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Evaluation of the performance of coffee varieties under low moisture stressed areas of Southern Ethiopia

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The experiment was conducted by using seven released coffee varieties at three locations in southern Ethiopia, Halaba, Loka Abaya and Dilla, to select coffee varieties with higher yield and tolerant to low soil moisture stress. It was arranged in RCBD having three replications. The result indicated that the varieties showed significant difference on main stem diameter, plant height at harvesting, plant height up to the first branch, number of primary branches, number of secondary branches, number of tertiary branches, number of main stems, fruiting nodes per branch (FNPB), number of beans per cherry (NBPC), canopy diameter, leaf area, number of leaves per branch, number of leaves per tree (NLPT), hundred bean weight (HBW), weight of fresh husk (WHF), weight of dried husk (WHD), weight of fresh husked bean (WHBF), and weight of dried husked bean (WHBD). Stand count at harvest (STCNT), leaf length (LL), leaf width (LW), bean thickness (BTH), bean length (BL), bean yield per tree (YPT), bean yield per plot (YPP), bean yield per hectare (YPHA) and weight of husked clean coffee (WHCC) were not statistically significant. Location specific significant variations were observed on some of the variables such as stand count, leaf length, and leaf width at Halaba; yield per tree, yield per plot, yield per hectare and weight of husked clean coffee were significant at all the three locations despite their non-significant value while combined. The coffee variety Catimor J-19 performed best at all location with respect to fresh bean yield and dried clean coffee followed by Angafa. Thus they can be promoted for larger commercial production at tested locations and locations with similar agro-ecological conditions.

Key words: *Coffea arabica*, husked coffee, clean coffee, agroecology.

INTRODUCTION

In Ethiopia, coffee cultivation plays a fundamental role both in the cultural and socioeconomic life of Ethiopians. It represents the major agricultural export crop, providing 20 to 25% of the foreign exchange earnings (ECFF, 2015). The coffee sector contributes about 4 to 5% to the country's Gross Domestic Product (GDP) and creates hundreds of thousands of local job opportunities (EBI, 2014).

A number of coffee varieties were developed through short and long term programs. The first 26 pure Arabica coffee varieties were developed from 1977 to 1981. Their performance varied with locations and management.

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From 1996 to 2006, 10 improved pure line varieties having a mean yield range of 15.4 to 25.5 and 9 to 21 q/ha on research and farmer managed field conditions, respectively were developed and released (Tesfaye et al., 2008). According to Minister of Agriculture (MoA, 2018), different high yielding, disease resistance, early bearing and high quality Arabica coffee varieties were identified and released for official production at major coffee growing areas of the country. But their performance varied with agro-climatic condition (Location) in addition to their genetic performance. Belete and Bayeta (2008) indicated that cultivar yield is affected by location, that is, those cultivars outperformed in one location performs differently in other location with different altitude and agro-climatic condition indicating the low stability of yield of coffee varieties across locations. 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).

The native home of coffee species is characterized by low-water-deficit conditions, which probably allowed evolution without the need to develop extensive mechanisms to cope with drought stress (Coste, 1992). Nevertheless, some coffee cultivars are known to differ in their responses to drought (Orozco and Jaramillo, 1978; Carr, 2001; DaMatta and Rena, 2001), suggesting that modern cultivars are not very close to their wild relatives in terms of drought tolerance. In fact, field observations have indicated that some cultivars may endure 6 to 7 months with no rain, even in sandy soils, but obviously at the expense of strong declines in crop yield (DaMatta and Ramalho, 2006).

The report by Chemura et al. (2014) indicated that C*offea arabica* varieties react differently to low soil moisture stress which otherwise had no statistically significant difference. They reported that no coffee variety was significantly superior in biomass before soil moisture deficit stress exposure. For most of the varieties, there was a reduction in fresh biomass and a slow buildup of dry biomass during period of soil moisture deficit stress. Some of coffee varieties showed positive changes in root biomass after 21 and 28 days of soil moisture. DaMatta (2004) pointed out that drought prone coffee farms are associated with low input systems and as such varieties that have better survival and yield stability under drought stress are of much greater value than those with greater yield potential under optimal conditions.

Despite the role of coffee in the national economy and in spite the country of origin of Arabica coffee, average national productivity has not exceeded six quintals (600 kg/ha) (Jefuka et al., 2012; Eshetu et al., 2000; 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., 2000; Workafes and Kassu, 1999).

Lack of suitable varieties that exhibit stable yield performances across wide ranges of environments is the major factor among several production constraints contributing to low productivity of Arabica coffee in Ethiopia (Beksisa et al., 2018; Belete and Bayetta, 2008). Thus testing the adaptability of coffee varieties at range of environments and specific location is paramount important. Hence, this paper deals with adaptability of coffee varieties under low moisture stressed area of Southern Region of Ethiopia and recommend the best performing variety for further wider production.

