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Evaluation of agronomic performance of coffee (*Coffea arabica* L.) cultivars in Gamo and Gofa, southern Ethiopia

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ABSTRACT

Ethiopia is identified as a primary centre of Arabica coffee plant origin and genetic diversity. Climatic variations, varietal differences, soil type, mulching, shade, the farming method used, pruning, and other cultural practices are the major factors that affect the development of plants including coffee. Amongst the various factors for having a good yield of coffee is growing of coffee plant in its specific agro-ecologies which has a great contribution to both the life span of the coffee trees and its yield. This experiment was conducted to evaluate the performance of different released and local Arabica coffee varieties across two locations at Gamo and Gofa zones, Southern Ethiopia. The varieties which were used for the study were transplanted in 2014 and laid out in randomized complete block design with three replications across locations. The varieties were planted at a spacing of 2m by 2m between plants and rows, respectively and were evaluated for growth, yield and yield components. The analysis of variance performed for average internodes number, canopy diameter, height up to the primary branch, length of the primary branch, number of branches on the main stem and total height of coffee plant showed significant variations across locations. From the present evaluation, it was noted that the highest Clean Coffee Yield (16.6 and 14.2 quintal per hectare) was scored by coffee cultivars F-59 and 1377A, respectively. Moreover, because of the low quality of coffee delivered to the market, the coffee produced in the Gamo Gofa area (garden coffee) is categorized under forest coffee at the national level. If the quality is improved, the coffee in the area would have its appropriate brand name and the growers and traders can get better returns from their investment. Therefore, those varieties investigated are good candidates for future coffee cup quality analysis.

Key words: Canopy diameter; Local and improved variety; Growth; Performance; Yield.

1 INTRODUCTION

Ethiopia is the centre of origin and diversity of coffee (C*offea arabica)* as genetically diverse strains of *C. arabica* exists in Ethiopia than anywhere else in the world (Fernie, 1966). Coffee plays a vital role in both the cultural and socio-economic life of the country. It is Ethiopia's leading foreign currency commodity earning 40 to 60% of the annual foreign currency in Ethiopia. For the 2011 production year, Ethiopia earned more than 800 million USD from coffee exports (International Coffee Organization - ICO, 2015). Some 25% of the population depends on coffee directly or indirectly through production, processing, transportation and marketing or commercial service. In Ethiopia, coffee is mainly produced in Kaffa, Illubabor, Wellega, Harerge and Jimma areas. Coffee is also grown in large quantity in areas particularly Sidama, Yirgacheffe, Bench Maji, and Gamo Gofa (Tesfaye et al., 2020). In these areas, there are different arabica coffee cultivars and landraces with desirable traits (yield, quality, disease resistance, drought and other stresses tolerance).

Coffee is growing in four main production systems in Ethiopia. These include forest, semi-forest, garden and plantation coffee, which account for 10, 35, 35 and 15-20% of the total volume produced in the country, respectively. Ethiopia is ecologically very diverse resulting in variations in genotypes, eco-physiology and the biosphere of coffee under different production systems (Demel et al., 1998). The optimum productive coffee plantations are located between 1500 to 1800 meter above sea level (m.a.s.l) (Ferreira et al., 2019). However, most released varieties of coffee in Ethiopia are recommended to suit the elevation ranges of 1000 to 2100 m.a.s.l. The suitable temperature ranges from 10 to 24 ºC while the annual rainfall requirement is >1400 mm (Ethiopian Ministry of Agriculture - MOA, 2018). Coffees grown under the range of environments differ in quality, disease resistance, yield potential and many other traits.

Ethiopia has 41 improved coffee varieties (23 pure lines, 15 speciality coffee varieties and 3 hybrids), which are high yielding, resistant to disease (coffee berry disease), and possess unique inherent quality attributes of different localities (MOA, 2018). Even though the multiplication and distribution of the improved and promising speciality coffee varieties are underway at their respective locations, the technologies are not reached all potential coffee producing areas in the country. In the past, the interest was to develop varieties that have wider adaptation and distribute to all coffee growing areas. It was, however, realized that distribution of such limited varieties to the diverse coffee growing areas adulterates the typical quality of each specific locality or region, manifested poor adaptation and less preference by the local farmers compared to their respective local cultivars (Bellachew; Labouise, 2007). This has consequences on the yield, quality and income.

