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Heterosis of early generation white maize (*Zea mays* L.) Inbred lines for yield and yield components in mid altitude sub-humid agroecology of Ethiopia

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Abstract

The objectives of this study were to calculate heterosis of twelve inbred lines of white maize and identify good hybrids based on grain yield data and other yield-related traits. Thirteen inbred lines (13) were crossed in 2017 with two inbred line testers using a line by tester mating design. Twenty-six crosses were generated and evaluated in a randomized incomplete block design (RCBD) with two standard checks and 3 replications during the long rainy seasons between June to December, 2018 at Bako National Maize Research Center, Ethiopia. Also, adjacent to the hybrid trial, thirteen parental lines with the two tester lines were evaluated using RCBD with three replications. Mean separation was done using least significant differences (LSD). The overall mean grain yields (GY) of the genotypes (crosses) were 6.32 t/ha ranging from 5.21 t/ha to 8.19 t/ha. Heterosis for mid parent, better parent and standard were estimated for inbred lines. The highest significant positive heterosis over the best standard check for GY was recorded for L10 XT2 (334.21%). Inbred lines that showed positive heterosis over better parent and midpart for GY can used for germplasm source for maize breeder.

Introduction

Commercial exploitation of heterosis is related to the superiority of the hybrids over the performance of the better performing parent or commercial hybrids or varieties. Such advantage of hybrid vigor is observed more frequently when breeders cross parents that are genetically diverse (George, 2007). Heterosis is considered as an expression of genetic divergence among cultivars. Applied maize breeding has been effective in developing improved hybrids during the past hundred years. The inbred lines hybrid concept was developed in the public sector and is still considered one of the greatest achievements in crop breeding (Hallauer *et al.*, 2010).

Heterosis is an important trait used by breeders to evaluate the performance of offspring in relation to their parents. It estimates the enhanced performance of hybrids compared to their parents. Often the superiority of F1 is estimated over the average of the two parents, or the mid parent. Heterosis is manifested as an increase in vigor, size, growth rate, yield or some other characteristics. But in some cases, the hybrid may be inferior to the weaker parent, which is also considered as heterosis. That means heterosis can be positive or negative. The interpretation of heterosis depends on the nature of a trait under study and the way it is measured. For example, a positive heterosis is preferred in yield studies, because it shows inclination towards high yield (Duvick, 2011). On the other hand, a negative heterosis is preferred in disease resistance and days to maturity.

A negative heterosis in disease parameters shows that, breeding outcomes could lead toward a resistance direction; while a positive heterosis would take the results towards susceptibility of the genotypes, and negative heterosis in days to maturity parameter shows the earliness of the inbred lines. Thus, evaluation of inbred lines for combining ability and heterosis is an important component of the maize hybrid breeding program. This study was therefore under-taken with the objective of estimating heterosis of early generation white maize inbred lines for yield and yield components.

Material and methods

Descriptions of Experimental Site

The experiment was conducted at Bako National Maize Research Center (BNMRC) during the 2018 main cropping season. BNMRC is located in East Wollega Zone of the Oromia National Regional State, Western Ethio-

Table 1 - List of maize inbred lines and testers used for test cross formation

Inbred line code	Pedigree of maize inbred lines	Source	Inbred line code	Pedigree of maize inbred lines	Source
L1	BKINT2012F2-1-1-1-1	BNMRC	L9	BKINT2012F2-44-1-1-1	BNMRC
L2	BKINT2012F2-1-1-2-1	>>	L10	BKINT2012F2-48-1-1-1	>>
L3	BKINT2012F2-1-1-2-2	>>	L11	BKINT2012F2-69-1-1-1	>>
L4	BKINT2012F2-1-1-2-3	>>	L12	BKINT2012F2-79-1-1-1	>>
L5	BKINT2012F2-7-1-1-1	>>	L13	BKINT2012F2-1-2-1-1	>>
L6	BKINT2012F2-16-2-1-1	>>	T2	PO'00E-3-2-1-2-1	Tester A
L7	BKINT2012F2-26-2-1-1	>>	T1	ILO'00E-1-9-1-1-1-1-1	Tester B
L8	BKINT2012F2-26-2-2-1	>>			

pia. The center is 250 km from Addis Ababa, the capital city of the country, and lies between 9°6' North latitude and 37°09' East longitude in the sub-humid agro-ecology and average altitude of 1650 meters above sea level. The mean annual rainfall of the previous 56 years was 1239.4 mm and the mean annual rain fall during the season, in 2017 was 1316.7mm; according to Metrological data from Bako Agricultural Research. The minimum, mean and maximum air temperature is 13.3, 28.0, and 20.6°C, respectively; and the relative humidity is 63.55%. The soil is reddish brown in colour and clay loam in texture (Wakene, 2001).