MATERIALS AND METHODS

Location description

The trials were conducted at four different locations in southern region of Ethiopia: Dilla, Halaba and Loka Abaya. They represented wider range of altitude, 1500-1900 masl (Table 1).

Research materials and source

Seven coffee varieties, Catimor J-19, Koti (85257), 74112, Odicha (97.4), Fayate (97.1), 1377 (Angafa), and one farmers' variety were tested at Dilla, Halaba and Loka Abaya. The first one was obtained from Tepi Agricultural Research Center while the other five were collected from Awadasub Center of Wondogenet Agricultural Research Center and the seventh was collected from farmers. The seedlings were developed by using 100 mm diameter and 250 mm length black polyethylene tube filled with 70% soil and 30% manure. Polyethylene tubes were covered with thick grass mulching until emergence after sowing. Mulch was removed just after emergence and the seedling were kept under shade structure. The developing seedlings were irrigated every three days by using watering can until 12 pair of leaves were developed which is the stage that the seedlings attain the final transplanting stage. Holes were dug and lest open for two months. The hole was filled with topsoil immediately before planting. The seedlings were field planted when they are approximately eight months old in randomized complete block design (RCBD) with three replications. The seedlings were planted 2 m between plants and 2 m between rows. They were mulched immediately after being planted so as to maintain soil moisture and protect the root zone from direct sun light. The plots received uniform application of NP fertilizer and other cultural practices throughout the growing period. The space left between plots was 4 m and the trees were arranged in a single raw. As it is a fast growing tree type, sesban (*Sesbania sesban* (L.) Merr.) was planted as temporary shading between every two coffee trees. The shade tree was planted at 4 m × 4 m spacing indicating that two coffee trees were shaded by one shade tree.

Data collected and analysis

Information such as date of sowing, field management, date of seed emergence, date of transplanting, growth stage at transplanting and other relevant information have been reported to be recorded. Major yield and vegetative data such as bean length (mm), bean width (mm), hundred bean weight (g), yield per tree (kg), yield/plot (which will be converted to yield/hectare), disease types and their incidences such as coffee berry disease (%), bacterial blight, rust

Table 1. Coordinates, annual temperature and rain fall of Dilla, Loca Abaya and Halaba (Data collected from the nearby metrological station).

Location	Altitude	Latitude	Longitude	Temperature (°C)		Annual rainfall (mm)
				Min.	Max.	
Dilla	1,570 m	6°24′38″N	38°18′37″E	13.1	28.2	1226.7
Halaba	1,726 m	7°17'60.00" N	38°06'60.00" E	15.3	29.4	879.1
Loka Abaya	1690	6° 25' 59.99" N	37° 52' 59.99" E	13.9	27.9	937.6

incidence (%), height up to first primary branch (cm), number of primary branches (no), leaf length (cm), leaf width (cm), leaf area (cm^2), plant height (cm) and canopy diameter (cm) were collected. Yield and other agronomic data were analyzed by using SAS statistical software version 9.2 (SAS, 2008). Based on the analyzed data the best performing varieties were recommended for the areas and similar agro ecological locations for wider commercial production.

RESULTS AND DISCUSSION

Analysis of variance

The combined analysis of variances indicated that there was statistically significant difference among varieties for main stem diameter (MSTD in cm), plant height at harvesting stage (PLHT in cm), plant height up to the first branch (PLHTFB in cm), number of primary branches (NPB), number of secondary branches (NSB), number of tertiary branches (NTB), number of main stems (NMST), fruiting nodes per branch (FNPB), number of beans per cherry (NBPC), canopy diameter (CAND in cm), specific leaf area (ELA in cm^2), leaf area (LA in m^2), number of leaves per branch (NLPB), number of leaves per tree (NLPT), hundred bean weight (HBW in g), weight of fresh husk (WHF), weight of dried husk (WHD), weight of fresh husked bean (WHBF in g per plot) and weight of husked bean (WHBD in g/plot). But the other yield and yield components were found to be statistically non-significant. These included stand count at harvest (STCNT), leaf length (LL in cm), leaf width (LW in cm), bean thickness (BTH in cm), bean length (BL in cm), bean yield per tree (YPT in g), bean yield per plot (YPP in g), bean yield per hectare (YPHA in kg) and weight of husked clean coffee (WHCC in q/ha). Location specific significant variations were observed on some of the variables such as STCNT, LL and LW at Halaba; YPT, YPP, YPHA and WHAC at all the three locations despite their non-significant value while combined (Table 2). All the significant variables were considered for mean separation so as to come up with the recommendation with special focus to clean coffee yield per hectare. The significant difference detected among cultivars indicates the existence of genetic variability, and that allowed the selection of better cultivars in regard to coffee yield, so as to include them in the next value for cultivation and use (Teixeira et al., 2013).