The different varieties developed through long and short term programs showed varied performance across locations and management practices (Tefera; Tesfaye; Abera, 2020). The yield of pure line improved coffee varieties in Ethiopia ranges from 6 to 21 quintal per hectare (Qt/ha) on-farm and 12 to 25 Qt/ha on research stations (MOA, 2018). In Gamo and Gofa zones, the yield ranges from 5-6 Qt/ha for local cultivar which is very low compared to the average values of both on-farm and research stations. Although evidence from the zonal agriculture and rural development department indicate that very few of the released varieties are brought to the zone, no research data is available on their adaptation, yield, quality and disease resistance. Such a large yield gap between the improved and local varieties need to be reduced by promoting improved cultivar selection, adaptation and improved cultural practices through specific agro-ecology based research.

Despite the present achievements in coffee research, development and extension, coffee farmers in Gamo and Gofa areas have not been benefited from such efforts. There are no improved varieties of coffee recommended based on specific agro-ecology research in the Gamo and Gofa areas. Moreover, coffee accessions were not collected from these areas for the local landrace development programs that have been addressed in areas like Jimma, Harar, Sidama and Wellega. Evidence from the zonal Agriculture & Rural Development department indicates that most of the coffee trees from farmers' gardens are being lost due to disease problems and the absence of clean and healthy seed source. At present coffee product that is provided for the milling station as well as the local market is declining in yield and quality. Therefore, this research was initiated to evaluate and screen coffee varieties that are superior in growth and yield in the study areas.

2 MATERIAL AND METHODS

2.1 Study area description

The experiment was carried out at Gamo and Gofa Zones, Southern Ethiopia in two districts namely; Demba Gofa, and Damble, which is a district close to Bonke during the 2012/13-2018/2019 growing season. The selected districts are supposed to represent the lowland agro-ecological areas of coffee adaptation. The soil conditions are generally clay loam in all conditions (Gamo Gofa Zone Agriculture and Rural Development-GGZAARD, 2009). The altitude, temperature and rainfall conditions of the study areas are described in Table 1.

2.2 Treatments and experimental design

The experiment consisted of four treatments (three improved and one farmers' variety) of coffee. The improved varieties were 1377A, F-59, 7454 selected among the released varieties in Ethiopia (Ministry of Agriculture and Rural Development - MoARD, 2010; Teferi, 2019). These cultivars were selected based on their agro-ecological adaptation in which the cultivars were identified for low land areas as the experiment was carried out in the low lands of Ethiopia. For local or farmers' variety, the seeds were harvested from selected healthy mother trees from each study location while the seeds of released varieties were obtained from Jimma Agricultural Research Center, national coffee research coordinating centre in Ethiopia. The seedlings were raised in the nurseries established at the respective research locations and then transplanted to the research plots at a spacing of 2m x 2m. In this experiment, nine (9) plants per plot were used. The experiment was arranged in a randomized complete block design (RCBD) with three replicates. Cultural practices like compost and weeding were applied as recommended for coffee production.

2.3 Data Collection

Various data were recorded by plants per plot on morphological quantitative characters of coffee plant performance using descriptors adopted from the International Plant Genetic Research Institute (Cannell, 1973, 1985; IPGR, 1996) four years after transplanting. These were: Number of nodes per branch, number of primary and secondary branches, internodes length of the main stem, length of the branches, plant height, canopy diameter, and ripe cherry yield.

Eleven coffee quantitative characters were recorded and their measurement descriptions are listed as follows:

Plant height (cm): total height of the tree from the ground level to the tip of the main stem

Number of main stem nodes: are total numbers of nodes count per tree

Stem girth (cm): measure as a girth of the main stem at five cm above the ground

Table 1: Ecological description of the study areas.

