ORIGINAL ARTICLE

Heterosis and Combining Ability of Coffee Quality Traits in Southwestern Ethiopian Origin Coffee Hybrids

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ABSTRACT

Agriculture in Ethiopia is the foundation of the country's economy playing an important role in gross domestic product (GDP), exports, and employment. Large parts of commodity exports are provided by the small agricultural cash-crop sector; principal crops being coffee. The current productivity per hectare is lower than many growing countries. Exploitation of hybrid vigor through selection of best parental lines and hybridization has been one of the most important strategies of improving productivity in some of the most economically important crops, such as Coffee. However, study for quality traits is generally over looked. Hence, this study was objectively designed to understand and estimate the nature and extent of heterosis and combining ability in selected Southwestern Ethiopian origin coffee genotypes for some of the most important coffee quality traits. Half diallel mating design using five parental lines, ten F1 hybrids and one hybrid check variety were laid out in a Randomized Complete Block Design (RCBD) with three replications across three locations Jimma, Metu and Tepi. The study locations represent the major coffee growing areas of the southwestern part of country. Some of the most important quality traits considered for this study includes: flavor, body, aromatic intensity, overall standard, shape and make. The better parent (BP) and mid-parent (MP) heterosis for the majority of quality traits was negative. This might indicate that these quality traits controlled by recessive genes. Some of the F1's revealed quality nearly similar value with that of maternal parent having better quality character. This might indicate cytoplasmic inheritance of quality characters. This calls for the need to further study the inheritance of these quality traits by crossing the best quality parents with known poor quality parents. The study also revealed highly significant and positive general combining ability (GCA) effect for the parental line74148: for traits flavor and overall quality. It also showed higher positive value for body and physical quality character like shape and make. This shows the importance of this parent for the contribution of additive genes in improving the quality traits in the future coffee quality breeding program.

Keywords: *Coffea arabica*, Combining ability, Heterosis, GCA, Quality, SCA,

INTRODUCTION

Coffee (*Coffea arabica* L.) belongs to the genus Coffea in the Rubiaceae family, and is a self-fertile allotetraploid species that is mostly grown in the tropical and subtropical regions . Coffee is not only one of the highly preferred international beverage, but also one of the important agricultural commodities in the world. It is known for the longest time and the widest spread species throughout the world, and Botanists regard the Arabica coffee as an evergreen shrub of variable size. It often multi stemmed shrub about 8 to 10m tall and its branches are long, flexible and thin. Branches are semi-erect when young and spreading or pendulous when old (Wrigly, G. 1988).

Coffee is the main source of export earnings for numerous countries around the world. Several hundred million people in the world drink coffee every day, and hence it is among the most traded commodities in the world. *Coffea arabica* L. is the preferred of all other species, for its superior quality and expected to continue as the exclusive product of all coffee in the world. It is cultivated in most parts of the tropics, accounting for more than 80 % of the world market and about 70% the global coffee production (Woldemariam et al., 2002). Ethiopian coffee germplasm is much more diverse and has a much broader genetic variability (Anthony et al., 2002; Alemayehu et al., 2010).The country is well known, not only for being the home of Arabica coffee, but also for its very fine quality coffee acclaimed for its unique aroma and flavor characteristics. The coffee types that are distinguished for such unique characteristics includes: Sidama, Yirgacheffe, Harer, Gimbi and Limu types (Workafes and Kassu, 2000). Such immense genetic diversity of coffee in the country provides a great opportunity for the genetic improvement and development of improved varieties of the crop in the country. However, such high genetic variability of the crop has not been sufficiently exploited by the breeding program. Breeding for high heterosis i.e., superior performance of the F1's relative to their mid parent value or the performance either of the parents, has been one of the most important breeding approaches that brought breakthrough in the productivity potential of several economically important crops, including coffee. Up to 60% heterosis for yield (Mesfin and Bayetta, 1983) and 30% for yield components (Mesfin, 1982) over the better parent were reported in the first attempt of coffee hybridization among five indigenous parental lines in the country. On the other study mid parent heterosis ranging 13% to 58% was observed (Ashenafi, 2013). Such appreciable heterosis might be obtained mainly due to the presence of high genetic variability of the crop in the country and high genetic divergence in the parental lines used for the crossing.

Efforts have been underway to utilize the different agro-ecological origin i.e., Sidama, Keffa and Illubabor, and morphological classes i.e., compact, intermediate, and open canopy parents with partial to high resistance to Coffee Berry Disease (CBD) for hybridization of coffee in the country to improve yield, quality and resistance to major diseases of coffee. Interestingly high and significant heterosis was reported between and within-region crosses, showing the importance of geographical origin and/or morphological genetic divergence for heterosis (Bayetta *et al.,* 2007; Wassu, 2004). However, Bayetta *et al.* (2007) reported that the contribution of morphological variation to heterosis is more important than geographical origin. Three hybrid varieties, namely Ababuna, Melko-CH2 and Gawe were released from the hybrid variety development program of Jimma Agricultural Research Center in the year 1998-2002 for the mid to low land coffee production areas of southwestern coffee growing areas of the country (Bayetta *et al*., 1998; MOA., 2010). Similarly, three hybrid varieties viz., EIAR 50/CH, Melko-ibsitu, TepiHC5 were released in the year 2016 for the low to mid altitude coffee growing areas of South-western Ethiopia (MoANR., 2016).

