Magnitude of Exploitable Heterosis for Yield and Quality Traits of Coffee (*Coffea arabica* L.) Hybrids as Affected by Distant Parents in Origin and Morphology in Ethiopia

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Abstract: This study was conducted to generate information on the effects of distant parents in origin, growth habit and leaf tip color on the magnitude of standard heterosis (SH) in *Coffea arabica* L. hybrids for yield and quality in 34 hybrids generated from 15 parents in Ethiopia. The results showed distant parents in origin produce hybrids with higher standard heterosis in magnitude in a greater number of hybrids. It was observed that 16 and 11 out of 17 between and within region hybrids exhibited standard heterosis ranging from 0.8 to 52.8% and from 3.58 to 44.95%, respectively, for fresh cherry yield. In comparison, hybrids obtained from crossing distant parents in all factors (origin, growth habit and leaf tip color) registered the highest magnitude of SH, which ranged from 21.05% (clean coffee yield) to 52.80% (fresh cherry yield) with mean SH of 36.64 and 28.95% for fresh cherry and clean coffee yield, respectively. For coffee quality parameters, the effect of parents' leaf tip color on the magnitude of heterosis was observed to be more important than the parents' geographical origin. Five out of six hybrids having both parents green leaf tip color (Kaffa x Kaffa and Kaffa x Sidamo) exhibited SH of 1 to 16% for the overall coffee quality. These hybrids also exhibited positive and significant SH (14 to 33%) for 6 out of 8 coffee quality parameters. The results of this study suggested the importance of including distant parents in all possible factors to produce greater number of high yielding hybrids with highest magnitude of standard heterosis in Ethiopia. The results further revealed the possibility of improving target region coffee quality through selection of parents on the basis of their leaf tip color for crossing regardless of their origin.

Keywords: Distant Parents; Growth Habit; Hybrids; Leaf Tip Color; Origin; Standard Heterosis

1. Introduction

Information on heterosis in *Coffea arabica* L. is scanty because its hybridization started only very recently, and the perennial nature of the crop requires several years to obtain meaningful results (Wrigley, 1988; Cilas *et al.,* 1998). Moreover, research results on the effect of parental diversity in terms of geographical origin and/or morphology on magnitude of heterosis is lacking. In heterosis breeding, it has been established that the more distant the parents in origin (geographical separation), ancestral relationships, gene frequencies and morphological characteristics, the greater is the potential for heterosis (Mopurtary and Frakes, 1973; Moll and Stuber, 1974; Falconer, 1989; Virmani, 1996; Wang *et al.,* 1996).

However, although systematic research result is scanty, reports indicating the importance of distant coffee parents to produce heterotic hybrids from separate coffee hybrid trials are observable around the world. In Ethiopia, where maximum diversity of *C. arabica* lines are expected to be involved, heterosis over the better parent of up to 60% for yield was reported (Mesfin and Bayetta, 1983). Similarly, Ferine (1970) in Tanzania and Srinivasan and Vishveshwara (1978) in India reported 53 and 100% highest heterosis over the mean of two standard varieties and over the better parent for yield, respectively. These hybrids had complementary parents, VC496 and Chochie, which were of Ethiopian origin. This showed the effect of parents' diversity in one or other factors on magnitude of heterosis displayed by hybrids. On the other hand, heterosis was reported to be lacking in crosses of selected indigenous *C. arabica* L. varieties in Brazil after several years of studies (Carvalho *et al.,* 1969) where diversity of parental lines were not expected.

In classical theories, genetic relationships, geographic origins, and morphological and isozymes markers were used to predict heterosis (Zhu and Zhang, 1987; Zhu *et al.*, 2001; Hinze and Lamkey, 2003). In agreement with the classical theories of heterosis, some authors in *Brassica* spp. such as Pradhan *et al.* (1993) in *Brassica juncea*, Falk *et al.* (1994) in *Brassica rapa* and Ali *et al.* (1995) in *Brassica napus* observed an increase in heterosis with increasing parental distance using morphological markers and geographic origin. Moll *et al.* (1962) and other authors reported hybrid superiority in crosses of maize inbreds, especially in crosses among divergent parents and their wide exploitation in commercial production.

Ethiopia has diverse and favorable environments in five major coffee growing regions (Onwueme and Sinha, 1991) for the production of *Coffea arabica* L. These regions also produce coffee types acclaimed for their unique flavor and taste and variable speciality distinguished as Sidamo, Yirgachefe, Hవిrarghe, Gimbi and Limu types (Workafes and Kassu, 2000). This wide genetic variability and diversity in Ethiopian coffee was also observed in a series of hybrid trials in Ethiopia. Starting in 1978 up to 2007, a total of 105 hybrids were tested of which 27 F_1 hybrids were selected and advanced to verification for final release. Hybrids obtained from crossing parents having different or similar geographic origin and morphological characteristics expressing average heterosis over standard check ranged from 16 to 43% for yield (Behailu *et al.*, 2007).

However, the effect of diversity of parents in geographic origin and/or morphology on magnitude of heterosis has not yet been well studied except in the case of two hybrid trials where attempts have been made to explain the effect of parents' diversity in geographical origin on heterosis (Bayetta *et al.,* 2007; Wassu *et al.,* 2007). Moreover, the effects of parents' leaf tip color (green and bronze) has not been discussed at all in the past works. The effect of parents' leaf tip color on the observed magnitude of heterosis is important since it is one of the distinguishable traits for two *Coffea arabica* L. varieties, typica and bourbon. Besides, the effect of geographical origin and/or leaf tip color of parents on magnitude of heterosis for coffee quality have not been studied. These justify the need to conduct research to reveal the effects of parents' diversity on heterosis, and identify the factor or combination of factors which affect

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the magnitude of heterosis for yield and coffee quality parameters. Therefore, this study was conducted to generate information on the effects of origin, growth habit and leaf tip color of parents on observed heterosis that can be considered in parental selection.

2. Materials and Data Analysis

2.1. Coffee Genotypes Included in the Study

Coffee parents and hybrids in three coffee hybrid trials conducted in different time and at different locations in Ethiopia (Mesfin and Bayetta, 1983; Bayetta *et al.,* 2007; Wassu *et al*., 2007) were considered for reanalysis in this study. The first and second hybrid trials were conducted at the Jima Agricultural Research Center for three and six years both for yield and other traits, respectively. The research results of Set I trial were published in 1983 in the Ethiopian Journal of Agricultural Science (Mesfin and Bayetta, 1983) while that of the second trial were reported at the Coffee Diversity and Knowledge, Four Decades of Coffee Research and Development in Ethiopia. The third trial was conducted at the Wonago Research Station for four years and its results were reported at the National Coffee Research Review Workshop (Wassu *et al*., 2007).

In all the trials, parents from different geographical origin were included. Parents from Sidamo represent south coffee growing region with bimodal rainfall while parents from Kaffa and Illubabor represent south-western Ethiopia representing regions with monomodal rainfall pattern. Parents also had distinct leaf tip color (bronze and green) which is the major difference between the two *Coffea arabica* L. varieties in the world. In two studies (Bayetta *et al*., 2007; Wassu *et al*., 2007), an attempt has been made to single out the importance of diversity of parents in origin on the observed magnitude of heterosis. However, Bayetta *et al.* (2007) suggested that morphological differences of parents were more important while Wassu *et al.* (2007) suggested that differences in geographical origin of parents were more important for the observed higher magnitude of heterosis. Both investigators did not consider all differences (geographical, morphological and leaf tip color) rather mainly focused on either geographical and morphological or geographical differences based on separate trials. In addition, both investigators made conclusions on the basis of mid and better parent heterosis and not on the standard heterosis which is supposed to determine the commercial exploitation of hybrids. Therefore, this study was conducted by considering all types of differences of parents in all the three hybrid trials on the basis of standard heterosis to provide more conclusive information for future coffee breeding program.

In three trials, 34 hybrids obtained by crossing 15 parents in half diallel fashion, Griffing's Method 2 Model 1 (Griffing, 1956) planted at two coffee growing regions following randomized block design (RCBD) in four replications, five trees per plot with 2 m x 2 m spacing were included. Details of the parental lines description is presented in Table 1.

