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Original Research Article

Growth Characteristics and Yield Performance Evaluation of Hybrid Coffee (*Coffea Arabica L.*) Genotypes in Sidama, Southern Ethiopia

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Abstract: Despite Ethiopia is endowed with diverse genetic base for the Arabica coffee and is the center of origin, there is still a limited availability of yield competitive improved variety; hence, the national average productivity is far below the world's average. Due to this reason, the national average productivity is very low. From the various sets of pure lines variety development program in Ethiopia, it had been observed that it is rarely possible to improve yield above 1800-2000 kg/ha through direct selection indicating the need to look heterotic hybrids to maximize yield as high as 2500- 3000 kg/ha. Thus, it could be useful to further evaluate the performance of the best performing hybrids for yield and growth characters at full bearing stage to identify high yielding hybrids for commercial use. Therefore, to bridge this gap and improve coffee productivity, it is essential to develop hybrid coffee varieties that are high yielding, stable and disease resistant. Therefore, this study aimed to evaluate coffee hybrid genotypes for yield and yield components. The experiment was conducted at Awada and Leku to depict the growth and yield characteristics of four Arabica coffee promising hybrid genotypes). The experiment was conducted by using a randomized complete block design (RCBD) with three replications during the years from 2016 to 2021. Data were collected for plant height, number of primary branches, number of secondary branches, length of the longest primary branch, number of main stem nodes, stem girth, internode length on the main stem, canopy diameter and yield for three consecutive years (2019 to 2021) per hectare basis. The results revealed the existence of statistically significant variations among the growth characters. Total plant height (1.99-2.45m), stem diameter (2.82–3.45cm), canopy diameter (199– 221.77cm), number of main stem nodes (27.96 – 30.66), number of primary branches (52.08 – 58.83), number of secondary branches (148.23 – 179.25), average length of primary branches (107.00– 116.84cm). The study result revealed that total yield per hectare was higher for promising hybrid 75227x1681 (3491 Kg/ha) followed by 75227xAngafa (3023 Kg/ha) grown at Awada and for 75227X1681(1437 Kg/ha) at Leku. As the promising hybrid genotypes out performed than the existing improved varieties at Awada and Leku, 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.
Keywords: Clean Coffee, Coffee, hybrids, growth characters, yield.

1. INTRODUCTION

Arabica Coffee is the world's most widely traded tropical agricultural commodity (ICO, 2011), exceeded only by oil (Prakash *et al.*, 2002; Vega, 2008). Coffee is the most widely traded tropical product, with up to 25 million farming households globally accounting for 80 percent of world output (FAO, 2023). 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). From African countries, Ethiopia is well known for Arabica coffee (*C. arabica*) which is highly regarded for its very fine quality, unique aroma and flavor (Kebede and Bellachew, 2008).

The origin and the center of genetic diversity of *Coffea arabica lay* in the highlands of south-west of

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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 a tremendous economic, social and spiritual impact on many people of different geographical locations, cultural backgrounds and psychological makeup. It is one of the highly valuable international beverages used almost every day, sometimes twice, or more times a day.

In Ethiopia coffee contributes largely to 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$ 1.4 billion per year as its prime source of foreign exchange (CTA, 2022). 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, 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 a 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; Bertrand *et al*., 1997) have described heterosis in Coffea Arabica with average up to 30% hybrid F_1 cultivars. 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 a series of observations made since 1998 for yield, a maximum over best parent heterosis of 44.6% for yield was obtained for the 15 hybrids studied. Of these fifteen hybrids, eight of them exhibited an 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 of these eight hybrids, four (744xAngafa; 7440xAngafa; 75227xAngafa; 75227X1681) are promoted for further study to confirm their performance over years at Sidama Region in Awada & Leku growing conditions.

A variety and/or hybrid may adapt and fulfill the commercial interest in one coffee-growing region, but may not be 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 is designed for each locality using local landraces and crosses from the respective location.

Similarly, southern Ethiopia is one of the best coffee-quality growing areas and research works are in progress at Awada Agricultural Research Sub Center and its trial sites to develop coffee varieties that suit its growing environment. Therefore, this experiment was conducted to determine growth characteristics and yield performance of hybrid coffee variety.

2. MATERIAL AND METHODS

Description of the study area

The experiment was conducted in a verification trial plot of the Awada agricultural research sub- center (AARSC) and Leku trial site substation during the 2019 to 2021 cropping seasons. Awada (AARSC) is situated in the Tepid to cool semi-arid mid highland agroecology. 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 11.0^0C and 28.4^0C, respectively. The major soil types of the sub-center are eutric-nitosol and chromotic-cambisols which are highly suitable for coffee production (Mesfin and Bayetta, 2008). Leku trial site is located at 1805 m.a.s.l. The experimental site (Awada) is classified in mid-altitude and the rest experimental site (Leku) is classified in the high land of the coffee-growing agroecology of the country (AARSC, 2000).

