academicJournals

Vol. 6(11), pp. 171-178, November 2014
DOI: 10.5897/JPBCS2014.0447
Article Number: 65D03BC48010
ISSN 2006-9758

http://www.academicjournals.org/JPBCS

Journal of Plant Breeding and Crop Science

Full Length Research Paper

Performance evaluation of indigenous Arabica coffee genotypes across different environments

Yonas Belete[1]*, Bayetta Belachew[2] and Chemeda Fininsa[3]

[1]Jimma Agricultural Research Center, P. O. Box, 192, Jimma, Ethiopia.
[2]Inter Africa Coffee Organization (IACO), Abidjan, Ivory Coast.
[3]Haramaya University, P. O. Box 138, Dire Dawa, Ethiopia.

Received 21 February, 2014; Accepted 9 June, 2014

Evaluation of 30 Arabica coffee genotypes was carried out at four different locations in south-western Ethiopia to identify genotypes that exhibits stable performance across wide environments. The analyses of variances revealed that yield differences among genotypes were highly significant at all locations in both seasons except at Jimma during the second season. The interaction was also highly significant. Six genotypes: 8211, 808, 8219, 75187B, 8143 and 8213 exhibited higher overall mean yield that ranged from 1217 to 1633 kg of clean coffee per hectare at the first two bearings. Such mean yield is very high as climax yield in Arabica coffee is attained starting from the fourth bearing stage. However, only three of these genotypes: 8213, 8143 and 75187B exhibited superior performance consistently at all locations irrespective of the interaction. The result of the trials is considered as one remarkable success in the history of Arabica coffee research as identifying genotype that exhibits stable performance across wide environments has long been a major challenge and in practicable for decades.

Key words: Agro-ecologies, Arabica coffee, environments, indigenous, genotypes.

INTRODUCTION

Arabica coffee is an important crop in the national economy of Ethiopia. About 25% of the people in the country in one way or the other derive their livelihood from coffee. Depending on prices on world market the share that comes from coffee still constitutes 25 to 40% of the national export (Behailu et al., 2008; Nigussie et al., 2008). Furthermore, the land covered with coffee in Ethiopia currently is very substantial and is estimated to range from 400,000 to 650,000 the average being 550,000 ha.

Despite the role coffee plays in the national economy and in spite the country is origin of Arabica coffee, average national productivity has not exceeded six quintals (Jefuka et al., 2012; Eshetu et al., 1999; Workafes and Kassu, 1999). This is very low in contrast to yield levels reported usually in some Latin American countries. The factors attributed to such low productivity include lack of resistant varieties to various diseases and insect pests, and poor agronomic practices (Eshetu et al., 1999; Workafes and Kassu, 1999). Lack of stable varieties that exhibit wide adaptation across wide ranges of environments is also another factor attributed to the low

*Corresponding author. E-mail: yonasbelete85@yahoo.com, Tel: 251-928 26 50 82; Fax: 251-047 111 19 99.

Table 1. Characteristics of test locations where the trials were carried out.

Location	Altitude	Latitude	Longitude	Temperature (°C)		Annual rainfall (mm)
				Min	Max	
Jimma	1753 m	7°36'5"	36°E	11.5	26.2	1531.8
Agaro	1600	7°9'	36.6E	NA	NA	NA
Gera	1940 m	7°7'	36°E	10.4	24.4	1878.9
Metu	1550	8°3'3"	36°E	12.5	28.6	1810.6

NA = Not available.

productivity of Arabica coffee in the country (Yonas and Bayetta, 2008). To identify stable varieties and thereby increase productivity of Arabica coffee in the country, Mesfin and Bayeta (1987) carried out series of adaptation tests across wide ranges of environments. The result of their study illustrated that a genotype that exhibits better adaptation at one location in one geographic region does not perform well at other locations of a contrasting region. Multi-location adaptation tests carried out in other countries also illustrated similar result that genotype-environment interaction is a common scenario in Arabica coffee genotypes like other crops (Agwanda et al., 1997). Related studies by Yonas and Bayetta (2008) in Arabica coffee and Montagnon et al. (2000) in *Coffea canephora* also illustrated significant interaction effects of genotypes across different environments. However, these workers illustrated the possibility of identifying varieties which could exhibit stable performance across wide environments. Since Ethiopia has both wide genetic diversity of Arabica coffee and diverse environments for growing it, conducting multi-locations adaptation tests across wide environments is important to identify stable genotypes which can increase productivity of Arabica coffee in the country.