Experimental Materials

A total of twenty-eight entries composed of 26 testcrosses and two standard checks (BH546 and BH547) were used for this study. The test crosses made using line by tester mating design crossed 13 white maize inbred lines with two testers (referred to as tester A and tester B) in 2017 cropping season while the F1 hybrids were evaluated in 2018 season. In addition, the testers and the inbred line parents were evaluated in a separate trial along with the hybrid trial for estimation of the magnitudes of heterosis for each test cross during the same season. The list and the pedigrees of the inbred lines and testers used in the line × tester crosses are given in Table 1.

Experimental Design

The experiment was conducted using a (0, 1) alpha lattice design (Patterson and Williams, 1976) with 4 plots and 7 incomplete blocks with three replicates for hybrids, and a randomized complete block design with three replications for the parental inbred lines. Each entry was planted in one row by 5.1m^2 plot, with spacing of 0.75m between rows and 0.30m between plants within a row.

Trial Management

The experimental materials were hand planted with two seeds per hole, which were later thinned down to one plant to get a planting density equivalent to 44, 444 plant population per hectare. Planting was conducted on the onset of the main rainy season (June 3, 2018) after an ample amount of moisture level has been attained to ensure good germination and seedling development. Pre-emergence herbicide, Primagram–Gold was applied at the rate of 3 liters per hectare after planting to control weeds. Hand weeding and slashing was used to control weeds throughout the growing season. Di-ammonium phosphate (NPS) and urea fertilizers were applied at the rate of 180 kg/ha and 200 kg/ha, respectively. NPS fertilizer was applied once at sowing time, while urea was applied in split,

Table 2a - Analysis of variance for grain yield and other agronomic traits of parental lines involving 13 lines and 2 testers evaluated at Bako in 2018 cropping season

Source of variation	df	GY	DA	SD	ASI	DM	PH	EH	EPO
Replication	2	0.26^{ns}	4.55^{ns}	17.84**	1.31^{ns}	14.78^{ns}	0.27^{ns}	551.72^{ns}	0.009^{ns}
Genotype	13	4.99**	18.66**	21.09**	169.00^{ns}	71.79**	0.0004**	517.12^{ns}	0.006^{ns}
Error	25	29.92	80.06	2.95	3.34	13.18	403.39	325.2	0.003
CV%		29.93	2.07	1.96	257.92	2.1	1135	20.93	11.8
Mean		2.18	86.36	87.39	0.70	172.50	176.95	86.13	0.48

Df= degree of freedom; *= P ≤ 0.05 and ** ≤ 0.01 significant probability level, ns= not significant; GY=Grain Yield, DA=Days to anthesis, SD= Days to silking, ASI=Anthesis silking interval, DM=Days to mature, PH=Plant height, EH=Ear height

Table 2b - Analysis of variance for grain yield and other agronomic traits of parental lines involving 13 lines and 2 testers evaluated at Bako in 2018 cropping season continued

Source of variation	df	PA	EA	NE	NRPE	NKPR	EL	ED	TKW
Replication	2	0.62^{ns}	0.08^{ns}	11.47^{ns}	9.87^{ns}	12.00^{ns}	8.95^{ns}	1553.63^{ns}	8775.09*
Genotype	13	0.45*	0.60*	106.61**	10.51^{ns}	26.28*	13.00**	1430.02^{ns}	3571.12^{ns}
Error	25	0.2	0.25	9.79	12.61	12.41	4.39	1501.44	2531.06
CV%		18.10	21.60	22.99	25.84	13.08	14.43	389.63	23.26
Mean		2.35	2.31	13.60	13.74	26.92	14.52	9.94	216.25

Df= degree of freedom; *= P ≤ 0.05 and ** ≤ 0.01 significant probability leve, ns= not significant; PA= plant aspect, EA= ear aspect, NE= number of ears, NRPE=Number of rows per ears, EL=Ear length, ED= Ear diameter, TKW=Thousand kernels weight

half at planting and the remaining half at 10 to 12 leaves, or 35 to 40 days after planting. Other agronomic practices were carried out following the recommendations for the area.

