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Estimation of magnitudes of heterosis for grain yield and yield contributing traits of conventional maize (*Zea mays* L.) single cross hybrids

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This study was initiated with the objective of estimating magnitude of heterosis of selected conventional maize inbred lines. Ten elite inbred lines were selected based on over per se performances. The crosses were done in a 10 x 10 half-diallel mating design to produce 45 F_1 single crosses hybrids during 2016. The experiment was conducted at Bako National Maize Research Center in 2017 main cropping. The experimental material consisted of 45F1 single crosses and three standard checks with a total of 48 genotypes. The quantitative agronomic data were recorded following standard protocols of CIMMYT. Percent of mid-parent (MP), better parent (BP) and standard heterosis was estimated for agronomic traits that revealed significant under analysis of variance. Maximum percent of mid-parent (240.34%), better parent (220.85%) and standard heterosis of 18.79% were detected for grain yield. Crosses of L1 x L4, L1 x L5 and L2 x L4 showed significant heterosis over the best two standard checks for grain yield.

Key words: Heterosis, economic heterosis, grain yield, maize

INTRODUCTION

Maize (*Zea mays* L.) occupies a prestigious place in the world agriculture. It is a miracle crop in view of its widespread usage as food and nonfood items (Lone et al., 2016). It is also considered as the third important cereal crop in the world after rice and wheat (Devi et al., 2016). The world maize production area was around 196.08 million hectares, and that of wheat and rice was 220.83 million and 163.00 million hectares, respectively (USDA, 2020).

Despite a remarkable increase in maize yield starting from late 1990s, maize yield is still low relative to that of the developed countries and world average. According to USDA (2020) for example, the national average grain yield for USA, Canada, Turkey, Argentina, Egypt, and world average was 10.21, 10.21, 11.42, 8.06, 8.00 ton and 5.93 ton ha^{-1}, respectively.

Maize has a significant importance in the food security and diets of rural Ethiopia and gradually penetrated into

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urban centers. This is particularly evidenced by green maize being sold at roadsides throughout the country as a hunger-breaking food available during the months of February to May annually (Twumasi et al., 2012).

In Ethiopia, during 2017/18 main cropping season, maize was cultivated on 2.13 million hectares from which 8.4 million tons of maize grain was produced (CSA, 2017, 2018). Even though, more than forty hybrids were released by national maize research program and other agricultural research centers, the demand for maize is increasing from time to time due to the high food demand associated with increased human population. From 2015 (CSA) to 2017 (USDA) (USDA, 2017), the population of Ethiopia increased from 90.08 million to 103.9 million people out of which maize growers increased from 7.49 million to 10.86 million at household level. To ensure food security for the ever increasing human population in Ethiopia and the maize growing agro-ecologies of the country, information on heterosis of maize germplasm is essential in maximizing the effectiveness of hybrid development.

The phenomenon of heterosis has provided the most important genetic tool improving yield potential of crop plants. Heterosis breeding is primary based to the identification of parents and their cross combinations capable of producing the highest level of transgressive segregates. The magnitude of heterosis depends on the extent of genetic diversity between parents and helps in choosing the parents for superior Fl hybrids (Dhoot et al., 2017). Many scholars defined heterosis as the superiority in performance of hybrid individuals compared with their parents which implies that the hybrids obtained have more vigour than their parents. For example, Falconer et al. (1996) defined heterosis or hybrid vigour as the difference between the hybrid and the mean of the two parents. This difference is called mid-parent heterosis. The type of parents chosen and measurement of trait determines the level of heterosis in maize, hence it is important to select superior parents (Abuali et al., 2012). Better parent heterosis quantifies the performance of the F1 hybrid over the better performing parent (Springer and Stupar, 2007). Standard heterosis refers to the superiority or inferiority of F_1 crosses over the standard check hybrids and it indicates the usefulness or uselessness of the crosses. Both relative heterosis (MP) and heterobeltiosis (BP) are important parameters as they provide information about the presence of dominance and over dominance type of gene actions in the expression of various traits. Heterosis has been used in breeding and production of many crops, and in maize, an estimated 15% per annum on yield increase has been reported through the use of hybrids (Iqbal et al., 2010).

The study of heterosis can provide the basis for the exploitation of valuable hybrid combinations in the breeding program (Shrestha and Gurung, 2018). The present study aimed to estimate the magnitude of heterosis and yield advantage of the crosses for grain yield and related traits.

MATERIALS AND METHODS

Experimental locations

The experiment was conducted at Bako National Maize Research Center during 2017 main cropping season. Bako is located in East Wollega zone of the Oromia National Regional State, Western Ethiopia. The center lies between 9°6' North latitude and 37°09' east longitude in the sub-humid agro-ecology, at altitude of 1650 m above sea level (m.a.s.l). It is 250 km far from Addis Ababa, the capital city of the country. The mean annual rainfall in the last half century is 1238 mm. The rainy season covers April to October and maximum rain is received in the months of July and August. The mean minimum, mean maximum and average air temperature is 12.8, 29.0, and 20.9°C, respectively; and relative humidity is 51.04% (Appendix Table 1). The soil is reddish brown in color and clay and loam in texture (Wakene, 2001). According to USDA (2015) soil classification, the soil is Alfisols developed from basalt parent materials, and is deeply weathered and slightly acidic in reaction (Wakene, 2001).

Experimental materials

Ten inbred lines namely, L1, L2, L3, L4, L5, L6 and L7 from BNMRC (Bako National Maize Research Center), L8 and L9 from CIMMYT and L10 from IITA were used in this study. The inbred lines were cross pollinated in a half diallel fashion to develop 45 single cross hybrids. A total of 48 hybrids, 45 single cross hybrids and three commercial standard checks (BH546, BH547 and SPRH1) were evaluated during 2017 main cropping season for grain yield and related agronomic traits.

Experimental design

Each 48 hybrid was sown in 5.1 m-long rows with row to row and plant to plant spacing of 75 cm and 30 cm respectively. The experiment was laid out in alpha lattice (0, 1) with two replications.

