Global Scientific JOURNALS

GSJ: Volume 8, Issue 1, January 2020, Online: ISSN 2320-9186
www.globalscientificjournal.com

Genetic variability study of Tepisurroundings Coffeegermplasm accessions *(Coffeaarabica*L.) Based on Quantitative Traits in Ethiopia.

Abdulfeta Tariku *[1],Hussein Mohammed Ali[2] and AshenafiAyano[3]
[1] Ethiopian Institute of Agricultural Research,Chiro National Sorghum Research and Training Center, P.O. Box190,Chiro,Ethiopia.
[2] Hawassa University College of Agriculture, School of Plant and Horticultural Sciences, P.O. Box 05, Hawassa, Ethiopia.
[3]Ethiopian institute of Agricultural Research, Jimma Agricultural Research Center, P.O. Box 192, Jimma, Ethiopia

Abstract

The aim of the study was to find out heritability, variance components, variability and genetic advance for some yield and yield related agronomic characters. 93 coffee (*Coffeaarabica* L.) germplasm accessions,including five standard checks,which were collected from Tepi surroundings,were evaluated at Tepi National spice research station.The experiment was conducted in augmented design of four blocks during 2016 cropping season by superimposing on four years old coffee trees. Data on 22 quantitative characters were recorded. Analysis of variance of 22 quantitative traits revealed significant difference among the accessions in leaf length, leaf width,leaf area,number of primary branches, fruit length, bean length, bean width, bean thickness, hundred bean weight and green bean yield. The contrast between the mean of accessions and the mean of checks was significant for all traits except for leaf length, number of main stem node, girth of stem, number of nodes on primary branches,canopydiameter,fruit width and fruit thickness indicating the presence of variability. Genetic advance as percent of the mean was very high (62.6%) for green bean yield which also had very high PCV (36.7%),GCV (33.4%) and heritability (83.0%).Over all, the study confirmed the presence of trait diversity in Tepi surroundings coffee accessions and this could be exploited in the genetic improvement of the crop through hybridization and selection.

Key words: *Coffeaarabica*, genotypic coefficient, phenotypic coefficient, genetic advance, variability, heritability,

*Corresponding author. E-mail: abdulfetah02@gmail.comTel:+251-906-535-987

Introduction

Coffee belongs to the genus *Coffea*in the *Rubiaceae* family.The genus *Coffea*comprises nearly 124 well identified species; however, *Coffeaarabica*L. and *Coffeacanephora*P. are the two commercially important species(Davis *et al.*,2012).*Coffeaarabica*is by far the most important commercial species because of its best cup quality as well as wide choice of flavor and contributes to more than 70% of the world coffee production (Gray *et al.*, 2013).Arabica coffee is the highly preferred nonalcoholic international beverage, and is a very important source of foreign exchange income for many countries. Some estimated that the entire coffee supply chain provides a livelihood for 125 million people worldwide (Bunn, 2015) and is the second most exported commodity after oil worldwide (Davis *et al*., 2012). Specifically, it is one of the most important commodities and source of income to severalLatin American, African and Asian countries. Particularly, it is an integral part of cultural and nucleus of Ethiopian economy which accounts for 24 percent of the country's exports(ECFF, 2015).

Ethiopia is first producer and exporter in Africa and 5th in the world contributing to about 4.2 % of the total world coffee production. The crop is mainly produced in the Southern, Southwestern and Eastern parts of the country. Its total area coverage is estimated to be around 700,474.69 hectares; with annual national production of clean coffee469091.12 tons with average productivity of 669.6 kg ha^{-1}(CSA,2017). Ethiopia is not only the major producer and exporter of Arabica coffee, but also origin and center of genetic diversity in the southwestern highlands of the country. Such existence of genetic diversity provides immense opportunity for coffee improvement(Gole and Senebeta,2008).