2.2. Data Collection

In the Set I hybrid trial, fresh cherry yield was recorded on tree basis in grams while in Sets II and III hybrid trials, the fresh cherry yield was recorded and converted to kilograms per tree. Yields of clean coffee obtained as the product of fresh cherry weight and out turn ratio of each genotype were recorded in kg per tree in Sets II and III hybrid trials. In all trials, an average of five trees was computed for each experimental unit and used for statistical analysis. An average of three, six and four years yield data were considered for statistical analysis for Sets I, II and III hybrid trials, respectively.

2.3. Data Analysis

Standard heterosis for fresh cherry and clean coffee yield were computed as SH (%) = (HYB-CV)/CV) x 100 where CV is commercial varieties yield used as a checks in three trials. The mid parent heterosis (MPH) and better parent heterosis (BPH) were registered as reported by the investigators. However, systematic arrangement has been made to fulfil the objectives of this study. In Set III, the three heterosis viz., MPH (%), BPH (%) and SH (%) for 12 hybrids were computed for the Sidamo coffee quality parameters as MP = P1+P2/2; MPH = HY-MP; MPH (%) = (MPH/MP) x 100; BPH = HY-BP; BPH (%) = (BPH/BP) x 100 and SH (%) = (HYB-CV)/CV) x 100 where MP = mean of the two parents involved in producing the hybrids computed as (P1+P2)/2, HY = hybrid value; BP = the better parent value of a hybrid and CV is commercial variety value. The significance of the percent heterosis was tested by comparing mean differences between F_1, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance.

Coffee quality parameters used in the study are shape and make which accounts for 15%, odour (10%), color (15%) and all summed to raw coffee quality that accounted for a total of 40%, and acidity, body and flavor each accounting for 20% and summed to 60% which is categorized as coffee cup quality. The overall coffee quality was the sum of raw coffee quality and cup quality and sums up to 100%. Coffee quality was determined by the blind evaluation method (no information provided about the origin and type of coffee samples) of hybrids and their parents at the National Coffee and Tea Liquoring and Inspection Center.

Hybrids' heterosis effects for fresh cherry and clean coffee yield as well as coffee quality parameters were systematically organized in relation to their parents' origin, growth habit and leaf tip color. This helped to asses the effects of distant parents in these factors on the observed magnitude of heterosis.

Table 1. Description of *Coffea arabica* L. parental lines used in three hybrid trials in Ethiopia.

Parental lines	Geographical origin	Growth habit and some special features of coffee parents
		Set I hybrid trial
741 (P1)	Gera, Kaffa	Highly resistant to CBD
7332 (P2)	Gera, Kaffa	Resistant to CBD
7395 (P3)	Yayu, Illubabor	70-75% resistant to CBD
2970 (P4)	Yirgachefe, Sidamo	High yielding and resistant to CBD
F-59 (P5)	Bonga, Kaffa	High yielding and resistant to CBD used as check
		Set II hybrid trial [Note: F-59 (P5) named as Desu used as a check]
74110 (P1) 74158 (P2)	Bishare, Illubabor	Compact with flexible stem, small leaves and internodes length, medium and round beans
20071 (P3) 221A71 (P4)	Maji, Kaffa	Medium open to open, with short and broad leaves, small and round beans
1377 (P5) 1577 (P6)	Wonago and Handida, Sidamo	Open with vigorous growth, broad leaves, bronze tip, bold bean
		Set III hybrid trial
744 (P1)	Washi, Kaffa (South-western Ethiopia) 1700 masl	Released Coffee Berry Disease (CBD) resistant cultivar; good adaptation to medium and high altitude; open canopy; green leaf tip color and broad leaves; bold beans.
7440 (P2)	Washi, Kaffa, (South-western Ethiopia) 1700 masl	Released CBD resistant cultivar; good adaptation to medium and high altitude; open canopy; green leaf tip color and broad leaves; small beans.
75227(P3)	Near Washi, Kaffa, (South-western Ethiopia) 1900 masl	Released CBD resistant cultivar; good adaptation to higher altitudes; open canopy; green leaf tip color and broad leaves; small beans.
1377 (P4)	Wonago, Sidamo (Southern Ethiopia) 1850 masl	First released Sidamo coffee variety, high yielding; open canopy; bronze leaf tip color and broad leaves; bold beans. Used also as a check commercial variety.
1681(P5)	Areka, Sidamo (Southern Ethiopia) 1850 masl	High yielding; open canopy; green leaf tip color, broad leaves; medium size beans.

***Kaffa and Illubabor regions lie along the same climatic belt and enjoy more or less similar weather (humid with mono-modal distribution of high rainfall and categorized as south-western coffee growing region, which are distinctly different from Sidamo characterized by lower humidity (drier weather), lower and bimodal pattern of rainfall; **Shorter internodes on main stem and primers, shorter and dense primary branches and overall reduced plant size are the main differentiating characteristics of compact growth, whilst the open types are mainly characterized by spreading branches and longer internodes; **Sidamo and Kaffa coffee parents are acclaimed for their different coffee quality (Sidamo and Limu); **Young leaves having bronze and green tip color is one of distinguishable trait for Coffea arabica L. var. typica and var. bourbon in the world.*

3. Results

3.1. Heterosis in Relation to Parents Origin and Morphology for Yield

3.1.1. Heterosis in Relation to Parents' Origin

Hybrids' heterosis for yield was rearranged and calculated based on parents origin to observe if it had an effect on hybrids heterosis expression and its magnitude (Tables 2a and 2b). The within region hybrids registered mean MPH of 23.33, 65.07 and 25.7% while the between region registered 49.33, 70.65 and 60.75% in Set I, II and III hybrid trials, respectively, for fresh cherry yield. The mean BPH calculated for the within region hybrids were 9.83, 58.9 and 7.68%, while that of the between region hybrids were 32.67, 47.8 and 44.02% in Set I, II and III trials, respectively, for fresh cherry yield. Moreover, 10.54, 10.79 and -1.61% mean SH were recorded for the within region hybrids whilst 11.28, 30.35 and 22.01% were recorded for the between regions hybrids in the trials of Sets I, II and III, respectively, for fresh cherry yield.

Heterosis calculated for clean coffee yield revealed that the within region hybrids exhibited mean MPH of 64.76 and 22.78% while the between regions hybrids recorded 80.46 and 58.3% in Set II and III trials, respectively. Mean BPH of 57.19 and 8.38% were calculated for the within region hybrids while mean BPH of 57.71 and 37.63% were obtained for the between region crosses in Set II and III trials, respectively. Similarly, mean SH values of 0.26 and -12.35% were calculated for the within region hybrids and the calculated between region hybrids' SH values were 20.57 and 10.59 in Set II and III trials, respectively (Table 2b).

In all the trials, 15 and 13 out of 17 between region hybrids exhibited positive and significant different MPH and BPH, respectively, for fresh cherry yield. In Sets II and III hybrid trials, 11 out of 14 between region hybrids registered significantly ($P < 0.05$) different percent MPH and BPH for clean coffee yield. Eight out of 14 between region hybrids exhibited positive and significant ($P < 0.05$) different SH for fresh cherry yield which ranged from 28.51 to 52.8%. Five of the between region hybrids displayed positive and significant ($P < 0.05$) different SH for clean coffee yield which ranged from 23.17 to 44.62% in Sets II and III hybrid trials. On the other hand, 11 and 8 out of 17 of within region hybrids registered positive and significantly ($P < 0.05$) different MPH (%) and BPH (%), respectively, in all trials. However, only two out of 11 within region hybrids exhibited positive and significantly ($P < 0.05$) different SH of 35.27 and 44.95% for fresh cherry and 25.1 and 33.6% for clean coffee yield in Set II and III hybrid trials.

Table 2a. Mid parent (MPH), better parent (BPH) and standard heterosis (SH) for fresh cherry yield in relation to parents' origin of coffee (*Coffea arabica* L.) hybrids in Ethiopia.