Thus, the objective of the study was designed to identify stable genotypes that increase productivity of Arabica coffee across wide environments.

METHODOLOGY

Experimental sites

The trials were conducted at four different locations in southwestern region of Ethiopia: Jimma, Agaro, Metu and Gera. The first three locations represent medium altitude and Gera represents high land (Table 1).

Materials

The trials consisted of 30 pure lines Arabica coffee genotypes. They represent all the three types of canopy configuration: compact, intermediate or open. They were selected for their high potential for resistance to Coffee Berry Disease (CBD), yield and cup quality during a preliminary evaluation carried out at Gera. Primarily, they were collected from different farmers' field of southwestern region of the country along with quite large numbers of coffee accessions. The seeds (beans), which were used for preparing the seedlings, were prepared from representative bushes of each genotype. The beans were sown and raised in polythene bags for 10 months. Holes were dug and filled with topsoil before planting. The seedlings were field planted when they are approximately 10 months old in randomized complete block design of three replications. They were mulched in September immediately after planted. Each seedling was also protected from direct sunlight by small grass shelters starting from October until the normal rain in 2006 commenced. The shelters were removed when the normal rain after the dry months started. *Sesbania sesban* (temporary shade bush) were planted to provide regular shade over the plots. Each plot consisted of 10 bushes in single row. The spacing between rows and bushes within row were 2 × 2 m, respectively. The plots received uniform application of fertilizer and other cultural practices throughout the period of data collection. All coffee bushes were maintained on single stem pruning system. Yield was recorded in fresh cherry to the nearest 50 g from 10 bushes and converted to clean coffee bean yield per hectare. The mean clean coffee yield in kg/ha of the different genotypes was used for analysis. Over the course of time, some bushes had died so that by 2008/2009 and 2009/2010 some plots no longer had full 10 bushes stand. During analysis, the yield data of the plots with missing bushes were adjusted to represent a full stand of 10 bushes. The yield at harvest was multiplied by the ratio of the number of plants at the expected full stand to the number of plants harvested. No adjustment factor was used for the missing bushes as the orchards were at their first and second bearing and yield advantage for a plot with a poor stand compared to the one with a full stand is noticed only after the fourth bearings. The test materials are presented in Table 2.

Statistical analysis

First analyses of variance for clean coffee yield were carried out at the specific environments/location-year combinations using Agrobase software. Later, combined analysis of variance was carried out after confirming homogeneity error variances at the different environments to calculate environmental, genotypic and genotype by environment interaction effects. Since error variances at the different environments were homogenous, the pooled error mean square was used to calculate coefficient of variation (CV) and least significant differences for the combined means.

Analyses of variance of growth parameters for the different locations were also done. Phenotypic correlation between yield and growth characters was calculated as:

$$r_{pxy} = \frac{Cov_p(xy)}{\sqrt{\left(\sigma^2{}_p x \sigma^2{}_p y\right)}}$$

Where, r_{pxy} is phenotypic correlations coefficients between yield and

Table 2. The thirty arabica coffee genotypes evaluated at four different locations in south west Ethiopia.

S/No.	Genotype designation	S/No.	Genotype designation
1	74191	16	8011
2	75187-B	17	8017
3	7453	18	8019
4	74145	19	8021
5	75194	20	8112
6	7512	21	8133
7	7574	22	8136
8	7803-A	23	8143
9	7803-B	24	8144
10	7809-B	25	827
11	802	26	878
12	804	27	8211
13	808	28	8213
14	809	29	8219
15	8010	30	8223

growth characters; Cov_p is phenotypic variances of x and y, respectively.