Although many factors hampered production and yield per unit area, the major factors contributing to such low coffee yield include predominant use of unimproved local coffee landraces, as well as conventional husbandry and processing practices, which in turn seriously hampers the overall national coffee production and productivity of the smallholder coffee farmer in the country (Taye, 2010). Furthermore, despite the availability of coffee genetic diversity in the country, coffee genetic resources are under serious threats of extinction, mainly due to deforestation, replacement of traditionally grown landrace by improved varieties, environmental degradation and change in land use (Gole and Teketay, 2001).To minimize such risks, coffee germplasm collections have been made during the national coffee collection program to capture the available coffee genetic variability for the purpose of

selecting and developing adaptable coffee varieties.About 5731 accessions are *ex-situ* conserved at Institute of Biodiversity Conservation (Taye,2010) and 6721 accessions on Jimma Agricultural Research Center field gene bank is a typical evidence for the huge and untapped coffee genetic wealth of coffee in the country (Tadesse, 2017). Up to date the center released 34 pure lines and six hybrids varieties. The released varieties are under production in different coffee growing areas of the country (Ashenafi*et al*.,2017).

Information on the nature and magnitude of variability and heritability in a population is one of the prerequisites for successful breeding program in selecting genotypes with desirable characters .It is therefore, of great importance for breeders to know the heritability of the agronomical characters to improve the yield of the crop effectively (Larik*et al*., 2000). Knowledge of the extent and pattern of variability, heritability of the trait and genetic gain present in a population of coffee collections under diversified agro-climatic condition of Ethiopia is limited. Hence,this study was done with the objective to assess the variability, heritability and genetic advance of coffee bean yield and some of its related components to select a more desired trait that may contribute for the improvement of some Tepi and its surrounding(Bench-Maji&Sheka zones) coffee accessions.

MATERIALS AND METHODS

Experimental material, design and management:

The experiment was conducted on 93 coffee accessions germplasm, including the five standard checks (Table 1) at Tepi National Spices Agricultural Research Center, Southwest Ethiopia. Tepi is located at a latitude of 7° 3' N and longitude of 35° 18' E. and at an altitude of 1200masl.The mean annual rainfall of the area is 1678mm per annum well distributed over eight months with an average maximum and minimum air temperatures of 30°C and 16°C, respectively and Soil PH=6.9-8 with fine textured 30-80% clay soil. The experimental design was augmented design with four blocks. Each accession was planted a single row of 12 trees using spacing of 2m by 2m. All the management practices such as shading, weeding and fertilization were uniformly applied to all plots as per the recommendation (Endale*et al.*,2008).

Table 1. Description of *Coffeaarabica* L. germplasm accessions studied

Zones	District (Woreda)	Peasant association	Altitudes (m)	Number of collected accession
Bench-Maji (65 accessions)	Bero	Bero	1629-1680	5
		Garo	1708	1
		Jeba-01	1698-1718	3
		Kasi	1601-1676	4
		Sirit	1656-1664	2
	Menit-Shasha	Bus	1438-1449	6
		Kudum	1532-1611	6
		Dargach	1870-1930	4
		ShawaJebabo	1900-1950	2
		Kuju	1975	2
		Era	1537-1573	3
	Sheko	Gizemeret	1049-1338	10
		Shimi	1047-1250	6
		Sanka	1215-1450	4
		AyibranaSanka	1220-1290	7
Sheka (23 accessions)	Andracha	Gemedro	1510-1650	8
		Yokichich	1810-1900	8
		Chegechecha	1890-2000	7
**Geisha*	*Check 1*	****FIVE*** **STANDARD CHECKS**		**88**
**CatimorJ-19*	*Check 2*			
**Dessu*	*Check 3*			
**7454*	*Check 4*			
**7440*	*Check 5*			
TOTAL ACCESSIONS				**93**

Data collection: Data on 22 quantitative traits were recorded on plot basis with three trees fromeach accession by random sampling method.These quantitative date includes leaf length (cm), leaf width (cm), leaf area (cm^2),bean length (mm), bean width (mm), bean thickness (mm),fruit length(mm),fruit width (mm), fruit thickness (mm), hundred bean weight (gm), yield (kg/ha),plant height(cm),stem diameter(cm), number of main stem nodes (no),canopy diameter (cm), average internodes of stem (cm), length of primarybranches (cm), number of primary branches(no),number of secondary branches(no), height up to first primary branches (cm),number of node on primary branch(no)and coffee leaf rust (%)(IPGRI, 1996).