Data collection

Data on grain yield and other important agronomic traits collected include days to anthesis, number of ears per plant, plant height (cm), grain weight (t/ha), anthesis-silking interval, stand count at harvest, days to silking, thousand kernel weight (gm), actual moisture content, days to physiological maturity, ear aspects, ear height (cm), ear cob length (cm), plant aspects, ear cob diameter (cm), number of rows per ear and number of kernels per row.

Data Analysis

The data collected were subjected to analysis of variance (ANOVA) using the procedure in SAS (SAS Institute, 2014) to determine the differences among the genotypes. Genotypes were considered as fixed effects while replications and blocks within replications were considered random effect. Significant differences were further subjected to least significant difference (LSD).

Estimation of heterosis

Calculation of better parent heterosis (BPH), mid parent heterosis (MPH) and standard heterosis (SH) or economic heterosis in percent were performed for parameters that showed significant differences as follows according to the method suggested by Falconer and Mackay (1996).

$$\text{MPH}(\%)=\frac{((\text{F1-MP}))}{\text{MP}} * 100$$

$$\text{BPH}(\%)=\frac{((\text{F1-BP}))}{\text{BP}} * 100$$

$$\text{SH}(\%)=\frac{((\text{F1-SV}))}{\text{SV}} * 100$$

Where, F1 = Mean value of the cross

MP = Mean value of the two parents

BP = Mean value of the better parent

SV = Mean value of standard variety

Significance of heterosis was tested using the t-test. The critical differences (CD) for testing the significance of MPH, HPH and SH was calculated as suggested by Cochran (1960) and Singh (1985) as follows:

1 Critical difference for heterosis over mid-parent (MP)

$$\text{SE(d) for MP}= \frac{(\pm\sqrt{\text{ems}})}{\text{r}} \ \text{me} = \frac{(\pm\sqrt{3\text{e}})}{\text{r}}$$

$$\text{SE(d) for MP}= \frac{(\pm\sqrt{3\text{ems}})}{2\ \text{r}} \ \text{me} = \frac{(\pm\sqrt{3\text{e}})}{2\text{r}}$$

2 Critical difference for heterosis over BP or SH

$$\text{SE(d) for BP and SH}= \frac{(\pm\sqrt{2\text{ems}})}{\text{r}}$$

$$\text{SE(d)for BT}= \frac{(\pm\sqrt{2\text{ems}})}{\text{rxt}}$$

$$\text{t (mid-parent)}=\frac{((\text{F1-MP}))}{((\text{SE(d)}))}$$

$$\text{t (better parent)}=\frac{((\text{F1-BP}))}{((\text{SE(d)}))} \text{,and}$$

$$\text{t (standard parent)}=\frac{((\text{F1-SV}))}{((\text{SE(d)}))}$$

Table 3a - Analysis of variance for grain yield and other agronomic traits of Hybrids (F1), line by tester crosses involving 13 lines and 2 testers evaluated at Bako in 2018 cropping season

Source of variation	df	GY	DA	SD	ASI	DM	PH	EH
Replication	2	2.64*	2.68^{ns}	2.58^{ns}	0.62^{ns}	10.71^{ns}	484.82^{ns}	850.30^{ns}
Block (Rep)	18	1.20^{ns}	0.73^{ns}	0.78^{ns}	0.37^{ns}	2.91^{ns}	150.66^{ns}	126.67^{ns}
Genotype	27	1.98**	11.27**	11.02**	1.26**	45.09**	699.23**	447.12**
Error	36	0.71	1.3	1.74	0.54	5.21	129.68	183.41
CV%		13.34	1.48	1.71	237.43	1.48	3.99	8.70
Mean		6.32	77.03	77.34	0.31	154.07	285.71	155.59

Df= degree of freedom; *= P ≤ 0.05 and ** ≤ 0.01 significant probability level, ns= not significant; GY=Grain Yield, DA=Days to anthesis, SD= Days to silking, ASI=Anthesis silking interval, DM=Days to mature, PH=Plant height, EH=Ear height

Where, SE (d) is standard error of the difference, ems is the error mean square, r is the number of replications and F1, MP, BP and SV are mean values of hybrids, mid; better parents and standard variety, respectively. The computed t values were tested against the critical t value with degrees of freedom for error at 5% and 1%.