Collected data

The agronomic data were recorded on ten random competitive plants following standard protocols of CIMMYT (Magorokosho et al., 2009). The recorded quantitative traits were;

Days to anthesis (AD): The number of days from planting date to 50% pollen shedding was recorded.

Days to silking (SD): The number of days from planting date to when 50% of the plants in a plot have grown 2-3 cm silk length.

Plant height (PH): The height from the soil surface to the first tassel branch of ten randomly taken plants from each experimental unit was measured in centimetres. Like ear height, this was also measured two weeks after pollen shedding had ceased from the same plants that EH measured.

Ear height (EH): The height from the ground level to the upper most ear-bearing node of ten randomly taken plants from each experimental unit was measured in centimetres. The measurement was made two weeks after pollen shedding ceased.

Table 1. Range of mid- parent and better parent heterosis of F_1 crosses for yield and yield contributing traits.

Traits	Mid-parent heterosis (%)						Better parent heterosis (%)					
	G. Mean	Minimum	Cross	Maximum	Cross	SE (±)	G. Mean	Minimum	Cross	Maximum	Cross	SE (±)
GY	70.01	-15.56	L9 x L10	240.34	L3 x L7	0.78	40.94	-36.45	L9 x L10	220.85	L3 x L7	0.9
AD	-8.6	-15.52	L3 x L4	-3.01	L2 x L10	1.48	-6.84	-14.53	L3 x L4	0.62	L5 x L7	1.71
SD	-9.5	-17.42	L3 x L4	-4.07	L8 x L10	1.21	-7.87	-16.95	L3 x L4	-0.6	L8x L10	1.4
PH	74.11	32.36	L9 x L10	109.18	L7 x L8	6.73	91.24	32.36	L9 x L10	134.12	L5 x L8	7.77
EH	79.11	44.52	L2 x L9	142.08	L3 x L8	6.33	111.84	45.53	L2 x L9	184.09	L3 x L6	7.31
ED	17.56	2.41	L2 x L6	38.12	L3 x L7	0.09	8.73	-6.32	L3 x L6	33.38	L3 x L7	0.1
EL	29.05	-1.44	L9 x L10	61.51	L3 x L7	0.82	20.83	-7.81	L9 x L10	55.47	L3 x L7	0.95
TKW	25.03	-8.33	L9 x L10	68.42	L1 x L5	23.74	15.4	-14.47	L8 x L9	50	L1 x L5	27.41
SHP	5.71	0.09	L4 x L8	12.09	L2 xL8	1.35	2.9	-3.87	L2 x L5	8.14	L3 x L6	1.56
HI	-23.65	-48.68	L3 x L4	-4.54	L6 x L6	5.82	-29.64	-57.92	L3 x L4	-7.86	L6 x L8	6.73

GY = Grain Yield (tonha^{-1}); AD = 50% Days to Anthesis; SD = 50% Days to Silking; PH = Plant Height (cm); EH = Ear Height (cm); ED = Ear Diameter (cm); EL = Ear Length (cm); TKW = Thousand Kernel Weight (g); SHP = Shelling Percentage; HI = Harvest Index (%); G. mean = Grand Mean; SE (±) = Standard Error.

Grain weight per plot (GY): Ears were removed from all plants in each plot leaving other crop residues (husk, leaf, stem and tassel) intact. The total field weight from all the ears of each experimental unit was recorded and converted to ton ha^{-1}.

Ear diameter (ED): This was measured at the mid-section along the ear length, as the average diameter of ten randomly taken ears from each experimental plot in centimetres using digital calliper.

Ear length (EL): Length of ears from the base to tip was measured in centimetres. Data recorded represents the average length of ten randomly taken ears from each experimental unit.

Thousand kernel weight (TKW): After shelling each ten randomly selected ear, random kernels from the bulk of shelled grain in each experimental unit was taken and thousand kernels were counted using a seed counter and weighed in grams and then adjusted to 12.5% grain moisture.

Harvest index (HI) (%): The ratio of grain yield to total above ground dry biomass yield multiplied by 100.

$$\mathrm{HI} = \frac{\text{Grain yield per plot}}{\text{Total above ground dry biomass per plot}} \text{ x } 100$$

Where, GY = Grain yield per plot in tons, AGDB = above ground dry biomass in tons.

Shelling percentage (SHP): The ratio of weight of ten sampled cob after shelling to the weight of ten sampled cob before shelling multiplied by 100.

$$\mathrm{SHP} = \frac{\text{Shelled sampled grain yield}}{\text{Not shelled sampled grain yield}} \text{ x } 100$$

Data analysis

Heterosis was estimated over the mid-parent, better parent (Heterobeltiosis), and over the checks (Economic heterosis) for traits revealed significant under analysis of variance and test of significance was carried out. The significance of heterosis was determined as the least significant differences (L.S.D) at 0.05 and 0.01 levels of probability according to formula suggested by Steel et al. (1997).

Estimation of heterosis

Mid parent heterosis (MPH), better parent heterosis (BPH) and standard variety heterosis (SH) were calculated for the character that showed significant differences between genotypes (crosses and parents) following the method suggested by Falconer et al. (1996).

Mid parent heterosis (%) = $\frac{F_1 - MP}{MP} \times 100$

Better parent heterosis (%) = $\frac{F_1 - BP}{BP} \times 1000$

Standard Variety heterosis (%) = $\frac{F_1 - SV}{SV} \times 100$

Where, F_1 = Mean value of the crosses
MP = Mean value of the two parents
BP = Mean value of the better parent
SV = Mean value of standard varies.

The standard error of the difference for heterosis is calculated as follows:

SE (m) for MP = $\pm\sqrt{\frac{3Me}{2r}}$

SE (m) for BP = $\pm\sqrt{\frac{2Me}{r}}$

SE (m) for SH = $\pm\sqrt{\frac{2Me}{r}}$

SE (d) for MP = SE (m) for MP x t value at error degree of freedom,
SE (d) for BP = SE (m) for BP x t value at error degree of freedom,
SE (d) for SH = SE (m) for SH x t value at error degree of freedom.