Statistical analysis:

Estimation of magnitude of variation

The phenotypic and genotypic variances were estimated according to the method suggested by Burton and De Vane (1953).

$$\sigma^2 g = \frac{(Mst - Mse)}{r} \sigma^2 e = Mse \sigma^2 p = \sigma^2 g + \sigma^2 e$$

Where, $\sigma^2 p$=Phenotypic variance, $\sigma^2 g$ =Genotypic variance, σ^2e=Environmental variance,*MSt=mean square of treatment, MSe=mean square of error,r=number of replications and$\bar{x}$=Grand Mean of the population*

The coefficient of variations at phenotypic and genotypic level variation was estimated using the formula adopted by Johnson *et al.* (1955) as*:*

Phenotypic Coefficient of Variation (PCV) = (σ p/$\bar{x}$) x 100

Genotypic Coefficient of Variation (GCV) = (σ g/ $\bar{x}$)x100

Estimate of broad sense heritability and expected genetic advance:

Heritability (h^2) in broad sense for all characters was computed using the formula suggested by Falconer (1989):

$H^2 b$= ($\sigma^2 g/\sigma^2 p$) x 100 , $\sigma^2 p = \sigma^2 g + \sigma^2 e$

Where $\sigma^2 p$ = *Phenotypic variance,* $\sigma^2 g$ = *Genotypic variance,* σ^2e = Environmental

Genetic advance as percent of mean for each character was computed using the formula by Allard (1960).

GA=kσph * h^2 b **GAM =** (GA/$\bar{x}$)*100

Where, H =heritability in broad sense. GA = the expected genetic advance under selection; σph =the phenotypic standard deviation; square root of phenotypic variance and k is selection Intensity at 5% (K = 2.063)

RESULTS AND DISCUSSION

Analysis of variance

Mean squares for the 22 quantitative traits from analysis of variance (ANOVA) are presented in Table 2.The results of analysis of variance of 22 quantitative traits revealed significant

difference among the 93 accessions in leaf length, leaf width,leaf area, number of primary branches, fruit length, bean length, bean width, bean thickness, hundred bean weight and green bean yield. On the other hand, non-significant difference was observed among the accessions for plant height, length of primary branches, number of secondary branches, canopy diameter, fruit width and fruit thickness that the genotypes are similar in these traits.The contrast between the mean of accessions and the mean of checks was significant for all traits except for leaf length, number of main stem node, girth of stem, number of nodes on primary branches, canopy diameter, fruit width and fruit thickness.The 88 accessions also differed significantly in these same traits while the checks differed in all traits except in plant height, height up to first primary branch,number of main stem node, girth size, number of node on primary branch, fruit traits (fruit length, fruit width and fruit thickness),bean traits(bean length, bean width and bean thickness), tolerance to coffee leaf rust, hundred bean weight and green bean yield,indicating the presence of variability which can be exploited through selection. The variations observed for measured quantitative characters in this study were in agreement with the earlier findings of Mesfin and Bellachew (2005) who reported the significant difference among the genotypes in 100 Harargecoffee accession germplasm using 14 quantitative characters. Similarly, Olika*etal. (*2011) found that significant variation between 22 quantitative characters of 49 coffee accessions.Other researchers (Bayetta,1997;Yigzaw,2005)have also confirmed present of significance difference amongcoffeegermplasms collected from major coffee growing regions of Ethiopia.

Estimates of variance components

The estimate of the variance component is presented in Table 3.PCV values ranged between 2.57 for height up to first primary branch to 36.7% for green bean yield. It was high (>20%) for coffee leaf rust (24.5%) and it was also relatively high for number of secondary branch (19.2%).Low PCV value was observed (<10%) for all other traits.GCV varies between 0.48% for girth size to 33.4% for green bean yield. It was relatively high (17.5%) for coffee leaf rust. For most traits both PCV and GCV were less than 5% (number of node on primary branch,canopy size, fruit length, fruit width, fruit thickness, bean length,bean width, leaf length, bean thickness and height uptofirst primary branch),indicating low variability of most of the traits.These results are in agreement with the findings of Olika*et al.*,(2011) and Getachew*et al.*,(2013) who have reported high phenotypic and genotypic coefficients of

variation were number of secondary branches and yield per tree. And medium phenotypic and genotypic coefficients of variation were recorded for hundred beans weightand height up to first primary branches.