Performance of coffee varieties across locations

Main stem diameter (cm), PLHT, PLHTFB varied with varieties as the largest value was recorded from variety Angafa. But the highest result on NPB and NSB was obtained from variety Catimor J-19 while variety Koti showed the highest performance on number of tertiary branches (NTB) and number of main stem per plant, while the value obtained from Odicha was statically non-significant with Koti in case of NMST. Varieties Catimor J-19(5.6), Koti (5.0), 74112 (4.7) and Odicha (5.4) showed statistically non-significant result on fruiting nodes per branch (FNPB). Catimor J-19 also showed higher value for ELA, LA, NLPB and NLPT. As Shown in Table 3, varieties Catimor J-19 and Angafa outperformed all other varieties (Table 3). The least value was recorded from local farmer variety. This indicated that performance of coffee varied with varieties. The result is in line with the work of Tirunesh et al. (2015). They reported that three coffee genotypes: 8213, 8143 and 75187B exhibited superior performance consistently at all locations. Similarly, Gebreselassie et al. (2017a) indicated the existence of statistically significant differences among coffee hybrids for stem girth/diameter, plant height, number of main stem nodes and yield with the highest stem girth (7.13 cm), plant height (323.3 cm), and number of main stem nodes (58.06), while the lowest stem girth (6.36 cm), plant height (281.63 cm) and number of main stem nodes (45.06). On the contrary, Belete and Bayetta (2008), Demissie et al. (2011) and Belete et al. (2014) also confirmed that varieties exhibiting better adaptation at one location did not perform well at other locations.

All improved varieties showed statistically different performance compared with the local (farmers') variety for HBW, WHD, WPBF and WPBD. The highest value ofHBW was recorded by the variety Angafa despite the non-significant difference with the values obtained from Catimor J-19, Koti, Odicha, 74112, and Fayate (Table 4). The coffee variety Fayate showed the top performance with regard to WHD while variety Catimor J-19 outperformed all other varieties in case of WPBF and WPBD. However, the result obtained from Odicha and

Table 2. Analysis of variance indicating treatment, location, treatment by location interaction and error mean squares across locations.

Variable	Mean square								
	Dilla		Halaba		Loca Abaya		Combined		
	Treatment (6)	EMS (12)	Treatment (6)	EMS (12)	Treatment (6)	EMS (12)	Treatment (6)	(TrtxLoc)	EMS (12)
STCNT	0.2063^{NS}	0.4683	0.7619*	0.76	0.2698^{NS}	0.27	0.471^{NS}	0.384^{NS}	0.4
MSTD	0.3411**	0.0390	0.7848*	0.23	5.8013**	0.076	3.82**	1.55**	0.1
PLHT	730.28*	206.60	2234.9**	292	284.7^{NS}	171.1	2291**	479.5*	229.9
PLHTFB	75.805**	7.7988	95.716*	5.23	28.86**	4.582	99.0**	50*	5.8
NPB	120.46*	40.386	434.58**	31.1	22.7*	5.137	247.7**	165.0**	23.5
NSB	105.33**	6.6281	36.998**	2.03	31.0**	0.533	111.6**	30.9**	3.8
NTB	5.5265**	0.1048	0.0476^{NS}	0.05	0.9433**	0.034	3.43**	1.54**	0.1
NMST	1.0494*	0.2730	1.0299^{NS}	0.41	0.1515^{NS}	0.194	0.62*	0.81**	0.3
FNPB	11.691**	1.0022	4.6835**	0.39	0.0153^{NS}	0.723	7.9**	4.2**	0.9
NBPC	4.4643**	0.507	5.7918*	1.49	0.0030^{NS}	0.526	3.05**	3.6**	0.8
CAND	1651.8**	84.38	2290.3**	101	287.5^{NS}	117.4	3216.4**	506.6**	97.6
LL	2.0677^{NS}	2.436	13.214*	3.24	1.4^{NS}	2.886	11.6**	2.52^{NS}	2.6
LW	0.7805^{NS}	0.644	2.7793**	5.97	0.2863^{NS}	0.694	2.56**	0.64^{NS}	0.7
ELA	73.542*	25.71	331.65**	45.7	48.86*	10.43	312.5**	70.8*	31.3
LA	7.454**	0.0624	0.9833**	0.02	0.2513**	0.024	83.1**	34.12**	0.1
NLPB	313.54**	3.03	1.53^{NS}	27.3	10.3030^{NS}	8.959	216**	74.8**	8.3
NLPT	66953**	10404	64584**	2867	12451**	1883	354615**	201432**	4644.1
BTH	0.245^{NS}	0.3009	0.0137^{NS}	0.29	0.055^{NS}	0.175	0.05^{NS}	0.132^{NS}	0.3
BL	0.3469^{NS}	0.6327	0.0028^{NS}	0.30	0.1521^{NS}	0.215	0.062^{NS}	0.22^{NS}	17.6
HSW	200.83^{NS}	287.775	5214.6**	444	594.3^{NS}	480.5	105*	2479.3**	450.9
YPT	920276*	240455	968555*	200000	952555*	300000	2544276**	148556^{NS}	319666.2
YPP	14491575**	648408	6806556**	800000	4636568*	1000000	24083971**	925364^{NS}	864302.5
YPHA	5660772**	253284	2658811**	300000	2000000*	500000	9407801**	361471^{NS}	337618.18
WHF	653915*	226787	57688^{NS}	41500	40882^{NS}	100000	165922^{NS}	293281*	121508.69
WHD	121963**	8799.90	55646**	1603	7043**	365.9	81521**	51566**	3432.754
WPBF	1383855**	275358	60185^{NS}	100000	336629*	74264	1356315**	296917*	154112.06
WPBD	332189**	66396.5	848218**	10966	166902**	10843	803725**	27179**	31249.76
WHAC	16.003*	4.1812	16.8421*	3.707	16.56*	5.807	44.24**	2.58^{NS}	5.5586443
CBD	1.2^{NS}	0.56	5.7**	0.15	1.5*	0.42	4.72**	1.7**	1.2
CLS	0.825*	0.278	4.54**	0.42	1.22*	0.389	3.35**	1.61**	0.41

