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Arabica Coffee (*Coffea arabica L.*) Hybrid Genotypes Evaluation for Growth Characteristics and Yield Performance under Southern Ethiopian Growing Condition

[1]Habtamu Gebreselassie, [2]Gizachew Atinafu, [3]Meseret Degefa, [4]Ashenafi Ayano.

[1]Ethiopian Institute of Agricultural Research, Awada Research Sub-Center, P.O. Box 205 Yirgalem, Ethiopia
E-mail: habteline@gmail.com, Phone +251 922 490 318

[2] Ethiopian Institute of Agricultural Research, Jima Research Center P.O. Box 192 Jima, Ethiopia

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Despite Ethiopia is endowed with diverse genetic base for the Arabica coffee and is the center of origin for it, there is still a limited availability of yield competitive improved variety; hence, the national average productivity is far below the world's average. For contributing in filling the existing gaps, identification of improved hybrid Arabica coffee varieties that are stable, high yielding and disease resistant are necessary for south coffee growing areas of Ethiopia. Therefore, this experiment was conducted at Awada, Komato & Wonago to depict the growth and yield characteristics of five Arabica coffee promising hybrid genotypes (744xAngafa, 7440x2077, 75227xAngafa, 75227x2077 and 75227x1681) and 2 standard check (Ababuna & Angafa). The experiment was conducted by using randomized complete block design (RCBD) with three replication during the years 2006 to 2014. Data were collected for eight growth characteristics and yield for five consecutive years (2010 to 2014) per hectare basis. The results revealed that the existence of statistically significant variations for interaction effect of three traits and for the main effect four traits. The highest plant height 323.3 cm & 307.77 cm were recorded at Awada & Wonago respectively; highest length of longest primary 114.43 cm & 108.86 cm was observed at Komato & Wonago respectively. Statistically highest canopy diameter (214.31 cm), stem girth (6.78 cm), number of main stem node (57.68) and number of nodes on longest primary branch (29.57) were observed at Awada, Awada, Wonago and Komato growing condition respectively. The study result revealed that total yield per hectare was higher for promising hybrid 744 x Angafa (2067.8 Kg/ha) followed by 75227x1681 (1955.1 Kg/ha) grown at Awada and for 75227xAngafa (1169.2 Kg/ha) at Wonago. As the promising hybrid genotypes out performed than the existing improved varieties at Awada and Wonago, there will be a better chance of getting improved Arabica coffee hybrid varieties within south Ethiopian growing environment. Therefore, the experiment should be repeated in different representative trial site to recommend suitable and stable hybrid variety for south coffee growers.

Key words: Arabica coffee hybrids, Clean Coffee Yield, Growth Characters, Southern Ethiopia

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INTRODUCTION

Coffee belongs to the family *Rubiaceae* and the genus *Coffea* (Berthaud and Charrier, 1988; Coste, 1992; Davis *et al*., 2007). The family *Rubiaceae* consists of 500 genera (ITC, 2002), of which *Coffea* is economically the most important (Wellman, 1961). Although earlier studies has indicated the genus *Coffea* consists 90 to 100 species (Wrigley, 1988; Tadesse, 2017), the recent study reported that 124 species have so far been identified in the genus (Davis, 2011). Of those species only two species namely, *Coffea arabica* and *Coffea canephora* Pierre which belong to the subsection *Erythrocoffea* are economically important species (Pearl *et al*., 2004).

The origin and the centre of genetic diversity of *Coffea arabica* lays in the highlands of south-west of Ethiopia (Gebre-Egziabher, 1990; Harlan, 1992; Anthony *et al*., 2002, Shimekit, 2012). Coffee is the most important gift of Ethiopia to the world which had and still has tremendous economic, social and spiritual impact on many people of different geographical locations, cultural background and psychological makeup. It is one of the highly valuable international beverages used almost every day, sometimes twice, or more times a day.