Estimates of broad sense heritability and expected genetic advance

The estimate of the broad sense heritability is presented in Table 3.According to VermaandAgarwal (1982), heritability values greater than 50% are considered as high, whereas values less than 20% are to be low and values between 20 and 50% as medium. Based on this, characters which showed high heritability values were for green bean yield (83%), fruit length (88%), bean width (86%) and bean thickness(84%), which were obtained not from high genotypic variance, but from the very little difference between genotypic and phenotypic variances, although both were low (except for green bean yield). Heritabilities between 70 and 80% were obtained for bean length (77%), leaf length (73%), hundred bean weight (75%) and leaf area (71%), which indicated that improvement of these characters through selection may be efficient. Selection for any of these characters, which are highly heritable and easy to measure, will help to improve coffee bean yield in this population. High heritablities (50-70%) were obtained for number of primary branch (65%),coffee leaf rust (51%) and leaf width (68%). The result is in agreement with Gizachew*et al.*, (2015) who reported high heritabilityvalues of quantitative characters in coffee. Medium heritability values were recorded for Heritabilities between 30 and 50% were observed for length of primary branch,number of secondary branches, fruit width,fruit thickness and height. The result is in agreement with Walyaro and Vossen(1979) who reported medium heritability values of quantitative characters in coffee.For the remaining eight traits broad sense heritabilities were very low (<30%), indicating the availability of little genotypic variance to be exploited in selection. Olika*et al.*, (2011) also reported low heritability values of quantitative characters in coffee oncanopydiameter(1.51%),average internode length of stem (0.09%),average length of primary branches (16.03%) and percentage of bearing primary branches were grouped under low heritability. For number of secondary branches and coffee leaf rust which had relative high PCV and GCV, heritabilities were not high (34 and 51%) because the magnitude of genotypic variance relative to phenotypic variance was low; these traits were highly influenced by the environment.Maximum genetic advance as percentage of mean (GAM) at 5% selection intensity was recorded for green bean yield (62.6%) and coffee leaf rust (25.7%). It was

relatively high fornumber of primary branch (11.9%), number of secondary branch (13.6%), hundred bean weight (10%) and leaf area (11.7%). All other traits had GAM lower than 5% indicating the difficulty of improving them through cyclical recurrent selection. For number of node on primary branch (0.3%), number of main stem node on (0.65%) and girth size (0.10%) GAM was near zero.According to Ali *et al. (*2002),high heritability estimates along with the high genetic advance is usually more helpful in predicting gain under selection than heritability estimates alone. The present study reveals high heritability coupled with high expected genetic advance as percent of mean was very high (62.6%) for green bean yield which also had very high PCV (36.7%), GCV (33.4%) and heritability (83.0%). By recombining the highest

yielding 5% accessions green bean yield can be improved by 240 kg ha^{-1} $cycle^{-1}$ of selection (3 $year^{-1}$). Genetic advance as percent of the mean was high for coffee leaf rust (25.7%), which can be improved (lowered) by 0.33 disease score per cycle of selection. Number of primary branch, number of secondary branch and leaf area had relatively high GAM and can be improved by 5.8 and 9.0 branches and 8.0 cm^2 $cycle^{-1}$ of selection respectively. The currentfinding is partly in agreement with Olika*et al.* (2011);Getachew*et al.* (2013)and Lemi and Ashenafi(2016) who studied on some arabica coffee collections and reported higher heritability and genetic advance for most of the studied quantitative traits.

NO	Trait	Mean squares						
		Block(adj)	**Trt(Adj)**	**Among accessions**	**Among checks**	***Tests Vs control***	**Error**	**CV %**
		DF=3	DF=92	DF=87	DF=4	DF=1	DF=12	
1	LL	0.86^{ns}	1.17^{**}	1.16^{**}	1.32^{*}	0.96^{ns}	0.31	3.57
2	LW	0.31^{ns}	0.46^{**}	0.36^{*}	2.21^{***}	2.47^{***}	0.15	5.84
3	LA	96.70^{ns}	118.72^{**}	101.84^{*}	410.93^{***}	418.34^{**}	34.26	8.58
4	LPB	45.29^{ns}	76.90^{ns}	65.73^{ns}	248.79^{**}	360.86^{**}	49.36	7.27
5	PH	128.62^{ns}	1394.47^{ns}	1316.22^{ns}	1041.33^{ns}	9614.79^{**}	896.85	10.26
6	HUFB	11.75^{*}	4.30^{ns}	4.29^{ns}	2.56^{ns}	13.15^{*}	3.25	4.47