*Significant at p≤0.05, **significant at p≤0.01, the numbers in the parenthesis are degree of freedom, EMS=error mean square, NS=non-significant.

Angafa were statistically non-significant compared with Catimor J-19.

Location specific performance of coffee varieties

The performance of coffee varieties varied with locations. At Halaba, stand count at harvest (STCNT), average leaf length (LL) and average leaf width (LW) showed specific and significant differences. Accordingly, higher value of stand count was recorded from varieties Catimor J-19, 74112, Odicha, Fayate, Angafa and local variety. The lowest was recorded from the variety Koti but not statistically significant from varieties Catimor J-19, 74112, Odicha, and local farmers' variety. In the same way coffee variety Fayate showed statistically higher average leaf length and width compared with 74112 and local variety. But it showed statistically no significant difference compared with Catimor J-19, Koti, Odicha, and Angafa. They are statistically at par (Table 5). It can be seen that the vegetative performances of improved varieties outweighed the local one in all aspects. Similarly, Abdulfeta (2018) reported very higher results of leaf width(8.77 m) and leaf length (18.4 m) coffee varieties.

Some yield traits such as YPT, YPP, YPHA and WHAC showed specific performance across all location despite their combined effect which was statistically non-significant. Accordingly, the highest values were obtained from Catimor J-19 irrespective of location differences following Angafa (Figure 1). Their performances were still

Table 3. Growth (agronomic) performance of coffee varieties combined over locations.

Variable	Varieties							CV
	Catimor J-19	Koti (85257)	74112	Odicha (97.4)	Fayate (97.1)	Angafa (1377)	Local	
MSTD	1.8^{c}	1.8^{c}	1.3^{d}	2.1^{c}	2.5^{b}	3^{a}	1.1^{d}	17.5
PLHT	77.1^{bc}	89.6^{b}	68.6^{c}	84.2^{b}	92.4^{b}	111.3^{a}	64.0^{c}	18.1
Plhtfb	8.1^{d}	13.6^{b}	10.6^{c}	12.0^{bc}	11.9^{bc}	18.6^{a}	10.3^{cd}	19.8
NPB	29.7^{a}	21.8^{b}	22.8^{b}	30.8^{a}	26.3^{ab}	26.1^{ab}	15.4^{c}	19.6
NSB	12.7^{a}	6.7^{b}	4.4^{c}	8.3^{b}	8.0^{b}	7.9^{b}	1.4^{d}	27.6
NTB	2.0^{b}	2.5^{a}	1^{d}	1^{d}	2.2^{b}	1.5^{c}	1^{d}	15.4
NMST	1.8^{ab}	2.3^{a}	2.0^{ab}	2.3^{a}	2.1^{ab}	2.1^{ab}	1.6^{b}	26.1
FNPB	5.6^{a}	5.0^{ab}	4.7^{ab}	4.1^{b}	4.0^{b}	5.4^{a}	2.9^{c}	21.3
NBPC	4.7^{ab}	4.0^{bc}	3.9^{bc}	4.1^{bc}	4.3^{ab}	5.2^{a}	3.4^{c}	21.5
CanD	83.8^{bc}	76.9^{c}	59.8^{d}	77.9^{c}	91.8^{ab}	100.6^{a}	45.0e	12.9
ELA	33.3^{a}	27.1^{b}	21.7^{c}	28.9^{ab}	33.8^{a}	32.6^{ab}	18.8^{c}	20
LA	2.7^{a}	1.2^{b}	0.6^{c}	1.0^{b}	1.2^{b}	1.2^{b}	0.5^{c}	20.2
NLPB	25.8^{a}	20.7^{b}	12^{d}	13.1^{d}	14.8^{cd}	16.5^{c}	14.1^{cd}	17.2
NLPT	810.4^{a}	528.7^{b}	257.3^{d}	364.9^{c}	353.2^{c}	395.7^{c}	226.1^{d}	16.2

Table 4. Coffee bean yield and yield related treat combined over locations.

