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Hybrid Vigour Study of Yield and Yield Related Characters on Limmu Coffee (*Coffea arabica* L.) Genotypes at South-Western Ethiopia

Gemechu Asefa*[A, C], Hussein Mohammed[B] and Ashenafi Ayano[A]

[A] Ethiopian Institute of Agricultural Research, Jimma Agricultural Research Center, Jimma, Ethiopia
[B] Hawassa University College of Agriculture, School of Plant and Horticultural Sciences, Hawassa, Ethiopia
[C] Ethiopian Institute of Agricultural Research, Bako National Maize Research Center, Bako, Ethiopia

*Corresponding author; email: gameasefa12@gmail.com

Abstract

Coffee (*Coffea arabica* L.) is one of the most important crops cultivated worldwide and has a great economic impact in many countries including Ethiopia. Hybrid vigor (heterosis) breeding can enhance productivity of coffee. Hybrid vigor study was conducted on 5 x 5 half-diallel mating involving 17 coffee genotypes (5 parents, 10 F_1 hybrids and two checks) for yield and its related traits in 2018. The study locations include Jimma, Agaro and Gera research centers of south-western Ethiopia using randomized completely block design with three replications. There are significant differences among 17 genotypes and 15 diallel genotypes (checks excluded) for all traits; the crosses showed significant and positive average heterosis (mid parent) and heterobeltiosis (better parent) for all traits. Crosses showed significant variation in the expression of standard heterosis (SH) and useful heterosis (UH) for fruit length (FL), fruit width (FW), bean length (BL), bean width (BW), bean thickness(BT), and hundred bean weight (HBW) across locations. Heterobeltiosis ranged from -9.06 to 88.79% and -17.81 to 67.98% for yield at Jimma and Gera, respectively. Mean SH and UH was positive and between 5 and 10% for BL and BT and <5% for all fruit characters and BT across locations. Mean of SH and UH was 14.62% and 11.82%, respectively for HBW. Crosses P_4 x P_5, P_1 x P_5 and P_2 x P_5 increased yield by 25.13% (637.75 kg), 14.05% (356.64 kg) and 5.78% (146.59 kg) over commercial pure line variety across three locations, respectively. Based on heterosis and mean performance hybrids P4 x P5, P1 x P5, P3 x P5, and P1 x P2 found as promising hybrids for yield and bean characters. Thus, these hybrids should be advanced in the next breeding program and tested through incorporating other traits.

Keywords: coffee, heterobeltiosis, heterosis, vigour

Introduction

Arabica Coffee (*Coffea arabica* L.) which is a tetraploid (2n= 4x = 44), belongs to genus *Coffea* and family Rubiaceae (Davis et al., 2006). Coffee is one of the most important agricultural cash crops in the world; it occupies the second position after oil in terms of monetary value worldwide (Musoli et al., 2009). The worldwide coffee production in 2017/18 was 9.59 million ton, of which about 5.69 million ton (59.3%) was *C. arabica* while the remained was *C. canephora* (FAS, 2018).

In Ethiopia, the annual production of *C. arabica* L. in 2017/18 was about 423.3 ton (7.4%) that would rank the country as the first producer of *C. arabica* L. in sub-Saharan Africa, and the fourth largest producer of *C. arabica* L. in the world after Brazil, Colombia and Honduras (FAS, 2018). In 2015/16, Ethiopia exported around 180,000 tons of coffee at a value in excess of 800 million USD, which makes the world's fifth largest coffee exporter (ICO, 2016). The total area of production in Ethiopia is estimated to be about 758,523.29 ha (CSA, 2020). The estimated annual national production of clean coffee 482.56 tons and the national yield of coffee is 636.2 kg per hectare, which is quite low (CSA, 2020).

Economically, coffee provides US$ 90 billion per year in the global market (ICGN, 2017). In Ethiopia, it provides 30% of the foreign exchange earnings (ICO, 2014). About 15 to 16 million people are directly or indirectly deriving their livelihood from coffee (Abu et al., 2013 and Kufa, 2013). Even if, a coffee play significant role in the national economy and it becomes today's one of the leading marketable commodity next to oil, the average national productivity has not exceeded 636.2 kg per ha (CSA, 2020). Various authors have reported different major contributing factors for such low yields like lack of resistant varieties to various disease and insect pests, lack of pure line and hybrid varieties to produce high yield (Eshetu et al., 1999; Bayetta, 2001; ACRP, 2015).

Among several strategies of enhancing coffee production, development of hybrid coffee appears to be one of the important approaches to enhance the levels of productivity under coffee producing environments. The utilization of the effect of heterosis is considered to be one of the most outstanding achievements of the coffee breeders in the last 40 years. With constant and concerted efforts, hybrids have been produced in coffee by Ethiopian Institute of Agricultural Research (EIAR), Jimma Agricultural Research Center (JARC). Over the last four decades (1977-2018), 42 coffee varieties i.e., thirty-five pure lines and seven hybrids, were released for various major coffee growing agro-ecologies of the country (Tadesse, 2017; JARC, 2018).

For successful exploitation of heterosis and developing the stable performance of the hybrid, the crucial and most important requirement is choice of promising genotypes from the diverse genetic base. In Ethiopia, the presence of high level of heterosis in crosses among elite indigenous coffee (*Coffea arabica* L.) cultivar has been well determined. Different authors dealing with various aspects of hybrid coffee found level of heterobeltiosis (heterosis over better parent) for yield ranging from 60 to 120% (Mesfin and Bayetta, 1983), 9.6 to 120.3% (Bayetta, 2001), -41.13 to 98.23% (Mohammed, 2004), 12.1 to 41.8% (Ayano, 2013) and 4.68 to 56.10% (Asefa, 2018).