Table 2: Analysis of variance of 22 quantitative traits

7	AILS	0.12 ns	1.52 ns	1.33 ns	3.20*	11.68**	1.14	16.35
8	NMN	1.73 ns	10.29 ns	9.68 ns	24.68 ns	5.60 ns	9.61	9.19
9	GS	113.00**	21.77 ns	21.73 ns	22.98 ns	20.12 ns	21.57	9.98
10	NPB	53.52 ns	74.22*	57.03*	436.25***	121.21*	26.02	10.51
11	NNPB	0.91 ns	3.00 ns	2.93 ns	5.29 ns	0.04 ns	2.88	8.53
12	CD	416.99 ns	280.93 ns	247.81 ns	963.67**	430.79 ns	201.60	7.17
13	NSB	2788.98**	640.22 ns	631.16 ns	393.18 ns	2416.51*	420.28	31.07
14	FL	0.03 ns	1.21***	1.22***	0.17 ns	5.22***	0.15	2.40
15	FW	0.45 ns	0.57 ns	0.59 ns	0.33 ns	0.50 ns	0.32	4.82
16	FT	0.06 ns	0.83 ns	0.83 ns	0.88 ns	0.54 ns	0.55	5.27
17	BL	0.09	0.63**	0.63**	0.07	2.96***	0.14	2.95
18	BW	0.24***	0.14***	0.15***	0.01	0.13*	0.02	2.68
19	BT	0.01 ns	0.20***	0.18***	0.04 ns	2.54***	0.03	2.17
20	CLR	13.69 ns	16.04 ns	12.06 ns	50.98*	222.35***	13.51	81.8
20	CLR2	0.12 ns	0.50 ns	0.42 ns	0.55 ns	7.53***	0.25	34.22
21	YLD	91913.44**	78769.01***	79477.71**	13703.97	277371.84**	13520.48	30.43
22	HBW	0.51 ns	5.23**	5.42**	0.12 ns	9.34*	1.30	6.26

*Where * =Significant at probability level of 0.05 and ** =Significant at probability level Where *=Significant at probability level of 0.05;**=Significant at probability level of 0.01,and *** = Significant at probability level of 0.001.DF= Degree of freedom, NS=non significance CV%=Coefficient of variation in percentage, LL=leaf length, LW=leaf width, LA=leaf area, FL=fruit length, BL=bean length, HBW=hundred bean weight YLD=green bean yield, PH=plant height, NPB=number of primary branches, LPB=length of primary branches, NSB=number of secondary branches, CD=canopy diameter, FW=fruit width FT=fruit thickness; BW=bean width; BT=bean thickness; CLR=Coffee leaf rust; CLR2=log(Coffee leaf rust+1); GS=Girth of stem; HUFB=height upto first primary branch ; AILS=* average inter node length of primary branches*;NMN= number of main stem node ; NNPB= number of node on primary branches*

Table 3. Estimates of genetic components of variance, heritability and genetic advance genotypes

Traits	**Range**	**mean**	**σ^2g**	**σ2e**	**σ^2p**	**PCV(%)**	**GCV(%**	**H^2 (%)**	**GA**	**GAM**
YIELD	1568.4	399.3	16312.13	3380.12	19692.2	36.72	33.42	0.83	239.46	62.66
LPB	49.4	97.6	6.88	12.34	19.22	4.53	2.71	0.36	3.23	3.35
NPB	35.0	48.0	12.05	6.5	18.55	8.88	7.15	0.65	5.76	11.88
NNPB	7.1	19.9	0.03	0.72	0.75	4.35	0.85	0.04	0.07	0.34
CD	114.5	199.0	19.83	50.4	70.23	4.23	2.25	0.28	4.88	2.46
NSB	126.0	68.2	54.99	105.07	160.05	19.18	11.24	0.34	8.95	13.57
FL	5.96	16.1	0.27	0.04	0.30	3.44	3.23	0.88	1.00	6.23
FW	5.2	11.7	0.06	0.08	0.14	3.22	2.13	0.44	0.34	2.90
FT	3.9	14.1	0.07	0.14	0.21	3.22	1.86	0.33	0.31	2.21