Coffee is the world's most widely traded tropical agricultural commodity (ICO, 2011), exceeded only by oil (Prakash *et al*., 2002; Vega, 2008). It account for nearly half of total exports of tropical products (FAO, 2009). In many producing countries, besides contributing a tremendous amount to the foreign exchange currency as a main cash crop, it serves as a means of livelihood for millions of people (Steiger *et al.,* 2002). It represents an important source of income for millions of people in coffee growing countries in Africa, Asia and Latin America (Mishra *et al*., 2008).

Ethiopia is well known for Arabica coffee (*C. arabica*) which is highly regarded for its very fine quality, unique aroma and flavor (Mesfin and Bayetta, 2008). In Ethiopia coffee contributes largely the national foreign currency income and accounts for more than 35% of the total major export commodities earnings (FAO/WFP, 2008) and the commodity earn is US$500 million per year as its prime source of foreign exchange (ITC, 2011). Ethiopia is endowed with a good production environment for growing coffee with a combination of appropriate altitude, temperature, rainfall, soil type, and pH. The country possesses a diverse genetic base for this Arabica coffee with considerable heterogeneity and is the center of origin for *Coffea Arabica (*Bart *et al,* 2014*)*. Ethiopia produces a range of distinctive Arabica coffees and has considerable potential to sell a large number of specialty coffees (Nure, 2008). Smallholder farmers produce 95 percent of Ethiopia's coffee (Abu and Teddy, 2013).

Coffee production in Ethiopia in general and the southern part of Ethiopia in particular has been largely constrained by lack of high yielding, disease resistant that having best quality hybrid cultivars suitable for the prevailing environmental condition of the region.

Several reports (Srinivasan and Vishveshavara, 1978; Walyaro, 1983; Bayetta & Mesfin, 1993) have described heterosis in Coffea Arabica with average up t o 30% hybrid F_1 cultivars. In an effort to develop high yielding, coffee berry disease (CBD) resistant coffee hybrids that possess the standard quality of Sidama and Gedeo coffee, a hybridization experiment was initiated in 1996. Through series of observations made since 1998 for yield, a maximum over parent heterosis of 44.6% for yield was obtained for the 15 hybrids studied. Of these fifteen hybrids, eight of them exhibited average yield of above 15 Kg/ha of clean coffee, which is well above the performance of the standard checks included in the experiment (Wassu, 2004). Finally, out these eight hybrids, five (744xAngafa; 7440x2077; 75227xAngafa; 75227x2077; 75227X1681) were promoted for farther study to confirm their performance over years at Sidama Zone in Awada & Komato growing condition and at Gedeo Zone Wonago growing condition.

A variety may adapt and fulfill the commercial interest in one coffee growing region, but may not suitable to use in another due to the influences of environment; such as soil, temperatures, humidity and rainfall; thus a variety must be adapted to or suited to a region (Haarer, 1962). In Ethiopia, to minimize adaptation problems and avoid blending effects of known quality coffee growing areas with coffee from another area(s), the selection and breeding work designed for each locality using local land races and crosses from the respective location.

Southern Ethiopia is one of best coffee quality growing areas and research works are on progress at Awada Agricultural Research Sub Center (AARSC) and its trial sites to develop coffee varieties that suit its growing environment. Therefore, this study was done to identify the best performing Arabica coffee hybrids for variety development.

MATERIAL AND METHODS

Description of the study area

The experiment was conducted in a verification trial plot of Awada agricultural research sub- center (AARSC), Komato trial site and Wonago substation during 2006 to 2014 cropping seasons.

Awada (AARSC) is situated in the Tepid to cool semi arid mid highland agro-ecology. It is located in Sidama Zone at about 43 Km South of Hawassa and at 315 km south of Addis Ababa at $6^0 3'$ N of latitude and 38^0 E of longitude at an altitude of about 1750 m.a.s.l. nearby Yirgalem town. The area has a semi-bimodal rainfall distribution characterized by double wet and dry seasons with an average precipitation of 1342 mm per annum (AARSC, 2000). The annual average minimum and maximum air temperatures are 11.0^{0}C and 28.4^{0}C, respectively. The major soil types of the sub center are eutric-nitosol and chromotic-cambisols that are highly suitable for coffee production (Mesfin and Bayetta, 2008). Wonago sub-station is located at 6^{0}3'N latitude, and 38^{0}3'E, longitudes and at an altitude of 1850masl and also Komato trial site is located 1600 m.a.s.l. The two experimental sites (Awada and Komato) are classified in mid-altitude and the rest experimental site (Wonago) is classified in the high land of the coffee growing agro-ecology of the country (AARSC, 2000).