Ayano (2013) and Tefera (2017) reported the expression standard heterosis (heterosis above the standard hybrid variety check) of coffee yield, which was ranged from -27.9 to 11.5% and -36.8 to 29.5% and, respectively. The expression of useful heterosis (heterosis above pure line variety check) for coffee yield which was ranged from -33.9 to 68 0% and -5.8 to 10.2% also reported by Tefera (2017) and Asefa (2018), respectively.

Limmu coffee is one of the coffee types of Ethiopia that is distinguished for its very fine quality that is acclaimed for its unique wine flavor characteristics (Woldetsadik and Kebede, 2000). It shares 11% of washed exported coffee (Nure, 2008). The presence of genetic diversity among parental lines is the most important requirement in breeding program for exploitation of heterosis. Different authors Kitila et al. (2011) ; Beksisa and Ayano (2016) ; Beksisa et al. (2017) ; Weldemichael et al. (2017) reported the presence of the genetic diversity among Limmu Coffee germplasm accessions and the possibility of developing improved varieties through selection and/or hybridization.

Estimation of heterosis for yield and yield related characters is useful to judge best hybrid combinations for exploiting superior hybrids among limmu coffee genotypes. However, information on heterosis for yield and yield related characters among limmu coffee landrace was not assessed. Therefore, the present study has been carried out for the objective to estimate the magnitude of heterosis(%) over mid-parent, better parent and standard check, and to generate information about heterosis for yield, fruit and bean characters of limmu coffee types tested in south western Ethiopia.

Materials and Methods

Description of the Study Area

The experiment was conducted in three representative sites of major coffee growing areas in southwestern Ethiopia, i.e. Jimma Agricultural Research Center (JARC), Gera Agricultural Research Sub-centre (GARSC) and Agaro Agricultural Research Sub-centre (AARSC) (Table 1). The first two locations (Jimma and Agaro) represent mid altitude area where as Gera represents a highland area.

Table 1. Summary of ecological description of the study sites

Location	Altitude (m a.s.l.)	RF (mm)	RH (%)	Coordinate		Temperature (^{0}C)		Soil	
				Latitude	Longitude	Min.	Max.	Type	pH
Jimma	1753	1572	67	7^{0}40’00’’N	36^{0}47’00’’E	11.6	26.3	Reddish brown/ nitosols	5.2
Agaro	1650	1616	-	7^{0}50’35’’N	36^{0}35’30’’E	12.4	28.4	Mollic nitosols	6.2
Gera	1940	1878.9	75.03	7^{0}7’0’’N	36^{0}00’00’’E	10.4	24.4	Loam	-

Source: Jimma Agricultural Research Center (JARC) profile; m a.s.l.= meter above sea level; RF= rainfall; RH = Relative humidity; Min and Max = Minimum and maximum average annual temperature.

Experimental Materials

Limmu coffee genotypes were collected from Limmu-kossa in 2001 and 2003 G.C. Among collected genotypes five elite advanced pure lines promoted to verification trials were selected as parents were crossed in a half diallel fashion in 2014 and resulted ten hybrids by $\frac{p(p-1)}{2}$ formula p is number of parental lines. The main characteristics of the five selected parental lines were indicated in Table 2. One month after harvest, seeds of the parents and their respective F1 hybrid $\frac{p(p+1)}{2}$ = 15 entries were sown at nursery along two checks in December 2014 G.C. This study was conducted on this established nursery. Summary of all experimental materials (parents, their crosses and the checks) described in Table 3.

Experimental Design and Field Management

Five parental lines and their respective 10 F1 hybrids along two checks were sown in polythene tubes filled with a finely prepared mixture of top-soil and sand soil in December 2014. Six months old seedlings were transplanted in the field in July, 2015, at Jimma, Agaro and Gera research centers that represent the Limmu coffee growing area. One-row plots consisting of six plants and a spacing of 2m x 2m were used area. The experiments were laid down in three replications of the randomized completely block design. All agronomic crop management practices were uniformly applied to the plots following the recommendation from Jima Agricultural Research Centre. The experimental plots were maintained under temporary shade trees known as *Sesbania sesban,* planted with 4 m x 4 m spacing.

Data Collected

Yield data taken from all plants whereas fruit and bean characters were taken from the entire four plants of each entry. The quantitative traits were recorded as recommended by IPGRI (1996), including yield, fruit and bean characteristics. Yield is the total fresh cherries harvested per plot or from all trees during the first two years (2017 and 2018) bearing season and weighed in grams per plot basis and converted in to clean coffee (kg.ha^{-1}). Fruit characteristics were measured from five normal matured fruits as recommended by IPGRI (1996). Fruit length (FL) (mm) is the average length of five normal matured fruits of each sample tree, measured at the longest part using digital caliper. Fruit width (FW) (mm) is the average width of five normal matured fruits of each sample tree was measured at widest part using digital

Table 2. Parental lines selected for crossing and their morphological descriptions

Parents	Origin			Altitude (m.a.s.l.)	Description
	Zone	Woreda	Collection place		
P_1	Jimma	Limmu-kossa	Tenebo	1650	High yield, open canopy, vigorous, stiff stem, bold and oblong bean, deep green leaf, good survival
P_2	Jimma	Limmu-kossa	Eyru	1600	High yield, many primary, secondary and tertiary fruit bearing branches, vigorous, intermediate canopy, open fruiting nodes, 100% survival, moderate resistance to coffee leaf rust (CLR)
P_3	Jimma	Limmu-kossa	Weleke-Sombo	1550	Moderate resistance to coffee berry disease (CBD), strong branching, many primary, secondary and tertiary branches, good fruit setting (high yield), late maturing nature, compact canopy, 100% survival rate
P_4	Jimma	Limmu-kossa	Cheraki	1500	Compact canopy, leafy (good leaf to stem ratio), vigorous stem, good resistance to coffee berry disease (CBD) and coffee leaf rust (CLR)
P_5	Jimma	Limmu-kossa	Chime	1660	High yield (large number of fruits from top to bottom), 100% survival, vigorous, compact canopy, moderate resistance to coffee leaf rust (CLR).