Variety	HBW	WHD	WPBF	WPBD
Catimor J-19	98.0^{bc}	288.5^{b}	2296.2^{a}	1426.9^{a}
Koti (85257)	116.7^{ab}	235.5^{bc}	1850.3^{b}	803.2^{b}
74112	114.5^{ac}	292.2^{b}	1802^{b}	907.7^{b}
Odicha (97.4)	114.7^{ac}	205.6^{c}	2591.8^{a}	1332.1^{a}
Fayate (97.1)	106.6^{ac}	445.8^{a}	1747.1^{b}	841.4^{b}
Angafa (1377)	123.1^{a}	138.5d	2572.6^{a}	1434.7^{a}
Local	93.1^{c}	271.7^{b}	1744.9^{b}	829.2^{b}
CV	19.4	21.8	18.8	16.3

Table 5. Stand count (STCNT) in cm, leaf length (LL) in cm and leaf width performance of coffee varieties tested at Halaba.

Variety	Stcnt	LL	LW
Catimor J-19	3^{ab}	11.1^{ab}	5.4^{ab}
Koti (85257)	2.33^{b}	10.5^{ab}	5.4^{ab}
74112	3^{ab}	8.1^{bc}	4.2^{bc}
Odicha (97.4)	3.67^{a}	11.3^{ab}	5.4^{ab}
Fayate (97.1)	3.67^{a}	11.8^{a}	5.9^{a}
Angafa (1377)	3.67^{a}	11.3^{ab}	6^{a}
Local	3^{ab}	6.2^{c}	3.3^{c}
CV	16.04	17.91	13.87

in comparison with their initial yield which was recorded during their first release. In the same way the variety Catimor J-19 showed higher clean coffee per hectare in quintal across all locations followed by Angafa as shown in Figure 2. Accordingly, the highest clean coffee yield 11.96, 12.8 and 11.1 q/ha at Dilla, Halaba and Lokabaya, respectively were obtained from Catimor J-19 followed by Angafa (Figure 2). Such mean yield at the first two

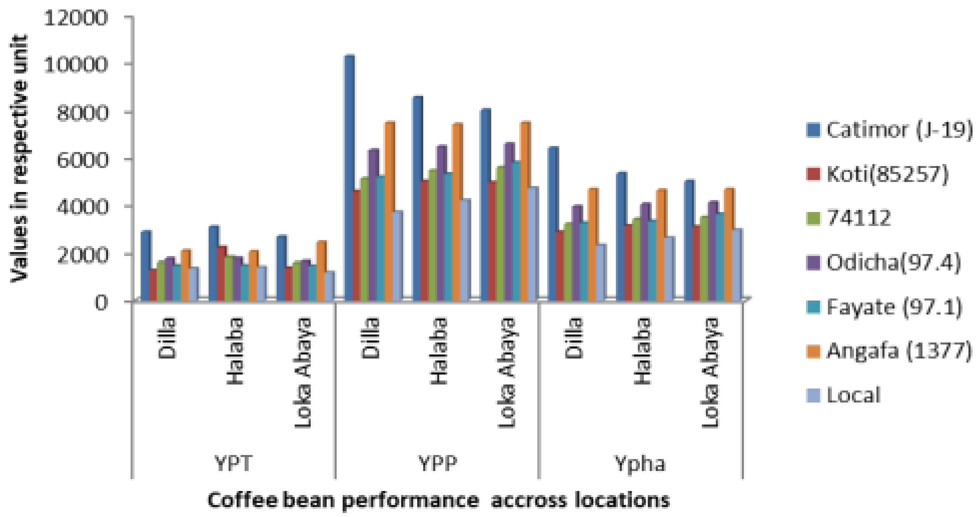

Figure 1. Coffee bean yield per tree, per plot and per hectare across locations.