Combining ability analysis is a very important tool in evaluating the performance of parental lines in hybrid combinations. identifies the best hybrid combinations and generates information on the type of gene actions that are responsible for the control of different agronomic traits (Griffing, 1956; Gravios and McNew, 1993; Kambal and Webster, 1965). Despite, the availability of high genetic diversity of the crop in the country and the high level of heterosis depicted in coffee F1 hybrids, the effort made to exploit hybrid vigor, and study the combining ability of different coffee parental lines and determine the genetic control of inheritance for coffee quality traits has not been sufficient. Hence, the objective of this write up is to estimate the extent of heterosis and combining ability, to identify good combiner parental line and as a result identify the best single cross *coffea arabica* hybrids for some of the most important quality traits.

MATERIALS AND METHODS

Experimental Materials and Study Locations

Five parental lines that were selected from the national coffee germplasm collections trials representing the

different agro-ecological origins of Southwestern Ethiopia and dissimilar canopy classes were used as parents for the crossing. The agro-ecological origin and some of the most important features of the parental lines used in the crossing effort is presented in Table 1.

Table1.Coffee parental lines, their specific origin and character descriptions

	Parental Line	Specific collection site	Altitude (m.a.s.l.)	Description
P1	75227	Gera	1900	Open canopy, highly resistant to CBD and high yielder, released pure line variety
P2	744	Washi, Kefa	1700	Open canopy, highly resistant to CBD, high yielder, bold bean size, released pure line
P3	74148	Bishari, Illuababora	1600	Compact canopy, highly resistant to CBD and high yielder, released pure line
P4	F-34	Mizan-Teferi	1430	Open canopy, moderate resistant to CBD, quality, not released (pipeline variety)
P5	206/71	Maji	1600	Compact canopy, moderate resistance to CBD, high yielder, small bean size, bronze leaf tipped, not released(pipeline variety)

Source: Extracted from data base of coffee breeding and genetics research division, JARC

The study was conducted in three locations of Southwestern Ethiopia that includes: Jima Agricultural Research Center /JARC, Metu Agricultural Research Sub-Center and Tepi National Spice Research Center/TNSRC. The study locations represent wet humid sub-tropical region and the low to mid-altitude and high rainfall major coffee producing areas of Southwestern Ethiopia. The bulk of the soil in the south-west coffee growing region in general is described as EutricNitosol and clay; deep and well drained, with PH of 5-6 medium to high in exchangeable cation (Paulos, 1994; Brhanu, 1978; Tesfu and Zebene, 2006). The agro-ecological description of the study sites is presented in Table 2.

Table2. Agro-ecological description of the study sites

Location	**Latitude**	**Longitude**	**Altitude (masl)**	**Rainfall/ annum (mm)**	**Temperature (^{o}c)**		**Relative humidity (%)**
					Min	**Max**	
Melko	7^{0}40'N	36^{0}47'E	1753	1572	11.6	26.3	67
Metu	8^{0}19''N	35^{0}35''E	1580	1829	12.7	28.9	-
Tepi	7^{0}11''N	35^{0}25''E	1220	1594	15.7	29.9	70

Source: Labouisse, 2006.

Data Collected

The quality assessment was done at the coffee liquoring laboratory of Jimma Agricultural Research Center on the coffee samples, collected from each experimental plot. The procedure followed for the quality assessment on sample preparation, and organoleptic (cup testing) data collection is described as follows:

Ripe red coffee cherries were handpicked and fully ripened and healthy berries were separated from foreign materials before pulping. A total of 144 samples were prepared from the hybrids and parents. Samples, which were prepared from ten trees per plot per replication at peak harvest period, were bulked. The samples were carefully prepared using wet processing method (pulping, fermentation, and drying) following the recommended processing method (Behailu *et al*., 2007).

a) **Pulping**: Fully ripened beans of berries were separated from the skin and pulp using a hand pulping machine that squeezes the berries between fixed and moving surfaces.

b) **Fermentation**: The beans were stored in a plastic bucket for 48 hours at Melko and Metu, and 24 hours at Tepi till first washing (Behailu *et al*., 2007). Then, samples were stored for 24 hours for final washing. On average, it took 64 hours at Melko and Metu, and 48 hours at Tepi until the final washing (IAR/JARC, 1996).

c) **Drying:** Samples were placed on mesh wire under sun for drying, and the moisture content of the bean was monitored during drying using moisture tester to uniformly maintain the moisture level at 10-12% for all the samples. About 300-500gm of green coffee bean samples was prepared per entry per replication, separately for each hybrids and parents for physical and organoleptic quality analysis.

d) Roasting and grinding: The roaster machine was first heated to about 160-200^{o}c. About 100 g of green coffee bean sample was prepared per entry per replication for roasting. Medium roast (7 minutes on average) was used, and it was blown to remove the loose silver skins before grinding. Then, medium sized ground coffee was prepared using electrical grinder with middle adjustment.

e) **Brewing:** Soon after grinding, coffee powder weighing 8g was placed in a cup with a capacity of 180 ml. Then, boiled water poured onto the ground coffee up to about half way in the cup. Soon after, volatile aromatic quality and intensity parameters were recorded by sniffing. Then, the contents of the cup were stirred to ensure an infusion of all coffee grounds. The cup was then filled to the brim with boiled water. The brew was made ready for panelists within eight minutes.

f) There was also an overall standard for liquor quality based on the above attributes that ranged from 0 to 5 (as per the coffee quality assessment format of JARC) (Table 3). Mean of each variable by the panel were used for statistical analysis.

g) **Cup tasting**: Cup tasting was carried out by well experienced 3-5 cuppers of Jima Agricultural Research Center in each session. Cupping was performed after once the beverage cooled to around 60^{0}C (Drinkable temperature). Three cups per sample were prepared for tasting session. Aroma (aromatic quality and intensity), acidity, body, bitterness and astringency were scored using scales ranging from 0 to 5 (Table 3). Typical flavor was assessed as an after taste aromatic quality.