Set I hybrid trial			
Hybrid	MPH (%)	BPH (%)	SH (%)
P1 x P2	25*	5	11.63
P1 x P3	22	15	-6.38
P1 x P5	38**	18	18.42
P2 x P3	4	-8	3.58
P2 x P5	13	9	16.21
P3 x P5	32**	20*	19.77
Mean (K x K)	22.33	9.83	10.54
P1 x P4	69**	60**	14.69
P2 x P4	27*	2	8.06
P3 x P4	52**	36**	11.09
P4 x P5	-	-	-
Mean (K x S)	49.33	32.67	11.28
Grand mean	31.33	17.45	10.79

Set II hybrid trial			
Hybrid	MPH (%)	BPH (%)	SH (%)
P1 x P2	13.7	9.0	-27.09*
P3 x P4	56.7**	54.0*	-0.95
P5 x P6	62.3**	41.2**	44.95**
P1 x P3	64.9**	59.0**	6.40
P1 x P4	47.7*	44.8*	-3.09
P2 x P3	119.1**	117.7**	35.27*
P2 x P4	91.1**	86.7**	20.04
Mean (Within)	65.07	58.91	10.79
P1 x P5	80.2**	48.8**	52.80**
P1 x P6	81.5**	70.8**	29.64*
P2 x P5	65.4**	32.1*	35.60*
P2 x P6	87.2**	69.3**	28.51*
P3 x P5	61.6**	29.7*	33.13*
P3 x P6	55.2**	41.1*	7.13
P4 x P5	62.8**	32.4*	35.89**
P4 x P6	71.3**	58.2**	20.11
Mean (Between)	70.65	47.8	30.35
Grand mean	68.0	53.0	21.22
LSD (0.05) = 0.741 and LSD (0.01) = 0.986			

Set III hybrid trial‡			
Hybrid	MPH (%)	BPH (%)	SH (%)
P1 x P2	8.7	-12.8	-14.89
P1 x P3	59.5*	41.3*	9.53
P2 x P3	52.0**	36.4**	33.10
P4 x P5	-17.4	-34.2*	-34.17*
Mean (Within)	25.7	7.68	-1.61
P1 x P4	52.8*	22.1	22.08
P1 x P5	116.4**	115.9**	29.06
P2 x P4	-13.9	-14.2	-14.23
P2 x P5	28.4	3.3	0.80
P3 x P4	66.7**	48.0*	47.87**
P3 x P5	114.0**	89.0**	46.50**
Mean (between)	60.73	44.02	22.01
Grand mean	46.72	29.48	12.57
LSD (0.05) = 1.214 and LSD (0.01) = 1.622			

‡*, ** = *Significant at P < 0.05 and P < 0.01 levels, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; SH = Standard heterosis. Note: The within region crosses in Set II include Ilubabor x Ilubabor (P1 x P2), Kaffa x Kaffa (P3 x P4), Sidamo x Sidamo (P5 x P6) and Ilubabor x Kaffa (P1 x P3, P1 x P4, P2 x P3 and P2 x P4) and the between region crosses include Ilubabor x Sidamo (P1 x P5, P1 x P6, P2 x P5 and P2 x P6) and Kaffa x Sidamo (P3 x P5, P3 x P6, P4 x P5 and P4 x P6). The within region crosses in Set III include Kaffa x Kaffa (P1 x P2, P1 x P3 and P2 x P3) and Sidamo x Sidamo (P4 x P5) while the between region crosses include Kaffa x Sidamo (P1 x P4, P1 x P5, P2 x P4, P2 x P5, P3 x P4 and P3 x P5); F-59 (P5 in Set I) was used as check and the commercial variety yielded 4779 g per tree and 2.75 kg per tree in Sets I and II, respectively and P4 (1377) yielded 3.64 kg per tree in Set III. In Set I: P1 = 741, P2 = 7332, P3 = 7395, P4 = 2970 and P5 = F-59; in Set II, P1 = 74110, P2 = 74158, P3 = 20071, P4 = 221A71, P5 = 1377 and P6 = 1577, and in Set III, P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377 and P5 = 1681. The significance of the percent heterosis was tested by comparing mean differences between F_1, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance, where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of the commercial variety (check).*

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Table 2b. Mid parent (MPH), better parent (BPH) and standard heterosis (SH) for clean yield in relation to parents' origin in Sets II and III coffee (*Coffea arabica* L.) hybrid trials in Ethiopia.

Set II hybrid trial‡			
Hybrid	MPH (%)	BPH (%)	Standard heterosis (%)
P1 x P2	13.1	9.6	-36.03**
P3 x P4	55.1*	50.2*	-8.91
P5 x P6	66.0**	39.4**	33.60**
P1 x P3	55.4*	53.3*	-10.53
P1 x P4	56.7**	53.8*	-6.68
P2 x P3	124.4**	120.3**	25.10*
P2 x P4	82.6**	73.7**	5.26
Mean for within	64.76	57.19	0.26
P1 x P5	84.4**	48.3**	42.31**
P1 x P6	96.1**	86.0**	21.05
P2 x P5	70.3**	33.8*	28.34*
P2 x P6	107.1**	90.5**	24.09
P3 x P5	66.5**	32.5*	27.13*
P3 x P6	67.2**	56.5**	2.02
P4 x P5	72.8**	41.0**	35.22**
P4 x P6	79.3**	73.1**	12.75
Mean for between	80.46	57.71	20.57
Grand mean	73.10	57.50	12.96
LSD (0.05) = 0.124 and LSD (0.01) = 0.165			

Set III hybrid trial‡			
Hybrid	MPH (%)	BPH (%)	Standard hetrosis (%)
P1 x P2	-1.2	-14.4	-26.60
P1 x P3	55.7**	48.1*	-2.47
P2 x P3	59.2*	40.9**	20.78
P4 x P5	-22.6*	-41.1*	-41.13*
Mean for within	22.78	8.38	-12.35
P1 x P4	25.2	-0.3	-0.29
P1 x P5	107.3**	94.6**	15.41
P2 x P4	-13.1	-19.3	-19.33
P2 x P5	34.4	8.0	-7.41
P3 x P4	74.3**	44.6**	44.62**
P3 x P5	121.7**	98.2**	30.52
Mean for between	58.3	37.63	10.59
Grand mean	44.3	25.93	1.16
LSD (0.05) = 0.219 and LSD (0.01) = 0.296			

‡*, ** = *Significant at P < 0.05 and P < 0.01levels, respectively, MPH = Mid parent heterosis, BPH = Better parent heterosis. Note: The within region crosses in Set II include Ilubabor x Ilubabor (P1 x P2), Kaffa x Kaffa (P3 x P4), Sidamo x Sidamo (P5 x P6) and Ilubabor x Kaffa (P1 x P3, P1 x P4, P2 x P3 and P2 x P4) and the between region crosses include Ilubabor x Sidamo (P1 x P5, P1 x P6, P2 x P5 and P2 x P6) and Kaffa x Sidamo (P3 x P5, P3 x P6, P4 x P5 and P4 x P6). The within region crosses in Set III include Kaffa x Kaffa (P1 x P2, P1 x P3 and P2 x P3) and Sidamo x Sidamo (P4 x P5) while the between region crosses include Kaffa x Sidamo (P1 x P4, P1 x P5, P2 x P4, P2 x P5, P3 x P4 and P3 x P5); F-59 which yielded 0.494 kg per tree was used as check in Set II and P4 (1377) which yielded 0.688 kg per tree was used as a check in Set III. In Set II, P1 = 74110, P2 = 74158, P3 = 20071, P4 = 221A71, P5 = 1377 and P6 = 1577 and in Set III, P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377 and P5 = 1681. The significance of the percent heterosis was tested by comparing mean differences between F, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance, where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of the commercial variety (check).*

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3.1.2. Heterosis in Relation to Parents' Origin and Growth Habit

Heterosis in relation to parents origin and growth habit was calculated for Set II hybrid trial (Table 3) since hybrids included in Set III had parents with similar canopy class (open canopy) and all parents' canopy classes in Set I were not provided in the report. Coffee hybrids generated from similar parents in origin and growth habit registered the lowest mean MPH of 44.2 and 44.7% and mean BPH of 34.7 and 8.0% for fresh cherry and clean coffee yields, respectively. On the other hand, the Illubabor x Kaffa hybrids which their parents enjoy nearly similar environmental condition (south-western Ethiopia coffee growing region) but having distinctly different canopy classes (compact and medium open) registered higher mean MPH of 80.7 and 76.68% and mean BPH of 77 and 75.3% for fresh cherry and clean coffee yields, respectively. On the other hand, the Kaffa x Sidamo hybrids having parents distinct distant in origin (south-western and southern Ethiopia coffee growing regions) but with nearly similar canopy class (open) registered the lowest mean MPH of 62.7 and 71.5% and mean BPH of 40.4 and 50.8% for fresh cherry and clean coffee yields, respectively. The hybrids generated from distant parents both in origin and growth habit (Illubabor x Sidamo, compact x open) registered lower mean MPH of 78.6 and 89.5% and mean BPH of 55.3 and 64.7% for fresh cherry and clean coffee yields, respectively (Table 3). These results are extracted from Bayetta *et al.* (2007) report.