Districts	Altitude of study locations (m.a.s.l.)	Temperature (ºC)	Rainfall (mm)	Districts
Demba Gofa	1297	13-28	1400-1600	Demba Gofa
Damble	1435	10.1-27.5	810-1600	Damble

Canopy diameter (cm): average length of tree canopy measure twice, east-west and north-south, from the widest portion of the tree canopy

Average internodes length of the main stem (cm): by computing per tree as (TH–HFPB)/TNN-1, where TH = total plant height, HFPB =height up to the first primary branch, TNN = total number of main stem nodes

The average length of primary branches (cm): is the average length of three primary branches per tree

Height up to first primary branches (cm): Height of the tree from the ground level to the first primary branch of the main stem

Cherry and bean yield (qt/ha) = it was expressed in quital as this unit is commonly used to determine the yield of coffee per area. 1qt = 100kg.

- Yield per hectare = trees per hectare x yield per tree
- Yield per tree = number of fruits per tree x weight of beans per fruit
- Number of fruits per tree = number of fruiting nodes per tree x number of fruits per node
- Weight of beans per fruit = weight per fruit x bean/fruit weight ratio for the consecutive three harvests. (Cannell, 1973, 1985)

2.4 Statistical analysis

The collected data were subjected to analysis of variance (ANOVA) using SAS version 9.4. Treatment means were separated using LSD at 0.05 probability level whenever the F-test yields significant differences. Pearson's correlation coefficient analysis was also conducted to see the association between traits measured and calculated in the experiment.

3 RESULTS

Analysis of variance (ANOVA) showed highly significant differences ($P < 0.05$) between the environments (location) for all the traits studied and significant differences ($p<0.05$) among genotypes only for stem girth, average internode length and clean coffee yield (Table 2). This result indicated the presence of variability in performance across environments and the possibility of obtaining a superior variety. However, the genotype × location interaction yielded a non-significant ($P > 0.05$) effect for all the traits studied, implying that the genotypes did not show a difference in their response patterns to changes in the environments used for these traits.

3.1 Growth and yield performance among genotypes

The genotypes showed significance differences on the growth and yield performance as shown in Table 3.

The mean of Plant height was highly significantly different ($P\leq 0.05$) among the tested genotypes throughout the growing period. Genotypes F-59 (172.8 cm) and local (170.5cm) had significantly higher plant height than other genotypes while genotype 7454 had the lowest plant height (151.3cm) and with an overall mean of plant, height ranged from 1.51-1.72 meters across all genotypes (Table 3). The maximum height (230 cm) was recorded from 1377A and F-59 (Supplementary Table 1). The difference in plant height among the genotypes could be associated with the genetic variability among tested genotypes; this is because maximum phenotypic differentiation for a trait is expressed under optimal environments and genetic compositions of the genetic materials.

The mean values of height up to the first primary branches were statistically non-significant differences ($P > 0.05$) among the studied genotypes. The genotypes showed numerical values ranging from 10.2 (local variety) to 12.2cm (1377A variety) mean height up to first primary branches per plant (Table 3).

Table 2: Mean squares from combined analysis of variance for growth and yield-related traits recorded from coffee varieties evaluated across Damble and Demba-Gofa, Ethiopia

Source	DF	PH	HFPB	SG	LPB	NMSN	CD	AVIL	YLD
Rep	2	2848.76	61.01*	1.68*	1516.56*	26.06	3587.23	11.71**	4.99
Location	1	23508.35***	178.30**	25.44***	20043.36***	264.50***	51574.01***	37.48***	14.31*
Genotype	3	1725.24	16.19	1.09*	350.82	11.17	1866.39	6.22**	252.81***
Location x genotype	3	192.46	42.39	0.35	39.43	8.65	192.57	0.72	0.1
Error	16	992.9	17.19	0.4	365.06	19.01	1162.08	1.46	2.66
Mean		164.01	11.25	3.19	75.38	24.86	139.14	6.27	7.14
CV		19.21	36.87	19.72	25.35	17.54	24.5	19.29	22.85

*, **, ***, † Significant at probability < 0.05, 0.01, and 0.001 levels, respectively. PH = Plant Height (cm), HFPB = Height up to First Primary Branch (cm), SG= Stem Girth (cm), LPB = Length of 1st Primary Branch (cm), NMSN = Number of Main Stem Nodes, CD = Canopy Diameter (cm), AVIL = Average Internodes Length (cm), and YLD = Yield (Qt/ha).