Table 3. Quality parameters and their descriptive value

	Character		Description of each scale					
		Scale	0	1	2	3	4	5
1	Aromatic intensity	0-5	Nill	Very light	Light	Medium	Strong	Very strong
2	Aromatic quality	0-5	Nill	Very light	light	Medium	Strong	Very strong
3	Acidity	0-5	Nill	Very light	light	medium	Strong	Very strong
4	Astringency	0-5	Nill	Very light	light	medium	Strong	Very strong
5	Bitterness	0-5	Nill	Very light	light	medium	Strong	Very strong
6	Body	0-5	Nill	Very light	light	medium	Strong	Very strong
7	Flavor	0-5	Nill	Very light	light	medium	Strong	Very strong
8	Overall standard	0-5	Nill	Very light	light	medium	Strong	Very strong
9	Shape and make	1-5		Small	Mixed	average	good	Very good
10	Over screen 14	%	Described in percentage					

Statistical Analysis

Analysis of variance (ANOVA)

All physical and organoleptic quality data were subjected to statistical analysis in a randomized complete block design(RCBD) using XLSTAT, and SAS (SAS, 2002) version9.2 software's. Mean separation was done using Least Significant Difference (LSD at $P < 0.05$). Combining ability analysis was performed using SAS DiallAll05 program of SAS statistical software version 9.2 (Zhang *et al.,* 2005). Individual locations ANOVA was done for each of the three locations, separately, and then combined ANOVA over the three locations was done for the traits that showed homogeneity of error variances namely: aromatic intensity (AI), astringency (AST), bitterness (BIT),body (BOD), flavor (FLA), over all standard (OVS)

shape and make (SH and MK) and over screen 14(OS14) following (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Analysis of variance for across location

Both, the genotypes and test locations showed highly significant difference for the quality traits in the across locations combined ANOVA for the studied quality traits (Table 4). The fact that the genotypes showed significant difference indicates the presence of reasonable difference among genotypes for the quality traits. The combined ANOVA revealed highly significant ($p<0.01$) genotype x location interactions for aromatic intensity (AI), bitterness (BIT), body (BOD), flavor (FLA), overall standard (OVS) and significant ($P<0.05$) for astringency (AST) and shape and make (SH and MK). The reason that all the quality parameters exhibited significant genotype x environment interaction suggests the importance of environmental factors in determining coffee quality. This result was in line with the finding of Getu (2009) who reported highly significant interaction for all organoleptic quality attributes, except astringency and bitterness. Similarly, Agwanda *et al* (2003) reported the presence of strong Genotype x Environment interaction for quality traits that challenges the development of wide adapting cultivars across different environments. In contrast, Walyaro (1983) reported lower Genotype x Environment interaction for coffee quality traits, while Van der Vossen (1985) reported non-significant Genotype x Environment interaction. These results indicate the need to further investigate and understand the nature of Genotype x Environment interaction for coffee organoleptic quality traits.

Performance of Quality characters for parents and their crosses across the three environments

Liquor quality is undoubtedly the most important factor that determines the suitability of coffee for human consumption (Agwanda, 1999). Performance of hybrids and parental lines of each location is presented in table 5. Among the F1 hybrids P1 X P2, P1 X P5, P2 X P4, and P2 X P5 showed significantly higher aromatic intensity over the standard check Ababuna at Melko, while only hybrids P2 X P5 produced superior aromatic intensity over Ababuna at Mettu. At Tepi, F1 hybrids P1XP3, P1XP4, P2XP4, P2XP5, and P3XP4 showed better aromatic intensity than the check. Regarding the parental lines, P5 at Melko, P3 at Metu and P4 at Tepi produced significantly superior aromatic intensity than Ababuna. Six hybrids and two parents at Melko, three hybrids and one parent at Metu, nine hybrids and two parents at Tepi showed higher value than the respective mean value. Best aromatic intensity value was recorded for the parental line P3 at Metu followed by parental line P5 at Melko with respective value of 4.0 and 3.9.

Table 4:Mean squares of genotype, location, and their interactions for quality traits

* ,** significant at 0.05 and 0.01 probability level. Ns=non- significant AI=aromatic intensity, AST=astringency, BIT=bitterness, BOD=body, FLA=flavor, OVS=over all standard, SH&MK=shape and make, OS14=over screen 14

Source	Genotype	Loc	Genotype *Loc	Block	Error
DF	15	2	30	2	94
Quality parameters					
AI	0.123**	0.438**	0.097**	0.142**	0.001
AST	0.045**	0.001ns	0.011*	0.009ns	0.006
BIT	0.051**	0.074**	0.018**	0.005ns	0.003
BOD	0.077**	1.921**	0.195**	0.083**	0.001
FLA	0.343**	1.359**	0.097**	0.003ns	0.001
OVS	0.323**	0.843**	0.107**	0.003ns	0.0006
SH&MK	5.733**	0.674ns	2.363*	7.001**	0.026
OS14	4.102**	6.049**	1.900**	1.507*	0.001