Test of significance for heterosis was done by comparing (F_1-MP) with SE (d) for mid parent, (F_1 -BP) with SE (d) for better parent heterosis and for standard heterosis (F_1 – SV) with SE (d). Where, SE (m) is standard error of the mean, SE (d) is standard error of the difference, Me is error mean square and r is the number of replications.

RESULTS AND DISCUSSION

The range of percent of mid-parent and better parent for all traits under the study as respects crosses was summarized in Table 1 whereas, for standard heterosis in Table 2. The extent of mid parent, better parent and standard heterosis for best five hybrids for yield and yield contributing traits at 10% selection intensity was summarized in Table 3.

Significance of heterosis was tested and presented in Appendix Table 2 (for mid parent and better parent heterosis) and Appendix Table 3 (for standard or economic heterosis).

Percent of mid and better parent heterosis

Heterosis may be defined as the superiority of an F_1 hybrid over both of its parents in terms of yield and other characteristics (Bhat and Singh, 2005). Krivanek et al. (2007) declared that heterosis is prerequisite for developing a good economically viable hybrid maize variety.

In the present study, most crosses showed positive significant mid and better parent heterosis for grain yield and related traits (Appendix Table 2). In this study, maximum mid and better parent heterosis obtained for grain yield was 240.34% and 220.85% respectively in Table 1. Similar results were reported by Tollenaar et al. (2004) who estimated heterosis in maize hybrids and their parental inbred lines for grain yield and its components and also reported 167% heterosis for grain yield.

Similarly, Gudeta (2007) found that all the crosses manifested positive and highly significant heterosis over the mid-parents while most of the crosses manifested positive and highly significant heterosis over the better parents; he also showed maximum mid parent heterosis (259.17%) and better parent heterosis (226.68%). Berhanu (2009) also reported, all crosses showed positive and significant MPH and HPH and can get 202.34% of MPH and HPH value for grain yield. Besides, Wende (2014) reported out of 81 crosses, thirty-three hybrids displayed positive mid-parent heterosis up to 250% and thirty-three crosses displayed positive high parent heterosis up to 235% for grain yield.

Majority of the crosses showed negatively significant heterosis over mid parent and better parent for days to anthesis and silking indicating the progenies are earlier than their respective inbred lines. Crosses that exhibited negatively significant heterosis over mid and better parent had gene combinations that reduce 50% days to anthesis and silking. In general, almost all crosses showed significant difference and had negative mid and better parent heterosis for days of anthesis and silking (Appendix Table 1). The present result is in agreement with Bayisa (2004), Dagne et al. (2007) and Berhanu (2009) who, reported that almost all crosses showed negative and significant MPH and BPH for days to anthesis and silking indicating F_1 crosses were earlier on days to anthesis and silking than their parents and Dagne et al. (2013) also reported all the hybrids showed negative MPH and BPH for days to anthesis and silking at Bako and Harare environments.

For mid and better parent heterosis for 50% days to physiological maturity, all crosses depicted negative heterosis whereas majority of crosses showed negative heterosis respectively. Similar findings were previously reported by Habtamu (2015) that both mid-parent and better parent heterosis for days to maturity are negative for all the crosses. This showed that hybrids tend to be earlier in maturity compared to their parents.

All crosses expressed positive highly significant heterosis over both mid and better parent heterosis for plant and ear height (Appendix Table 2). The result indicates vigorousity of the crosses over their parents. This result is in agreement with earlier findings of Bayisa et al. (2005), Gudeta (2007) and Berhanu (2009). They reported that the positive MPH and BPH for plant and ear height in all crosses except some crosses. Dagne et al. (2013) also reported positive MPH for plant and ear height was positive at Bako and Harare locations and an average of 50.2 and 62.6% for the two locations respectively. The current result is in disagreement with Amanullah et al. (2011). They reported less positive heterotic values for plant height and ear height in their F_1 population. The reason could be due to the materials used in making crosses which might be population or early generation inbred lines rather than fixed and homozygous lines.

Heterosis over mid and better parent for ear diameter varied from 2.41% (L2 x L6) to 38.12% (L3 x L7) and -6.32% (L3 x L6) to 33.38% (L3 x L7) respectively. All 45 crosses showed highly significant positive heterosis over the mid parent whereas, most crosses showed significant positive better parent heterosis. For ear length also, almost all crosses manifested passively significant mid and better parent heterosis into desired direction (Appendix Table 2). Similar results were reported by Bayisa (2004) who reported positive and significant heterosis over better-and-mid-parent for ear length in most of the crosses across Ambo and Kulumsa locations. Gudeta (2007) reported that most crosses showed positive and significant heterosis over the better parent while more than 98% of the crosses showed positive and significant heterosis over the mid parent in combined analysis of three locations. According to the result of

Table 2. Range of standard (economic) heterosis over three standard checks for yield and yield contributing traits.