Experimental treatment and design

Four Arabica coffees promising hybrids, of which the parents had south and southwest Ethiopia origin and three standard checks cultivars were used as a treatment (Table 1). Normal and healthy seedlings were planted in experimental plots in 2016 using a randomized complete block design (RCBD) with three replications; consisting of 20 trees per plot with a spacing of 2mx2m. All standard management practices were strictly applied uniformly for all plots as per the recommendation (Endale *et al*., 2008).

Table 1: Description of experimental coffee genotypes

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

Data Collection

During the study period, data for eight growth characteristics, namely; plant height, number of primary branches, number of secondary branches, length of the longest primary branch, number of main stem nodes, stem girth, internode length on the main stem, canopy diameter and average of three years yield were recorded from every treatment using the standard procedures of IPGRI (IPGRI, 1996).

The method of data collection for each character was as follows:

Plant height was measured using a pocket meter from the base up to the tip of the tree in centimeters.

Stem girth: This was measured at the ground level (at 5cm above the ground) in centimeters using a Vernier caliper.

Canopy diameter: this was measured in centimeters using a pocket meter from north to south and east to west then the average was taken.

Internode length on the main stem: this was calculated by Total plant height (TPH) -heigh up to first primary branches (HUFPM) /Number of main stem nodes (NMSN).

Number of primary branches: this character was recorded by counting the number of primary branches.

Number of secondary branches: this character was recorded by counting the number of secondary branches.

Length of the longest primary branch: this was measured in centimeters using a 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 was recorded and the latter was changed to fresh cherry by multiplying with 2.6 as a correction factor and then converted into Kg/ha (Gebreselassie *et al.*, 2018).

Data Analysis

The data were analyzed by using SAS statistical software package (version 9.3) and the mean values were compared using the procedure of Least Significant Difference (LSD) Test at the 5% level of significance (Gebreselassie *et al.*, 2018).

Heterosis Estimation

The hybrid performance for each cross combination was evaluated based on the better parent and heterosis. Heterosis in percent was calculated for the characters that showed significant differences for crosses following the method suggested by Nyquist (1991). Best-Parent heterosis (Heterobeltosis): It refers to the superiority the F1 hybrid performance over its best parent.

3. RESULTS AND DISCUSSION

Yield

The overall mean analysis of variance (ANOVA) indicated that the significant difference among the treatments (Table 2) among the genotypes showed that the genotypes differed in their yield potential. The highest three years mean yield (2464 Kg/ha) was obtained from 75227*1681; whereas the lowest three years mean yield (1897 Kg/ha) was obtained from 744* Angafa. Among the standard checks, Angafa recorded the highest three years mean yield 1630 Kg/ha; whereas, Ababuna gave the least yield, which was 1271 Kg/ha (Table 2).

Considering the individual location analysis, the highest three years mean yield (3491 Kg/ha) was obtained from 75227*1681; whereas the lowest three years mean yield (2602 Kg/ha) was obtained from 744* Angafa at Awada. Among the standard checks, Angafa recorded the highest three years mean yield of 2095 Kg/ha; whereas, Ababuna gave the least yield, which was 1573 Kg/ha at Awada. According to mean yield data result at Leku site, the highest three years mean yield (1437 Kg/ha) was obtained from 75227X1681; whereas the lowest three years mean yield (1192 Kg/ha) was obtained from 744X Angafa. Among the standard checks, Angafa recorded the highest three years mean yield 1166 Kg/ha; whereas, Ababuna gave the least yield, which was 800 Kg/ha at Leku (Table 2).

The existences of sufficient variability among the evaluated materials create an immense opportunity to bring considerable improvement through selection and cross-breeding in the future coffee improvement program. The significant difference observed for yield in this study were in agreement with the finding of earlier authors who reported considerable genetic variability within the arabica coffee for yield, disease resistance and growth characters (Lemi and ashenafi, 2016; Gizachew *et al*., 2017; Habtamu *et al*., 2018; Masreshaw, 2018).

Growth Characters

All quantitative traits examined at Awada and Leku growing conditions showed significant ($P<0.05$) variation among coffee hybrids, except the number of main stem nodes, the number of secondary branches, and the average length of primary branches (Tables 3 and 4).