In Set II, hybrids standard heterosis relative to the best yielding commercial cultivar used as check is presented in Table 4a. Standard heterosis was considered as most important since decision making on economic importance of hybrids and accordingly release for growers depends on it. Hybrids generated from distant parents both in origin and growth habit (Illubabor x Sidamo, compact x open) registered the highest mean SH of 36.64 and 29.95% for fresh cherry and clean coffee yield, respectively. The Kaffa x Sidamo hybrids having distant parents in origin but similar canopy class (open) registered the second highest mean SH of 24.06 and 19.28% for fresh cherry and clean coffee yields, respectively. Hybrids having similar parents in origin and growth habit registered the lowest mean SH of 5.64 and -3.78% for fresh cherry and clean coffee yields, respectively. The Illubabor x Kaffa hybrids generated from near to similar parents in origin but having distinct canopy classes (compact and medium open) recorded lower mean SH of 14.65 and 0.26% for fresh cherry and clean coffee yields, respectively. None of the hybrids obtained from distant parent in origin either with distinct or similar growth habit exhibited negative SH. In Set II hybrid trial, the highest (42.31%) and the second highest (35.22%) positive and significant SH for yield were registered for hybrids obtained by crossing parents distant both in origin and in morphology. On the other hand, two out of four hybrids having parents with distinct growth habit but similar in origin exhibited negative SH for clean coffee yield.

In this study, the yields of three hybrids generated from distant parents both in origin and growth habit (Illubabor x Sidamo, compact x open) for fresh cherry and two hybrids for clean coffee exhibited positive and significant SH. Two Kaffa x Sidamo hybrids having distant parents in origin but similar canopy class (open) registered positive and significant SH for fresh cherry and clean coffee yields. One hybrid each for other combinations registered positive and significant SH for fresh cherry and clean coffee yields.

3.1.3. Heterosis in Relation to Parents' Origin and Leaf tip Color

Heterosis in relation to hybrids parents' leaf tip colors (green and bronze) was calculated for Set II and Set III hybrid trials for which the parents' leaf tip colors are reported in the materials and methods section of the original reports. The hybrids generated from distant parents for leaf tip colors (green and bronze) regardless of their differences in origin and growth habit registered the highest mean MPH, BPH and SH of 70.65, 47.85 and 30.35%, respectively, for fresh cherry yield (Table 4a). Similarly, this group of hybrids registered the highest mean MPH, BPH and SH of 80.5, 57.75 and 24.12%, respectively, for clean coffee yield in Set the II hybrid trial. The green x green leaf tip color hybrids registered mean MPH, BPH and SH of 57.95, 54.3 and 0.32%, respectively, for fresh cherry yield. These group of hybrids also registered mean MPH, BPH and SH of 55.45, 52.6 and -5.3%, respectively, for clean coffee yield. In the Set III hybrid trial, green x green leaf tip color hybrids recorded the highest mean MPH, BPH and SH of 63.17, 45.52 and 17.35% for fresh cherry yield and 62.85, 45.9 and 5.04%, respectively, for clean coffee yield. The green x bronze leaf tip color registered 22.05, 5.42 and 5.39% mean MPH, BPH and SH, respectively, for fresh cherry yield. This group of hybrids resulted in the lowest mean MPH, BPH and SH of 15.95, -4.03 and -4.03% for clean coffee yield, respectively (Table 4b).

Hybrids' heterosis effects on yield considering all differences of parents (origin, growth habit and leaf tip colors) which were used as sources of parents distant are presented in Tables 4a and 4b. In Set II, hybrids generated from distant parents in all factors (Illubabor x Sidamo with compact x open and green x bronze leaf tip color) exhibited the highest mean SH of 36.64 and 28.95% for fresh cherry and clean coffee yields, respectively (Table 4a). The second highest mean SH of 24.06 and 19.28% for fresh cherry and clean coffee yields, respectively, were registered for hybrids obtained from crossing of distant parents in origin and leaf tip color but nearly similar for growth habit (Kaffa x Sidamo with green x bronze with medium to open and open). Hybrids having less distant parents in origin and similar leaf tip color but with distinct growth habit (Illubabor x Kaffa, compact x medium to open, green x green leaf tip color) registered the second lowest mean SH of 14.65 and 0.26%. Hybrids having similar parents for all factors recorded the lowest mean SH of -14.02 and -22.47% for fresh cherry and clean coffee yields, respectively.

In Set III, hybrids obtained by crossing distant parents in origin with similar leaf tip color (Kaffa x Sidamo with green x green) registered the highest mean SH of 25.45 and 12.84% followed by hybrids generated from distant parents in origin and leaf tip color (Kaffa x Sidamo with green x bronze) with mean SH of 18.57 and 8.33% for fresh cherry and clean coffee yields, respectively (Table 4b). Hybrids having parents similar in origin and leaf tip color (Kaffa x Kaffa, green x green) registered the lowest mean SH of 9.25 and -2.76% for fresh cherry and clean coffee yields, respectively. In Set II, one hybrid that obtained from crossing both Sidamo coffee parents and bronze tip color registered 44.95 and 33.60% SH while the other hybrid in Set III, which was obtained from crossing both Sidamo coffee parents but having green and bronze leaf tip colors recorded -34.17 and -41.13% for fresh cherry and clean coffee yield, respectively (Table 4b).

Table 3. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for fresh cherry and clean coffee yield in relation to parents' origin and growth habit in Set II coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

Origin	Growth habit	Hybrid	Fresh cherry yield (kg tree^{-1})‡ MPH (%)	BPH (%)	SH (%)	Clean coffee yield(kg tree^{-1})‡ MPH (%)	BPH (%)	SH (%)
Ilubabor x Ilubabor	C x C	P1 x P2	13.7	9.0	-27.09*	13.1	9.6	-36.03**
Kaffa x Kaffa	MO x MO	P3 x P4	56.7**	54.0*	-0.95	55.1*	50.2*	-8.91
Sidamo x Sidamo	O x O	P5 x P6	62.3**	41.2**	44.95**	66.0**	39.4**	33.60**
Mean			44.2	34.7	5.64	44.7	8.0	-3.78
Ilubabor x Kaffa	Compact x	P1 x P3	64.9**	59.0**	6.40	55.4*	53.3*	-10.53
	Medium to	P1 x P4	47.7*	44.8*	-3.09	56.7**	53.8*	-6.68
	open	P2 x P3	119.1**	117.7**	35.27*	124.4**	120.3**	25.10*
	canopy	P2 x P4	91.1**	86.7**	20.04	82.6**	73.7**	5.26
Mean			80.7	77.1	14.65	76.8	75.3	0.26
Ilubabor x Sidamo	Compact x	P1 x P5	80.2**	48.8**	52.80**	84.4**	48.3**	42.31**
	Open	P1 x P6	81.5**	70.8**	29.64*	96.1**	86.0**	21.05
	canopy	P2 x P5	65.4**	32.1*	35.60*	70.3**	33.8*	28.34*
		P2 x P6	87.2**	69.3**	28.51*	107.1**	90.5**	24.09
Mean			78.6	55.3	36.64	89.5	64.7	28.95
Kaffa x Sidamo	Open x	P3 x P5	61.6**	29.7*	33.13*	66.5**	32.5*	27.13*
	Open	P3 x P6	55.2**	41.1*	7.13	67.2**	56.5**	2.02
		P4 x P5	62.8**	32.4*	35.89**	72.8**	41.0**	35.22**
		P4 x P6	71.3**	58.2**	20.11	79.3**	73.1**	12.75
Mean			62.7	40.4	24.06	71.5	50.8	19.28
Grand mean			68.0	53.0	21.22	73.1	57.5	12.96
			LSD (0.05) = 0.741; LSD (0.01) = 0.986			LSD (0.05) = 0.124; LSD (0.01) = 0.165		

‡ **, ** = Significant at P < 0.05 and P < 0.01 levels, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; SH = Standard heterosis, C x C = Compact x Compact, MO x MO = Medium to open x Medium to open, O x O = Open x Open, in Set II, P1 = 74110, P2 = 74158, P3 = 20071, P4 = 221A71, P5 = 1377 and P6 = 1577. The significance of the percent heterosis was tested by comparing mean differences between F, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance, where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of the commercial variety (check).*