Traits	Checks	G. mean	Minimum	Cross	Maximum	Cross	SE (±)
	BH546	-13.16	-41.16	L8 x L10	18.79	L1 x L4	
GY	BH547	-12.98	-41.04	L8 x L10	19.03	L1 x L4	0.90
	SPRH1	11.72	-24.30	L8 x L10	52.82	L1 x L4	
	BH546	-1.34	-6.37	L3 x L4	5.10	L8 x L10	
AD	BH547	1.23	-3.92	L3 x L4	7.84	L8 x L10	1.71
	SPRH1	-1.35	-6.37	L3 x L4	5.10	L8 x L10	
	BH546	-1.22	-6.96	L3 x L4	4.43	L8 x L10	
SD	BH547	1.34	-4.55	L3 x L4	7.14	L8 x L10	1.40
	SPRH1	-1.85	-7.55	L3 x L4	3.77	L8 x L10	
	BH546	-2.28	-18.78	L1 x L3	14.15	L2 x L5	
PH	BH547	1.09	-15.98	L1 x L3	18.08	L2 x L5	7.77
	SPRH1	-0.17	-17.03	L1 x L3	16.61	L2 x L5	
	BH546	3.44	-16.10	L1 x L3	26.88	L5 x L10	
EH	BH547	-7.64	-25.08	L1 x L3	13.30	L5 x L10	7.31
	SPRH1	1.01	-18.06	L1 x L3	23.91	L5 x L10	
	BH546	1.30	-14.60	L3 x L8	11.18	L2 x L4	
ED	BH547	-10.90	-24.89	L3 x L8	-2.21	L2 x L4	0.10
	SPRH1	12.27	-5.36	L3 x L8	23.21	L2 x L4	
	BH546	-4.59	-18.35	L9 x L10	7.99	L3 x L7	
EL	BH547	6.28	-9.05	L9 x L10	20.29	L3 x L7	0.95
	SPRH1	8.33	-7.29	L9 x L10	22.62	L3 x L7	
	BH546	0.84	-24.05	L8 x L10	25.32	L7 x L9	
TKW	BH547	-2.85	-26.83	L8 x L10	20.73	L7 x L9	27.41
	SPRH1	20.71	-9.09	L8 x L10	50.00	L7 x L9	
	BH546	-2.48	-11.17	L2 x L5	3.19	L3 x L8	
SHP	BH547	0.26	-8.68	L2 x L5	6.09	L3 x L8	1.56
	SPRH1	-3.54	-12.14	L2 x L5	2.07	L3 xL8	
	BH546	-7.73	-40.56	L4 x L9	21.77	L4 x L6	
HI	BH547	1.01	-34.94	L4 x L9	33.30	L4 x L6	6.73
	SPRH1	-7.64	-40.51	L4 x L9	21.89	L4 x L6	

GY = Grain Yield (tonha^{-1}); AD = 50% Days to Anthesis; SD = 50% Days to Silking; PH = Plant Height (cm); EH = Ear Height (cm); ED = Ear Diameter (cm); EL = Ear Length (cm); TKW = Thousand Kernel Weight (gm); SHP = Shelling Percentage; HI = Harvest Index (%); G. mean = Grand mean; SE (±) = Standard.

Dagne et al. (2007), all crosses showed positive mid parent heterosis for ear length. Besides, Berhanu (2009) also reported positive and significant mid and better parent heterosis values for ear length. Habtamu (2015) noticed that ear length showed relatively higher and positive mid and better parent heterosis.

For thousand kernels weight, most crosses showed above 20% mid parent hetrosis while crosses which showed above 40% of mid-parent heterosis was found in L1 x L2, L1 x L4, L1 x L5, L1 x L7, L2 x L7, L3 x L5, L3 x L7 and L5 x L7 with maximum of 68.42%. In this case, crosses involving L1 and L7 as one of their parents have expressed high positive mid parent heterosis. This might be the dominant effect of alleles which is found in line L1

Table 3. Extent of mid parent, better parent and standard heterosis for best five hybrids for yield and yield contributing traits at 10 % selection intensity mid-parent heterosis.

Crosses	Traits									
	GY	AD	SD	PH	EH	ED	EL	TKW	SHP	HI
Mid parent heterosis										
L3 x L7	240.34	-10.51	-13.12	87.89	118.36	38.12	61.51	45.9	5.38	-32.19
L7 x L8	227.81	-10.39	-11.63	109.18	138.97	30.17	54.35	23.73	3.61	-33.8
L3 x L8	156.14	-8.05	-9.3	99.49	142.08	17.86	47.78	18.52	8.9	-17.46
L3 x L5	137.27	-10.6	-13.48	74.12	84.21	22.34	31.15	50	7.07	-19.82
L1 x L7	136.2	-7.32	-7.46	92.71	90.12	32.48	37.04	48.28	7.48	-29.65
SE (±)	0.98	1.34	1.6	6.38	6.31	0.09	0.82	23.74	1.35	5.82
Better parent heterosis										
L3 x L7	220.85	-7.45	-10.24	98.42	159.55	33.38	55.47	34.85	2.38	-32.75
L7 x L8	180.85	-6.21	-8.43	109.18	169.71	27.14	49.88	10.61	2.4	-42.42
L3 x L8	131.27	-6.98	-9.04	103.68	153.64	16.48	38.3	14.29	4.61	-28.7
L1 x L4	99.16	-8.98	-8.88	109.27	103.87	16.06	36.02	27.78	-2.17	-32.49
L2 x L8	91.01	-7.19	-9.83	102.69	76.31	-0.42	21.06	14.52	3.93	-9.25
SE (±)	1.13	1.55	1.85	7.37	7.29	0.1	0.95	27.41	1.56	6.73
Standard Heterosis over Best check (BH546)										
L1 x L4	18.79	-3.18	-2.53	-2.68	-0.86	9.87	-0.52	16.46	-8.5	-6.51
L2 x L4	7.46	-1.27	-1.9	-2.52	-3.6	11.18	1.05	8.86	-8.56	-2.8
L1 x L5	4.94	-3.82	-5.7	-2.2	-2.05	6.95	0.52	21.52	-3.24	-20.25
L7 x L8	2.72	-3.82	-3.8	1.19	11.3	-8.96	-3.67	-7.59	1.01	-12.61
L4 x L6	1.71	0	-0.63	3.9	12.33	7.15	0.79	10.13	-2.66	-29.87
SE (+)	1.13	1.55	1.85	7.37	7.29	0.1	0.95	27.41	1.56	6.73

GY = Grain Yield ($tonha^{-1}$); AD = 50% Days to Anthesis; SD = 50% Days to Silking; PH = Plant Height (cm); EH = Ear Height (cm); ED = Ear Diameter (cm); EL = Ear Length (cm); TKW = Thousand Kernel Weight (gm); SHP = Shelling Percentage; HI = Harvest Index (%); SE (±) = Standard.

and L7. Most crosses showed positive MPH and BPH for this trait. This result corresponds with the previous finding of Berhanu (2009),Gudeta (2007) and Habtamu (2015) who reported most crosses showed positive heterosis over the better and mid parent for the trait.

All crosses showed positive and significant heterosis over the mid parent heterosis for shelling percentage while 86.67% of crosses manifested positive significant heterosis over better parent with maximum of 8.28% (L3 x L6) in desired way. For harvest index, all crosses exhibited negative mid and better parent heterosis indicating that harvest index of inbred lines was higher than that of F_1 crosses.

