2g	σ^2p	GCV (%)	PCV(%)	H^2b	GA	GAM
Number of 1st primary branch	63.15-32.00	52.10	21.21	21.21	42.42	8.84	12.5	50.00	6.72	12.90
Canopy diameter	194.93-136.08	166.68	126.03	78.48	204.51	5.31	8.58	38.37	11.32	6.79
Internodes length	7.78-5.37	6.42	0.13	0.16	0.30	6.32	8.52	54.99	0.62	9.66
Number of main stem nodes	33.15-16.50	16.86	4.19	11.46	15.65	20.07	23.46	73.21	5.98	35.43
Length of 1st primary branch	108.85-63.85	85.95	78.31	34.92	113.23	6.87	12.38	30.84	6.77	7.88
Height up to 1st primary branch	45.35-25.20	34.32	12.94	9.89	22.84	9.16	13.92	43.33	4.27	12.45
Stem diameter	4.96-2.65	3.92	0.08	0.09	0.17	7.72	10.59	53.28	0.46	11.64
Total plant height	256.50-145.15	206.77	396.05	151.40	547.45	5.95	11.31	27.65	13.35	6.46
Yield	2624.9-1108.2	1814.97	118739.38	73465.04	192204.42	14.93	24.15	38.22	345.68	19.05

σ^2g = Genotypic variance, σ^2e = Environmental variance, σ^2p= Phenotypic variance, H^2b = Broad sense heritability, GCV (%) = Genotypic coefficient of variation, PCV (%) = Phenotypic coefficient of variation, GA= Genetic advance, GAM= Genetic advance as percent of mean.

GCV values showed the lowest value less than 10%, it is the indication of the traits vulnerability to different environments. Whereas, number of first primary branch, length of first primary branch, height up to first primary branch, stem diameter and total plant height showed medium PCV.

Heritability and Variance Components: High broad sense heritability (>50%) was revealed for number of first primary branch, internodes length, number of main stem nodes and stem diameter (Table 2).This indicated that the accession plays a large role in determining the observed phenotype. This finding was in agreement with previous work of [29] who reported high broad sense heritability for main stem girth, number of primary branches and internodes length. Canopy diameter, length of first primary branch, height up to first primary branch, total plant height and yield showed medium (20 to 50%) broad sense heritability. None of the traits evaluated in this study was showed the lowest heritability. The results suggesting most likely the effective selection can be done by the studied traits for Arabica coffee improvement since genotypic coefficient of variation showed from medium to high for all traits.

Genetic advance under selection (GA) refers to the improvement of traits in genotypic value for the new population compared with the base population under one cycle of selection at a given selection intensity [23]. Values of expected genetic advance (GA) expected from selection of the top 5% of the accessions indicated that 6.72 for number of first primary branch, 11.32 cm for canopy diameter, 0.62 cm for internodes length, 5.98 for number of main stem nodes, 6.77 cm for length of first primary branch, 4.27 cm for height up to first primary branch, 0.46 cm for stem diameter, 13.35 cm for total plant height and 345.68 kg ha^{-1} for yield. In this study, the high genetic advance was revealed for yield, total plant height and canopy diameter. This is interestingly for very important traits and the improvement of Arabica coffee accessions are most of the time depends on yield, canopy diameter and plant height.

For instance in this study, if the selections for improvement is depend only on yield, whenever we select the best 5% high yielding accessions as parents, mean grain yield of progenies could be improved by 345.68 kg ha^{-1}, that is, mean genotypic value of the new population for yield will be improved from 1814.97 to 2160.65 kg ha^{-1}. In the same way, it will be 58.81 for number of first primary branch, 178.00 cm for canopy diameter, 7.04 cm for internodes length, 22.84 for number of main stem nodes, 92.72 cm for length of first primary branch, 38.59 cm for height up to first primary branch, 4.37 cm for stem diameter and 220.12 cm for plant height. Maximum genetic advance as percentage of mean (GAM) at 5% selection intensity was also recorded for yield, canopy diameter and number of first primary branch (Table 3). This indicated that, some increase in yield should be possible by any of selection techniques providing environmental variations are held to a minimum.

High heritability estimates have been found to be helpful in making selection of superior accessions on the basis of phenotypic performance. [16] suggested that heritability estimates along with genetic gain were more useful in predicting selection of the best individual. High heritability estimates relatively coupled with high genetic advance in percentage of mean for number of main stem nodes; stem diameter and internodes length, suggesting a wide scope for improvement through selection of these traits. High genetic advance in percentage of mean was recorded for yield, but moderate heritability, while high heritability coupled with low genetic advance in percentage of mean for number of first primary branch.

CONCLUSION

The present study illustrated the existence of wide ranges of variations for all traits studied for the Arabica Coffee accessions, which provides good opportunities for genetic gain through selection or hybridization. The phenotypic coefficient of variation values was higher than genotypic coefficient of variation values for all the traits which reflect the influence of environment on the expression of traits. High amount of broad sense heritability with higher value of genetic advance were observed for number of main stem nodes; stem diameter and internodes length which provided the evidence that these plant attributes might be under the control of additive genetic effects and selection can be beneficial for improvement of Coffee accessions. Therefore, Coffee breeders can use this good opportunity for coffee improvement in future through selection and/or hybridization of less environmentally induced traits.

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