Morphological and growth characters examined at Awada described in Tables 3 show the total plant height (1.99–2.45 m), stem diameter (2.72–3.45 cm), canopy diameter (199.10 –221.77 cm), number of main stem nodes (27.96– 49.79), Inter node length on the main stem (7.13 – 9.04cm), number of primary branches (52.08–59.21), number of secondary branches (148.25–179.25), and average length of primary branches (107.00–116.84 cm) of the plant.

Morphological and growth characters examined at Leku described in Tables 4 show the total plant height (2.71–3.07 cm), stem diameter (5.20–5.42 cm), canopy diameter (191.33–219.00 cm), number of main stem nodes (30.60–34.33), Inter node length on the main stem(6.06 – 8.66cm), number of primary branches (55.13–66.93), number of secondary branches (99.00–108.46), and average length of primary branches (107.33–115.33 cm) of the plant. The occurrence of enough variation among the examined materials creates a huge chance to significantly advance the future coffee variety development program through cross-breeding. The significant difference observed for measured quantitative traits in this study were in agreement with the finding of earlier authors (Abdi, 2009; Olika *et al*., 2011; Getachew *et al*., 2013; Habtamu *et al*., 2017; Abdulfeta, 2018; Masreshaw, 2018).

Table 2: Mean yield of clean coffee (Kg/ha) and survival rate of candidate hybrids and their checks under verification trial at Awada and Leku Location

Candidate hybrids and checks	Awada					Leku					Over all mean
	2019	2020	2021	Mean	Survival rate (%)	2019	2020	2021	Mean	Survival rate (%)	
75227 x Angafa	2109	4442	2520	3023	90	828	1854	1258	1313	100	2168
744 x Angafa	2152	3713	1942	2602	96	867	1573	1134	1192	100	1897
75227 x 1681	3189	4976	2309	3491	100	660	2679	971	1437	100	2464
7440 x Angafa	2639	3942	2272	2951	100	729	1987	1289	1335	100	2143
Checks											
Ababuna	696	2953	1070	1573	100	999	1106	800	968	100	1271
Feyate	707	4032	1086	1941	100	693	2257	974	1308	100	1625
Angafa	1305	3447	1534	2095	100	682	1530	1285	1166	100	1630
LSD	2.97	8.11	10.03	4.44		8.27	8.21	5.33	4.32	100	2.56
CV	9.12	11.61	30.99	9.88		59.64	24.88	27.21	19.49	100	7.64
Sig.	***	**	*	***		Ns	*	Ns	Ns		***

Table 3: Mean growth characteristics of candidate hybrids and their checks under Hybrid Verification trial plot at Awada location

Candidate Hybrids and Checks	Height(m)	Canopy diameter (cm)	Stem girth(cm)	No. of nodes on the main stem	Inter node length on the main stem(cm)	No. of primary branches	No. of secondary branches	Length of first primary(cm)
75227 x 1681	2.27ab	221.77a	3.43ab	30.96ab	8.75ab	53.62b	169.25ab	115.833ab
75227 x Angafa	2.24ab	210.02bc	3.21abc	29.04ab	8.52ab	55.08ab	179.25a	116.837a
7440 x Angafa	2.45a	216.02ab	3.45a	29.88ab	9.04a	58.46a	173.92ab	113.753ab
744 x Angafa	2.42a	209.02bc	3.13bcd	30.66ab	8.15ab	58.83a	173.33ab	111.543abc
Feyate	2.24ab	211.87ab	2.72e	29.46ab	8.00ab	55.87ab	178.34a	113.963ab
Angeffa	2.44a	206.23bc	3.07cd	49.79a	7.93ab	59.21a	148.25b	109.75bc
Ababuna	1.99b	199.10c	2.82de	27.96b	7.13b	52.08b	167.46ab	107.00c
Mean	2.294	210.57	3.12	31.68	8.22	56.19	169.97	112.66
CV	7.34	2.92	5.62	26.62	11.83	4.64	8.58	3.18
LSD	0.2998	10.97	0.314	15	1.73	4.64	25.956	6.37

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

Table 4: Mean growth characteristics of candidate hybrids and their checks under Hybrid Verification trial plot at Leku location