Standard (economic) heterosis

Standard heterosis to grain yield, L1 x L4, L1 x L5, L2 x L4, L4 x L6, L7 x L8 and L7 x L9 crosses were relatively high positive significant standard heterosis over the best two checks (BH546 and BH547) (Appendix Table 3). In the case of breeding program, hybrids performing better than the best standard variety could be used as a commercial production (Table 2). The result is similar to the previous finding of Legesse et al. (2008) and Habtamu (2015).

For 50% days to anthesis and silking, most crosses showed negative significant heterosis over BH546 and SPRH1 standard checks indicating that, these crosses exhibited earliness for this trait than those standard checks (Appendix Table 3). The current finding was in line with Shushay (2014) who reported both positive and negative significant heterosis for days to anthesis and silking.

Most crosses showed negative significant standard heterosis for plant and ear height over BH546 and SPRH1 standard checks. Negative value indicated shortness of the checks while high positive heterosis also indicated the tallness from the checks. The current finding agreed with Shushay (2014) who reported both positive and negative significant levels of heterosis for plant and ear height was observed.

For ear diameter, most crosses exhibited positively significant standard heterosis over BH546 and SPRH1 standard checks. All crosses showed significant negative standard heterosis over BH547 indicating that the ear diameter of all crosses is lower than this check. In the case of ear length, most crosses showed negative standard heterosis over BH546 check in undesired direction. Most crosses manifested positive highly significant heterosis over BH547 and SPRH1 standard checks for ear length. For thousand kernel weight, most crosses manifested positive highly significant standard heterosis over SPRH1 than BH546 and BH547 standard checks indicate that 1000 kernels weight of those crosses were higher than that of checks. Similar to the current study, both undesirable and desirable heterosis for 1000 kernel weight in maize has been previously reported by Shushay (2014).

Most crosses exhibited positive highly significant standard heterosis over BH547 than BH546 and SPRH1 standard heterosis for shelling percentage (Appendix Table 3), indicating that the crosses showed higher shelling percentage than the three checks in desired direction. For harvest index, 33.3, 60 and 33.3% of crosses showed positive standard heterosis over BH546, BH547 and SPRH1 respectively in desired direction.

CONCLUSION AND RECOMMENDATION

Hybrid namely L1 x L4 was superior hybrids, exhibited >18.79% standard heterosis over best check hybrids (BH546) for grain yield. Both mid parent and better parent heterosis were higher in L3 x L7 hybrid for yield and yield attributing traits such as ear diameter and length. Therefore the findings of this study suggested that farmers cultivate L1 x L4 hybrid for commercial utilization in achieving higher maize grain yield.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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APPENDIX

Table 1. Mean monthly rain fall, temperature and relative humidity of Bako areas in 2017.

Month	Rainfall (mm)	Air temperature (°C)		Average	Relative Humidity (%)
		Minimum	Maximum		
January	0	8.8	32.2	20.5	46
February	57.8	9.5	31.5	20.5	47
March	33	9.7	33.2	21.45	48.6
April	155.8	10	33.4	21.7	47
May	146.5	14.2	28.6	21.4	49
June	270	14.3	27.8	21.05	52.3
July	240.7	14.4	26.9	20.65	57
August	291.3	14.2	24.7	19.45	55.3
September	230.2	14.8	25.1	19.95	55
October	86.4	14.7	26.5	20.6	54
November	86.3	14.3	27.4	20.85	52.3
December	0	14.5	30.8	22.65	49
Total	1598	153.4	348.1	250.75	612.5
Mean	133.2	12.8	29.0	20.9	51.04

Source: Bako Agricultural Research Centre, Unpublished

Table 2. Mid-parent and better parent heterosis for grain yield and yield contributing traits of 45 F_1 single crosses.

Crosses	Traits									
	GY		AD		SD		PH		EH	
	Percent Mid parent (MP) and Better parent (BP) heterosis									
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
L1xL2	70.87**	64.03**	-10.18	-10.18	-11.70	-10.65	65.48**	94.41**	54.87**	76.41**
L1xL3	52.74**	16.55**	-11.50	-10.18	-11.56	-9.47	74.80**	74.96**	94.44**	122.73**
L1xL4	105.40**	99.16**	-11.37	-8.98	-11.49	-8.88	94.32**	109.27**	90.77**	103.87**
L1xL5	89.71**	87.32**	-12.21	-9.58	-14.37	-11.83	69.08**	110.31**	61.13**	101.41**
L1xL6	41.13**	25.21**	-11.64	-11.38	-11.50	-11.24	60.16**	105.24**	58.60**	115.85**
L1xL7	136.20**	73.11**	-7.32	-5.59	-7.46	-6.63	92.71**	103.32**	90.12**	96.48**
L1xL7	70.18**	40.65**	-9.62	-7.19	-10.09	-7.69	88.35**	92.13**	107.62**	126.14**
L1xL9	22.64**	11.57**	-8.71	-8.43	-9.79	-9.52	73.34**	87.59**	68.22**	90.14**
L1xL10	1.29**	-18.72	-6.63	-6.06	-6.87	-6.02	63.05**	98.25**	76.24**	119.37**
L2xL3	117.66**	71.07**	-10.32	-8.98	-11.43	-10.40	85.85**	118.56**	103.77**	170.00**
L2xL4	93.29**	80.15**	-9.62	-7.19	-11.93	-10.40	67.46**	55.31**	64.14**	74.30**
L2xL5	76.08**	71.13**	-9.30	-6.59	-9.66	-8.09	73.01**	81.87**	67.30**	81.82**
L2xL6	30.78**	11.98**	-11.64	-11.38	-11.95	-11.18	44.90**	56.35**	46.01**	71.35**
L2xL7	104.80**	54.25**	-8.54	-6.83	-9.14	-7.23	64.61**	82.36**	66.37**	82.84**
L2xL8	123.44**	91.01**	-9.62	-7.19	-11.11	-9.83	76.44**	102.69**	111.92**	76.31**
L2xL9	20.08**	5.31**	-7.51	-7.78	-9.09	-7.74	54.10**	66.37**	44.52**	45.53**
L2xL10	21.64**	-5.33	-3.01	-2.42	-4.42	-2.41**	51.35**	55.96**	58.52**	71.63**
L3xL4	115.15**	60.73**	-15.52	-14.53	-17.42	-16.95	88.63**	103.33**	106.63**	155.00**
L3xL5	137.27**	82.66**	-10.60	-9.30	-13.48	-12.99	74.12**	116.81**	84.21**	170.45**
L3xL6	53.98**	8.36**	-9.41	-8.33	-10.09	-11.86	65.73**	112.61**	76.30**	184.09**
L3xL7	240.34**	220.85**	-10.51	-7.45	-13.12	-10.24	87.89**	98.42**	118.36**	159.55**
L3xL8	156.14**	131.27**	-8.05	-6.98	-9.30	-9.04	99.49**	103.68**	142.08**	153.64**
L3xL9	42.74**	2.14**	-8.28	-6.63	-8.99	-6.55	81.89**	97.02**	94.12**	155.00**
L3xL10	19.03**	-21.55	-5.04	-3.03*	-6.71	-3.61*	61.29**	96.32**	73.87**	154.09**