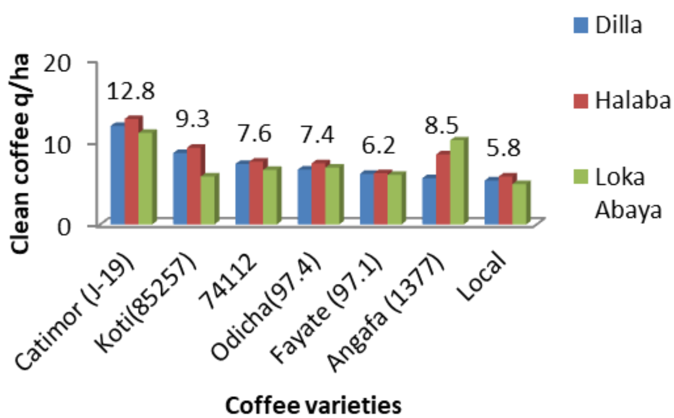

Figure 2. Clean cofee in quintal per hectare across locations.

bearing is very high as climax yield in Arabica coffee is attained starting from the fourth bearing stage (Wrigley, 1988). The overall performance of the varieties (Catimore (J-19) and Angafa was also higher at all environments. This is in line with the work of Agwanda et al. (1997) and Belete and Bayetta (2008) who reported the possibility of developing stable genotypes which can adapt across wide environments. The same result was obtained by Teixeira et al. (2013) as they reported that a significant difference was detected among coffee cultivars and the mean of the four harvests, green coffee yield was 14.7 q/ha with the range from 6.5 to 25.6 q/ha depending on cultivar. Gebreselassie et al. (2017b) also indicated that the existence of significant variation among coffee varieties for mean yield across locations with the highest five years mean yield 12.21 q/ha (2500 tree/ha) recorded at Awada followed by 5.342 q/ha at Komato and the lowest 4.34 q/ha recorded at Wonago growing condition.

Characters association

Coffee bean yield and clean coffee yield were statistically significant and positively correlated with different growth parameters. Yield of clean coffee in quintals per hectare was found to be positively and significantly correlated with stand count at harvest, main stem diameter, number of secondary branches, number of fruiting nodes per branch, number of beans per cherry, canopy diameter, leaf length, leaf width, specific/single leaf area, leaf area per plant, number of leaves per branch, fresh bean yield per tree, bean yield per plot, bean yield per hectare,

Table 6. Coffee growth variables association with bean yield and clear coffee.

Variable	HBW	YPT	YPP	Ypha	WHF	WHD	WPBF	WPBD	WHaC
Stcnt	0.29*	(0.6)**	0.07177	0.07177	0.17038	-0.1518	0.11274	0.22925	(0.59)**
MstD	-0.0397	0.26*	0.29*	0.29*	0.11344	-0.1717	0.34**	0.36**	0.26*
Plht	0.27*	-0.0286	0.17006	0.17006	0.21083	0.02749	0.16726	0.13584	-0.0286
PlhtFb	0.34**	-0.045	-0.0434	-0.0434	0.1208	-0.1553	0.0873	0.00938	-0.045
NPB	0.01394	0.03967	0.25*	0.25*	0.04485	0.35**	0.1372	0.19001	0.03967
NSB	0.01581	0.39**	0.60**	0.60**	-0.1025	0.10637	0.39**	0.26*	0.39**
NTB	0.06839	-0.0077	0.06925	0.06925	0.30*	0.14131	-0.1487	-0.0332	-0.0077
NMST	0.23014	-0.0765	-0.0285	-0.0285	-0.0265	0.14436	0.07184	-0.1578	-0.0765
FNPB	0.34**	0.31*	0.50**	0.50**	0.32*	-0.1897	0.23364	0.16831	0.31*
NBPC	0.02518	0.26*	0.27*	0.27*	0.00646	0.09616	0.10788	0.0053	0.26*
CanD	0.0209	0.31*	0.42**	0.42**	-0.0531	0.34**	0.35**	0.13385	0.31*
LL	0.08599	0.34**	0.32*	0.32*	0.01217	-0.0497	0.13399	0.22136	0.34**
LW	0.18414	0.30*	0.36**	0.36**	0.21255	-0.1301	0.31*	0.29*	0.30*
ELA	0.10639	0.36**	0.38**	0.38**	0.11394	-0.1004	0.22367	0.28*	0.36*
LA	-0.0079	0.34693	0.59**	0.59**	0.18772	0.00169	0.17897	0.32**	0.35**
NLPB	0.16743	0.26*	0.47**	0.46**	0.30*	(0.31)*	0.01397	0.28*	0.26*
NLPT	0.04402	0.22272	0.45**	0.45**	0.21957	0.04187	0.07906	0.22848	0.22272
BTH	0.20202	0.01814	0.10713	0.10713	0.30*	-0.1477	0.23747	0.19036	0.01814
BL	0.17693	-0.1219	0.01808	0.01808	0.27*	-0.1193	0.13764	0.24*	-0.1219
HSW	1	-0.1354	0.08513	0.08513	0.31*	(0.31)*	0.02444	0.14073	-0.1354
YPT		1	0.72**	0.72**	-0.0447	-0.0598	0.28*	0.30*	1**
YPP			1	1**	0.13273	-0.176	0.47**	0.52**	0.72**
Ypha				1	0.13273	-0.176	0.47**	0.52**	0.72**
WHF					1	-0.1844	-0.0806	-0.0164	-0.0447
WHD						1	-0.1643	-0.2235	-0.0598
WPBF							1	0.54**	0.28*
WPBD								1	0.30*

*Significant at p≤0.05, **=Significant at P≤0.01, numbers in the parenthesis are negative correlation coefficients.

weight of pulped bean per plot and weight of dried bean per plot (Table 6). This indicates that anything that contributed to improve the traits improves/bust clean coffee that could be harvested per hectare. The result is in line with the findings reported by Tirunesh et al. (2015). They reported that the growth characters such as canopy diameter with correlation coefficient of 0.57 and stem girth with the correlation coefficient of 0.59 exhibited strong positive correlation with yield indicating that these characters have strong tie to improve productivity per tree basis.