Results and Discussion

The analysis of variance (Table 2) revealed that mean squares due to genotype were highly significant (P< 0.01) for grain yield (t/ha), days to anthesis, days to silking, anthesis silking interval, days of maturity, plant height (cm), ear height (cm), plant aspect, number of ear per plant, number of row per ear (cob), ear length, ear diameter and thousand seed weight (gm). Also, significant difference (P<0.05) was only obtained for ear aspect while ear aspect was not significant.

Mid parent and Better parent Heterosis

Mid parent (MP) and better parent (BP) heterosis of crosses among 12 normal maize inbred lines for grain yield and yield related traits are summarized on Table 4a, b, and c. However, heterosis estimate for one of the 13 inbred lines could not be estimated due to its poor germination. Summarily, nine crosses had significant positive MPH which ranged from 60.03 to 616.49%. The highest significant positive heterosis over the mid parent for GY was estimated for L4 × T2 (616.49%) followed by L10 × T2 (553.46%), L12 × T2 (436.3%) and L1 × T2 (394.86%). While cross L6 × T2 (164.92%) showed the lowest significant positive heterosis over MP. On the whole, 14 crosses showed positive and highly significant (P < 0.01) heterosis over better parent for GY and five crosses showed positive significant (P < 0.05) heterosis over BP for this trait. These results corroborate the reports wich several authors have also previously reported, indicating a high positive heterosis for maize GY (Malik *et al.*, 2004; Gudeta, 2007; Ram *et al.*, 2015). However, low MPH and BPH for GY were also reported by Amanullah *et al.* (2011), Hundera *et al.* (2017) and Tolera *et al.* (2017) while Ali *et al.*, (2014) and Dagne (2008) observed negative heterosis over MP and BP for grain yield. The difference in heterosis in various reports involving different inbred parents is mainly attributed to the stage of inbreeding of the materials used, the environmental conditions in which they were exposed and the performance of the parental inbred lines (Berhanu, 2009).

The MPH for TSW ranged from -3.84% (L3 × T1) to 61.17% (L4 × T2) with only five crosses (L1 × T2, L4 × T2, L9 × T2, L11 × T2 and L13 × T2) exhibited positive significant heterosis over MP and one cross (L3 × T1) showed non-significant negative heterosis. On the

Table 3b - Analysis of variance for grain yield and other agronomic traits of Hybrids (F1), line by tester crosses involving 13 lines and 2 testers evaluated at Bako in 2018 cropping season continued

Source of variation	df	PA	EA	NE	NRPE	NKPR	EL	ED	TKW
Replication	2	0.24^{ns}	0.12^{ns}	30.3**	0.06^{ns}	5.63^{ns}	10.35^{ns}	0.10**	569.61^{ns}
Block (Rep)	18	0.20*	0.19^{ns}	3.45^{ns}	0.44^{ns}	15.77^{ns}	1.74^{ns}	0.03*	1127.64^{ns}
Genotype	27	0.26**	0.24^{ns}	24.87**	2.03**	34.89*	5.65**	0.16**	1512.46**
Error	36	0.10	0.14	4.51	0.47	18.43	0.98	0.02	739.11
CV%		13.27	15.29	10.99	4.89	11.26	5.16	2.72	10.20
Mean		2.34	2.47	19.33	13.97	38.31	19.16	4.77	266.46

Df= degree of freedom; *= P ≤ 0.05 and ** ≤ 0.01 significant probability level, ns= not significant; PA= plant aspect, EA= ear aspect, NE= number of ears, NRPE=Number of rows per ears, EL=Ear length, ED= Ear diameter, TKW=Thousand kernels weight

Table 4.1 - Mid parent and better parent heterosis of maize inbred evaluated at Bako, Ethiopia during 2018 cropping season