Table 3: The mean growth and yield performance of the coffee varieties for all the measured and calculated parameters across the two locations.

Genotype	PH	HFPB	SG	LPB	NMSN	CD	AVIL	YLD
F-59	172.8a	10.8a	3.4a	79.97a	25.94a	153.00a	6.35ba	11.54a
Local	170.5a	10.2a	2.9b	69.83a	24.72a	139.50ba	7.02a	4.51c
1377A	161.4ab	12.2a	3.24a	77.61a	24.72a	135.00ba	6.08b	8.92b
7454	151.3b	11.8a	3.22ba	74.10a	24.06a	129.06b	5.62b	3.58c
LSD (0.05)	21	2.8	0.4	12.73	2.91	22.72	0.81	1.09
CV	19.21	36.87	19.72	25.35	17.54	24.5	19.29	22.85

PH = Plant Height (cm), HFPB = Height up to 1st Primary Branch (cm), SG= Stem Girth (cm), LPB = Length of first Primary Branch (cm), NMSN = Number of Main Stem Nodes, CD = Canopy Diameter (cm), AVIL = Average Internodes Length (cm), and YLD = Yield (Qt/ha). Values with the same letter are not significantly different.

The mean values showed that there were statistically significant differences (P≤0.05) in stem diameter among the tested genotypes. Genotype F-59 showed the maximum (3.4cm) stem diameter and the local genotype exhibited the smallest (2.9cm). However, the three genotypes viz 1377A, 7454 and F-59 did not show statistically significant differences in the production of stem diameter (Table 3). The genotypes exhibited the mean stem diameter ranged from 2.9-3.4 cm per plant.

There was statically non-significant variation (P≤0.05) among the studied coffee genotypes in terms of the length of the first primary branch. All the three improved varieties of coffee namely F-59, 1377A and 7454 showed taller first primary branches without much significant difference among themselves. However, genotype F-59 was numerically the highest (79.97) value for this characteristic (Table 3).

The genotypes did not show a significant variation (P≤0.05) in the number of main stem nodes (Table 3). The highest average number of main stem nodes (25.94) was recorded by the F-59 variety and the lowest stem node was recorded from genotype 7454 (24.06) but the statistical difference was not observed among all genotypes.

3.2 Canopy diameter

The canopy diameter revealed a significant difference (P≤0.05) among the genotypes, with the differences observed between 7454 and each of the rest three genotypes. The highest canopy diameter (153.00 cm) was recorded for F-59 and the lowest (129.06 cm) was recorded for genotype 7454 (Table 3).

The average internode length on the main stem was a significant difference (P≤0.05) among the tested genotypes throughout the growth period. The local variety (7.02 cm) followed by F-59 (6.35 cm) had significantly higher internode length on the main stem than other varieties, while the 7454 variety had the lowest (5.62 cm) (Table 3).

The results showed that significant differences (P≤0.05) among the varieties were observed for clean coffee bean yield per hectare. The highest mean clean yield was recorded for F-59 followed by 1377A, with values 11.54 qt ha^{-1} and 8.92 qt ha^{-1}, respectively. These genotypes attained maximum yield across environments with F-59 (16.6 qt/ha) and 1377A (14.2 qt/ha) (Supplementary Table 1). The lowest mean clean yield, on the other hand, was obtained from local and 7454 varieties with values of 4.51 and 3.58 qt ha^{-1}, respectively (Table 3). However, the two low yielding varieties did not statistically differ from each other.