Experimental treatment and design

Five Arabica coffees promising hybrids, which the parents had south and southwest Ethiopia origin and two standard checks cultivars were used as a treatment (Table 1). Normal and healthy seedling were planted in experimental plots in 2006 using randomized complete block design (RCBD) with three replications; consisting of 15 trees per plots with spacing of 2mx2m. All standard management practices were strictly applied uniformly for all plots as per the recommendation.

Data collection

During the study period, data for nine growth characteristics, namely; plant height, number of primary branches, length of the longest primary branch, number of main stem nodes, stem girth, internodes length on the longest primary, number of nodes on the longest primary, inter node length on the main stem, canopy diameter and average of five years yield were recorded from every treatments using the standard procedures of IPGRI (IPGRI, 1996).
The method of data collection for each character was as follows:

Plant height was measured using pocket meter from the base up to the tip of the tree in centimeters.
Stem girth: this was measured at the ground level in centimeters using Vernier caliper.
Canopy diameter: this was measured in centimeters using pocket meter from north to south and east to west then the average was taken.
Inter node length on the main stem: this was measured in centimeters using pocket meter.
Number of nodes on the longest primary: this character was recorded by counting the number of nodes.
Internodes length on the longest primary: this was measured in centimeters using pocket meter.
Number of primary branches: this character was recorded by counting the number of primary branches.
Length of the longest primary branch: this was measured in centimeters using pocket meter.
N**umber of main stem nodes**: this was recorded by counting the number of nodes on the main stem.
Yield: Fresh cherry yield weight and dried cherry (buni) yield in gram per plot will be recorded and the latter will be changed to fresh cherry by multiplying with 2.6 as a correction factor and then converted in to Kg/ha

Data analysis

The data were analyzed by using SAS statistical software package and the mean values were compared using the procedure of Least Significant Difference (LSD) Test at the 5% level of significance.

RESULTS AND DISCUSSION

Growth Characters

Canopy diameter, stem girth and number of nodes on longest primary branch were significantly influenced by the growing environment; while, number of main stem node and stem girth were significantly ($p \leq 0.05$) influenced by genotype but the rest of the traits were non significant (Appendix Table 1).
The size of stem girth varies from 5.96 cm for standard check variety Ababuna as wide as to 6.48 cm for promising hybrid variety 75227xAngafa (Table 2).
Considering growing environment, statistically highest canopy diameter (214.31cm), stem girth (6.78 cm), number of main stem node (57.68) and number of longest primary branch (29.57) were observed at Awada, Awada, Wonago and Komato growing condition respectively (Table 2).

The interaction of location and Arabica coffee hybrid genotypes were significantly influenced by plant height and length of longest primary branch (Appendix Table 1).
Considering Awada growing environment, statistically highest plant height (323.3 cm) was recorded for check variety Angafa where as the lowest plant height (277.17 cm) was observed for promising Arabica coffee hybrid 7440X2077.

On the other hand, statistically highest plant height (307.77 cm) and highest length of longest primary (108.86 cm) were observed for Angafa check variety and 75227X1681 hybrid genotype respectively; whereas the lowest plant height (261.4) and length of longest primary (78.33 cm) were observed for Arabica coffee hybrid genotype 75227x2077 at Wonago growing environment.