Yield stability of coffee varieties across locations

The ASV parameter is used to quantify and classify the genotypes according to their stability performance. In this model, genotypes with least AMMI stability value (ASV) or have smallest distance from the origin are considered as the most stable, whereas those which have the highest ASV are considered as unstable (Mehari et al., 2014). The additive main effects and multiplicative interaction (AMMI) stability analysis of seven varieties on three environments indicated that the variability of performance of coffee varieties under different environmental condition. The clones 74112 followed by Catimor J-19 and Fayate had possessed wider adaptability as they found nearer to the origin. On the contrary, farmer varieties Angafa and Koti were found to be adapted to specific environmental conditions, Loca Abaya and Halaba, respectively which are far away from the origin of the plot (Figure 3). Similar research findings were reported by Beksisa et al. (2018) as they indicated that lack of suitable varieties that exhibit stable yield performances across wide ranges of environments is the major factor among several production constraints contributing to low productivity of Arabica coffee in Ethiopia. Two high yielding genotypes, namely (L52/2001) and (L55/2001), on average showed stable performance across environments. On the other hand, the study also illustrated the presence of location specific high yielding coffee genotype such as L56/2001. In this

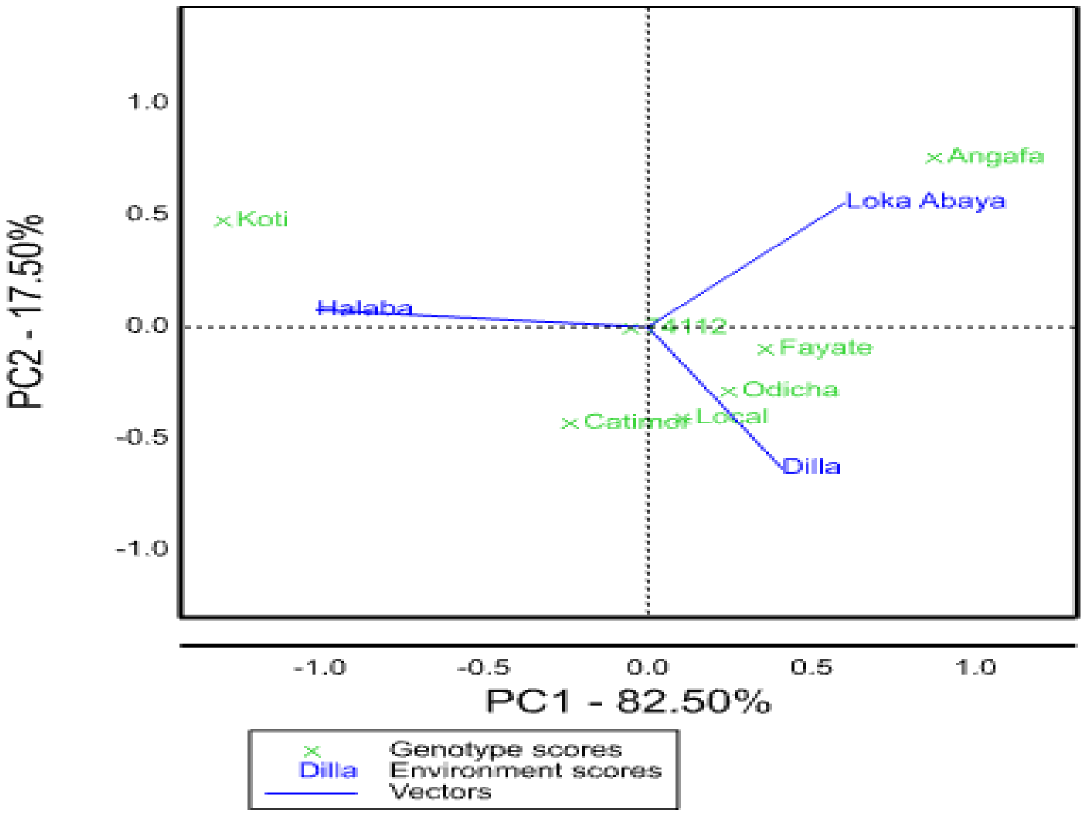

Figure 3. AMMI biplot (symmetric scaling indicating stability of coffee varieties across locations).

regard it can be seen that coffee by its very nature has a property to show stable and higher yield under different agro-ecological locations. Similarly, Tirunesh et al. (2015) confirmed that three coffee genotypes exhibited superior performance consistently at all locations irrespective of the interaction.