Table 2. Contd.

L4xL5	67.11**	60.05**	-12.18	-11.93	-12.85	-12.85	80.28**	106.36**	72.76**	100.31**
L4xL6	54.12**	40.60**	-8.72	-6.55	-10.03	-7.65	64.48**	93.64**	61.58**	103.10**
L4xL7	120.33**	58.36**	-8.61	-4.35	-10.14	-6.63	83.32**	86.93**	88.50**	94.72**
L4xL8	90.99**	54.05**	-9.09	-9.09	-10.36	-10.11	91.08**	101.51**	107.80**	143.15**
L4xL9	2.16**	-4.35	-8.19	-5.42	-8.93	-5.95	77.68**	76.88**	66.81**	75.85**
L4xL10	6.49**	-12.46	-8.50	-5.45	-8.99	-5.42	61.19**	80.61**	56.30**	80.50**
L5xL6	48.73**	30.50**	-7.83	-5.36	-8.31	-5.88	58.17**	62.16**	54.97**	66.43**
L5xL7	82.27**	34.69**	-4.14	0.62**	-4.93	-1.20**	69.13**	103.62**	73.11**	108.25**
L5xL8	118.78**	82.66**	-9.92	-9.66	-10.36	-10.11	87.11**	134.12**	101.80**	179.25**
L5xL9	48.55**	33.60**	-8.45	-5.42	-9.51	-6.55	56.79**	83.63**	57.91**	72.91**
L5xL10	13.21**	-10.01	-6.43	-3.03	-7.25	-3.61*	58.44**	65.69**	74.56**	75.18**
L6xL7	66.63**	13.37**	-6.38	-4.35	-7.14	-6.02	106.46**	106.46**	75.00**	128.71**
L6xL8	58.74**	19.50**	-8.14	-5.95	-8.62	-6.47	99.35**	106.05**	68.22**	154.77**
L6xL9	25.17**	21.73**	-10.18	-9.64	-11.24	-10.71	88.16**	92.76**	47.82**	74.86**
L6xL10	9.53**	-2.45*	-6.91	-6.06	-7.14	-6.02	69.88**	94.49**	49.12**	60.76**
L7xL8	227.81**	180.85**	-10.39	-6.21	-11.63	-8.43	109.18**	109.18**	138.97**	169.71**
L7xL9	114.72**	48.34**	-8.26	-6.83	-7.78	-7.23	85.41**	96.47**	93.65**	111.22**
L7xL10	52.38**	-2.34*	-3.07*	-1.86**	-4.22	-4.22*	80.34**	114.29**	102.75**	142.90**
L8xL9	24.53**	-4.42	-5.85	-3.01*	-5.20	-2.38**	67.87**	67.87**	86.64**	131.95**
L8xL10	-8.89	-36.45	-3.23	0.00**	-4.07	-0.60*	50.44**	67.72**	73.49***	139.00**
L9xL10	-15.56	-26.61	-6.34	-6.06	-5.99	-5.42	32.36**	32.36**	48.02**	61.45**
SE (±)	0.98	1.13	1.34	1.55	1.60	1.85	6.38	7.37	6.31	7.29