Source: Extracted from passport data file at Jimma Agricultural Research Center (JARC) Coffee Breeding and Genetics Department; P= parental line; m a.s.l. = meter above sea level.

Table 3. List of experimental materials with designations

No	Codes for parents, crosses and checks	Designation
1	P_1	L20/03
2	P_2	L67/01
3	P_3	L03/01
4	P_4	L55/01
5	P_5	L45/01
6	P_1 x P_2	L20/03 x L67/01
7	P_1 x P_3	L20/03 x L03/01
8	P_1 x P_4	L20/03 x L55/01
9	P_1 x P_5	L20/03 x L45/01
10	P_2 x P_3	L67/01 x L03/01
11	P_2 x P_4	L67/01 x L55/01
12	P_2 x P_5	L67/01 x L45/01
13	P_3 x P_4	L03/01 x L55/01
14	P_3 x P_5	L03/01 x L45/01
15	P_4 x P_5	L55/01 x L45/01
16	Hybrid check at Jimma and Agaro(Check1)	Ababuna
	hybrid check at Gera(Check1)	Gawe
17	Pure line check at Jimma and Agaro(Check2)	Dessu
	Pure line check at Gera(Check2)	74110

caliper. Fruit thickness (FT) (mm) is the average of five normal matured fruits of each sample tree was measured at the thickest part using digital caliper.
Bean characteristic measurement includes bean length (BL) (mm), i.e. the average length of ten normal beans of each sample tree was measured at the longest part using digital caliper; bean width (BW) (mm) is the average width of ten normal beans of each sample tree was measured at the widest part using caliper; bean thickness (BT) (mm) is the average thickness of ten normal beans of each sample tree was measured using digital caliper. Hundred bean weight at 11% moisture (HBW) (g) is the average of 100 matured beans was used to calculate hundred bean weights. Oven was used for drying of beans to make 0% moisture content and weight was recorded using sensitive balance by the following formula.

100-bean weight (g) at 11% moisture content =
[bean dry weight/(bean number x 0.89)] x 100

Statistical Analysis

Statistical analysis system (SAS) computer program version 9.3 Proc Mixed procedures was used to analysis collected data. The statistical analysis contained treatments as a fixed factor while block and location as random factors. Analysis of variance was carried out according to the procedure recommended for randomized completely block design to determine the existence of significant difference among the genotypes.

Heterosis Estimation

The estimates of mid-parent heterosis(MPH), better parent heterosis(BPH) and standard heterosis(SH) were calculated as the deviation of F1 from the corresponding mean performances described below following the method suggested by Nyquist (1991) and useful heterosis (UH) was calculated following method suggested by Pathak and Parkash (1976). Across the environment heterosis was calculated where error variance was homogeneous and mean square due to genotypes were significant.

Mid parent heterosis (MPH) = [(F1-MP)/MP] x 100
Heterobeltosis (BPH) = [(F1-BP)/BP] x 100
Standard heterosis (SH) = [(F1-SV)/SV] x 100
Useful heterosis (UH) = [(F1-CC)/CC] x 100
Mid parent (MP) = (P1 + P2)/2

where F1 is the mean performance of F1 hybrid, BP is mean performance of better parent, SV mean performance of commercial check hybrid, CC the mean performance of commercial check variety. In this study, commercial hybrid check (SV) at Jimma and Agaro was Ababuna where as at Gera Gawe coffee hybrid was used to calculate standard heterosis (SH). Commercial coffee check variety (CC) at Jimma and Agaro was Dessu and at Gera 74110 coffee variety to calculate useful heterosis (UH).

Test of significance for heterosis was made by using the t-test and t-value computed as follows:

t- Computed for mid parent heterosis (Average heterosis) is

$$t = \frac{F1 - MP}{\sqrt{3MSE/_{2r}}}$$

t- Computed for better parent heterosis (Heterobeltiosis) is

$$t = \frac{F1 - BP}{\sqrt{2MSE/_{r}}}$$

t- Computed for Standard heterosis is

$$t = \frac{F1 - SV}{\sqrt{2MSE/_{r}}}$$

t- Computed for Useful heterosis is

$$t = \frac{F1 - CC}{\sqrt{2MSE/_{r}}}$$

where MSE is Error mean square, r is number of replications

The computed t-value was compared with t-table value at 5% and 1% degree of freedom of error.

Results and Discussion

The 17 genotypes (parents, hybrids and two standard checks) and diallel genotypes (checks excluded) showed highly significant for bean yield at Jimma and Gera (Table 4). Similarly, the difference between crosses and parents lonely was statistically significant for yield at these locations. This may indicated presence of genetic variance for yield within the parents and crosses that can be used in the further improvement of coffee yield. Different authors reported the presence of variability among different coffee diallel genotypes and / or crosses for bean yield (Bayetta, 2001; Mohammed, 2004; Ayano, 2013 ; Tefera, 2017 and Asefa, 2018). Diallel genotypes (parents and hybrids) and parents with environment interaction (Dg x E and P x E) showed highly significant difference for yield, which indicates differential response of diallel genotypes and parents across the three locations. For this, heterosis estimated for bean yield calculated at individual locations.