RESULTS AND DISCUSSION

Coffee bean clean yield

The analyses of variances revealed that the differences among genotypes were highly significant for yield at Agaro, Gera and Metu in 2008/2009 and 2009/2010 and at Jimma in 2008/2009 only (Table 3). This indicates that there is real genetic difference among the different genotypes and improvement of yield by selection is possible. Similar result was reported by Mesfin et al. (2007), Bayetta et al. (2008), and Yonas and Bayetta (2008). However, the difference was non-significant at Jimma during the second year (2009/2010). The absence of yield difference during the second season could be attributed to the fact that genotypes usually exhibit less differentiation in less favorable environments. This is so because maximum phenotypic differentiation for any trait is expressed in optimum environments either from edaphic as well as the climatic points of view. Similar justification was reported for yield by Ariyo (1998) and for disease by Yonas (2014). Normally, in Arabica coffee, photosynthetic assimilates prior to the first flowering is totally used for vegetative growths. But in the later stages when coffee bushes start setting fruits, it moves to fill the developing fruits and undergoes vegetative growth. However, in unfavorable environments where either the edaphic or climatic conditions are sub-optimal, the balance of the assimilate movement could be disrupted where it may fully divert to the fruits if fruit buds are unproportionately heavy during the season and this restricts growth of secondary and tertiary branches which may bear fruiting buds for the next season. This is the root cause for alternate bearing or lack of irregularity of bearings of Arabica coffee or perennial crops in general over different seasons. The poor fertility status of the soil at Jimma was also reflected by stunted vegetative growths of plant heights, stem girths and canopy diameters ((Figures 1, 2 and 3).

The combined analysis of variance also revealed that mean square of genotypes, locations/environments, and genotype by environment interaction was highly significant (Table 4). However, regardless of the interaction genotypes: 75187B, 8143 and 8213 exhibited higher overall mean yields that ranged from 1355 to 1633 kg of clean coffee per hectare (Table 3). Such mean yield at the first two bearing is very high as climax yield in Arabica coffee is attained starting from the fourth bearing stage (Wrigley, 1988). The overall performance of these genotypes was also higher at all environments. This is in line with the work of Agwanda et al. (1997) and Yonas and Bayetta (2008) who reported the possibility of developing stable genotypes which can adapt across wide environments. But it disagrees with the earlier work of Mesfin and Bayetta (1987) who stated the difficulty of identifying stable genotypes that exhibit wide adaptation across wide environments. The disagreement between the two trials might attribute to differences of environmental diversity as it was more diverse in the former than the latter. This illustrates that it would be difficult to identify a genotype that exhibit stable performance across all locations over all geographic regions. But the result of the present study confirmed that it is possible to develop stable varieties for sub environments provided the coffee growing environments in Ethiopia are sub-divided into sub-geographic region. Such strategy can help to alleviate the problem of varieties inconsistent performance across very diverse

Table 3. Characteristic means of clean coffee yield (kilogram) per hectare of thirty Arabica coffee genotypes across four different locations in two seasons.

Genotype	Seasons								Combined mean
	2008/2009				2009/2010				
	Jimma	Agaro	Gera	Metu	Jimma	Agaro	Gera	Metu	
74191	447	868	965	1628	133	1013	920	986	870
75187B	1662	1457	1296	1905	299	1428	1656	1140	1355
7453	412	849	1001	1821	316	682	278	702	758
74145	886	1123	1518	2072	164	971	406	630	971
75194	726	927	1427	2385	256	758	528	344	919
7512	620	964	1281	1900	163	906	218	1176	903
7574	821	1685	1251	2428	155	224	761	243	946
7803A	952	1484	1340	2052	43	761	804	585	1003
7803B	936	1221	1219	1665	260	1048	1050	984	1048
7809B	684	1497	1496	1826	492	691	868	1056	1076
802	788	2115	1258	2196	216	849	755	358	1067
804	881	1822	718	1612	289	1049	562	61	874
808	816	1443	1995	2020	87	1201	764	1503	1229
809	935	1531	1209	2325	398	743	915	826	1110
8010	467	817	893	1652	261	858	668	855	809
8011	565	995	1110	1749	131	844	260	708	795
8017	569	969	1040	1716	293	904	623	600	839
8019	1010	2201	1045	1947	143	661	1488	749	1156
8021	929	1468	1388	1952	246	1133	576	404	1012
8112	981	1914	787	2492	326	946	870	412	1091
8133	465	1030	1241	1768	202	748	432	852	842
8136	733	1822	1590	1573	298	1008	552	365	993
8143	962	1827	2181	2280	184	1172	949	1473	1378
8144	730	2345	1206	1956	177	835	1034	852	1142
827	778	1686	1143	1597	436	887	599	942	1008
828	848	1525	1578	2005	172	1156	624	223	1016
8211	1006	2026	2614	2415	190	899	433	150	1217
8213	1218	2098	2763	3233	338	1497	883	1031	1633
8219	1111	2100	1741	1955	317	1235	1057	473	1249
8223	770	1547	1436	1665	343	685	999	126	946
Mean	824	1512	1391	1993	257	926	751	712	1046
CV	18.88	13.22	23.22	9.63	21	21.6	25	24.5	20.67
LSD 0.05	261	335	541	322	ns	335	315	292	332
LSD 0.01	352	452	730	434	ns	453	425	395	448