3.3 Correlation coefficient analysis

The association between yield and agronomic traits is important to the plant breeders as the traits correlated with yield will be used as a selection index. Correlation analysis showed that plant height (r = 0.29**), main stem girth (r = 0.25*), length of 1st primary branch (r= 0.29**) and canopy diameter (r = 0.31**) were significantly (p<0.01) and positively correlated with clean coffee yield per hectare (Table 4). Pearson correlation (r) of plant height was highly significantly and positively correlated with stem girth (r = 0.74***), length of 1st primary branch (r = 0.78***), number of main stem nodes (r =0.71***), average internode length (r = 0.55**) and canopy diameter (r = 0.90***), while height up to primary branches (r = -0.07) was non-significantly and negatively correlated with plant height (Table 4). All the above positive and strong association of growth characters implies those components are most important for clean coffee yield improvement across the environment. In addition, the stepwise regression analysis result showed that canopy diameter is the most important trait contributing to increasing the yield of coffee (data not shown).

3.4 The performances of genotype across locations

The genotypes showed significant differences in yield performance irrespective of differences in the two locations. Genotype F-59 followed by 1377A was the best performing genotypes in both locations (Figure 1). The trend of clean coffee bean yield performance for all the genotypes was similar across the two locations i.e., high yielding genotypes maintained high yield in both locations and vice versa. For instance, the lowest yielding (7454 and local) genotypes showed lower yield in the Demba gofa (Dgofa) location.

4 DISCUSSION

The high yielding genotypes in this study also attained higher canopy cover and stem girth. The higher canopy cover and stem diameter have a good contribution to the production of high yield (Yonas; Bayetta; Chemeda, 2014). Therefore, F-59 and 1377A released coffee varieties could be candidate varieties for these locations. The growing location had a significant effect on all the genotypes. The growth characters were better expressed in Bonke-Damble than in Demba Gofa (Figure 1), even if these environments have the same cropping patterns. Both environments experienced two cropping seasons with the main flowering in October/November and March/April. The difference in growth performance can also be attributed to variability in weather and soil conditions between the two locations. Wamatu, Thomas and Piepho (2003) reported that within the coffee growing regions, crop yields fluctuate from location to location. The results, however, showed that both the existing varieties and the newly released coffee varieties were affected almost equally by the change of environment. This was confirmed by the presence of significant differences across the environment.

In general, all the studied varieties revealed varying performance with regard to clean coffee yields per hectare. Only one variety, namely, F-59 has shown the highest yield variation with an average yield performance of about 11.5 qt ha^{-1} while 1377A was the second performed variety. Thus, this indicated that F-59 and 1377A have a better adaptive potential to the environment where this experiment is executed than the remaining ones. The yield difference could be attributed to the fact that genotypes usually exhibit different responses to the environment. These are a potential variable that induces genotype by environment interaction and only genotypes with wide adaptation across such environments butter yield stability this is in line with work of (Cooper; Hammer, 1996).

Table 4: Pearson correlation coefficients (r) of clean coffee yield and growth traits across the two locations, N = 72.

	Ht	HUFPB	GRT	LUPB	NMS	CD	AVIL	YLD
PH	1							
HUFPB	-0.10	1						
GRT	0.74***	-0.14	1					
LUPB	0.78***	-0.16	0.81***	1				
NMS	0.71***	-0.14	0.67***	0.54***	1			
CD	0.90***	-0.17	0.76***	0.81***	0.61***	1		
AVIL	0.55***	-0.10	0.39**	0.43***	0.05	0.56***	1	
YLD	0.29**	0.04	0.25*	0.29**	0.19	0.31**	0.10	1

*, **, ***, † Significant at probability < 0.05, 0.01, and 0.001 levels, respectively.Ht = Plant Height (cm), HUFPB = Height up to 1st primary Branch (cm), GRT= stem Girth (cm), LUPB = Length of 1st Primary Branch (cm), NMSN = Number of main stem nodes, CD = Canopy Diameter (cm), AVIL = Average Internodes Length (cm), and YLD = Yield (Qt/ha).