The combined ANOVA showed highly significant differences among 17 genotypes (checks included) and 15 diallel genotypes (only parents and crosses) for all fruit and bean characters (Table5). The statistical difference between crosses and parents was significant from p<0.05 to 0.001) for all fruit and bean characters except fruit thickness of crosses in combined locations. The presence of significant difference among these genotypes for these traits in the present study clearly indicated the presence of variability that provides the possibility to bring considerable improvement for these traits. Ayano (2015) and Tefera (2017) reported existence of variability among coffee genotypes for fruit and bean characters.

Dg x E showed non-significant difference for all fruit and bean characters except hundred bean weight (HBW). Interaction of crosses with environments (C

Table 4. Analysis of variance for mean squares in three locations for yield in 2017 and 2018

Source of variation	DF	Jimma	Agaro	Gera
Replication	2	178296.76^{ns}	77570.23^{ns}	7015.63^{ns}
Genotypes(G)	16	165792.05**	62867.60^{ns}	177733.42**
Diallel genotype(Dg)	14	190400.09***	53052.50^{ns}	192175.87***
Crosses	9	150819.35*	39447.40^{ns}	102902.63*
Parents	4	73860.17*	85722.59^{ns}	177599.75*
Error	32	59610.23	52008.69	37418.80
CV (%)		25.10	33.08	21.01

Note: values with *, ** and *** showed significant differences at 0.5, 0.1 and 0.01 probability level, respectively; ns= non-significant; DF = degree of freedom; CV = coefficient of variation

Table 5. Analysis of variance for mean squares of bean and fruit characters across locations in 2017

SOV	DF	Fruit characters				Bean characters			
		Yield	FL	FW	FT	BL	BW	BT	HBW
Environment (E)	2	161905.77**	14.95**	6.72**	13.03**	14.13**	1.13***	0.07 ns	43.79 ns
Rep (Environment)	6	51267.86ns	1.15 ns	0.55 ns	0.46 ns	0.33*	0.01 ns	0.06**	11.16**
Genotypes (G)	16	165895.27***	3.19***	1.21***	0.47**	2.86***	0.27**	0.30***	27.19***
Diallel genotype (Dg)	14	208263.5**	4.22***	1.83***	0.82**	2.66***	0.31***	0.25***	24.86***
Dg x E	28	98572.4**	0.81 ns	0.27 ns	0.24ns	0.16 ns	0.03 ns	0.02 ns	6.29*
Crosses (C)	9	268154.8**	2.41***	0.59**	0.29ns	2.10***	0.23***	0.20***	20.17***
Crosses x E	18	68214.8ns	0.532ns	0.14ns	0.12ns	0.16ns	0.02ns	0.01ns	3.16ns
Parents (P)	4	58535.4ns	5.46***	2.78**	0.73*	4.50***	0.49***	0.43***	41.12***
P x E	8	184578.8**	1.19*	0.27ns	0.23ns	0.15ns	0.04ns	0.04ns	8.75**
Error	84	44189.5	0.63	0.36	0.24	0.12	0.02	0.02	3.55
CV % (diallel)		27.0	4.86	4.52	4.30	3.38	2.12	3.16	9.77

Note: values with *, ** and *** showed significant differences at 0.05, 0.01 and 0.001 probability level, respectively; ns = non-significant; SOV = source of variation; DF = degree of freedom; FL = F=fruit length; FW = fruit width; FT = fruit thickness; BL = bean length; BW = bean width; BT = bean thickness; HBW = a hundred bean weight; CV = coefficient of variation.

x E) showed statistically non-significant for all fruit and bean characters. The P x E also showed non-significant for all fruit and bean characters except fruit length (FL) and HBW. This revealed consistency of performance of the crosses for all fruit and bean characters, and parents for majority of fruit and bean characters over the three locations.

Yield

The mean performance of 17 genotypes for bean yield, fruit and bean characters described in Table 6. All crosses gave higher bean yield (>621.18 $kg.ha^{-1}$) than three parents P_1 (L20/03), P_2 (L67/01) and P_5 (L45/01), but only five crosses P_1 x P_2, P_1 x P_5, P_2 x P_4, P_3 x P_5 and P_4 x P_5 gave higher bean yield than P_3(L03/01) (733.49 $kg.ha^{-1}$) at Jimma (Table 6). Three crosses P_1 x P_2, P_1 x P_5 and P_4 x P_5 gave higher bean yield than CH_2 (Dessu) (883.99 $kg.ha^{-1}$), and only one hybrid P_4 x P_5 gave higher bean yield than standard hybrid check1 (CH_1) Ababuna (1119.96 $kg.ha^{-1}$) at Jimma. This may indicate the possibility of improving yield through hybridization than parental lines and checks at Jimma.

At Gera, all crosses, except one (P_1 x P_3), gave higher bean yield (>768.97 $kg.ha^{-1}$) than four parents P_1, P_2, P_3 and P_5, but only five hybrids P_1 x P_4, P_2 x P_5, P_3 x P_4, P_3 x $P_5$and P_4 x P_5 exceeded P_4 (L55/01) (1062.33 $kg.ha^{-1}$) (Table 6). These hybrids also gave higher bean yield than check means (986.32 $kg.ha^{-1}$). However, only two hybrids P_3 x P_4 and P_4 x P_5 out yielded greater than standard hybrid (CH_1) (Gawe) (1131.04 $kg.ha^{-1}$) at Gera. The overall mean performances of diallel hybrids were greater than those parents and standard check variety for yield. It was likely that the advantage of hybrids over their parents and possibility of making further improvement of yield through hybridization program. This result agrees with Ameha and Belachew (1983); Belachew (2000); Mohammed (2004) and Ayano (2013). Walyaro (1983) in Kenya similarly reported outstanding performance for FI hybrids relative to their better parents and to their most productive commercial cultivar, SL28. They concluded that hybrid vigor may make an important contribution to breeding programs in Arabica coffee.