Significantly highest (114.43 cm) and lowest (97.76 cm) length of longest primary were observed for hybrid genotype 744XAngafa and check variety Angafa respectively at Komato growing environment (Table 3)

Table 1. Description of Experimental Materials

No	Arabica Coffee Hybrid genotypes	Designation	Germplasm composition	Cross category
1	744xAngafa	Arabica Coffee Hybrid	SWEXSE	CBD_R xHY+Q
2	7440x2077	Arabica Coffee Hybrid	SWEXSE	CBD_R xHY+Q
3	75227xAngafa	Arabica Coffee Hybrid	SWEXSE	CBD_R xHY+Q
4	75227x2077	Arabica Coffee Hybrid	SWEXSE	CBD_R xHY+Q
5	75227x1681	Arabica Coffee Hybrid	SWEXSE	CBD_R xHY+Q
6	Ababuna	Released Arabica Coffee Hybrid check Variety	SWEXSWE	CBD_RxHY
7	Angafa	Released Arabica coffee pure line check variety	SE	HY+Q

Whereas: SWE=South west Ethiopian coffee type, SE=South Ethiopian coffee type, CBD_R=Coffee berry disease resistance, HY=High yielder, Q=Quality.

Table 2. The effect of growing environment and Arabica coffee hybrid genotypes on growth characteristics.

	Parameters						
Growing Location	CD	SG	NNMS	ILMS	NP	NNLP	ILLP
Awada	214.31	6.78	52.27	6.04	108.02	26.79	5.87
Wonago	193.86	5.88	57.68	5.94	109.3	27.48	6.58
Komato	202.81	6.22	48.89	5.68	91.68	29.57	4.32
P-value	**	**	**	ns	ns	*	ns
LSD	6.65	0.24	2.96	ns	ns	1.84	ns
Arabica Coffee Hybrid Genotypes							
744xAngafa	204.22	6.06	50	5.84	96.42	28.71	9.58
7440x2077	198.12	6.47	53.27	6.54	96.78	27.41	5.19
75227xAngafa	209.13	6.48	57.03	5.78	105.93	26.9	5.03
75227x2077	203.1	6.38	54.27	5.71	101.87	26.96	4.76
75227x1681	206.96	6.4	50.78	5.8	95.52	27.32	5.12
Ababuna	201.36	5.96	49.63	5.78	92.98	28.22	4.71
Angafa	202.75	6.32	55.66	5.76	132.4	30.08	4.74
Significance	ns	*	**	ns	ns	ns	ns
LSD	ns	0.37	4.53	ns	ns	ns	ns
CV	5.24	6.16	8.98	12.43	28	10.55	94.16

Whereas; CD=Canopy diameter, SG=Steam girth, NNMS=Number of main stem nodes, ILMS=Inter node length on the main stem, NP= Number of primary, NNLP= Number of nodes on longest primary, ILLP= Inter node length on the longest primary.
** significant at $P \leq 0.01$, *, is significant at $P \leq 0.05$ and ns = not significant at $P \leq 0.05$.

Yield

The coffee bean yield mean analysis of variance (ANOVA) indicated that, the significant difference by location, genotypes and genotype x location in (Appendix Table 2). This indicates the big influence of location on yield performance of coffee hybrid genotypes in Southern Ethiopia. The significant effects of environments indicated that, the testing environments were statistically different in yield potential. The significant difference among the genotypes also showed that the genotypes differed in their yield potential.

Table 3. The interaction effect of growing environment and Arabica coffee hybrid genotype on Plant height and Length of longest primary.

Arabica Coffee Hybrid genotypes	Plant Height (cm)			Length of Longest Primary (cm)		
	Awada	Wonago	Komato	Awada	Wonago	Komato
744xAngafa	293.87	267.77	302.73	112.73	97.53	114.43
7440x2077	277.17	292.73	317.17	112.17	88.83	98.33
75227xAngafa	311.07	301.07	304.4	123.3	92.1	99.4
75227x2077	293.87	261.4	314.97	83.3	78.33	98.3
75227x1681	288.3	264.97	306.63	114.43	108.86	109.43
Ababuna	281.63	287.73	292.17	110.5	97.2	106.06
Angafa	323.3	307.77	283.83	112.77	96.4	97.76
CV	4.43	5.63	4.79	20.26	8.3	5.93
P-value	*	*	ns	ns	*	*
LSD(0.05)	15.28	18.58	ns	ns	9.14	7.16

Whereas *, is significant at $P \leq 0.05$ and ns = not significant at $P \leq 0.05$.