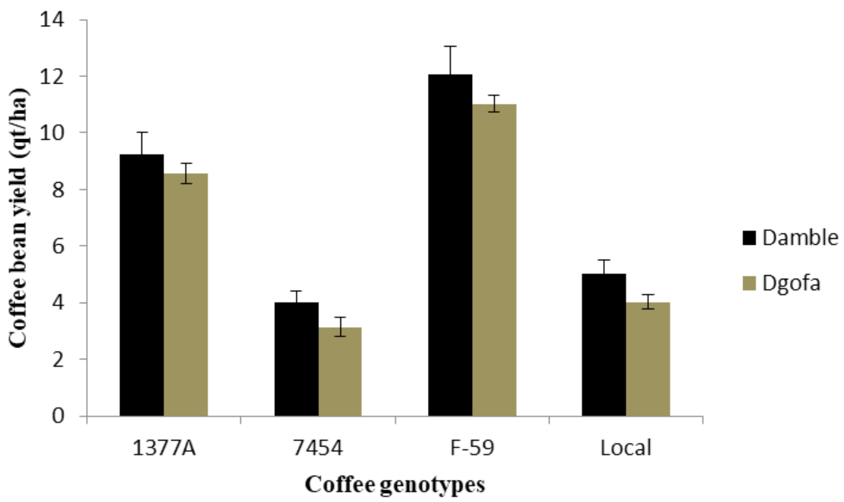

Figure 1: Clean coffee bean yield of the four genotypes across environments. Error bars were drawn based on the standard error of the mean. Dgofa = Demba Gofa.

Based on this evaluation variety 7454 is suspected to be poor yielding as the measured parameters can provide predictive information for yield estimation. (Yonas; Bayetta; Chemeda, 2014) reported that growth characters like canopy diameter and stem girth exhibit a strong correlation with yield. Therefore, variety F-59 and 1377A produced high stem girth and canopy diameter could attain maximum yield in these locations.

The results also showed that clean coffee yield was positively and significantly correlated with many of the parameters. Rodrigues et al. (2014) reported that vegetative characteristics including, the plagiotropic branch length, plant height, and stem diameter can contribute most to the increase in productivity. Plant height, stem girth, length of the first primary branch and canopy diameter in one hand and coffee bean yield, on the other hand, were significantly and positively correlated, demonstrating that those characters are highly important to improve the productivity of coffee per tree basis. Therefore, the vegetative growth characters with a positive correlation in this study could have a good contribution in increasing the yield of coffee cultivars. De Assis et al. (2014) also reported that plant height and yield showed the highest correlation values and the number of plagiotropic branches per plant showed a positive correlation with bean yield

5 CONCLUSION

Based on the results of the experiment, it appeared that the performance of the varieties differs across environments, indicating that the importance of conducting preliminary evaluation trials to identify the best adaptable genotypes for certain environmental conditions. F-59 qualifies to be considered as appropriate cultivar under the growing condition the study area; the cultivar had significantly higher yield and showed better agronomic performance followed by 1377A. Thus, these two cultivars can be used in the study area and localities having the same agro-ecological conditions. Local check and 7454 are not suitable to be cultivated in the study areas.

We recommend the farmers in the study areas to avoid the use of the low yielding varieties for clean coffee production. The absence of significant genotype and environmental interactions for yield in this study the best cultivar selected for a certain trait is independent of environmental factors. As the study result indicates that, the existence of promising high yielder selection over local check variety at Damble and Demba Gofa growing condition, the best performing promising selections has to be promoted to verification plot in order to test and release improved Coffee arabica varieties.

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7 AUTHORS' CONTRIBUTION

DAZ followed up the experiment, collected data, performed all the statistical analyses, and revised the draft manuscript, SF designed and supervised the experiment, collected data, wrote the draft manuscript, and SS designed and supervised the experiment. All authors contributed to the interpretation and discussion of the results and approval of the final version.

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