	ED		EL		TKW		SHP		HI	
	Percent Mid parent (MP) and Better parent (BP) heterosis									
	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH
L1xL2	17.21**	12.2**	19.47**	12.94**	41.07**	27.42**	6.44**	4.74**	-24.88	-31.09
L1xL3	20.00**	9.81**	26.90**	26.07**	32.08**	25.00**	5.63**	3.40**	-46.82	-49.54
L1xL4	20.09**	16.06**	38.63**	36.02**	50.82**	27.78**	1.34**	-2.17**	-21.17	-32.49
L1xL5	23.13**	21.09**	30.71**	20.48**	68.42**	50.00**	7.84**	4.72**	-38.20	-42.41
L1xL6	12.59**	4.28**	21.74**	15.66**	27.42**	6.76**	9.47**	7.02**	-17.97	-28.05
L1xL7	32.48**	17.45**	37.04**	31.10**	48.28**	30.30**	7.48**	2.29**	-29.65	-32.73
L1xL7	21.79**	10.26**	43.14**	33.15**	31.37**	28.85**	7.99**	1.64**	-47.82	-52.76
L1xL9	13.09**	8.36**	18.18**	13.02**	9.52**	-9.21**	6.47**	3.27**	-30.49	-37.96
L1xL10	14.89**	14.37**	9.17**	-2.04**	3.39**	-10.29**	8.78**	3.79**	-20.84	-28.62
L2xL3	21.04**	6.47**	34.51**	26.37**	35.59**	29.03**	4.14**	0.35**	-32.08	-40.59
L2xL4	16.27**	15.12**	32.82**	27.86**	28.36**	19.44**	2.86**	-2.23*	-9.29**	-15.90*
L2xL5	16.77**	10.01**	24.72**	21.43**	28.57**	26.56**	0.56**	-3.87	-13.89*	-15.34*
L2xL6	2.41**	-1.07	6.04**	5.47**	25.00**	14.86**	10.22**	6.08**	-16.26	-20.30
L2xL7	23.89**	5.74**	37.92**	25.04**	42.19**	37.88**	7.04**	0.33**	-19.73	-29.30
L2xL8	14.37**	-0.42	37.09**	21.06**	24.56**	14.52**	12.09**	3.93**	-7.93**	-9.25**
L2xL9	12.00**	11.89**	14.52**	13.13**	4.35**	-5.26**	4.54**	-0.17**	-8.00**	-10.74**
L2xL10	10.07**	4.9**	7.91**	2.10**	4.62**	0.00**	4.66**	-1.65**	-36.03	-37.22
L3xL4	16.79**	3.62*	43.75**	40.14**	31.25**	16.67**	5.75**	4.25**	-48.68	-57.92
L3xL5	22.34**	13.68**	31.15**	20.17**	50.00**	40.63**	7.07**	6.18**	-19.82	-28.82
L3xL6	9.73**	-6.32	35.98**	28.39**	21.54**	6.76**	8.28**	8.14**	-32.52	-43.42
L3xL7	38.12**	33.38**	61.51**	55.47**	45.90**	34.85**	5.38**	2.38**	-32.19	-32.75
L3xL8	17.86**	16.48**	47.78**	38.30**	18.52**	14.29**	8.90**	4.61**	-17.46	-28.70
L3xL9	12.76**	-0.73	19.10**	13.19**	15.15***	0.00**	6.04**	5.05**	-42.44	-50.94
L3xL10	16.34**	6.9**	16.93**	4.32**	12.90**	2.94**	6.66**	3.90**	-29.78	-39.56
L4xL5	19.35**	13.51**	32.26**	24.10**	33.82**	26.39**	5.33**	4.69**	-6.83**	-14.96
L4xL6	8.08**	3.4**	33.21**	28.90**	19.18**	17.57**	5.43**	4.07**	-30.96	-32.86

Table 2. Contd.

L4xL7	28.55**	10.64**	53.38**	44.09**	36.23**	30.56**	3.08**	1.57**	-5.12**	-21.70
L4xL8	22.59**	7.66**	38.43**	26.52**	22.58**	5.56**	0.09**	-2.50*	-13.95*	-19.15
L4xL9	10.17**	9.2**	29.62**	26.27**	18.92**	15.79**	4.27**	3.75**	-42.69	-45.32
L4xL10	15.87**	11.49**	15.42**	5.36**	11.43**	8.33**	2.08**	0.86**	-23.33	-27.66
L5xL6	11.56**	1.75**	26.34**	22.37**	37.68**	28.38**	7.45**	6.71**	-14.50	-19.92
L5xL7	28.44**	15.57**	34.69**	19.23**	43.08**	40.91**	5.54**	3.38**	-18.11	-26.78
L5xL8	29.06**	18.63**	49.28**	28.81**	39.66**	26.56**	6.61**	3.24**	-31.33	-33.44
L5xL9	12.24**	5.85**	18.20**	13.73**	12.86**	3.95**	7.81**	7.69**	-9.87*	-13.98**
L5xL10	14.04**	12.66**	11.70**	8.46**	27.27**	23.53**	2.60**	0.77**	-26.69	-29.24
L6xL7	16.81**	-3.11	37.81**	25.54**	31.43**	24.32**	5.46**	2.60**	-4.94**	-19.76
L6xL8	11.84**	-5.44	40.00**	24.20**	19.05**	1.35**	7.99**	3.86**	-4.54**	-7.86**
L6xL9	5.14**	1.46**	18.31**	17.50**	5.33**	3.95**	5.06**	4.21**	-6.49**	-8.32**
L6xL10	7.48**	-0.87	5.63**	-0.56**	0.00**	-4.05**	7.04**	4.40**	-12.80*	-15.48*
L7xL8	30.17**	27.14**	54.35**	49.88**	23.73**	10.61**	3.61**	2.40**	-33.80	-42.42
L7xL9	28.93**	10.14**	40.53**	28.82**	39.44**	30.26**	5.54**	3.50**	-23.74	-34.55
L7xL10	26.31**	12.43**	27.94**	10.39**	10.45**	8.82**	2.83**	2.55**	-16.68	-27.79
L8xL9	15.23**	0.42**	27.19**	13.53**	1.56**	-14.47**	5.80**	2.56**	-36.84	-37.84
L8xL10	14.43**	4.03**	17.60**	-1.01*	0.00**	-11.76**	3.71**	2.23**	-21.11	-21.46
L9xL10	7.67**	2.72**	-1.44*	-7.81	-8.33	-13.16**	3.96**	2.22**	-36.04	-36.78
SE (±)	0.09	0.10	0.82	0.95	23.74	27.41	1.35	1.56	5.82	6.73

Table 3. Economic heterosis over the best standard checks for grain yield and yield contributing traits of 45 F_1 single crosses.