Lower values of astringency (AST) and bitterness (BIT) are considered best, as both these traits are not desired quality traits in coffee. Hence, the lowest level of astringency of zero was found in F1 progenies P1XP3, P2XP3, and P4XP5 at Melko; P1XP3, P1XP5, P2XP3, P2XP4, P3XP5 and P4XP5 at Mettu; P1XP4, P2XP4, P3XP4, and P4XP5 at Tepi. Among the parental lines;P4 at Melko, P3 at Metu, P1 and P5 at Tepi produced the lowest astringency of zero. Similarly four of the F1 hybrids; P1XP4,P2XP5,P3XP4,P3XP5, and P4XP5

produced the lowest (zero) bitterness at Melko. On the other hand almost all F1's produced zero bitterness at Metu and only P1XP2, P2XP3 and P3XP5 produced the lowest bitterness zero. Among the parents; P3, P4 and P5 at Melko; all the parents, except P5 at Metu; P1 and P4 at Tepi produced the lowest bitterness result zero. In general, astringency and bitterness was relatively lower at Mettu compared to Melko and Tepi. Body (BOD) is one of the important estimators of coffee quality in which the mouth fullness of the coffee is manifested with high value of this characteristic (Agwanda, 1999). The higher body value exhibited by the parental lines P1, P3 and P5 than the standard check at Melko. Parental lines P3 at Metu, and P4 at Tepi showed relatively higher body value (Table 5). High average value of body was found at Melko followed by Metu and Tepi with 3.47, 3.39 and 3.09 body values, respectively.

Heterosis

Estimates of heterosis for some quality characters

The F1 hybrid P2XP4 gave positive and highly significant mid parent heterosis for aromatic intensity, while the F1 hybrids P1XP2, and P2XP5 produced positive and significant ($P<0.05$) mid parent heterosis for aromatic intensity (Table 6). None of the hybrids gave significant better parent heterosis for aromatic intensity. Positive and highly significant mid-parent heterosis is revealed in crosses P2XP4, and P2XP5 for body, while only cross P2XP4 showed significant ($P<0.05$) better parent heterosis for body. Hybrids P2XP4, and P2XP5 produced positive and highly significant mid-parent heterosis for flavor, while hybrid P1XP2 produced positive and significant mid parent heterosis for flavor. Only the cross P2XP5 gave positive and highly significant mid-parent heterosis for overall standard, while none of the crosses produced significant better parent heterosis for this trait. None of the hybrids produced significant mid parent and better parent heterosis for shape and make. Hybrids P1XP5, and P3XP5 gave positive and highly significant mid parent heterosis; while the mid parent heterosis of crosses P1XP4, P2XP5 and P4XP5 was positive and significant for over screen 14. Positive and highly significant heterosis was found for hybrids P1XP5, P3XP5 and P4XP5. In general hybrids P2XP4 and P2XP5 showed consistently high mid parent value for aromatic intensity, body and flavor.

Combining Ability

Analysis of variance of combining ability

Analysis of variance for combining ability revealed highly significant General Combining Ability (GCA) and Specific Combining Ability (SCA) for aromatic intensity, bitterness, body, flavor, overall standard, shape and make (Table 7). The result indicates that both additive and non-additive gene actions were important in the inheritance of these quality traits. However, the trait over screen14 showed significant SCA, indicating only non-additive gene action was important for the inheritance of this trait.

For all mentioned quality traits the relative contribution of SCA was found to be higher than the contribution of GCA indicating the relative predominance of non-additive gene action for the inheritance of these traits. The significant result of GCA x E and SCA x E for traits aromatic intensity (AI), astringency (AST), bitterness (BIT), flavor (FLV), overall standard (OVS) indicates that the gene actions (both additive and non-additive) are sensitive to environmental changes.

General combining ability effects

General combining ability effects of each parental lines for the different quality traits were estimated across locations (Table 8). None of the parental lines have significant GCA effect for aromatic intensity, bitterness, body and over screen 14. It is only P1 that showed positive and significant astringency, indicating that this parent is not important in reducing astringency that makes this parent undesirable for use as parental line in crosses, as astringency is undesirable trait in coffee. P1 showed negative and highly significant GCA effect for flavor; while P3 produced positive and highly significant GCA effect. This implies,P3 is the only parent that might be considered in the development of coffee hybrids with better flavor. Similarly, P3 is the only parent that might contributes additive genes to improve overall quality, shape and make in coffee, as depicted by the positive and highly significant GCA effect of this parent for overall quality, shape & make.

Table 5: Mean performance of parental lines and crosses in each of the test locations for quality characters