BL	3.87	12.95	0.12	0.04	0.16	3.07	2.70	0.77	0.63	4.88
BW	2.46	5.26	0.03	0	0.04	3.56	3.30	0.86	0.33	6.31
LL	5.8	15.613	0.21	0.08	0.29	3.45	2.96	0.73	0.82	5.21
BT	2.73	8.12	0.04	0.01	0.05	2.75	2.53	0.84	0.39	4.78
HBW	13.6	18.09	0.98	0.33	1.31	6.27	5.44	0.75	1.77	9.71
LW	3.7	6.5296	0.08	0.04	0.12	5.18	4.27	0.68	0.48	7.27
LA	63.34	67.59	21.11	8.57	29.68	7.98	6.73	0.71	7.98	11.70
PH	193.8	296.4	124.40	224.21	348.62	6.40	3.82	0.36	13.73	4.70
AILS	6.6	6.7	0.10	0.28	0.38	9.44	4.73	0.25	0.32	4.88
NMN	22.5	33.6	0.17	2.4	2.57	4.76	1.23	0.07	0.22	0.65
GS	14.0	46.7	0.05	5.39	5.44	5.01	0.48	0.01	0.04	0.10
HUFPB	10.3	40.1	0.26	0.81	1.07	2.57	1.27	0.24	0.52	1.30
CLR	20.61	3.81	0.06	0.06	0.13	24.47	17.49	0.51	0.37	25.75

Where σ^2p =Phenotypic variance; σ^2g=genotypic variance; PCV=phenotypic coefficient of variation; GCV=genotypic coefficient of variation; H^2=broad sense heritability; GA=expected genetic advance; GAM=genetic advance as percent of the mean.

Conclusion

The study confirmed the presence of traitthe existence of wide range of variations for some of studied Arabica Coffee accessions,and this could beexploited in the genetic improvement of the crop through hybridization and selection. The PCV and GCV values were high for number of primary branch,number of secondary branch, green bean yield and coffee leaf rust indicates the existence of genetic variation for such characters,suggesting the possibility of improving these traits through selection.The considerable lower values for GCV than PCV indicated the importance of environment in the expression of these traits. Green bean yield and coffee leaf rust exhibited high GCV, high heritability together with high genetic advance as percent of means have high amount of exploitable genetic variability.Therefore, these characters could be improved more easily than the other characters and would be useful as a base for selection and/orhybridization in the future coffee improvement program.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENT

We would like to acknowledge Ethiopian Institute of Agricultural Research, Jimma Agricultural Research Center for the source of budget for the research and Tepi National Spices Agricultural Research Center for land.

REFERENCES

Ali, Z., A.S. Khan, and M.A. Asad, 2002. Salt tolerance in bread wheat: Genetic variation and heritability for growth and ion relation. *Asian Journal of plant science*.**1**:420-422.

Allard, R.W. 1960. Principles of Plant Breeding.Wiley, New York.

AshenafiAyano, DemelashTeferi and TayeKufa.Coffee Research in Ethiopia and its contribution to the coffee sub-sector: A Review Paper presented in annual research symposium of Jima University. April 2017,Jima Ethiopia.

BayettaBelachew, 1997. Arabica coffee breeding in Ethiopia: A review.ASIC*1997, Nairobi, Kenya, 17:406-414*

Bunn,Ch.,2015. Modeling the climate change impacts on global coffee production. Dissertation for the completion of the academic degree Doctor rerumagriculturarum submitted to the faculty of Life Sciences at Humboldt-Universitätzu Berlin. P. 196

Burton, G.W., and H.E. de Vane, 1953. Estimating heritability in tall festuca (Festucaarudinacea) froim replicated clonal material. Agron. J. 45: 478-481.

Davis, A.P., J. Tosh, N. Ruch and M.F. Fay, 2012. Growing coffee: Psilanthus(Rubiaceae) subsumed on the basis of molecular and morphological data; implications for the size, morphology, distribution and evolutionary history of Coffea.Botanical J. Linnean Soc., 167: 357-377.