Candidate Hybrids and Checks	Plant height (m)	Canopy diameter (cm)	Stem girth (cm)	Number of nodes on the main stem	Inter node length on the main stem(cm)	No. of primary branches	No. of 2^0 branches	Length of longest primary(cm)
75227x1681	2.8967ab	210.83abc	5.34ab	31.93	7.46ab	61.2ab	99.00	108.00
75227 x Angafa	2.7533ab	191.33c	5.2ab	30.60	6.06b	55.13b	108.46	108.00
7440 x Angafa	3.0667a	204.17abc	5.38ab	34.33	7.66ab	66.93a	107.86	107.33
744 x Angafa	2.9633ab	216.33ab	5.36ab	32.80	6.86ab	62.53ab	101.33	111.80
Feyate	2.9433ab	218.33a	5.09ab	31.26	7.40ab	61.73ab	106.46	114.00
Angeffa	2.92ab	219.00a	5.42a	33.66	8.66a	66.40a	101.40	115.33
Ababuna	2.7067b	195.67bc	4.82	31.20	6.20b	59.33ab	102.13	108.66
Mean	2.8928	207.95	5.23	32.25	7.19	61.89	103.80	110.44
CV	6.80	6.06	6.12	7.64	17.89	8.90	7.55	4.08
LSD	35.23	22.42	0.56	NS	2.28	9.82	NS	NS

Estimation of Heterosis

Considering heterosis analysis relative to the better parent heterosis was detected for yield character measured. Estimated heterosis as percentage for yield for yield best parent heterosis ranged from 16.48 to 43.44% (Table 5). The highest best parent heterosis was in 75227x1681(43.44%) flowed by 75227xAngafa (33.27%) while the lowest best parent heterosis was in 744xAngafa (16.48%). In general, the magnitude of heterosis manifestation for this particular trait was good. This result is in agreement with the findings of the previous workers (Mesfin, 1982; Bayeta 2001; Wassu 2004, Ashenafi, 2013). who reported higher magnitude of better-parent heterosis for this character. Most probably, the deviations between the present and previous findings could be largely attributed to differences in parental lines involved and the environment under which the experiment was conducted.

Table 5: Heterosis parameters in yield of promising hybrid Arabica coffee

Hybrids and checks	Best parent heterosis
75227xAngafa	33.27
744xAngafa	16.48
75227x1681	43.44
7440xAngafa	31.57
Checks	
Ababuna	
Feyate	
Angafa	

4. SUMMARY AND CONCLUSION

Coffee is the backbone of the Ethiopian economy. Coffee farming provides a livelihood income for around four million smallholder families or 15 million Ethiopians (16% of the population). For many of these farmers, coffee is their single most important source of income. Thus, improvement of production and productivity is of paramount importance to assist the coffee growers. Hence, the present experiment was conducted to determine growth characteristics and yield performance of hybrid coffee variety.

The experiment was conducted at Awada and Leku to depict the growth and yield characteristics of four Arabica coffee promising hybrid genotypes). The experiment was conducted by using a randomized complete block design (RCBD) with three replications. From the various sets of pure lines variety development program in Ethiopia, it had been observed that it is rarely possible to improve yield above 1800-2000 kg/ha through direct selection indicating the need to look heterotic hybrids to maximize yield as high as 2500-3000 kg/ha. Thus, it could be useful to further evaluate the performance of the best performing hybrids for yield and growth characters at full bearing stage to identify high yielding hybrids for commercial use. Growth characteristics and yield performance were taken into account to identify and recommend Arabica coffee promising hybrid genotypes for southern Ethiopian coffee growing areas. Accordingly, the promising Arabica coffee hybrid 75227x1681 (3491 Kg/ha) followed by 75227x Angafa (3023 Kg/ha) best performed than the existing improved varieties at Awada growing environment and promising hybrid 75227X1681 (1437 Kg/ha) followed by 7440XAngafa (1335 Kg/ha) were outstanding over the existing improved check varieties at Leku growing condition. Hence, there is a better chance of getting improved Arabica coffee varieties for the Awada and Leku growing environment. The two hybrid arabica coffee varieties 75227X1681 known as Rorri and 75227 X Angafa known as Awada CH1 were made available for commercial coffee production. Therefore, to enhance production and productivity at Awada and Leku as well as the similar growing environment, further package development study for those best-performing promising hybrids has to be done side by side before the development of improved hybrid varieties.

Despite the immense potential that is available within coffee populations in Sidama and Gedio areas in southern parts of Ethiopia and the encouraging heterosis results reported from the crosses among elite coffee lines selected from this area, much work has not been done to exploit the available potential in germplasm diversity to develop superior hybrids and pure-line selections for the area. The present study clearly indicated the possibility to bring significant improvement through hybrid breeding. Therefore, continuous crossing program is required to acquire many more cross combinations for intensive and extensive evaluation to develop better performing and high yielding hybrids for the area.

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Conflicts of Interest: The authors declares no conflicts of interest.

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