Entries	**Aromatic Intensity**			**Astringency**			**Bitterness**			**Body**			**Flavor**			**Over all standard**			**Shape &Make**			**Over screen 14 (%)**		
	Melko	Metu	Tepi	Melko	Metu	Tepi	Melko	Metu	Tepi	Melko	Metu	Tepi	Melko	Metu	Tepi	Melko	Metu	Tepi	Melko	Metu	Tepi	Melko	Metu	Tepi
P1XP2	3.8	3.1	3.6	0.17	0.17	0.17	0.13	0.0	0.0	3.5	3.3	2.9	3.2	3.2	2.8	3.3	3.2	2.9	12.0	14.0	13.0	99.0	97.0	98.7
P1XP3	3.5	3.4	3.8	0.0	0.0	0.25	0.0	0.0	0.25	3.1	3.4	3.6	3.2	3.3	2.9	3.2	3.5	3.1	12.0	12.0	13.0	98.0	98.3	98.0
P1XP4	3.5	3.7	3.8	0.08	0.3	0.0	0.42	0.0	0.42	3.4	3.4	3.1	2.8	3.1	3.1	3.0	3.3	3.3	12.0	13.0	13.0	99.3	97.3	99.0
P1XP5	3.8	3.5	3.5	0.33	0.0	0.17	0.5	0.0	0.08	3.5	3.4	3.0	2.8	3.2	3.0	3.0	3.2	3.2	12.0	12.0	14.0	98.7	97.7	99.0
P2XP3	3.6	3.5	3.3	0.0	0.0	0.08	0.58	0.0	0.0	3.7	3.4	2.9	3.0	3.0	3.0	3.2	3.1	3.0	12.0	12.0	12.0	97.3	98.3	96.0
P2XP4	3.7	3.5	3.8	0.08	0.0	0.0	0.33	0.0	0.25	3.6	3.5	3.0	3.2	3.4	2.7	3.1	3.5	3.0	13.0	12.0	12.0	99.0	97.7	98.7
P2XP5	3.7	3.8	3.8	0.17	0.50	0.17	0.0	0.0	0.5	3.8	3.7	2.6	3.4	3.6	2.6	3.5	3.7	2.8	13.0	12.0	14.0	99.0	98.0	99.0
P3XP4	3.5	3.5	3.8	0.25	0.25	0.0	0.0	0.0	0.25	3.3	3.3	3.4	3.3	3.4	2.9	3.3	3.4	2.9	14.0	14.0	14.0	99.0	97.7	98.3
P3XP5	3.5	3.2	3.6	0.25	0.0	0.08	0.0	0.17	0.0	3.5	3.4	2.9	3.0	2.9	2.9	3.2	2.9	3.0	14.0	12.0	12.0	98.7	98.3	98.3
P4XP5	3.5	3.4	3.6	0.0	0.0	0.0	0.0	0.0	0.08	3.0	3.4	3.4	3.0	3.3	3.0	3.0	3.4	3.0	13.0	12.0	12.0	98.3	98.0	98.3
P1	3.4	3.3	3.6	0.33	0.50	0.0	0.17	0.0	0.08	3.6	3.4	3.0	2.8	3.1	2.7	3.0	3.3	2.9	12.0	13.0	10.7	98.3	97.3	98.0
P2	3.4	3.1	3.4	0.13	0.08	0.08	0.17	0.0	0.0	3.3	3.5	2.9	3.2	3.1	2.8	3.3	3.3	3.0	13.0	13.0	12.0	98.7	98.3	99.0
P3	3.7	4.0	3.4	0.08	0.0	0.08	0.0	0.0	0.0	3.8	3.7	3.3	3.8	4.0	3.5	3.8	4.1	3.7	15.0	15.0	14.0	98.0	98.0	98.0
P4	3.4	3.3	3.8	0.0	0.25	0.33	0.0	0.0	0.08	3.1	3.1	3.4	3.0	2.9	3.0	3.2	3.1	3.1	14.0	12.0	14.0	98.3	97.7	97.7
P5	3.9	3.3	3.5	0.33	0.25	0.0	0.0	0.08	0.0	3.8	3.2	3.0	3.5	3.1	3.0	3.6	3.0	3.1	10.0	12.0	12.0	94.7	97.3	98.0
Ababuna	3.6	3.6	3.6	0.08	0.25	0.0	0.0	0.17	0.25	3.5	3.3	3.0	3.3	3.3	2.8	3.3	3.3	2.9	12.0	12.0	14.0	97.3	94.7	97.3
Mean	**3.5**			**0.1**			**0.1**			**3.3**			**3.1**			**3.2**			**12.7**			**98.0**		
F test	**			*			**			*			**			**			**			**		
LSD (5%)	0.19			0.07			0.05			0.23			0.17			0.17			1.19			0.78		
CV(%)	5.8			9.62			7.4			7.5			5.9			5.6			10.0			0.9		

* ,** significant at 0.05 and 0.01 probability level

Table 6: Estimates of over mid-parent and over better parent heterosis for organoleptic and physical quality characteristics of coffee hybrids across locations

Crosses	Heterosis percentage											
	Aromatic intensity		Body		Flavor		Overall standard		Shape and Make		Over screen 14	
	OMP	OBP	OMP	OBP	OMP	OBP	OMP	OBP	OMP	OBP	OMP	OBP
P1XP2	3.9*	1.7	-2.4	-3.6	3.6*	0.3	-0.3	-2.2	5.9	2.6	-0.1	-0.5
P1XP3	-0.8	-4.6	-2	-5.8	-5.3	-16.5	-6.1	-15.8	-7.2	-16	0.2	0.1
P1XP4	5.2	4.3	0.8	-0.9	2.6	0.3	3.6	2.6	0.5	-5	0.7*	0.7
P1XP5	2.7	0.8	-0.5	-0.6	-1	-6.3	0.3	-2.5	9.1	6.6	1.2**	0.6**
P2XP3	-4	-9.4	-2.3	-7.2	-11.2	-19.5	-11.6	-19.4	-12.2	-18.2	-1.1	-1.5
P2XP4	7.7**	4.6	4.8**	4.3*	2.6**	1.6	0.6	-0.3	-5.2	-7.5	0.2	-0.2
P2XP5	8.6*	4.5	2.6**	1.5	2.4**	0	3.1**	2.2	8.3	2.6	1*	0
P3XP4	-1.1	-4	-2.5	-7.8	-5.9	-15.5	-8.9	-17.6	0	-4.6	0.4	0.3
P3XP5	-4.8	-6.7	-5.6	-9.4	-15.1	-21.3	-14.9	-21.8	-2.5	-13.6	1.1**	0.4**
P4XP5	-0.1	-1.1	0.6	-0.9	0.2	-3.1	-1.6	-3.4	0	-7.5	1*	0.3**