Table 4. Yield data of Arabica coffee promising hybrids grown at Awada, Wonago and Komato

Coffee Hybrid Genotype	Clean coffee yield in Kgh-1																	
	Awada						**Wonago**						**Komato**					
	Cropping Years						**Cropping Years**						**Cropping Years**					
	2010	2011	2012	2013	2014	Mean	2010	2011	2012	2013	2014	Mean	2010	2011	2012	2013	2014	Mean
744xAngafa	1856.3	1375.7	1887.0	1303.3	3916.7	2067.8	696.7	1272.7	1221.7	1080.0	1536.7	1161.5	570.0	190.0	388.7	1303.3	363.3	563.1
7440x2077	2673.7	156.0	1083.3	586.7	2936.7	1487.3	549.3	1009.0	636.7	696.7	1463.3	871.0	716.7	226.7	392.7	1226.7	486.7	609.9
75227x Angafa	1831.0	271.3	1694.3	680.0	3496.7	1594.7	753.3	1349.3	1076.7	1083.3	1583.3	1169.2	890.0	363.3	446.3	1513.3	203.3	683.3
75227x 2077	1873.7	1218.0	741.0	1193.3	2116.7	1428.5	510.0	1096.0	430.0	706.7	896.7	727.9	820.0	343.3	435.3	1436.7	333.3	673.7
75227x 1681	1957.7	1196.7	1600.3	1481.0	3540.0	1955.1	353.3	1127.0	1126.7	816.7	1296.7	944.1	880.0	310.0	549.7	1843.3	416.7	799.9
Ababuna	1699.0	332.0	1183.3	1516.7	2087.0	1363.6	423.3	809.0	621.7	960.9	1023.3	767.5	763.3	216.7	386.7	763.3	663.3	559.7
Angafa	1376.0	522.7	1243.3	1723.3	2857.3	1544.5	646.7	1086.0	570.0	603.3	1156.7	812.5	817.3	260.0	309.3	1393.3	243.3	604.7
P-value	Ns	***	ns	ns	Ns	**	Ns	NS	NS	*	NS	*	NS	*	Ns	Ns	Ns	Ns
LSD(0.05)	4.81	2.84	ns	ns	Ns	2.07	Ns	NS	NS	205.7	NS	200.1	NS	0.67	Ns	Ns	Ns	Ns
CV	21.81	33.61	35.21	47.2147	25.13	10.85	43.48	19.61	40.92	20.79	32.61	18.64	26.33	20.07	19.52	29.87	55.51	18.56

Whereas **, is significant at $P < 0.01$, ***, is significant at $P < 0.001$ and ns = not significant at $P \leq 0.05$.

The presence of significant genotypes by location interaction showed the inconsistency in performance of coffee genotypes across environments. The test genotypes exhibited significant differences in all environments for coffee bean yield. The result suggest that, as for coffee bean yield genotype x environment interaction is important for other traits and performance for a certain yield related trait depends on environments (Appendix Table 2).

Comparison of means yield at Awada growing environment revealed that hybrids over all mean had yield advantage of 523.3 Kg/ha clean coffee (2500 tree/ha) over best performed check mean. The highest five years mean yield (2067.8 Kg/ha) obtained from 744*Angafa; whereas the lowest five years mean yield (1363.6 Kg/ha) obtained from Ababuna. Among the standard checks Angafa recorded the highest five years mean yield 1544.5 Kg/ha; whereas, Ababuna gave the least yield, which was 1363.3 Kg/ha at Awada.

According to mean yield data at Wonago growing environment, the promising hybrids yield mean had yield advantage of 356.7 Kg/ha clean coffee over best performed check Angafa variety mean. The highest five years mean yield (1169.2 Kg/ha) obtained from 75227XAngafa; whereas the lowest five years mean yield (727.9 Kg/ha) obtained from 75227X2077.