ns, Non-significant difference; LSD, least significant differences; CV, coefficient of variation.

environments and increase coffee productivity. Furthermore, the landscape system of the major coffee growing environments in Ethiopia is characterized by undulating and irregular terrain features and a coffee orchard on such landscape system may fall on either flat land or valley bottoms or sloping land of varying degree of intensity or on an environment that is favorable or less favorable from nutrient and/or moisture availability point of view or it may be on sloping land that faces different light intensities. These are potential variables which induce significant genotype by environment interaction and only genotypes with wide adaptation across such environments buffer yield stability. This is in line with the work of Cooper and Hammer (1996).

Twenty-five out of 30 genotypes exhibited equal or more yield at Metu or Agaro (medium altitudes areas) than Gera (higher altitude area) where the genotypes were planted at the fertile forest soil (Table 3). Similar studies carried out at low and mid altitudinal areas also revealed that the latter is more suitable for coffee fruit production than the former if other edaphic and climatic factors are kept not limiting (Mesfin and Bayetta, 1987;

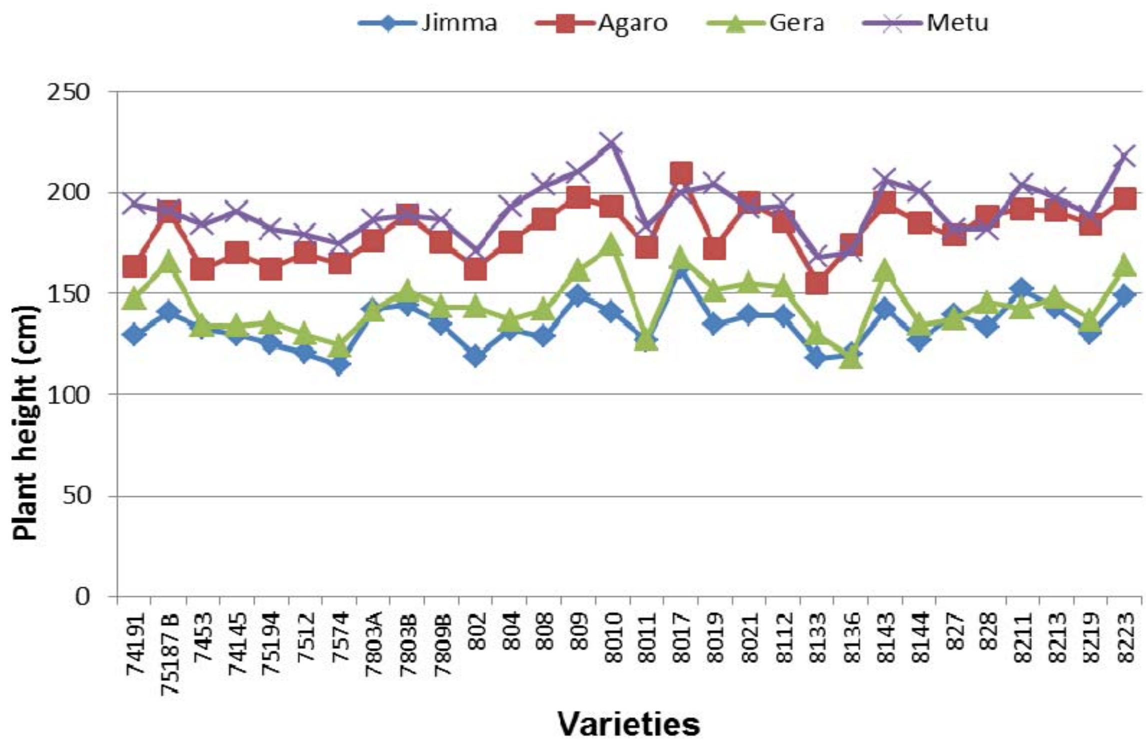

Figure 1. Characteristic means (cm) of thirty arabica coffee genotypes for plant height at four different locations: Jimma, Agaro, Gera and Metu.

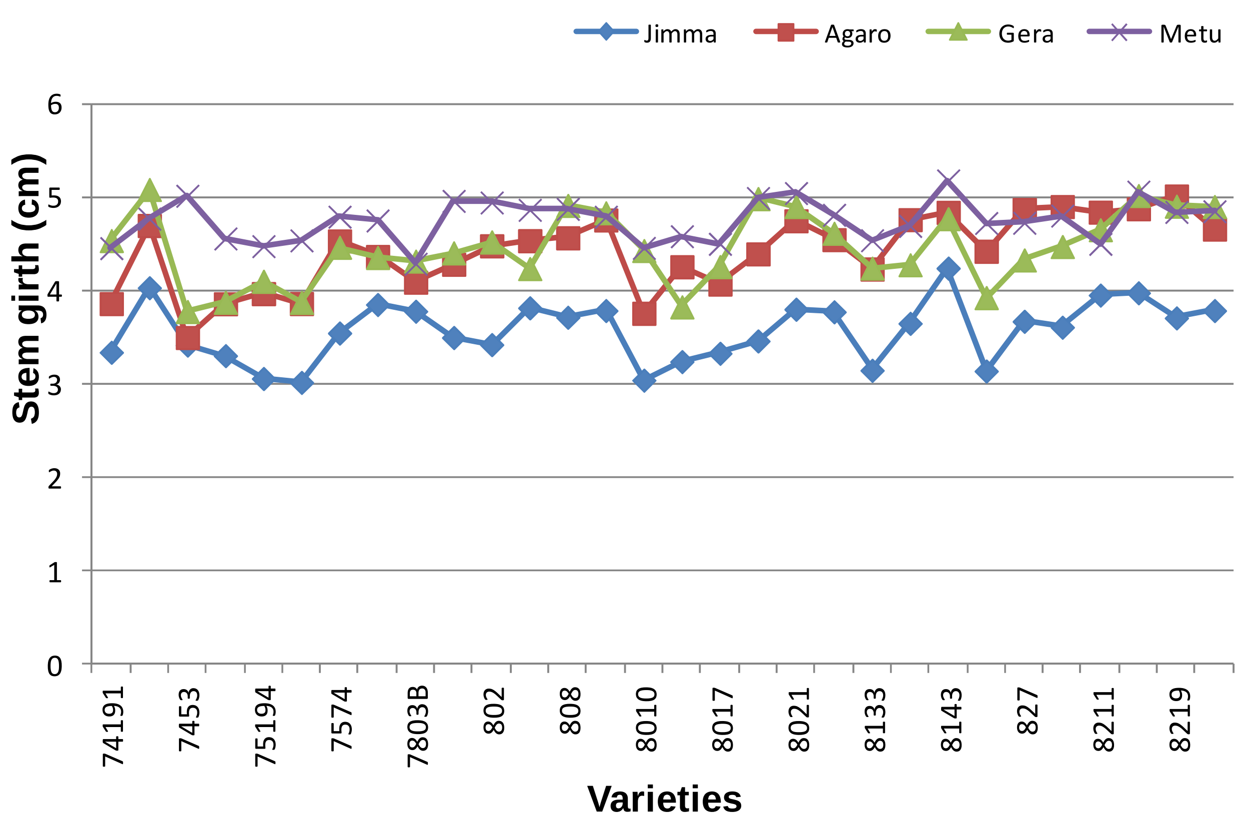

Figure 2. Characteristic means of thirty Arabica coffee genotypes for stem girth at Jimma, Agaro, Gera and Metu.