Traits	GY		AD		SD		PH	
Crosses	MPH %	BPH%	MPH %	BPH%	MPH %	BPH%	MPH %	BPH%
L1XT1	185.78	137.27**	-10.26**	-9.92**	-10.94**	-10.60	59.47**	48.78
L1XT2	394.86**	357.54	-10.76**	-8.43**	-15.5**	-12.80*	53.19**	46.34*
L3XT1	193.33	111.07*	-9.34**	-8.82**	-9.51**	-9.16	66.44**	58.97*
L3XT2	358.30*	308.55**	-10.59**	-8.43**	-12.11**	-10.00	48.46**	45.29*
L4XT1	333.87*	150.55**	-11.66**	-10.99**	-12.36**	-11.36	88.29**	73.70*
L4XT2	616.49**	357.24	-12.58**	-9.24**	-13.08**	-9.60	69.3**	52.67*
L5XT1	168.15	143.91**	-10.82**	-10.65**	-11.27**	-10.60	42.91**	27.01*
L5XT2	190.37	144.59**	-14.07**	-11.65*	-15.06**	-12.00	27.71**	16.06
L6XT1	164.92*	138.35**	-5.65ns	-2.81	-6.38ns	-4.34	59.44**	58.33*
L6XT2	212.02*	125.96**	-5.63ns	-5.63*	-7.76ns	-7.20	61.82**	58.92**
L7XT1	61.03	31.62	-13.04**	-12.88**	-12.88*	-12.88	30.64**	24.78
L7XT2	105.87	39.58	-16.34**	-13.65**	-14.00**	-11.6	33.62**	30.76
L8XT1	222.82	111.44**	-8.35*	-5.97**	-8.14*	-5.95	73.08**	53.98
L8XT2	341.53	242.76**	-8.80*	-8.43**	-6.77	-6.40	75.38**	52.67*
L9XT1	117.58	105.54*	-13.79**	-12.79**	-14.82**	-14.01*	56.6**	47.41
L9XT2	202.29	146.47**	-13.22**	-11.65**	-14.45**	-11.20	59.21**	46.42
L10XT1	250.16	107.38*	-8.92**	-6.75**	-8.29*	-6.67	58.81**	50.23
L10XT2	553.47**	334.21**	-10.57**	-10.04**	-12.08**	-11.20	62.31**	49.99
L11XT1	109.29	96.13*	-7.76**	-5.56*	-7.72ns	-5.90	63.17**	62.03*
L11XT2	150.22	86.45*	-7.39*	-6.83**	-6.35	-5.6	56.36**	53.57*
L12XT1	243.96*	146.86**	-12.69**	-11.36**	-12.81**	-10.99	79.63**	61.50*
L12XT2	436.30**	376.32	-12.10**	-8.04**	-12.77**	-8.40	73.6**	52.67**
L13XT1	115.73	104.98**	-9.46**	-8.67**	-10.73**	-10.23	64.17**	58.77*
L13XT2	171.52	104.32**	-9.53**	-7.63**	-9.48*	-6.40	52.20**	50.87*
SE(d)	2.19	0.40	2.96	0.54	3.43	0.62	29.59	5.37

*=0.05 and **= 0.01 significant probability level. GY=Grain Yield, AD=Days to anthesis, SD=Days to silking PH=Plant height, MPH=mid parent heterosis, BPH=Best parent heterosis, SE(d)=Standard error of difference.

other hand, six crosses showed negative heterosis for BP; whereas the remaining crosses exhibited positive heterosis for this trait. The negative BPH observed in this study is in contrast to other researchers who reported only positive and highly significant BPH for TSW in crosses evaluated at different locations (Gudeta, 2007; Berhanu, 2009).