Fruit Characteristics

The diallel crosses had higher means than parental means for all fruit characters revealing that possibility of improving fruit characters through crossing program. Hybrids showed the mean ranged from 15.76 to 17.25(mm for FL, 12.91 to 13.94 mm for FW, and 11.10 to 11.91 mm for FT across locations (Table 6). Longest and shortest fruit character was obtained from P_1 x P_3 (17.25 mm) and P_4 x P_5 (15.76 mm) respectively. Hybrid combination P_1 x P_2 showed the widest and thickest fruit size where as P_3 x P_5 showed the narrow and thinnest fruit characters. Out of ten hybrids, 80% of the diallel hybrids had greater than check means for FL and FW (Table 6).

Bean Characteristics

The hybrids showed higher means than parental means for all bean characters except HBW indicating that possibility of improving bean characters through crossing program. Hybrids showed the range from 9.86 to 11.15 mm for bean length (BL), 6.86 mm to 7.41 mm for bean width (BW) and 4.10 mm to 4.56 for bean thickness (BT) (Table 6). The longest and shortest BL was obtained from P_1 x P_5 (11.15 mm) and P_2 x P_5 (9.86 mm) respectively. Four hybrids gave longer BL than hybrid mean (10.41 mm). Highest and lowest BW obtained from P_1 x P_2 (7.41 mm) and P_2 x P_4 (6.86 mm), respectively. Total half of hybrids showed greater bean width than hybrid means (7.17 mm). The lowest and highest BT obtained from P_4 x P_5 (4.10 mm) and P_1 x P_2 (4.56 mm) respectively. Four hybrids revealed greater BT than hybrid means (4.31 mm). Similarly, all hybrids had heavier HBW than checks means, but 60% of total hybrids had lighter weight than parental means.

In general, among parental lines, P_1 performed better than the other parental lines for FL (22.90mm), FW (13.65 mm), BL (11.41 mm), BW (7.37 mm), BT (4.64mm) and HBW (22.90 g). In contrary to this, P_4 showed lowest FL (14.82 mm), FW (12.31 mm), FT (10.60 mm), BL
(10.60mm), BW (6.72 mm) and BT (4.10 mm).

Table 6. Mean performance of genotypes for bean yield, fruit and bean characters

	Combined mean yield in 2017 and 2018 (Kg/ha)			Fruit and bean characters across locations in 2017						
Entries	Jimma	Agaro	Gera	FL (mm)	FW (mm)	FT (mm)	BL (mm)	BW (mm)	BT (mm)	HBW (g)
P_1 x P_2	1056.26	597.98	828.09	17.12	13.94	11.91	10.99	7.41	4.56	20.98
P_1 x P_3	667.04	651.44	750.96	17.25	13.77	11.56	10.84	7.25	4.50	20.59
P_1 x P_4	656.32	741.25	1098.52	16.80	13.32	11.20	10.72	7.22	4.39	20.71
P_1 x P_5	1109.48	834.91	949.46	17.22	13.25	11.36	11.15	7.36	4.41	21.22
P_2 x P_3	670.05	605.46	961.49	16.05	13.34	11.45	10.20	7.23	4.29	18.42
P_2 x P_4	825.06	627.31	873.15	15.84	13.48	11.46	9.87	6.86	4.23	18.57
P_2 x P_5	682.72	911.09	1089.99	15.87	13.31	11.47	9.86	7.13	4.24	18.44
P_3 x P_4	679.76	665.24	1185.55	15.93	13.39	11.51	10.11	7.04	4.20	17.86
P_3 x P_5	768.15	699.72	1110.10	16.14	12.91	11.10	10.40	7.17	4.19	17.85
P_4 x P_5	1269.84	534.44	1370.68	15.76	13.04	11.37	9.95	7.07	4.10	17.33
H mean	838.47	686.89	1021.799	16.40	13.38	11.44	10.41	7.17	4.31	19.20
P_1	621.18	694.75	565.22	17.75	13.65	11.44	11.41	7.37	4.64	22.90
P_2	378.15	686.91	768.97	15.83	13.50	11.67	10.03	7.12	4.33	17.73
P_3	733.49	808.04	675.68	16.00	13.03	11.19	10.49	7.05	4.18	18.92
P_4	672.63	539.89	1062.33	14.82	12.31	10.60	9.55	6.72	4.10	17.77
P_5	513.67	416.13	413.57	15.62	12.45	11.00	9.99	7.10	4.16	20.02
Mean	629.15	629.15	697.15	16.00	12.99	11.18	10.30	7.07	4.28	19.47
CH_1	1119.96	941.85	1131.04	15.92	13.18	11.58	9.89	7.10	4.05	16.75
CH_2	883.99	810.79	842.43	15.80	13.09	11.52	9.47	7.12	3.99	17.17
Mean	1001.98	876.32	986.74	15.86	13.14	11.55	9.68	7.11	4.02	16.96
F-test	**	ns	***	***	***	**	***	***	***	***
LSD (5%)	406.06	379.29	321.72	0.76	0.6	0.49	0.44	0.18	0.17	2.30
CV (%)	31.19	33.07	20.98	3.66	3.49	3.38	3.43	2.06	3.15	9.61

Note: values with *, ** and *** = significant differences 0.05, 0.01 and 0.001 probability level, respectively; ns = non-significant; FL = fruit length; FW= fruit width; FT = fruit thickness; BL= bean length; BW = bean width; BT= bean thickness; HBW = hundred bean weight; LSD = least significant difference; CV = coefficient of variation; CH1 = Check 1; CH2 = Check 2.