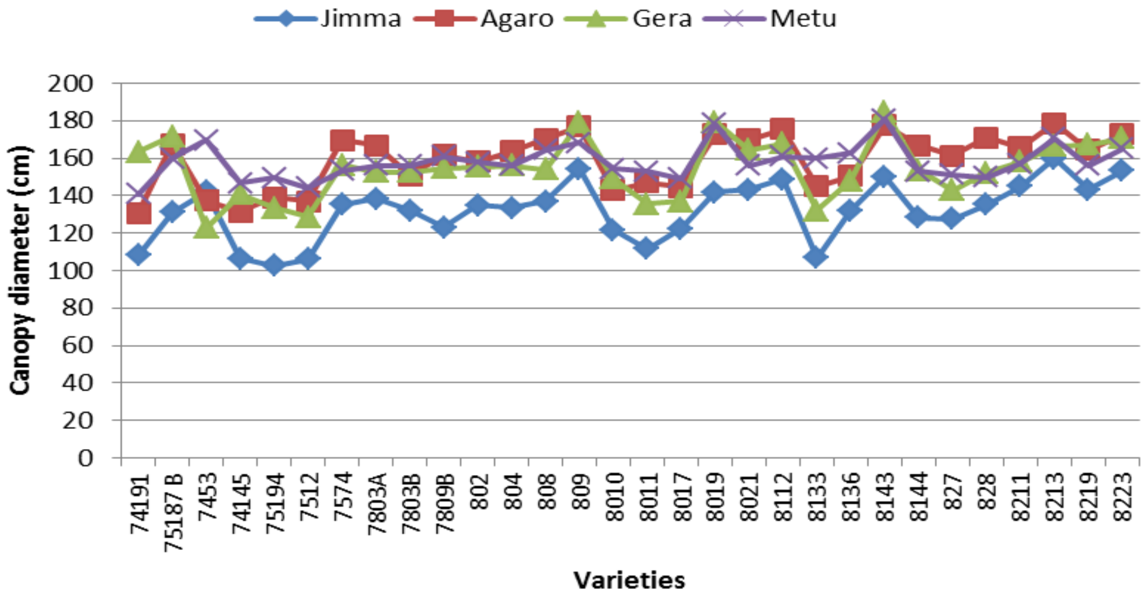

Figure 3. Characteristic means of 30 Arabica coffee genotypes for canopy diameter at Jimma, Agaro, Gera and Metu.

Table 4. Combined mean square of yield (kg) of thirty Arabica coffee genotypes evaluated across different environments.

Variance	Mean squares			
	Environments	Genotypes	G × E	Pooled error
DF	7	29	203	464
Clean yield	65268771**L	2572225.7**L	664704.7**	84945

**L, ** highly significant against mean square of G × E and mean square of error at 0.01 probability level.

Yonas and Bayetta, 2008). Probably the temperature at medium altitude areas could be more conducive for different ion of flower buds to fruiting flower than leaf at medium altitude areas than either high or low altitude areas to bear more fruits and result in higher yield performance.

It was also noticed from the table that selection of genotypes at the favorable environment of Gera favored those genotypes that respond favorably at similar environments of Agaro and Metu but not at Jimma. This indicates in general that genotypes selection at favorable or less favorable environments favors to select those genotypes which respond favorably at the respective environments only. This indicates the merit and demerit of conducting preliminary variety trial on either favorable or unfavorable environments to advance suitable variety to the type of environment in question. However, there are genotypes which exhibit linear response across wide environments. But to identify such genotypes, either the preliminary evaluation should be done in contrasting environments: one favorable and the other less favorable so that those genotypes which exhibit better performance in both environments could exhibit stable performance across wide environments or the selection intensity during the preliminary evaluation at any given environment should be low to advance large number of genotypes for the subsequent multi-location adaptation tests and identify the genotypes which exhibit wide adaptation. Similar justification was stated by Crossa (1990) and Basford and Cooper (1998) that genotypes should be tested across wide ranges of target environments before recommended for extensive use.