The MPH value for ear length (EL) and ear diameter ranged from 14.63% (L11 × T1) to 68.09% (L10 × T2) and -6.57% (L10 × T1) to 49.13% (L12 × T2) respectively. BPH value for EL ranged from 3.81% (L5 × T1) to 68.09% (L10 × T2); whereas value for ED varied from -19.21% (L12 × T2) extending to 48.43% (L12 × T2). Summarily, nine crosses expressed more than 50 % highly significant positive results over MPH for this trait which showed best heterosis. Only one cross showed positive significant heterosis over BP for EL and two crosses for ED. The current finding supports the reports of Ali *et al.* (2014), who observed significant and negative MPH and BPH for ear diameter in his study of heterosis for grain yield and its attributing components in maize using line x tester analysis method. None of crosses showed negative significant heterosis over BT for ear length. In line with the present finding, several authors reported significant and positive MPH and BPH for EL (Dagne *et al.*, 2007; Gudeta, 2007; Berhanu *et al.*, 2009; Habtamu, 2015). Habtamu (2015); Hundera *et al.* (2017) and Tolera *et al.*, (2017) reported that almost all crosses included in their study manifested positive and significant mid and better parent heterosis for EL. Crosses that manifested highly significant and positive heterosis for ear length and ear diameter could be used for improvement of these traits in the future of maize breeding program.

Table 4.2 - Mid parent and better parent heterosis of maize inbred evaluated at Bako, Ethiopia during 2018 cropping season

Traits	GY		AD		SD		PH	
Crosses	**MPH %**	**BPH%**	**MPH %**	**BPH%**	**MPH %**	**BPH%**	**MPH %**	**BPH%**
L1XT1	185.78	137.27**	-10.26**	-9.92**	-10.94**	-10.60	59.47**	48.78
L1XT2	394.86**	357.54	-10.76**	-8.43**	-15.5**	-12.80*	53.19**	46.34*
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L3XT2	358.30*	308.55**	-10.59**	-8.43**	-12.11**	-10.00	48.46**	45.29*
L4XT1	333.87*	150.55**	-11.66**	-10.99**	-12.36**	-11.36	88.29**	73.70*
L4XT2	616.49**	357.24	-12.58**	-9.24**	-13.08**	-9.60	69.3**	52.67*
L5XT1	168.15	143.91**	-10.82**	-10.65**	-11.27**	-10.60	42.91**	27.01*
L5XT2	190.37	144.59**	-14.07**	-11.65*	-15.06**	-12.00	27.71**	16.06
L6XT1	164.92*	138.35**	-5.65^{ns}	-2.81	-6.38^{ns}	-4.34	59.44**	58.33*
L6XT2	212.02*	125.96**	-5.63^{ns}	-5.63*	-7.76^{ns}	-7.20	61.82**	58.92**
L7XT1	61.03	31.62	-13.04**	-12.88**	-12.88*	-12.88	30.64**	24.78
L7XT2	105.87	39.58	-16.34**	-13.65**	-14.00**	-11.6	33.62**	30.76
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L10XT2	553.47**	334.21**	-10.57**	-10.04**	-12.08**	-11.20	62.31**	49.99
L11XT1	109.29	96.13*	-7.76**	-5.56*	-7.72^{ns}	-5.90	63.17**	62.03*
L11XT2	150.22	86.45*	-7.39*	-6.83**	-6.35	-5.6	56.36**	53.57*
L12XT1	243.96*	146.86**	-12.69**	-11.36**	-12.81**	-10.99	79.63**	61.50*
L12XT2	436.30**	376.32	-12.10**	-8.04**	-12.77**	-8.40	73.6**	52.67**
L13XT1	115.73	104.98**	-9.46**	-8.67**	-10.73**	-10.23	64.17**	58.77*
L13XT2	171.52	104.32**	-9.53**	-7.63**	-9.48*	-6.40	52.20**	50.87*
SE(d)	2.19	0.40	2.96	0.54	3.43	0.62	29.59	5.37

*=0.05 and **= 0.01 significant probability level. GY=Grain Yield, DA=Days to anthesis, ASI=Anthesis silking interval, DM=Days to mature, PH=Plant height, EH=Ear height, MPH=mid parent heterosis, BPH=Best parent heterosis, SE(d)=Standard error of difference.