3.2. Heterosis in Relation to Parents' Origin and Leaf Tip for Coffee Quality

3.2.1. Heterosis In relation to Parents' Origin

Heterosis was calculated for Sidamo coffee quality for 12 hybrids six each for the within and between hybrids (Tables 5a and 5b). Among the group of hybrids, the within region crosses viz., Kaffa x Kaffa registered the highest mean MPH, BPH and SH of 11.81, 6.28 and 7.35%, respectively, for overall Sidamo coffee quality parameters. Considering all coffee quality parameters, the Kaffa x Kaffa group of hybrids registered mean MPH, BPH and SH which ranged from 9.53 to 17.39,-3.7 to 17.39 and -2.38 to 11.11, respectively. The Kaffa x Kaffa group of hybrids registered negative mean BPH and SH only for acidity and shape and make, respectively. The between region hybrids (Kaffa x Sidamo) registered the second highest mean MPH, BPH and SH of 3.9, 0.37 and 0.16, respectively, for overall Sidamo coffee quality. This group of hybrids exhibited mean MPH, BPH and SH ranged from -1.45 to 12.17%, -10.32 to 8.80% and -10.42 to 8.80%, respectively, for all the quality parameters. The Kaffa x Sidamo group of hybrids exhibited positive mean MPH and BPH for acidity, shape and make, color, raw coffee quality and overall coffee quality (Table 5a). This group of hybrids registered positive mean SH for most important Sidamo coffee raw and overall quality. The Sidamo x Sidamo group of hybrids recorded the lowest mean MPH, BPH and SH of 3.60, -0.57 and -3.00%, respectively, for overall Sidamo coffee quality. This group of hybrids had mean MPH, BPH and SH ranging from -6.67 to 11.90%, -6.67 to 10.40% and -8.33 to 8.30%, respectively, for all coffee quality parameters. The Sidamo x Sidamo group of hybrids registered negative mean MPH, BPH and SH both for flavor and Sidamo coffee cup quality (Table 5a). Besides, they also exhibited negative mean BPH and SH for overall Sidamo coffee quality as well as negative mean SH for acidity. This group of hybrids registered positive mean SH only for color and Sidamo raw coffee quality.

Table 4a. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for fresh cherry and clean coffee yield in relation to parents' origin, growth habit and leaf tip color in Set II coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

Origin and leaf tip color	Growth habit	Hybrid	Fresh cherry yield (kg tree^{-1})			Clean coffee yield(kg tree^{-1})		
			MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)
Ilubabor x Ilubabor, Green x Green	Compact x Compact	P1 x P2	13.7	9.0	-27.09*	13.1	9.6	-36.03**
Kaffa x Kaffa, Green x Green	Medium to open x Medium to open	P3 x P4	56.7**	54.0*	-0.95	55.1*	50.2*	-8.91
Mean for within region, similar growth habit and leaf tip color			35.2	31.5	-14.02	34.1	29.9	-22.47
Ilubabor x Kaffa, Green x Green	Compact x Medium to open canopy	P1 x P3	64.9**	59.0**	6.40	55.4*	53.3*	-10.53
Ilubabor x Kaffa, Green x Green	Compact x Medium to open canopy	P1 x P4	47.7*	44.8*	-3.09	56.7**	53.8*	-6.68
Ilubabor x Kaffa, Green x Green	Compact x Medium to open canopy	P2 x P3	119.1**	117.7**	35.27*	124.4**	120.3**	25.10*
Ilubabor x Kaffa, Green x Green	Compact x Medium to open canopy	P2 x P4	91.1**	86.7**	20.04	82.6**	73.7**	5.26
Mean similar origin and different canopy and similar leaf tip color			80.7	77.1	14.65	76.8	75.3	0.26
Mean Green x Green leaf tip color			57.95	54.3	0.32	55.45	52.6	-5.30
Sidamo x Sidamo, Bronze x Bronze	Open x Open canopy	P5 x P6	62.3**	41.2**	44.95**	66.0**	39.4**	33.60**
Mean of similar leaf tip color crosses			60.13	47.75	7.82	60.73	46	0.26
Ilubabor x Sidamo, Green x Bronze leaf tip color	Compact x Open canopy	P1 x P5	80.2**	48.8**	52.80**	84.4**	48.3**	42.31**
Ilubabor x Sidamo, Green x Bronze leaf tip color	Compact x Open canopy	P1 x P6	81.5**	70.8**	29.64*	96.1**	86.0**	21.05
Ilubabor x Sidamo, Green x Bronze leaf tip color	Compact x Open canopy	P2 x P5	65.4**	32.1*	35.60*	70.3**	33.8*	28.34*
Ilubabor x Sidamo, Green x Bronze leaf tip color	Compact x Open canopy	P2 x P6	87.2**	69.3**	28.51*	107.1**	90.5**	24.09
Mean different origin , canopy and leaf color (G x B)			78.6	55.3	36.64	89.5	64.7	28.95
Kaffa x Sidamo, Green x Bronze leaf tip color	Medium to Open x Open canopy	P3 x P5	61.6**	29.7*	33.13*	66.5**	32.5*	27.13*
Kaffa x Sidamo, Green x Bronze leaf tip color	Medium to Open x Open canopy	P3 x P6	55.2**	41.1*	7.13	67.2**	56.5**	2.02
Kaffa x Sidamo, Green x Bronze leaf tip color	Medium to Open x Open canopy	P4 x P5	62.8**	32.4*	35.89**	72.8**	41.0**	35.22**
Kaffa x Sidamo, Green x Bronze leaf tip color	Medium to Open x Open canopy	P4 x P6	71.3**	58.2**	20.11	79.3**	73.1**	12.75
Mean of different origin and leaf color (G x B) with nearly similar canopy			62.7	40.4	24.06	71.5	50.8	19.28
Mean Green x Bronze leaf tip color			70.65	47.85	30.35	80.5	57.75	24.12
Grand mean			68.0	53.0	21.22	73.1	57.5	12.96

‡*, ** = *Significant at P < 0.05 and P < 0.01 levels, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; SH = Standard heterosis. In Set II, P1 = 74110, P2 = 74158, P3 = 20071, P4 = 221A71, P5 = 1377 and P6 = 1577. The significance of the percent heterosis was tested by comparing mean differences between F, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance, where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of the commercial variety (check).*

Table 4b. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for fresh cherry and clean coffee yield in relation to parents' origin and leaf tip color in Set III coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

Origin and leaf tip color	Hybrid	Fresh cherry yield (kg tree^{-1})‡			Clean coffee yield (kg tree^{-1})‡		
		MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)
Kaffa x Kaffa, Green x Green	P1 x P2	8.70	-12.8	-14.89	-1.20	-14.40	-26.60
Kaffa x Kaffa, Green x Green	P1 x P3	59.50*	41.3*	9.53	55.70**	48.10*	-2.47
Kaffa x Kaffa, Green x Green	P2 x P3	52.0**	36.40**	33.10	59.20*	40.90**	20.78
Mean similar origin and leaf tip color (Green x Green)		40.07	21.63	9.25	37.90	24.87	-2.76
Kaffa x Sidamo, Green x Green	P1 x P5	116.40**	115.90**	29.06	107.30**	94.60**	15.41
Kaffa x Sidamo, Green x Green	P2 x P5	28.40	3.30	0.80	34.40	8.00	-7.41
Kaffa x Sidamo, Green x Green	P3 x P5	114.00**	89.00**	46.50**	121.70**	98.20**	30.52
Mean between region and similar leaf tip color (Green x Green)		86.27	69.40	25.45	87.80	66.93	12.84
Mean of Green x Green leaf tip color		63.17	45.52	17.35	62.85	45.90	5.04
Kaffa x Sidamo, Green x Bronze leaf tip color	P1 x P4	52.80*	22.10	22.08	25.20	-0.30	-0.29
Kaffa x Sidamo, Green x Bronze leaf tip color	P2 x P4	-13.90	-14.20	-14.23	-13.10	-19.3	-19.33
Kaffa x Sidamo, Green x Bronze leaf tip color	P3 x P4	66.70**	48.00*	47.87**	74.30**	44.60**	44.62**
Mean between region and different leaf tip color (Green x Bronze)		35.20	18.63	18.57	28.80	8.33	8.33
Sidamo x Sidamo, Green x Bronze leaf tip color	P4 x P5	-17.40	-34.20*	-34.17*	-22.60*	-41.10*	-41.13*
Mean of Green x Bronze leaf tip color		22.05	5.42	5.39	15.95	-4.03	-4.03
Grand mean							

‡**, ** = Significant at P < 0.05 and P < 0.01levels, respectively,* ‡**, ** = Significant at P < 0.05 and P < 0.01 levels, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; SH = Standard heterosis, P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377 and P5 = 1681. The significance of the percent heteerosis was tested by comparing mean differences between F, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance, where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of the commercial variety (check).*

Table 5a. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for Sidamo coffee cup and overall quality in relation to parents' origin in Set III coffee hybrid (*Coffea arabica* L.) trial in Ethiopia.