As a whole the yield obtained during the first season was much higher than the second (Table 3). Such imbalance in fruit setting over the two seasons is largely attributed to the very conducive environment prevailed at all locations during 2007/2008 (Table 5). But the weather condition noticed during 2008/2009 was also conducive for vegetative growth and fruit production but the heavy fruiting noticed in the previous season restricted growth of fruit bearing branches that could set fruit in the following season. This subsequently reduced the yield in 2009/2010 season. This illustrates in general that analyzing stability of performance of Arabica coffee

Table 5. Monthly mean rain fall distribution (mm) of four different locations: Jimma, Gera and Metu during 2005, 2006 and 2007.

Year	Jimma			Gera			Metu		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
Jan	16.4	102.5	29.8	13.8	86.2	30	0	19.1	0
Feb	10.7	5.9	49.9	78.5	9.2	91.7	19.3	3.9	38
Mar	70.9	103	79.5	114.7	179	169.1	28.3	45.9	87.7
Apr	75	86.2	133.1	146.7	99.3	219.5	52	81.1	43.9
May	237.7	76.3	17.2	253.7	204	59.2	188.4	90	79.9
June	236.3	316.3	272.2	318.5	308	319.9	294	295	365.6
July	281.6	150.3	190.6	265.3	151	281.8	265.6	111	225.2
Aug	186.7	219.8	210.8	255.7	219	207	484.1	260	252.9
Sep	202.9	196	235.9	294.7	293	337.3	228.1	219	340.9
Oct	214	56.5	88.8	298.3	118	62.5	179.1	100	142
Nov	58.9	9.1	14.1	29	37.9	84.9	29.4	28.5	29.8
Dec	4.6	128	26.1	37.1	52.2	74.2	32.1	12.7	36
Mean	133	121	112.3	175	145	161	164	106	137

Table 6. Phenotypic correlation coefficients among the different Arabica coffee growth parameters.

Parameter	CLY	TPH	SGR	NPB	IN	CD
CLY	1	0.15**	0.59**	-0.13**	0.31**	0.57**
TPH		1	0.36**	0.36**	0.58**	0.44**
SGR			1	-0.12*	0.39**	0.73**
NPB				1	-0.32**	-0.21**
IN					1	0.56**
CD						1

CLY = Clean yield, TPH = total plant height, SGR= stem girth, NPB = number of primary branches, IN = internode length, CD = canopy diameter.

varieties using individual season's mean as independent variable by the Eberhart and Russel stability model (which is suitable for annual crops) is invalid and leads to wrong conclusions and refinements are required or an appropriate model has to be devised by statisticians for perennial crops (coffee Arabica) to calculate stability of varieties performance across different environments.

Growth characters

Differences among genotypes for plant heights stem girths and canopy diameters were highly significant at all locations. However, means are indicated in Figures 1, 2 and 3. These three growth characters were favored at the mid altitudes where the temperature was high (Table 1). Similar result was reported by Mesfin and Bayeta (1987). But the stunted growth at Jimma as shown in the figures was attributed to poor edaphic factors. Generally, from the growth characters considered, canopy diameter (0.57**) and stem girth (0.59**) exhibited strong positive correlation with yield (Table 6) indicating that these characters have strong tie to improve productivity per tree basis.

Conclusion

Even though genotypes exhibit significant interaction in performance across wide environments, there are special genotypes which exhibited stable performance across such environments. This shows that it is possible to maximize coffee production across the target coffee growing environments in Ethiopia by subdividing the whole environments into sub-regions and developing independent varieties for each sub-region separately.

From the evaluation of genotypes across different environments it was seen that fluctuation of yield of Arabica coffee over seasons was higher at less favorable than favorable environments. However, such fluctuation of yield can be minimized by applying agronomic practices such as adequate fertilization, mulching or growing coffee orchards in optimum shade levels.