Disease incidences

Coffee berry disease (CBD) is very sever and causes appreciable yield loss in areas and/or seasons where the weather is favorable. Temperature and rainfall (amount and duration), and relative humidity are decisively determining the occurrence, prevalence and severity of the diseases (Belachew and Demelash, 2015; Arega et al., 2008; Girma et al., 2008). Totally, more than 13 types of diseases were registered to affect coffee plant in Ethiopia. While major coffee diseases are coffee berry diseases (CBD) caused by *Colletotrichum kahawae,* coffee wilt disease (CWD) of *Gibberella Xylariales* and coffee leaf rust caused by *Hemileia vastatrix,* however, the rest diseases were considered to be minor (Eshetu et al., 2000; Belachew et al., 2015). Even if coffee is infected by different diseases, there was no severe disease attach on the tested varieties with the exception of coffee berry disease and coffee leaf spot. Varieties Catimor J-19, Koti, 74112, Odicha and Fayate showed resistant reaction to coffee berry disease compared with Ahgafa and the local farmers' variety. Among the three locations, the disease pressure at Dilla was very low compared to other location as there was no any statistically significant difference among the varieties on disease score (Table 7). Similarly, coffee leaf spot was prominent on some of the varieties while others showed less infestation level. Varieties Koti, Catimor J-19, 74112 and Angafa showed statistically non-significant but lower infestation level of coffee leaf spot. Odicha, Fayate and local farmers' varieties were highly infested by disease. The result obtained was in line with the findings of Arega et al. (2008), Bayetta (2001), Bayetta et al. (2000), and Mohammed and Jambo (2015). They indicated the existence of wider genetic variability among coffee cultivars for the reaction against coffee diseases.

Conclusion

Despite the role of coffee in the national economy and in spite the country of origin of Arabica coffee, average national productivity has not exceeded six quintals (600 kg/ha). This is very low in contrast to yield levels reported

Table 7. Coffee berry and coffee leaf rust diseases incidence.

Treatment	CBD				CLS			
	Locations			Mean	Locations			Mean
	Dilla	Halaba	Loka Abaya		Dilla	Halaba	Loka Abaya	
Catimor J-19	1^{a}	1^{a}	2^{a}	1.3^{a}	1.7^{a}	2^{ac}	2.7^{b}	2.1^{ac}
Koti (85257)	1.7^{a}	2.3^{ac}	2.3^{ac}	2.1^{ab}	1.7^{a}	1^{a}	2.7^{b}	1.8^{a}
74112	1.7^{a}	2.7^{ad}	2^{ac}	2.1^{ab}	2^{ab}	2.3^{bc}	2.7^{b}	2.3^{ad}
Odicha (97.4)	1.3^{a}	1^{a}	2^{ac}	1.4^{a}	1.3^{a}	3^{c}	3.3^{b}	2.6^{bd}
Fayate (97.1)	2.7^{a}	2.3^{ac}	2.3^{ac}	2.4^{ac}	2^{ab}	4.7^{d}	3^{b}	3.2^{d}
Angafa (1377)	2.7^{a}	4^{c}f	2^{ac}	2.9^{bc}	2^{ab}	1.3^{ab}	1.3^{a}	1.6^{a}
Local	1.7^{a}	4.7^{d}f	3.7^{b}f	3.3^{c}	3^{b}	3^{c}	3^{b}	3^{cd}
CV	45.5	15.1	28.4	27.9	27	26.2	23.4	37.1

Values in the column followed by the same letter(s) are statistically non-significant; disease scoring was carried out by using 1-5 scale as 1 refers to zero while 5 refers to very high infestation

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.

Lack of suitable varieties that exhibit stable yield performances across wide ranges of environments is the major factor among several production constraints contributing to low productivity of Arabica coffee in Ethiopia which indicated that testing the adaptability of coffee varieties at range of environments and specific location is paramount important.

A number of coffee varieties developed through short term and long term programs. But their performance varies with agro-climatic condition (Location) in addition to their genetic potential. Coffee cultivars yields are affected by location, that is, those cultivars outperformed in one location might perform differently in other locations with different altitude and agro-climatic condition. Accordingly, variety Catimor J-19 performed best at all location with respect to fresh bean yield and dried clean coffee followed by Angafa indicating that the materials are well adapted to the edaphic and agro-climatic condition of Dilla, Halaba and Loka Abaya. In line with the great yield performance and stable yield across locations, coffee varieties tested were tolerant to common coffee diseases (CBD and CLR).

Thus, these coffee varieties can confidently widely be promoted for larger commercial production at tested locations and locations with similar agro-ecological conditions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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