*,** significant at 0.05 and 0.01 probability levels, respectively

Table 7:Mean squares due to general combining ability and specific combining ability for quality characters in coffee diallel crosses across location

Sources of variation	Df	Traits							
		Aromatic intensity	Astringency	Bitterness	Body	Flavor	Overall quality	Shape & Make	Over screen14
GCA	4	0.0029**	0.0197**	0.0113**	0.0050**	0.0178***	0.0097***	0.0989**	0.0019
SCA	10	0.0093***	0.0234***	0.0255***	0.0036**	0.0178***	0.0193***	0.0827**	0.0079***
GCA X E	8	0.0053***	0.0110*	0.0191***	0.0251***	0.0063***	0.0083***	0.0364	0.0063***
SCA X E	20	0.0055***	0.0211***	0.0298***	0.0105***	0.0077***	0.0075***	0.0440	0.0032***
Error	84	0.0013	0.0059	0.0032	0.0013	0.0009	0.0005	0.0269	0.0008
Relative contribution of GCA		11.1	25.2	15.0	36.2	28.6	16.7	32.4	8.7
Relative contribution of SCA		88.9	74.8	85.0	63.8	71.4	83.3	67.6	91.3

*= significant at P<0.05, **= significant at P<0.01, and ***= significant at 0.001

Specific combining ability effects

The F1 progenies P2XP5 showed positive and highly significant specific combining ability, while the SCA effects of the crosses P2XP4 and P2XP3 were positive and negative, respectively, and significant at (P<0.05) for aromatic intensity (Table 9). Negative and highly significant SCA effect was found in the cross P3XP5 for the trait aromatic intensity. Negative and highly significant SCA effect was found for a cross P4XP5 for astringency, while the SCA effect of the F1 hybrid P3XP4 was positive and significant at (P<0.05) for the same trait. This shows that P3XP4 cross is a desirable cross in maintaining astringency low. Positive and highly significant SCA effect was found in a cross P1XP4 for bitterness; indicating that this cross is not good cross combination for bitterness; while the cross P1XP2 showed negative and significant SCA effect which makes this cross combination the only good cross in reducing bitterness. None of the crosses produced significant SCA effect for body. SCA effect of the cross P2 XP3 was consistently negative and highly significant for the traits flavor, overall quality, shape and make; while similar negative and highly significant SCA effects were found in a cross P3XP5 for the quality traits flavor, overall quality, and negative and significant at (P<0.05) for shape and make indicating these cross combination are undesirable for improving coffee quality.

Table 8**:** Estimates of General combining ability effects of parental lines for quality characters in coffee diallel crosses across location

Parents	GCA effects of each Traits							
	Aromatic intensity	Astringency	Bitter ness	Body	Flavor	Overall quality	Shape & Make	Over screen 14
P1	-0.0009	0.0228*	0.0140	-0.0037	-0.021**	-0.007	-0.028	0.003
P2	-0.0096	-0.003	0.0098	-0.0042	-0.002	-0.003	-0.015	0.003
P3	-0.0036	-0.023	-0.0182	0.0169	0.028***	0.023***	0.057**	-0.008
P4	0.0077	-0.0144	0.0062	-0.0044	-0.005	-0.007	0.030	0.006
P5	0.0064	0.0154	-0.0118	-0.0046	-0.001	-0.006	-0.044	-0.004
SE (gi)	0.0083	0.011843	0.015586	0.0178	0.008979	0.010238	0.021492	0.00897
SE (gi-gj)	0.0131	0.018725	0.024643	0.0282	0.014196	0.016188	0.033982	0.01418

* = significant at P<0.05, **= significant at P<0.01, and ***= significant at 0.001, SE (gi)= standard error of general combining ability effects, SE (gi-gj)= standard error of the difference of general combining ability effects

Table 9**:** Estimates of specific combining ability effects of F1 Hybrids of coffee for quality characters across locations