Crosses	Traits									
	GY	AD	SD	PH	EH	ED	EL	TKW	SHP	HI
	Standard Checks (BH546)									
L1xL2	-8.11	-4.46	-4.43*	-9.59*	-14.21*	8.36**	-10.75	0.00**	-8.83	-4.57*
L1xL3	-34.71	-4.46	-3.16*	-18.78	-16.10*	-3.02	-11.27	-11.39**	-6.04	-22.16
L1xL4	18.79**	-3.18*	-2.53*	-2.68**	-0.86**	9.87**	-0.52**	16.46**	-8.50	-6.51**
L1xL5	4.94**	-3.82	-5.70	-2.20**	-2.05**	6.95**	0.52**	21.52**	-3.24*	-20.25
L1xL6	-9.42	-5.73	-5.06	-4.55**	4.97**	8.06**	-9.57	0.00**	-2.49**	-0.36**
L1xL7	-3.02	-3.18*	-1.90**	-5.45**	-4.45**	3.73**	-7.73	8.86**	-1.45**	2.09**
L1xL7	-21.21	-1.27**	-1.27**	-10.65**	-6.68**	-2.62	-6.29	-15.19**	0.26**	-34.58
L1xL9	-23.73	-3.18*	-3.80*	-12.76*	-7.53**	4.43**	-12.84	-12.66**	-4.36	-14.08*
L1xL10	-24.74	-1.27**	-1.27**	-7.80**	6.68**	1.01**	-13.24	-22.78**	-0.53**	-1.14**
L2xL3	-11.84	-3.18*	-1.90**	1.46**	1.71**	2.82**	-0.13**	1.27**	-8.81	-8.36**
L2xL4	7.46**	-1.27**	-1.90**	-2.52**	-3.60**	11.18**	1.05**	8.86**	-8.56	-2.80**
L2xL5	-6.55	-0.64**	0.63**	14.15**	13.01**	6.24**	1.31**	2.53**	-11.17	1.26**
L2xL6	-18.99	-5.73	-4.43*	-1.87**	6.51**	2.52**	-16.64	7.59**	-3.35*	-7.88**
L2xL7	-20.50	-4.46	-2.53*	-5.85**	-5.14**	2.11**	-1.18**	15.19**	-3.33*	7.29**
L2xL8	-1.56	-1.27**	-1.27**	-1.95**	9.59**	-3.83	-4.33	-10.13**	2.52**	4.89**
L2xL9	-28.01	-1.91**	-1.90**	-9.92**	-10.79**	8.06**	-10.59	-8.86**	-7.55	3.17**
L2xL10	-12.34	2.55**	2.53**	-2.11**	6.68**	1.31**	-9.57	-13.92**	-5.75	-27.44
L3xL4	-4.13	-6.37	-6.96	-5.61**	-3.94**	-1.91	2.49**	6.33**	-2.49**	-35.09
L3xL5	-0.25**	-0.64**	-2.53*	0.65**	1.88**	-2.92	0.26**	13.92**	-1.89**	9.80**
L3xL6	-21.61	-1.91**	-1.27**	-1.30**	7.02**	-2.92	0.39**	0.00**	-1.47**	-12.71*
L3xL7	-5.44	-5.10	-5.70	-7.89**	-2.23**	-2.22	7.99**	12.66**	-1.36**	3.75**
L3xL8	-15.42	1.91**	1.90**	-5.45**	-4.45**	-14.60	-3.93	-18.99**	3.19**	9.99**
L3xL9	-30.18	-1.27**	-0.63**	-8.54**	-3.94**	-4.33	-12.71	-3.80**	-2.72*	-24.32
L3xL10	-27.36	1.91**	1.27**	-8.86**	-4.28**	-6.45	-7.60	-11.39**	-0.43**	-6.77**

Table 3. Contd.

L4xL5	-4.53	-1.27**	-1.27**	10.73**	10.79**	7.45**	3.54**	15.19**	-2.08**	1.72**
L4xL6	1.71**	0.00**	-0.63**	3.90**	12.33**	7.15**	0.79**	10.13**	-2.66*	-29.87
L4xL7	-5.54	-1.91**	-1.90**	-3.50**	1.03**	4.73**	5.37**	18.99**	-2.14**	18.82**
L4xL8	-8.11	1.91**	1.27**	-2.52**	0.34**	1.91**	-7.47	-3.80**	-3.82	-9.22**
L4xL9	-34.61	0.00**	0.00**	-4.23**	-2.74**	5.24**	-2.62	11.39**	-2.96*	-40.56
L4xL10	-18.94	-0.64**	-0.63**	-3.09**	-0.17**	5.54**	-6.68	-1.27**	-3.35*	-19.49
L5xL6	-5.59	1.27**	1.27**	12.20**	21.40**	5.44**	2.10**	20.25**	-1.40**	-4.21**
L5xL7	-26.45	3.18**	3.80**	5.12**	8.05**	-1.31	-0.52	17.72**	-0.39**	11.11**
L5xL8	-0.25**	1.27**	1.27**	13.25**	15.24**	1.31**	7.47**	2.53**	1.84**	-20.38
L5xL9	-8.66	0.00**	-0.63**	-0.57**	5.99**	2.01**	-5.11	0.00**	-0.27**	2.90**
L5xL10	-16.68	1.91**	1.27**	10.33**	26.88**	-1.41	-3.93	6.33**	-3.44**	-15.36*
L6xL7	-17.98	-1.91**	-1.27**	6.59**	18.66**	0.40**	-1.83*	16.46**	-1.15**	21.77**
L6xL8	-13.55	0.64**	0.63**	-0.33**	5.14**	-2.01	-2.88	-5.06**	2.46**	3.45**
L6xL9	-11.94	-4.46	-5.06	-0.49**	7.19**	5.14**	-8.13	0.00**	-3.49*	-0.34**
L6xL10	-9.67	-1.27**	-1.27**	0.41**	16.44**	2.72**	-11.93	-10.13**	0.05**	-5.94**
L7xL8	2.72**	-3.82	-3.80*	1.19**	11.30**	-8.96	-3.67	-7.59**	1.01**	-12.61*
L7xL9	1.41**	-4.46	-2.53**	-4.96**	9.59**	6.14**	-0.66**	25.32**	-0.29**	-0.69**
L7xL10	-9.57	0.64**	0.63**	3.66**	26.03**	-1.61	-2.23	-6.33**	-1.20**	9.58**
L8xL9	-34.66	2.55**	3.80**	-9.11**	-4.28**	-3.22	-12.45	-17.72**	1.17**	-30.21
L8xL10	-41.16	5.10**	4.43**	-9.19**	-1.37**	-8.96	-12.32	-24.05**	0.85**	-11.82**
L9xL10	-32.04	-1.27**	-0.63**	-11.87**	-1.03**	-1.01	-18.35	-16.46**	-2.05**	-29.65
SE (±)	1.13	1.55	1.85	7.37	7.29	0.10	0.95	27.41	1.56	6.73