For number of rows per ear (NRPE), MPH ranged from -16.08% to 9.52% and BPH ranged from -24.95% to 4.71%. All crosses showed insignificant heterosis over the better parent, except two crosses (L10 × T1 and L10 × T2) showed significant negative heterosis for both MP and BP. The MPH ranged from -16.34 to -5.63 % and -15.5 to -6.35% for AD and SD, respectively; while the BPH ranged from -13.65 to-2.8 % for AD and -14.01 to % -5.6 for SD. All crosses for AD and SD showed negative significant heterosis for MP except two crosses (L6 × T1 [-5.63%], L 6 × T2 [-5.65%]) for AD; and only L6 × T1 (-2.81%) for SD exhibited no significant negative heterosis of MP. The lowest negative and significant heterosis values over MP values for Ad and SD were observed in L7 × T2 (-16.34%) and L1 × T2 (-15.5%), respectively. Similarly, the lowest values of BPH were observed in L7 × T2 (-13.65%) for AD and L9 × T1 (-14.01%) for SD. The negative heterosis for these traits indicates earliness of the crosses as compared to the mean performances of the parents, thus the hybrids take will less number of days to flower than their respective parents. The results are in general agreement with the findings of Dagne*et al.* (2013). Berhanu (2009) observed negative and significant MPH and BPH for days to anthesis and silking, whereby the AD and SD values decreased by 9% and 16% over the mid and the better parents, respectively.

The MPH and BPH for ASI ranged from -100% to 500.6% and -706.06% to 299.9% respectively. However, all the crosses showed no significant heterosis for MP and BP for both directions. The MPH for PH and EH ranged from 27.71% (L5 × T1) to 88.29% (L4 × T1) and 40.54 % (L7 × T1) to 120.64% (L4 × T1), respectively. Similarly, BPH for PH ranged from 16.06 %(L5 ×

Table 4.3 - Mid parent and better parent heterosis of maize inbred evaluated at Bako, Ethiopia during 2018 cropping season continued

Traits	GY		AD		SD		PH	
Crosses	**MPH %**	**BPH%**	**MPH %**	**BPH%**	**MPH %**	**BPH%**	**MPH %**	**BPH%**
L1XT1	66.84*	60.93	39.31*	27.00	17.19	6.95	22.37	19.01
L1XT2	40.38	32.90	51.30**	26.52	34.01**	25.27	44.79*	33.66
L3XT1	44.41*	31.34	32.62	22.59	19.10*	7.62	-3.84	-18.10
L3XT2	32.01	31.15	51.00**	27.83	34.41**	26.94	14.03	-7.06
L4XT1	47.60*	34.28	41.68*	34.50	22.37**	10.98	26.38	19.35
L4XT2	29.17	28.36	51.22**	31.11	27.19	19.83	61.17*	60.56
L5XT1	47.70	46.82	15.88	3.81	16.72	10.31	16.54	14.50
L5XT2	33.58	22.9	29.73	6.81	41.14**	27.45*	44.05	34.27
L6XT1	49.25	41.47*	31.11	30.81	17.93*	15.02	3.42	-10.72
L6XT2	32.62	27.76	52.53**	38.27	37.09**	20.28	17.36	-3.14
L7XT1	34.15	24.53	21.40	12.65	9.78	9.41	9.59	3.92
L7XT2	34.08	32.00	44.11*	22.42	21.36*	4.51	35.27	21.93
L8XT1	54.05	44.52	29.43	24.50	19.75*	11.43	3.31	-5.05
L8XT2	39.44	35.76	60.30**	40.63	34.09**	22.91	28.96	12.87
L9XT1	57.07	47.51	40.79*	30.47	11.05	4.70	21.87	18.49
L9XT2	-2.32	-15.56	67.48**	63.89	30.34**	17.97	49.33*	45.45
L10XT1	46.30*	40.95	53.14**	39.12	-6.57	-17.85*	3.32	-0.18
L10XT2	28.26	21.56	68.09**	68.07*	4.62	-19.21*	30.73	19.92
L11XT1	57.12*	51.37	14.63	7.79	16.80	9.86	22.90	5.82
L11XT2	31.28	24.43	42.01*	22.07	25.66**	13.99	57.96*	42.48
L12XT1	49.06	39.23	27.65	13.96	23.46**	5.60	27.34	18.50
L12XT2	32.24	13.76	49.70*	46.83	49.13**	48.43**	47.79	44.97
L13XT1	33.57	23.54	30.96	26.734	17.73*	9.41	21.50	16.93
L13XT2	35.34	33.766	64.28**	44.89	27.16**	16.71	45.40*	32.88
SE(d)	13.22	14.18	14.77	15.23	12.33	13.12	17.09	18.76

*=P=0.05 and **= P =0.01 significant probability level, ED=Ear diameter, NKPR=Number of kernels per rows, EL=Ear length, TKW=Thousand kernels weight, MPH=Mid parent heterosis, BPH=Best parent heterosis, SE(d)=standard error of difference.