	Acidity			Body			Flavor			Cup quality			Overall quality		
Hybrid[‡]	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)
P1 x P2	28.57	0.00	13.00	20.00	0.00	0.00	11.11	0.00	0.00	20.69	0.00	5.00	8.09	0.00	1.00
P1 x P3	14.29	-11.11	0.00	9.09	-14.29	0.00	1.69	-14.29*	0.00	8.70	-13.04	0.00	13.32*	4.83	6.00
P2 x P3	0.00	0.00	13.00	23.08*	14.29	33.00**	23.08*	14.29*	33.00*	13.64	8.70	25.00**	14.01**	14.01**	16.00**
Mean (K x K)	9.53	-3.70	8.33	17.39	0.00	11.11	11.57	0.00	11.11	14.34	-1.45	10.00	11.81	6.28	7.35
P4 x P5	-42.86**	-50.00**	-50.00**	0.00	0.00	0.00	-20.0*	-20.0*	-20.00*	-32.63**	-36.00**	-36.00**	-13.13*	-15.69**	-16.00**
P4 x P6	28.57	12.50	13.00	0.00	0.00	0.00	0.00	0.00	0.00	10.53	5.00	5.00	7.81	1.47	1.00
P5 x P6	50.00**	50.00**	13.00	0.00	0.00	0.00	0.00	0.00	0.00	16.67	16.67	5.00	16.13**	12.50*	6.00
Mean (S x S)	11.90	4.17	-8.00	0.00	0.00	0.00	-6.67	-6.67	-6.67	-1.81	-4.78	-8.33	3.60	-0.57	-3.00
Mean (Within)	10.72	0.24	0.17	8.70	0.00	5.50	2.45	-3.34	2.22	6.27	-3.12	0.84	7.71	2.86	2.18
P1 x P4	23.08	0.00	0.00	20.00	0.00	0.00	11.11	0.00	0.00	18.34	0.00	0.00	7.37	0.00	0.00
P1 x P5	63.64**	50.00**	13.00	20.00	0.00	0.00	11.11	0.00	0.00	32.08*	16.67	5.00	22.28**	17.19**	10.00
P2 x P4	-41.18**	-44.44**	-38.00**	-33.33*	-33.33*	-33.00**	-20.0*	-20.00*	-20.00*	-32.68**	-34.29**	-31.00**	-10.95*	-11.59*	-10.00
P2 x P5	-20.00	-33.33**	-25.00	0.00	0.00	0.00	0.00	0.00	0.00	-3.59	-10.48	-6.00	-3.76	-7.25	-6.00
P3 x P4	-5.88	-11.11	0.00	-7.69	-14.29	0.00	-7.69	-14.29*	0.00	-6.98	-13.04	0.00	2.19	1.45	3.00
P3 x P5	-6.67	-22.22	-13.00	-7.69	-14.29	0.00	-7.69	-14.29*	0.00	-7.32	-17.39	-5.00	6.27	2.42	4.00
Mean (Between)	2.17	-10.18	-10.42	-1.45	-10.32	-5.56	-1.42	-8.10	-3.33	-0.03	-9.76	-6.17	3.90	0.37	0.16
Grand mean	7.73	5.97	-3.36	4.35	-6.19	1.85	0.62	-5.72	-0.55	3.74	-7.73	-1.50	6.96	1.94	1.50
	LSD (0.05) = 3.90, LSD (0.01) = 4.51			LSD (0.05) = 2.48, LSD (0.01) = 2.87			LSD (0.05) = 1.95, LSD (0.01) = 2.26			LSD (0.05) = 7.30, LSD (0.01) = 8.44			LSD (0.05) = 7.88, LSD (0.01) = 9.11		

[‡]*, ** = Significant at $P < 0.05$ and $P < 0.01$ levels, respectively; MPH = Mid parent heterosis; BPH = Better parent heterosis; SH = Standard heterosis, K x K = Kaffa x Kaffa, S x S = Sidamo x Sidamo, K x S Kaffa x Sidamo coffee hybrids P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377 and P5 = 1681. Note: The significance of the percent heterosis was tested by comparing mean differences between F_1, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance where MP = Mean performance of the two parents, BP = Mean performance of better parent and CV = Mean performance of commercial variety (check).*

Table 5b. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for Sidamo raw coffee quality parameters and ranking in relation to parents' origin in Set III coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

	Shape and Make			Color			Raw quality			
Hybrid	MPH	BPH	SH	MPH	BPH	SH	MPH	BPH	SH	Rank
P1 x P2	-7.69	-14.29	-14.29	1.41	2.86	0	-2.39	-4.67	-3	Cup: acceptable
P1 x P3	23.29**	7.14	7.14	27.27*	20.00	17	17.59**	9.35	11	Raw: better than usual Sidamo coffee ,Cup: acceptable
P2 x P3	25.37**	16.67	0.00	16.42	8.33	8	14.43*	8.82	6	Raw: better than usual Sidamo coffee ,Cup: highly acceptable
Mean (K x K)	13.72	3.17	-2.38	15.03	10.40	8.33	9.88	4.50	4.7	
P4 x P5	7.69	0.00	0.00	0.00	0.00	0	4.35	2.86	3	Raw: better than usual Sidamo coffee ,Cup: not acceptable
P4 x P6	-7.69	-14.29	-14.29	20.00	0.00	0	4.62	-2.86	-3	Cup: acceptable
P5 x P6	25.00**	25.00**	7.14	20.00	0.00	0	15.63*	8.82	6	Raw: better than usual Sidamo coffee ,Cup: acceptable
MS x S	8.33	3.57	-2.38	13.33	0.00	0.00	8.20	2.94	2	
Mean (Within)	11.03	3.37	-2.38	14.18	5.2	4.17	9.04	3.72	3.35	
P1 x P4	-7.14	-7.14	-7.14	-1.41	-2.78	-3	-1.89	-2.80	-1	Cup: acceptable
P1 x P5	15.38	7.14	7.14	26.76*	25.00*	25*	14.83*	12.15	14*	Raw: better than usual Sidamo coffee ,Cup: highly acceptable
P2 x P4	15.38	7.14	7.14	8.33	8.33	8	10.14	8.57	9	Raw: better than usual Sidamo coffee ,Cup: acceptable
P2 x P5	0.00	0.00	-14.29	0.00	0.00	0	0.00	0.00	-3	Cup: acceptable
P3 x P4	15.07	0.00	0.00	13.43	5.56	6	11.68	4.76	5	Raw: better than usual Sidamo coffee ,Cup: acceptable
P3 x P5	34.33**	25.00**	7.14	25.37*	16.67	17	20.62**	14.71*	11	Raw: better than usual Sidamo coffee ,Cup: acceptable
Mean (Between)	12.17	5.36	-2.38	12.08	8.80	8.8	9.23	6.23	6.5	
Grand mean	11.41	4.03	-2.38	13.48	6.4	5.71	9.1	4.56	4.4	
	LSD (0.05) = 2.59, LSD (0.01) = 2.99			LSD (0.05) = 3.00, LSD (0.01) = 3.46			LSD (0.05) = 4.95, LSD (0.01) = 5.72			

**, **, Significant at P < 0.05 and P < 0.01 levels, respectively; K x K = Kaffa x Kaffa, S x S = Sidamo x Sidamo, K x S = Kaffa x Sidamo coffee hybrids P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377, P5 = 1681; Note: - The significance of heterosis was tested by comparing mean differences between F_1, MP, BP and CV means to LSD values derived from genotypes (F_1 and parent) analysis of variance; MP = Mean performance of the two parents; BP = Mean performance of better parent and CV = Mean performance of commercial variety (check).*