Table 7. Estimation of heterosis as a percentage for yield at individual locations in 2017 and 2018

Crosses	Jimma				Agaro				Gera			
	MPH	BPH	SH	UH	MPH	BPH	SH	UH	MPH	BPH	SH	UH
P_1 x P_2	111.39**	70.04*	-5.69	19.49	-13.44	-13.93	-36.51	-26.25	24.13	7.69	-26.79	-1.70
P_1 x P_3	-1.52	-9.06	-40.44*	-24.54	-13.30	-19.38	-30.83	-19.65	21.03	11.14	-33.60*	-10.86
P_1 x P_4	1.46	-2.42	-41.40*	-25.75	20.07	6.69	-21.30	-8.58	34.99*	3.41	-2.88	30.40
P_1 x P_5	95.53**	78.61*	-0.94	25.51	50.32	20.17	-11.35	2.98	94.01**	67.98**	-16.05	12.70
P_2 x P_3	20.55	-8.65	-40.17*	-24.20	-19.00	-25.07	-35.72	-25.33	33.11	25.04	-14.99	14.13
P_2 x P_4	57.04	22.66	-26.33	-6.67	2.27	-8.68	-33.40	-22.63	-4.64	-17.81	-22.80	3.65
P_2 x P_5	53.11	32.91	-39.04*	-22.77	65.19	32.63	-3.27	12.37	84.35**	41.75*	-3.63	29.39
P_3 x P_4	-3.31	-7.32	-39.30*	-23.10	-1.30	-17.67	-29.37	-17.95	36.43*	11.60	4.82	40.73*
P_3 x P_5	23.18	4.72	-31.41	-13.11	14.32	-13.41	-25.71	-13.70	103.83**	64.29**	-1.85	31.77
P_4 x P_5	114.08**	88.79**	13.38	43.65	11.81	-1.01	-43.26	-34.08	85.74**	29.03	21.19	62.70**
Mean	47.15	27.03	-25.13	-5.15	11.69	-3.96	-27.07	-15.28	51.30	24.41	-9.66	21.29
Min.	-3.31	-9.06	-41.4	-25.75	-19	-25.07	-43.26	-34.08	-4.64	-17.81	-33.6	-10.86
Max.	114.08	88.79	13.38	43.65	65.19	32.63	-3.27	12.37	103.83	67.98	21.19	62.7

Note: values with * and ** showed significant differences at 0.5 and 0.01 probability level, respectively; ns = non-significant; MPH = mid parent heterosis; BPH = better parent heterosis; SH = standard heterosis; UH = useful heterosis, Min = Minimum heterosis value; Max = maximum heterosis value

Heterosis for Yield

The expression of heterosis varied with the crosses as well as with locations for bean yield indicated in Table 7. At Jimma, hybrids showed mid parent heterosis (MPH) ranged from -3.31% to 114.08% with the mean of 47.15%. Eight of the crosses expressed positive MPH ranged from 1.46 to 114.08%. Crosses expressed BPH ranged from -9.06 % (P_1 x P_3) to 88.79 % (P_4 x P_5) with the mean value of 27.03%. Three of crosses P_1 x P_2, P_1 x P_5 and P_4 x P_5 were statistically highly significant heterosis over mid parent and significant to highly significant heterosis over better parent. This indicated that these hybrids had higher yield than their average parent and the best performed parents at Jimma.

At Agaro, although the hybrids showed non-significant heterosis, five hybrids P_1 x P_4, P_1 x P_5, P2 x P_5, P_3 x P_5 and P_4 x P_5, showed positive MPH ranged from 11.81 % to 50.32%. Similarly, three hybrids P_1 x P_4, P_1 x P_5 and P_2 x P_5 depicted positive BPH for yield at Agaro.

All ten hybrids showed the mean of MPH and BPH of 51.3% and 24.41%, respectively for yield at Gera. Nine of ten hybrids expressed positive MPH and BPH ranged from 21.03% (P_1 x P_3) to 103.83% (P_3 x P_5) and 3.41 % (P_1 x P_4) to 67.98% (P_1 x P_5), respectively for yield at this site. Four hybrids P_1 x P_5, P_2 x P_5, P_3 x P_5 and P_4 x P_5 showed highly significant MPH and two hybrids P_1 x P_4 and P_3 x P_4 exhibited positive and significant MPH for yield at Gera. Two hybrids P_1 x P_5 and P_3 x P_5 exhibited positive and highly significant BPH for yield, and P_2 x P_5 showed positive and significant BPH for the same trait at this site. This result indicated that crosses P_1 x P_5, P_2 x P_5 and P_3 x P_5 performed better as compared to both their average parents and their best parents.

Several coffee researchers have been reported heterosis for coffee yield in the past. In agreement with the current findings, different authors reported the presence of yield heterosis over mid parent ranged from 4% to 69 % (Mesfin and Bayetta, 1983); -22.6 to 121.73 % (Mohammed, 2004); 13.1 to 124.4% (Bayetta, 2001) and 12.8-57.8% (Ayano, 2013). The results of present study showed BPH ranged from -26.75% (Agaro) to 88.79% (Jimma).This result in line with the previous result reported for BPH ranged from 5% -60% (Mesfin and Bayetta, 1983); -41.3% - 98.23% (Mohammed, 2004); 9.6% -120.3% (Bayetta, 2001); 12.1% - 41.8 % (Ayano, 2013).