Crosses	SCA effects of each Traits							
	Aromatic intensity	Astringency	Bitter ness	Body	Flavor	Overall quality	Shape & Make	Over screen 14
P1XP2	-0.0048	0.0072	-0.0662*	-0.0216	0.0160	-0.0064	0.0816	-0.0044
P1XP3	0.0058	-0.0250	-0.0104	0.0062	0.0035	0.0010	-0.0784	0.0011
P1XP4	0.0178	-0.0136	0.0762**	0.0031	0.0020	0.0192	-0.0073	0.0100
P1XP5	0.0304	-0.0538	0.0858	-0.0058	0.0173	0.0229	0.1289	0.0356
P2XP3	-0.0311*	-0.0348	0.0504	-0.0078	-0.0456**	-0.0415**	-0.1366**	-0.0433***
P2XP4	0.0298*	-0.0412	0.0371	0.0235	0.0095	0.0045	-0.0655	0.0044
P2XP5	0.0896***	0.0871	0.0827	0.0260	0.0376	0.0298	0.0738	0.0078
P3XP4	0.0005	0.0621*	-0.0060	-0.0087	-0.0029	-0.0181	0.0856	0.0100
P3XP5	-0.0722**	-0.0040	0.0291	-0.0651	-0.1767***	-0.1842***	-0.1662*	0.0189
P4XP5	0.0091	-0.1476**	0.0180	0.0191	0.0271	0.0009	-0.0596	0.0267
$SE(S_{ij})\pm$	0.021614	0.042245	0.05021	0.02975	0.025515	0.025232	0.061050	0.016417
$SE(S_{ij}-S_{ik})\pm$	0.032421	0.063367	0.07531	0.04462	0.038273	0.037848	0.091575	0.024626
$SE(S_{ij}-S_{kl})\pm$	0.029596	0.057846	0.06875	0.04073	0.034938	0.034551	0.083596	0.022481

* = significant at P<0.05, **= significant at P<0.01, and ***= significant at 0.001, S.E (Sij)± =standard error of specific combining ability effect; S.E (Sij-Sik)± =standard error of the difference of specific combining ability having one parent in common and S.E (Sij-Skl) ± =standard error of the difference of specific combining ability effects of the crosses having no parents in common.

CONCLUSIONS

The study was conducted on hybrid coffee where parental lines originated from Southwestern Ethiopia coffee growing areas. The objectives were to determine the magnitude of heterosis and identify single cross *coffea arabica* hybrids for quality characteristics and thus; to estimate GCA of selected parents, and SCA of hybrids. The experimental material consisting of five indigenous *coffea arabica* lines namely P1(75227), P2 (744), P3 (74148), P4 (F34) and P5(206/71) which were selected based on yield, quality, disease resistance and different morphological characteristics. The lines were crossed in half diallel fashion as per Griffing (1956) model I method 2 to produce 10 F1 hybrids. The F1's, parental lines and check hybrid Ababuna planted at Melko, Metu and Tepi research centers situated in Southwestern Ethiopia major coffee growing areas. The design used was RCB design in three replications. The data were recorded for quality characters.

The mean value of hybrids is less than the mean value of parental lines for quality characters. This result is in opposite of yield and other morphological characters. So, coffee breeders supposed to selected best parent having good yield and reasonably quality to go for crossing.

Heterosis for quality characters was dominantly negative over mid and better parent. This might indicate that these quality traits controlled by recessive genes, which might have been masked under heterozygous conditions. Some of the F1's revealed quality nearly similar value with that of maternal parent having better quality character; which might indicate cytoplasmic inheritance of quality characters. This calls for the need to further study the inheritance of these quality traits by crossing the best quality parents with known poor quality parents.

GCA and SCA for Aromatic intensity, Bitterness, Body, Flavor, Overall standard shape and make were significant indicating importance of both additive and non-additive gene actions in the inheritance of these quality traits. For the majority of quality traits the relative contribution of SCA found to be high than the contribution of GCA indicating the relative greater importance of non-additive gene action for the inheritance.

The study also revealed highly significant and positive general combining ability effect for the parent P3 (74148) for traits: flavor and overall quality; higher positive value for body and physical quality character shape and make. This shows the importance of the parental line for the contribution of additive genes in improving the quality traits in the future coffee quality breeding program. For the trait aromatic intensity cross P2xP4 and P2xP5 were found to be good combinations showing positive and significant SCA effects. Those cross combinations having negative significant SCA effects were P3xP4 and P4xP5 for astringency. Since this trait is negatively quality affecting trait the mentioned cross combinations appeared to be good combinations. Similarly bitterness is the other negatively affecting organoleptic quality character for coffee. Cross combination P1xP2 had shown negative and significant combination and appeared to be good combination for this trait. No significant SCA effect was observed for body, flavor and overall over screen 14, shape and make.

REFERENCES

Agwanda. 1999. Flavour: an ideal selection criterion for the genetic improvement of liquor quality in Arabica coffee.In Proceedings of the 18th International Conference on Coffee Science (ASIC '99), pp. 302–307, Paris, France, 1999.

Agwanda, R.W., Baradat, A.B., Eskes, C., Cilas and A. Charrier. 2003. Selection for bean and liquor qualities with in related hybrids of Arabica coffee Arabica coffee in multi-local field trials. Euphytica, 131: 1-14.

Alemayehu T. N., Pétiard V., Broun P. and Crouzillat, 2010. Molecular genetic diverstiy of Arabica coffee (Coffeaarabica L.)Using SSR Markers. ASIC conference, Bali (IND) Oct 2010, to be published.

Anthony F., Combes M. C., Astorga C., Bertrand B., Graziosi G. and P. Lashermes, 2002. The origin of cultivated Coffeaarabica L. varieties revealed by AFLP and SSR markers. Theor Appl Genet, 104:894–900.

Ashenafi, A., 2013. Heterosis and Combining Ability for Morphological, Yield and Quality Characters in Coffee(Coffea arabica L.)Hybrids. A Thesis Submitted to the School of graduate Studies. Jimma University College of Agriculture and Veterinary Medicine.

BayettaBelachew, 2007. Terminal report. Coffee breeding and genetics research division. Dec.2007. EIAR, JARC.

Baytta, B., Behailu, A., and Gibramu, T. 1998. Description and production Recommendation for new Cultivars of Coffee.IAR Research Report, No. 34.