Two hybrids each from Kaffa x Kaffa and Sidamo x Sidamo and four from Kaffa x Sidamo registered positive SH for Sidamo raw coffee quality. Similarly, three hybrids each from Kaffa x Kaffa and Kaffa x Sidamo and two Sidamo x Sidamo hybrids recorded positive SH for overall Sidamo coffee quality. None of the Kaffa x Kaffa and Kaffa x Sidamo hybrids were evaluated as having internationally unacceptable Sidamo coffee quality, but one Sidamo x Sidamo hybrid was evaluated as having internationally unacceptable Sidamo coffee quality. Two and four Kaffa x Kaffa and Kaffa x Sidamo hybrids, respectively, were evaluated as having coffee raw quality better than usual Sidamo coffees. Even though, two Sidamo x Sidamo hybrids were evaluated as having coffee raw quality better than the usual Sidamo coffees, one hybrid's overall Sidamo coffee quality was internationally unacceptable. One Kaffa x Kaffa (P2 x P3) and one Kaffa x Sidamo (P1 x P5) hybrids were evaluated as having internationally highly acceptable overall Sidamo coffee quality. These hybrids also exhibited positive SH for all other coffee quality parameters. None of the Sidamo x Sidamo hybrids exhibited positive and significant SH for any one of the Sidamo coffee quality parameters.

3.2.2. Heterosis in Relation to Parents' Origin and Leaf tip Color

Hybrids obtained from green x green leaf tip color parents regardless of parents origin registered positive mean MPH for all coffee quality parameters which ranged from 1.14 to 17.38%. Hybrids having green x bronze leaf tip colors regardless of parents origin exhibited negative MPH for all Sidamo coffee parameters except shape and make (7.75%), color (5.09%) and raw quality (6.07%) which exhibited positive mean MPH. The result is presented in Tables 5c and 5d.

Hybrids obtained by crossing parents with green x green leaf tip color registered positive BPH for shape and make, color and Sidamo raw coffee, and the over all quality ranged from 2.78 to 6.94% while acidity, flavor, body and Sidamo coffee cup quality had negative mean BPH ranging from -2.38 to -2.78. On the other hand, hybrids having parents' green and bronze leaf tip colors registered positive BPH of 2.78 and 3.35% only for color and Sidamo raw coffee quality, respectively. This group of hybrids exhibited negative mean BPH for all other coffee quality parameters which ranged from -6.46 to -20.83%. Hybrids obtained from both parents with green leaf tip color had mean advantages over the best commercial Sidamo coffee variety/cultivar for all the Sidamo coffee quality parameters except for shape and make. The mean SH for all coffee quality parameters ranged from 0.17 to 11.17%. On the other hand, hybrids obtained by crossing parents with green x bronze leaf tip colors registered positive mean SH of 2.75 and 4.00% only for color and Sidamo raw coffee quality, respectively, while negative mean SH (-5.75 to -26.39%) were observed for all the other coffee quality parameters (Tables 5c and 5d). Five out of six hybrids generated from parents both having green leaf tip color but either similar or distant parents in origin (Kaffa x Kaffa and Kaffa x Sidamo) exhibited positive SH in the range of 1 to 16% for over all the Sidamo coffee quality which is a single most important parameter that determine the acceptability of Sidamo coffee in international coffee market. On the other hand, only one hybrid among the green x bronze hybrids having distant parents in origin (Kaffa x Sidamo) exhibited a positive SH (3%) for this important trait.

4. Discussion

In Ethiopia, consistently hybrids yield advantages over the better parents and best yielding checks (commercial cultivars) were observed and progressively increased as distant parents in origin included in crossing. It was observed that 20% of SH for a hybrid obtained by crossing parents from similar origin in Set I progressed to 42.3% for Set II for hybrid obtained by crossing parents from different geographical origin. Besides, in Set III the magnitude of SH was increasing to 44.62% for hybrids obtained by crossing distant parents in origin. Most of the hybrids obtained by crossing distant parents in origin exhibited higher SH for coffee yield. In Ethiopia, the observed magnitude of standard heterosis was much greater than other coffee growing countries. In Brazil, heterosis in terms of yield was studied over several years in crosses of selected indigenous C. *arabica* L. varieties, but it was reported to be lacking (Carvalho *et al.,* 1969; Carvalho, 1988). In this country, the absence of heterosis in *Coffee arabica* L. lead to in crossing of Catuai lines (*Coffea arabica*) with 12 descendents from the Hybrido Timor (*Coffea canephora*). In one of such trial, heterosis values of 28.7 and 19.1% over the best control yield, respectively, in the first four and six years were recorded (Fontes *et al.,* 2000). In Kenya Van der Vossen and Walyaro (1981) reported better parent heterosis of 19.7% in Catura x Hybrido Timor and 15% heterosis in Padang x SL34 hybrids (Van der Vossen, 1985). The higher magnitude of heterosis over the best checks in Ethiopian coffee hybrids might be due to high genetic variability among and between coffee growing regions' coffee types as it was reported by many researchers (IBPGR, 1980); Carneriro, 1997; Fazuoli *et al.*, 2000).

This study revealed that coffee hybrids generated from distant parents both in origin and growth habit were most heterotic for coffee yield. Other group of hybrids which had distant parents in origin but similar growth habit were the second most heterotic hybrids. The lowest magnitude of SH was recorded for hybrids having both parents similar in origin and growth habit. Hybrids obtained from parents having nearly similar origin but distinct difference in growth habit also registered lower magnitude of SH. These results are in contrast to Bayetta *et al. (*2007) who reported the superiority of hybrids having parents nearly similar origin but distinct differences in growth habit. The authors also suggested that variation in geographical origin had no significant effect on heterosis. Bayetta *et al.* (2007) who compared hybrids based on mean MPH (%) and BPH (%) for yield and other traits reported that the hybrids that exhibited the highest mid and better parent heterosis did not always exhibit the highest yield and standard heterosis. Besides, economically important heterosis is standard heterosis and selection and ranking of hybrids based on the degree of mid and better parent heterosis per se is misleading in respect to commercial importance of hybrids. Therefore, on the basis of the results of standard heterosis, it is possible to suggest the importance of considering parents diversity both in origin and growth habit; if not possible the origin of parents' should be considered to obtain heterotic commercial hybrids.

Table 5c. Mid parent (MPH), better parent (BPH), and standard (SH) heterosis for Sidamo coffee cup quality parameters in relation to parents' origin and leaf tip color in Set III coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

Origin and leaf tip color‡	Hybrid	Acidity			Body			Flavor			Cup quality		
		MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)
Kaffa x Kaffa, Green x Green	P1 x P2	28.57	0.00	13	20.00	0.00	0	11.11	0.00	0	20.69	0.00	5
Kaffa x Kaffa, Green x Green	P1 x P3	14.29	-11.11	0	9.09	-14.29	0	1.69	-14.29*	0	8.70	-13.04	0
Kaffa x Kaffa, Green x Green	P2 x P3	0.00	0.00	13	23.08*	14.29	33**	23.08*	14.29*	33*	13.64	8.70	25**
Mean similar origin and Green x Green		9.53	-3.70	8.67	17.39	0.0	11.11	11.57	0	11.11	14.34	-1.45	10
Kaffa x Sidamo, Green x Green	P1 x P5	63.64**	50.00**	13	20.00	0.00	0	11.11	0.00	0	32.08*	16.67	5
Kaffa x Sidamo, Green x Green	P2 x P5	-20.00	-33.33**	-25	0.00	0.00	0	0.00	0.00	0	-3.59	-10.48	-6
Kaffa x Sidamo, Green x Green	P3 x P5	-6.67	-22.22	-13	-7.69	-14.29	0	-7.69	-14.29*	0	-7.32	-17.39	-5
Mean between region and Green x Green		12.32	-1.85	-8.33	4.10	-4.76	0	1.14	-4.76	0	7.06	-3.73	-2
Mean of Green x Green leaf tip color		13.31	-2.78	0.17	10.75	-2.38	5.50	6.55	-2.38	5.50	10.70	-2.59	4.00
Kaffa x Sidamo, Green x Bronze	P1 x P4	23.08	0.00	0	20.00	0.00	0	11.11	0.00	0	18.34	0.00	0
Kaffa x Sidamo, Green x Bronze	P2 x P4	-41.18**	-44.44**	-38**	-33.33*	-33.33*	-33**	-20.0*	-20.0*	-20*	-32.68**	-34.29**	-31**
Kaffa x Sidamo, Green x Bronze	P3 x P4	-5.88	-11.11	0	-7.69	-14.29	0	-7.69	-14.29*	0	-6.98	-13.04	0
Mean between region and Green x Bronze		-7.99	18.52	-12.67	7.01	-15.87	-11	-5.53	-11.43	-3.33	-7.11	-15.78	-10.33
Sidamo x Sidamo, Green x Bronze	P4 x P5	-42.86**	-50.00**	-50**	0.00	0.00	0	-20.0*	-20.0*	-20*	-32.63**	-36.0**	-36**
Mean of Green x Bronze leaf tip color		-16.71	-26.39	-22.00	-5.26	-11.91	-8.25	-4.15	-13.57	-10.0	-13.49	-20.83	-16.75