Statistically significant yield data observed at Komato growing environment in 2011 cropping year; but the mean yield and the rest cropping year yields were non significant. Accordingly, the highest 2011 cropping year yield data (363.3 Kg/ha) was observed for 75227XAngafa; whereas the least (190.0 Kg/ha) yield were observed for 744XAngafa (Table 4).

Moreover, when there is the larger the relative size of interaction component, the more complex the problem of identifying broadly adapted genotypes. The significant yield differences between genotypes and environments and significant interaction of genotypes with environments indicated the need to develop cultivars that are adapted to specific environmental conditions and the need to identify cultivars that are exceptional in their stability across environments.

SUMMARY AND CONCLUSION

Growth characteristics and yield performance were taken into account in order to identify and recommend Arabica coffee promising hybrid genotypes for southern Ethiopian coffee growing areas. Accordingly, the promising Arabica coffee hybrid 744xAngafa (2067.8 Kg/ha) followed by 75227x1681 (1955.1 Kg/ha) best performed than the existing improved varieties at Awada growing environment and promising hybrid 75227XAngafa (1169.2 Kg/ha) followed by 744XAngafa (1161.5 Kg/ha) were outstanding over the existing improved check varieties at Wonago growing condition. Hence, there is a better chance of getting improved Arabica coffee varieties for Awada and Wonago growing environment. Therefore, in order to enhance production and productivity at Awada and Wonago as well as similar growing environment, farther adaptability test and study should have undergo to develop improved Arabica coffee hybrid variety. So that, by adding the representative trial site, the experiment should be repeated in terms of different locations to recommend suitable and stable hybrid variety to southern Ethiopian coffee growers. In addition to this, farther package development study for those best performed promising hybrids has to be done side by side before the development of improved hybrid varieties.

Hence, there is no significant variation at komato growing environment; the researcher has to look for further selection and hybrid development strategy to develop yield competitive improved varieties for Komato growing environment.

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Appendix Table 1; Mean squares for coffee Growth parameters obtained from analysis of variance

Source of variations	DF	Mean Square								
		CD	SG	HT	NNMS	ILMS	NP	LP	NLP	ILLP
Reps	2	376.63*	0.34ns	463.84ns	0.79ns	0.24ns	590.02ns	505.69ns	6.01ns	24.78ns
Loc	2	2206.98**	4.26**	2093.30**	413.42**	0.72^{ns}	2026.52^{ns}	1310.61*	44.19*	27.88^{ns}
Var	6	117.43^{ns}	0.38*	609.54*	7537*	0.77^{ns}	1697.17^{ns}	218.43^{ns}	11.90^{ns}	28.16^{ns}
Var*Loc	12	59.76^{ns}	0.17^{ns}	826.30**	41.53^{ns}	0.38^{ns}	1184.57^{ns}	388.80*	2.35^{ns}	26.89^{ns}
Error	40	113.78	0.15	220.78	22.6	0.54	832.03	194.11	8.69	27.71

*, **, ***, are significant at P ≤ 0.05, P ≤ 0.01, P ≤ 0.001, respectively and ns = not significant at P > 0.05.

Appendix Table 2; Mean squares for coffee bean yield obtained from analysis of variance

Source of variations	DF	Mean Square					
		Cropping Years					
		2010	2011	2012	2013	2014	Mean
Reps	2	43818.1^{ns}	28719.35^{ns}	157304.9^{ns}	34408.7^{ns}	381630.0^{ns}	48696.2^{ns}
Loc	2	10746907.87**	3661344.1**	4594203.7**	1422539.2*	36829925.5**	5500112.8**
Var	6	141222.40^{ns}	376697.1**	543207.3**	261470.1^{ns}	800402.6*	194805.7**
Locxvar	12	210663.65*	268211.9**	126331.7^{ns}	363199.2*	495103.9^{ns}	71621.9*
Error	40	92410.1	63730.4	111590.9	176187.6	273721.4	30829.8

*, **, ***,^{ns}, are significant at P ≤ 0.05, P ≤ 0.01, P ≤ 0.001, respectively and ns = not significant at P > 0.05.