Most hybrids showed negative mean of standard heterosis (SH) and useful heterosis (UH) for the yield. However, one hybrid P_4 x P_5 (13.38%) showed positive SH for yield. Although UH was not significant for yield, three hybrids P_1 x P_2, P_1 x P_5 and P_4 x P_5 depicted positive yield heterosis over commercial pure line variety (Dessu) which had the value of 19.49%, 25.51% and 43.65%, respectively, at Jimma. At Gera, eight crosses exhibited positive UH ranged from 3.65 % (P_2 x P_4) to 62.70 % (P_4 x P_5) with the overall crosses mean of 21.29%, for yield. Hybrids showed yield heterosis over standard hybrid (Gawe) ranged from -33.60 to 21.19% at Gera. However, all hybrids except P_3 x P_4 and P_4 x P_5 showed negative SH for the same trait at Gera. Two hybrids P_3 x P_4 and

Table 8. Estimation of heterosis as a percentage for fruit characters across location in 2017

Crosses	Fruit length			Fruit width			Fruit thickness
	MPH	SH	UH	MPH	SH	UH	MPH
$P_1 \times P_2$	1.96	7.56*	8.38**	2.73	5.77*	6.52*	3.05
$P_1 \times P_3$	2.24	8.40**	9.22**	3.23	4.46	5.20	2.17
$P_1 \times P_4$	3.14	5.54	6.34*	2.59	1.00	1.72	1.65
$P_1 \times P_5$	3.19	8.18**	9.00**	1.54	0.50	1.21	1.17
$P_2 \times P_3$	0.85	0.84	1.61	0.57	1.19	1.91	0.22
$P_2 \times P_4$	3.37	-0.47	0.29	4.47	2.25	2.98	2.94
$P_2 \times P_5$	0.89	-0.32	0.44	2.63	1.00	1.71	1.19
$P_3 \times P_4$	3.35	0.06	0.83	5.67*	1.56	2.28	5.66*
$P_3 \times P_5$	2.07	1.38	2.15	1.30	-2.10	-1.41	0.02
$P_4 \times P_5$	3.51	-1.02	-0.26	5.36*	-1.07	-0.37	5.26*
Mean	2.46	3.02	3.80	3.01	1.46	2.18	2.33
Min	0.85	-1.02	-0.26	0.57	-2.1	-1.41	0.02
Max	3.51	8.4	9.22	5.67	5.77	6.52	5.66

Note: values with * and ** showed significant differences at 0.05 and 0.01 probability level, respectively; MPH = mid parent heterosis; SH = standard heterosis; UH = useful heterosis; Min = Minimum heterosis value; Max = Maximum heterosis value

$P_4 \times P_5$ showed positive SH and significant to highly significant UH bean yield at Gera. In line to this, Tefera (2017) reported UH and SH ranged from 7.0 to 68.0 and -21.1 to 23.90% at Jimma, and -33.9 to 35.5 and -36.8 to 29.5% at Tepi, respectively. Likewise Leroy et al. (2006) reported F1 hybrids allowed significant improvement of yield (30-70%) more than traditional varieties without affecting cup quality.

Heterosis for Fruit Characters

The expression of heterosis varied with the crosses and fruit characters across locations indicated in Table 8. All ten hybrids had positive MPH for fruit length (FL), fruit width (FW) and fruit thickness (FT) with mean value of 2.46, 3.01 and 2.33%, respectively across locations. Significant MPH was detected in two hybrids $P_4 \times P_5$ and $P_3 \times P_4$ for FW and FT ranged from 5.36 to 5.67% and 5.26% to 5.66%, respectively. For FL, significant to highly significant SH was exhibited in three crosses $P_1 \times P_2$, $P_1 \times P_3$ and $P_1 \times P_5$, which ranged from 7.56 to 8.40%, which indicated that these crosses had longer fruit length than standard hybrid across locations. In addition, these hybrids revealed also highly significant UH for FL, which indicated that commercial pure line variety (check 2) had lower fruit length than these hybrids. One cross ($P_1 \times P_2$) expressed significant SH and UH for FW with the value 5.77% and 6.52%, respectively. This revealed that this hybrid had wider fruit than both standard hybrid and commercial variety checks.

Heterosis for Bean Characters

The expression of heterosis differs with the crosses as well as bean characters across locations indicated below in Table 9. From the ten crosses, seven crosses for bean length (BL), nine crosses for bean width (BW) and eight crosses for bean thickness (BT) expressed positive MPH with over all mean MPH of 1.08%, 1.47% and 0.67%, respectively. The maximum positive MPH was observed for BL by cross $P_1 \times P_5$ (4.18%) followed by $P_1 \times P_2$ (2.53%) and $P_1 \times P_4$ (2.21%).

All hybrids for BT, eight hybrids for BL, seven hybrids for BW showed positive SH with the mean of 6.45, 5.28 and 0.99%, respectively. For BL, highly significant SH was displayed in four hybrids ($P_1 \times P_2$, $P_1 \times P_3$, $P_1 \times P_4$ and $P_1 \times P_5$) ranged from 8.39 to 12.77%. This indicated that these crosses had longer bean size than standard hybrid across locations. For BW, positive and significant SH was expressed in two crosses $P_1 \times P_2$ (4.27%) and $P_1 \times P_5$ (3.65%). For BT, positive and significant to highly significant SH was observed in five crosses ($P_1 \times P_2$, $P_1 \times P_3$, $P_1 \times P_4$, $P_1 \times P_5$ and $P_2 \times P_3$) ranged from 5.93 ($P_2 \times P_3$) to 12.60 % ($P_1 \times P_2$) which indicated that these hybrids had thicker bean size than standard hybrid.