*, ** = *Significant at P < 0.05 and P < 0.01levels, respectively, B x B = Bronze x Bronze, P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377 and P5 = 1681*

Table 5d. Mid parent (MPH %), better parent (BPH %), and standard (SH %) heterosis for Sidamo raw coffee parameters and overall quality in relation to parents' origin and leaf tip color in Set III coffee (*Coffea arabica* L.) hybrid trial in Ethiopia.

Origin and Leaf tip color	Hybrid	Shape and Make			Color			Raw quality			Overall coffee quality		
		MPH	BPH	SH	MPH	BPH	SH	MPH	BPH	SH	MPH	BPH	SH
Kaffa x Kaffa, Green x Green	P1 x P2	-7.69	-14.29	-14.29	1.41	2.86	0	-2.39	-4.67	-3	8.09	0.00	1
Kaffa x Kaffa, Green x Green	P1 x P3	23.29**	7.14	7.14	27.27*	20.00	17	17.59**	9.35	11	13.32*	4.83	6
Kaffa x Kaffa, Green x Green	P2 x P3	25.37**	16.67	0.00	16.42	8.33	8	14.43*	8.82	6	14.01**	14.01**	16**
Mean similar origin and Green x Green		13.72	3.17	-2.38	15.03	10.40	8.33	9.88	4.50	4.7	11.81	6.28	7.35
Kaffa x Sidamo, Green x Green	P1 x P5	15.38	7.14	7.14	26.76*	25.00*	25*	14.83*	12.15	14*	22.28**	17.19**	10
Kaffa x Sidamo, Green x Green	P2 x P5	0.00	0.00	-14.29	0.00	0.00	0	0.00	0.00	-3	-3.76	-7.25	-6
Kaffa x Sidamo, Green x Green	P3 x P5	34.33**	25.00**	7.14	25.37*	16.67	17	20.62**	14.71*	11	6.27	2.42	4
Mean between region and G x G		16.57	10.71	0	17.38	13.89	14	11.82	8.95	7.33	8.26	4.12	2.67
Mean of G x G leaf tip color		15.11	6.94	-1.19	16.21	12.14	11.17	10.85	6.73	6.00	10.04	5.20	5.17
Kaffa x Sidamo, Green x Bronze	P1 x P4	-7.14	-7.14	-7.14	-1.41	-2.78	-3	-1.89	-2.80	-1	7.37	0.00	0
Kaffa x Sidamo, Green x Bronze	P2 x P4	15.38	7.14	7.14	8.33	8.33	8	10.14	8.57	9	-10.95*	-11.59*	-10
Kaffa x Sidamo, Green x Bronze	P3 x P4	15.07	0.00	0.00	13.43	5.56	6	11.68	4.76	5	2.19	1.45	3
Mean between region and Green x Bronze		7.77	0.00	0.00	6.78	3.7	3.67	6.43	3.51	4.33	-0.46	-3.38	-2.33
Sidamo x Sidamo, Green x Bronze	P4 x P5	7.69	0.00	0.00	0.00	0.00	0	4.35	2.86	3	-13.13*	-15.69**	-16**
Mean of Green x Bronze leaf tip color		7.75	0	0.00	5.09	2.78	2.75	6.07	3.35	4.00	-3.63	-6.46	-5.75

*, ** = *Significant at P < 0.05 and P < 0.01 levels, respectively; * Set III, P1 = 744, P2 = 7440, P3 = 75227, P4 = 1377, P5 = 1681*

The findings of the present study are in agreement with Pradhan *et al.* (1993), Falk *et al.* (1994) and Ali *et al.* (1995) who using morphological markers and geographic origin observed an increase in heterosis with increasing parental distance in *Brassica juncea*, *Brassica rapa* and *Brassica napus,* respectively..

Hybrids heterosis effects calculated in relation to parents' leaf color regardless of their origin and growth habit revealed that hybrids having parents with different leaf tip colors were more heterotic for yield than hybrids which had parents with similar leaf tip color. Two hybrids that exhibited the highest SH (P3 x P4, 44.62% in Set II and P1 x P5, 42.31% in Set III for yield were obtained by crossing distant parents in origin with different leaf tip color and distant parents in all factors origin, morphology and leaf tip color). This result could be a good indicator of the need to consider leaf tip color differences in parental lines selection to produce heterotic hybrids.

The Kaffa x Kaffa (P2 x P3) and Kaffa x Sidamo (P1 x P5) hybrids were evaluated as having highly acceptable Sidamo coffee quality for international coffee market. These hybrids also exhibited positive SH for all other Sidamo coffee quality parameters. Besides, the Kaffa x Kaffa and Kaffa x Sidamo hybrids were superior over the Sidamo x Sidamo hybrids for all coffee quality parameters. This suggested the possibility of improving target region coffee quality as well as yield through selection and then crossing coffee parents regardless of their origin. This result was in agreement with Montagnon *et al.* (1998) who reported variation of yield and quality traits are independent form genetic correlations study between yield and several quality traits, in crosses of Congolese and Guinean group of parents.

Hybrids heterosis effects calculated for quality parameters in relation to parents' origin and leaf tip color revealed the superiority of hybrids generated from parents with similar leaf tip color (green) over the hybrids obtained from parents with different leaf tip colors. Distant parents in origin had little effect on hybrids magnitude of SH. The hybrids obtained from crossing of two Sidamo coffee parents either considering or without considering their leaf colors did not perform better than the hybrids obtained from Kaffa x Kaffa hybrids in both combinations. This result suggested the importance of considering parents leaf tip color to improve the target region coffee quality than the coffee parents' to be originated in target region.

5. Conclusions

The magnitude of standard heterosis progressively increased in Ethiopian coffee hybrids (*Coffea arabica* L.) as distant parents' in all factors were included in the crossing program. It was recorded the highest standard heterosis of 20% for the within region hybrids in the first hybrid trial which progressed to 42.3% for clean coffee yield for hybrid generated from distant parents in all factors (origin, growth habit, leaf tip color) in second hybrid trial. The highest standard heterosis (44.62%) for clean coffee yield was also observed in the third hybrid trial. This hybrid was obtained from distant parents in origin and leaf tip color. The advantage of inclusion of distant parents in all possible factors was not only observed in the magnitude of exploitable heterosis but also in obtaining greater number of heterotic hybrids from each trial. These results suggested the importance of inclusion of distant parents in one or more factors to produce greater number of coffee hybrids with highest magnitude of heterosis.

In this investigation, the within region (Kaffa x Kaffa) and the between region (Kaffa x Sidamo) hybrids showed superiority over the released Sidamo coffee parent used as check. These hybrids also showed superiority over the hybrids obtained from crossing of two Sidamo parents for Sidamo coffee quality parameters. The superiorities of the Kaffa x Kaffa and Kaffa x Sidamo over the Sidamo x Sidamo coffee hybrids did not only exhibit higher magnitude of standard heterosis but also most of the hybrids displayed higher magnitude of SH. It was also observed that the parents green leaf tip color affected the magnitude of heterosis regardless of their distant in origin. It was interesting to observe the superiority of hybrids generated from parents' other than the target region crossed among them or crossed with the target region coffee parents for the target region coffee quality. This indicates inclusion of parents other than the target region did not negatively blend the target region coffee quality. It is suggested to consider and study further on the effects of parents leaf tip color on the magnitude of heterosis for coffee quality to design appropriate breeding method to improve the target region coffee quality.

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