EndaleTaye, TayeKufa, AntenheNestre, TesfayeShimber, AlemsegedYilma and TesfayeAyano, 2008.Research on coffee field management.pp.187-195. In: GirmaAdugna, BayettaBelachew, TesfayeShimber, EndaleTaye and TayeKufa (eds.).Coffee Diversity and Knowledge. Proceedings of a National Workshop Four Decades of Coffee Research and Development in Ethiopia, 14-17 August 2007, Addis Ababa, Ethiopia.

Environment and Coffee Forest Forum (ECFF), 2015.Coffee production system in Ethiopia. Addis Ababa, Ethiopia.

Falconer, D.S. and Mackay, T.F.C. 1996.Introduction to Quantitative Genetics.4th ed. Longman, Susex, England

GetachewWeldeMichael,SentayehuAlamerew,TayeKufa and TadesseBenti, 2013.Genetic Diversity Analysis of Some Ethiopian Specialty Coffee(*Coffeaarabica* L.) Germplasm Accessions Based on Morphological Traits.

GizachewAtinafu, Hussein Mohammed and Tayekufa,2015.Agro-morphological characterization ofSidamacoffeeaccessions tested at Awada, Southern Ethiopia.

Gole, T.W. and Senebeta, F., 2008.Sustainable management and promotion of forest coffee in Bale, Ethiopia. Bale Eco-Region Sustainable Management Programme SOS Sahel/FARM-Africa, Addis Ababa.

Gole, T.W. and Teketay, D., 2001.The forest coffee ecosystem crisis, problem and opportunities for coffee gene conservation and sustainable utilization.pp 131-142. In: Imperative problems associated with forestry in Ethiopia (ed.BSE), Biological society of Ethiopia, Addis Ababa.

Gole, T.W.,Senebeta ,F. 2008. Sustainable Management and Promotion of Forest Coffee in Bale, Ethiopia.

Gray, Q., Tefera, A., and Tefera, T., 2013.Coffee Annual Report. GAIN Report No.ET 1302.

IPGRI(International Plant Genetic Resource Institute).1996.Diversity for development.Rome, International Plant Genetic Resources Institute.

Johnson, H.W., H.F. Robinson, R.F and Comstock. 1955. Estimates of genetic and environmental variability in Soya bean Agronomy, J. 47: 314-318.

Larik AS, Malik SI, Kakar AA, Naz MA (2000).Assesment of heritability and genetic advance for yield and yield components in Gossypiumhirsutum L. Scientific Khyber 13: 39-44.

Lemi, B., and Ashenafi, A., 2016. Genetic variability, heritability and genetic advance for yield and yield components of limmu coffee *(Cofeaarabica*L.) accessions in South Western Ethiopia. *Middle-East Journal of Scientific Research,* **24 (6):** 1913-1919.

MesfinKebede and BayettaBelachew, 2005.Genetic Divergence of Harragie coffee *(Coffeaarabica L.).*Germplasm accessions at pre- bearing stage. 20`h Int. Sci. Colloq.On coffee ASIC, Montpellier, France.

OlikaKitila, SentayehuAlamerew, TayeKufa and WeyessaGaredew. 2011. Variability of quantitative Traits in Limmu Coffee (*Coffeaarabica* L.) in Ethiopia. *International Journal of Agricultural Research, 6: 482-493.*

SAS, 2010.SAS User's Guide: Statistics. 5th Edn.,SAS Institute, Cary, NC.USA

Tadese,B.,2017.Progress in Arabica coffeeBreeding in Ethiopia:Achievment,Challenges and prospects.International Journal of Science:Basic and Applied Research, 33:15-25

TayeKufa . 2010. Environmental Sustainability and Coffee Diversity in Africa.

Verma, P.S. and V.K. Agarwal, 1982.Genetics. S. Chand and Co. Ltd., Ram Nagar, New Dehlhi, pp: 555.

Walyaro, D.J.and H.A.M Van der Vossen, 1979.Early determination of yield potential in Arabica coffee by applying index selection.*Euphytica*, **28:** 465-472.

Yigzaw, D., 2005. Assessment of cup quality, morphological, biochemical and molecular diversity of *Coffeaarabica*L. genotypes of Ethiopia.Ph.D. Thesis, University of Free State, South Africa.