All hybrids showed positive SH for hundred-bean weight (HBW) ranged from 3.47 to 26.72% with the mean of 14.62%. Specifically, four hybrids $P_1 \times P_2$, $P_1 \times P_3$, $P_1 \times P_4$ and $P_1 \times P_5$ revealed significant to highly significant SH ranged from 22.93% ($P_1 \times P_3$) to 26.72

Table 9. Estimation of heterosis as a percentage for bean characters across location in 2017

Crosses	Bean length			Bean width			Bean thickness			Hundred bean weight	
	MPH	SH	UH	MPH	SH	UH	MPH	SH	UH	SH	UH
P_1 x P_2	2.53	11.20**	16.13**	2.27	4.27*	4.03*	1.62	12.60**	14.26**	25.24**	22.18*
P_1 x P_3	-1.05	9.64**	14.50**	0.60	2.1	1.87	2.11	11.19**	12.84**	22.93*	19.93*
P_1 x P_4	2.21	8.39**	13.20**	2.55	1.67	1.44	0.43	8.38**	9.98**	23.67**	20.65*
P_1 x P_5	4.18	12.77**	17.77**	1.76	3.65*	3.41*	0.12	8.78**	10.39**	26.72**	23.63**
P_2 x P_3	-0.59	3.19	7.76*	2.04	1.74	1.51	0.81	5.93*	7.50**	9.98	7.3
P_2 x P_4	0.83	-0.12	4.31	-0.76	-3.39*	-3.61*	0.36	4.47	6.01*	10.89	8.19
P_2 x P_5	-1.47	-0.23	4.19	0.24	0.31	0.08	-0.14	4.68	6.23*	10.08	7.4
P_3 x P_4	0.84	2.25	6.78*	2.27	-0.91	-1.14	1.49	3.71	5.24	6.65	4.04
P_3 x P_5	1.51	5.16	9.82**	1.37	0.97	0.74	0.54	3.47	5.00	6.59	3.98
P_4 x P_5	1.77	0.6	5.06	2.34	-0.48	-0.71	-0.63	1.29	2.79	3.47	0.95
Mean	1.08	5.28	9.95	1.47	0.99	0.76	0.67	6.45	8.02	14.62	11.82
Min	-1.47	-0.23	4.19	-0.76	-3.39	-3.61	-0.63	1.29	2.79	3.47	0.95
Max	4.18	12.77	17.77	2.55	4.27	4.03	2.11	12.6	14.26	26.72	23.63

Note: values with * and ** are significantly different at 0.05 and 0.01 probability level, respectively; MPH = mid parent heterosis; SH = standard heterosis; UH = useful heterosis; Min = minimum heterosis value ; Max = maximum heterosis value.

(P_1 x P_5) for HBW which indicated that these hybrids had heavier bean weight than standard hybrid across location.

These results are in line with the findings of Ayano (2013) who reported the existence of heterosis in diallel crosses of coffee over the standard hybrid for bean and fruit characters.

All crosses for BL, BT and seven crosses for BW showed positive useful heterosis (UH) with the mean value of 9.95, 8.02, and 0.76%, respectively. Seven out of ten crosses showed significant to highly significant and positive UH for BL and BT ranged from 6.78 (P_3 x P_4) to 17.77 % (P_1 x P_5) and 6.01(P_2 x P_4) to 14.26% (P_1 x P_2), respectively. This may revealed that 70% of crosses had longer and thicker bean size as compared to commercial pure line variety across locations. For BW two hybrids P_1 x P_2 and P_1 x P_5 revealed positive and significant UH with the value of 4.03 and 3.41%, respectively.

For hundred-bean weight (HBW), all crosses expressed positive UH ranged from 0.95 to 23.63% with over all mean of 11.82%. Moreover, four hybrids P_1 x P_2, P_1 x P_3, P_1 x P_4 and P_1 x P_5 showed positive and significant to highly significant SH and UH which ranged 22.93 to 26.72% and 19.93 to 23.63%, respectively. This indicated that these hybrids had heavier bean weight (ranged from 20.59 g to 21.22 g) as compared to the commercial hybrid (16.75 g) and the pure line varieties (17.17 g).

Generally, hybrid combination, which obtained from parental line P_1 showed positive and significant standard heterosis and useful heterosis for physical characteristics of fruit and bean traits. This may emanated from the boldness characteristics of parental line P_1. A hybrid not only gives high bean yield also more uniform bean size than line beans in coffee bean production. Uniformity of bean size is suitable for evenly roasting process. The physical trait of coffee is related with the price. Boldness bean size is may be preferable for coffee sellers that output good price. Price is related to bean size and small beans of the same variety bring lower prices (Bing et al., 2016). In line to this result, when roasting with uneven beans, the smallest tend to burn or over roasted while the largest tend to be under roasted, which affects both the visual appearance of coffee beans and cup quality (Muschler, 2001).

Conclusion

Limmu coffee genotypes displayed a significant magnitude of heterosis for yield, fruit and bean characters which is the result of increase in the value of F_1 hybrids for these traits. In the present study, average heterosis and heterobeltiosis for yield ranged from -3.31 to 114.08% and -9.06 to 88.79% at Jimma and -4.64 to 103.83% and -17.81 to 67.98% at Gera, respectively. Crosses namely P_1 x P_2, P_1 x P_5

and P_4 x P_5 at Jimma P1 x P_5, P_2 x P_5 and P_3 x P_5 at Gera exhibiting high positive and significant average heterosis and heterobeltiosis for yield. Significant standard and useful heterosis for some fruit and bean characters were observed across locations from hybrid combination from P_1. In general, hybrid combination P_4 x P_5, P_1 x P_5, P_2 x P_5 and P_3 x P_5 were found as promising hybrids for yield and bean characters for commercial exploitation of F1 based on their exhibited heterosis. The first three hybrids out yielded 25.13% (637.75 kg), 14.05% (356.64 kg) and 5.78% (146.59 kg) increased yield over commercial pure line variety across three locations, respectively. Further evaluation of these hybrids should be conducted for extrapolating yield heterosis, and tested rigorously for other important traits such as quality, disease and insect pest resistance.

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