Generally, genotypes of all branch configuration (compact, intermediate or open) exhibited superior fruit production and vegetative growth at medium than high altitude areas showing the fact that the former is more favorable and productive for coffee production than the latter if other climatic and edaphic factors are kept not limiting.

Pre-selection of genotypes at favorable environment favored those genotypes which responded favorably at similar than different environments. Therefore, preliminary evaluations before multi-location adaptation tests should be done in contrasting environments of one favorable and the other unfavorable so that genotypes with better performance in both environments can be fit to be used across wide environments.

Conflict of Interest

The author(s) have not declared any conflict of interest.

REFERENCES

Agwanda CD, Baradat PC, Charrier A, (1997). Genotype by Environment Interaction and its Implication. In: Xvlle Colloque Scintifique International due café Nairobi (Kenya). 7:20-25.

Ariyo OJ (1998). Use of additive main effects and multiplicative interaction model to analyses multi-location varietal trial. J. Genet. Breed. 53:129-134.

Basford KE, Cooper M (1998). Genotype x environment interactions for wheat breeding in Australia. Aus. J. Agric. Res. 49:153-174. http://dx.doi.org/10.1071/A97035

Cooper M, Hammer GL (1996). Synthesis of strategies for crop improvement. In: Plant adaptation and crop Improvement. (Eds M. Cooper and GL Hammer.) pp. 591-623. (CAB. International: Wallingford, UK.) PMid:9239671.

Bayetta B, Behailu A, Fikadu T, Ashenafi A, Tadesse B (2008). Genetic diversity and hetrosis in Arabica coffee. In the proceedings of Coffee diversity and Knowledge Workshop EIAR, Addis Ababa, pp. 50-57.

Behailu W, Abrar S, Nigussie M, Solomon E (2008). Coffee processing and quality research in Ethiopia. In the Proceedings of Coffee Diversity and Knowledge Workshop EIAR, Addis Ababa, pp. 345-356.

Crossa J (1990). Statistical analysis of multi- location trials. Adv. Agron. 44:55-85. http://dx.doi.org/10.1016/S0065-2113(08)60818-4

Eshetu D, Teame G, Girma A (1999). Significance of Minor disease of Coffea arabica Ethiopia: A review. In the Proceedings of the Workshop on Control of Coffee Berry Disease (CBD) in Ethiopia. pp. 58-65.

Jefuka C, Adugna G, Teferi D, Zeru A, Bogale S, Adem A (2012). Development and Release of Coffee Berry Disease Resistant Varieties to Specialty Coffee Producing Regions in Ethiopia. In the Proceedings of the 24th International Conference on Coffee Science San José (Costa Rica), 12th -16th November 2012.

Mesfin K, Bayetta B, Seyoum S (2007). Diversity in the south Ethiopian coffee. 21st Int. Sci. Colloq. On coffee. ASIC, Montpellier, France Mesfin A, Bayetta B (1987). Genotype- environment interaction in coffee, Coffea arabica L. (submitted to EJAS for publication)

Montagnon C, Cilaschristianleory A, Yapo A, Charmentant P (2000). Genotype-locationinteraction for coffee canephora yield in Ivory Coast. Agronomic 20:101-109. http://dx.doi.org/10.1051/agro:2000110

Nigussie E, Deresse T, Berhanu M, Getachew W (2008). Research Center Based Extension Intervention on Improved Coffee Technologies. In the Proceedings of Coffee Diversity and Knowledge Workshop EIAR, Addis Ababa, pp. 345-356.

Yonas B, Bayetta B (2008). Cultivar by environment interaction and stability analysis of Arabica genotypes. In the Proceedings of Coffee Diversity and Knowledge Workshop EIAR, Addis Ababa. pp. 58-63.

Yonas B (2014). Assessments of resistances of Indigenous Arabica Coffee Genotypes for Multiple Diseases. Greener journal of plant breeding and crop science. 2(3):054-061.

Workafes W, Kassu K (1999). Coffee production system in Ethiopia. In the Proceedings of Coffee Diversity and Knowledge Workshop EIAR, Addis Ababa, pp. 99-106.

Wrigley G (1988). Coffee. Longman Scientific and Technical. England. P. 639.