Behailu, W., Abrar, S., Negussie, M., and Solomon, E. 2007.Coffee Processing and Quality Research in Ethiopia.*In*: Proceedings of the workshop on four decades of coffee research and development in Ethiopia: A National workshop, 14-17 August 2007, Addis Ababa (Ghion Hotel), Ethiopia.

Bertrand B, Vaast P, Alpizar E, Etienne H, Davrieux F, Charmetant P. 2006. Comparison of bean biochemical composition and beverage quality of arabica hybrids involving Sudanese-Ethiopian origins with traditional varieties at various elevations in Central America. Tree Physiol 26:1239–1248

Bertrand B, Etienne H, Cilas C, Charrier A, Baradat P. 2005. *Coffeaarabica* hybrid performance for yield, fertility and bean weight.Euphytica 141:255–262

BrhanuDebele. 1978. Preliminary report for detailed soil survey of Jima Agricultural Research Station, IAR. Appendex No. 1, Addis Abeba.

Getu, B. 2009.Genotype X Environment interaction of arabica coffee (coffeaarabica L.) for bean biochemical composition and organoleptic quality characteristics.Msc. Thesis presented to school of graduate studies of Haramaya University.

Gravios, K.A. and McNew. 1993. Combining ability and heterosis in U.S. southern long rice grain. Crop sci. 33:90-95.

Gomez, K.A., and A.A. Gomez.1984.Statistical Procedures for agricultural research.Second edition.John Willy and Sons. Inc., New York.

Griffing, B. 1956.Concept of general combining ability and specific combining ability in relation to diallel crossing system.*Austr. Jour. Biol. Sci.,* 9: 463-493.

IAR, 1969. Jima research station coffee department progress report for the period 1967-69,IAR, Addis ababa, pp. 1-2.

Inamullah, H. Ahmed, F. Muhammad, Sirajuddin, G.Hassan and R. Gul. 2006. Evaluation of heterotic and heterobeltiotic potential of wheat genotype for improved yield. *Pak. J. Bot.,* 38(4): 1159-1168.

Kambal, A.E. and O.J. Webster. 1965. Estimate of general combining ability in grain *sorghum vulgare.* Crop Sci. 5:521-523.

Labouisse, J.P. 2006. Summary of passport data of coffee germplasm maintained at JARC. Ethiopian Institute of Agricultural Research, Jima.Unpublished.

MesfinAmeha and Bayettabellachew. 1983. Heterosis in crosses of indigenous coffee (coffee Arabica L.). Selected for yield and resistance to coffee berry disease II- First three years. Ethiopian Journal of Agricultural Science, V: 13-21. Addis Ababa, Ethiopia.

MesfinAmeha. 1982. Heterosis in crosses of indigenous coffee (coffee Arabica L.). Selected for yield and resistance to coffee berry disease at first bearing stage.Ethiopian Journal of Agricultural Science. 4: 33-45. Addis Ababa

MOA. 2010. Crop Variety Register Issue No.13. Minstry of Agriculture.Animal and Plant Health Regulatory Directorate. June 2010. Addis Ababa, Ethiopia

MoANR., 2016. Minstry of Agriculture and Natural Resource.Plant Variety Release, Protection and Seed Quality Control Directorate. Issue No.19.June 2016. Addis Ababa, Ethiopia

Paulos, D. 1994. Mineral fertilization of coffee in Ethiopia.Institute of Agricultural Research, Addis Abeba.

SAS (statistical Analysis System Institute).2002. Statstical Analysis System Software.V.g. SAS institute Inc., Cary, NC USA.

TesfuKebede and ZebeneMikru. 2006. The nutrient status of long term fertilized soils of coffee plantation in south western Ethiopia. Paper presented on 22nd International Conference on Coffee Science, ASIC, 11 to 15 September 2006. Monpellier, France.

Van der Vossen, H.A.M. 1985. Coffee selection and breeding. In: coffee botany, biochemistry and production of beans and beverage. Eds M.N. Clifford and K.C.WilsonCroom Helm, London, New york, Sidney.

Walyaro, D.J. (1983). Consideration breeding for improved yield and quality in arabica coffee (coffeaarabica), PhD thesis, Agricultural University, Wageningen.

Wassu Mohammed. 2004. Heterosis and combining ability analysis of yield and yield related traits in coffee (*coffeaarabia L.*). M.sc Thesis, Alemaya University of agriculture, Alemaya, Ethiopia.

Woldemariam, T., M. Denich, D. Teketay and P.L.G. Vlek, 2002.Human impacts on Coffeaarabica.L. genetic pools in Ethiopia and the need for its in situ conservation. pp. 237-247. In: J.M.M. Engels, V.R. Rao, A.H.D. Brown and M.T. Jackson (Eds.), Managing plant genetic diversity. IPGRI, Rome.

WorkafesWoldetsadik and Kassu Kebede.2000.Coffee production system in Ethiopia. Pp 90-106. In: Proceedings of work shop on control of coffee berry disease in Ethiopia.13-15th. August 1999, Addis Ababa, Ethiopia.

Wrigly, G. 1988. Coffee. Tropical agriculture series. Longman Scientific and Technica, Longman group UK Limited, England.

Zhang, Y., Kang, M.S., and Lamkey, K.R. 2005.Diallel SAS05. A comprehensive program forGriffing's and Gardener-Eberhart. Analysis. Agronomy Journal 97: 1097-1106.