T2) to73.7% (L4 × T2). A majority of the crosses showed significant positive heterosis of better parent for plant height. However, none of crosses showed significant heterosis for better parent of EH for both directions. All crosses revealed highly significant positive heterosis of MP for plant height; whereas only two crosses (L6 × T2 and L12 × T2) showed highly positive significant heterosis for MP for ear height. Crosses showed positive significant heterosis of MP and BP for both PH and EH can uses to develop late and high yielder hybrid in maize breeding program.

Concerning plant aspect, the value of MP heterosis obtained ranged from -14.28% to 42.97%; while the range was 0% to 61.71%for BP heterosis. Only three crosses showed positive and significant heterosis for MP and BP for this trait. The least positive significant heterosis of MP and BP for trait was obtained from L9 × T1 (42.97%) and L × T1 (61.71%), respectively. However, the best value of MP and BP significant heterosis for this trait was observed from L7 × T1 (30.77%) and L × T (41.5%), respectively. Eight crosses showed positive significant heterosis; whereas only one cross showed negative heterosis for ear aspect. Also only three crosses showed positive heterosis for better parent for this trait; whereas none of the crosses showed negative significant heterosis for EA.

In general, traits like TSW, EL, ED, NRPE and NKPE expressed positive heterosis over MP and BP are good for selection and granted for grain yield. Significant heterosis for one or more yield contributing characters was related tohigh and significant heterosis for grain yield (Jiban *et al.*, 2018). While negative significant

Table 5 - Standard heterosis for grain yield, yield related and other traits of hybrids evaluated at Bako in the 2018 main season

Traits	GY		AD		SD		ASI	
	SH%		SH%		SH%		SH%	
Crosses	BH 546	BH 547	BH 546	BH 547	BH 546	BH 547	BH 546	BH 547
L1XT1	15.03*	8.43	-2.07**	-0.83	-2.88**	-1.26	-100.00	-100.00
L1XT2	46.51**	38.11**	-5.39	-4.20	-10.28**	-8.79**	49.25	203.03
L3XT1	2.33	-3.54	-1.24	0.00	-2.06**	-0.43	-100.00	-100.00
L3XT2	11.09	4.72	-5.39**	-4.20**	-7.41	-5.86	-199.48**	-301.97**
L4XT1	21.47**	14.5*	-2.49**	-1.26	-3.70**	-2.10**	-24.93	52.42
L4XT2	24.33**	17.2**	-6.22**	-5.04**	-7.00**	-5.45**	-100.00	-100.00
L5XT1	18.25**	11.47	-2.49**	-1.26**	-2.88**	-1.26	-100.00	-100.00
L5XT2	-2.86	-8.43	-8.71**	-7.56**	-9.47**	-7.96**	-100.00	-100.00
L6XT1	44.54**	36.26**	0.42	1.69	-0.41	1.26	-100.00	-100.00
L6XT2	37.03**	29.17**	-2.49	-1.26	-4.53**	-2.94**	-249.3	-403.03**
L7XT1	0.54	-5.23	-4.56**	-3.35**	-5.35**	-3.77**	-100.00	-100.00
L7XT2	6.62	0.51	-10.78**	-9.66**	-9.05**	-7.53**	198.51**	506.06**
L8XT1	2.50	-3.37	-2.07**	-0.83	-2.47**	-0.84	-50.75	0.00
L8XT2	-6.80	-12.14	-5.39**	-4.2**	-3.7**	-2.1**	198.51**	506.06**
L9XT1	-0.36	-6.07	-6.64**	-5.46**	-6.58**	-5.02**	0.00	103.03
L9XT2	6.26	0.17	-8.71**	-7.56**	-8.64**	-7.12**	0.00	103.03
L10XT1	0.54	-5.23	-2.49**	-1.26	-2.06**	-0.43	49.25	203.03
L10XT2	18.07**	11.30	-7.05**	-5.87**	-8.64**	-7.12**	-189.55**	-281.82**
L11XT1	8.77	2.53	-1.24	0.00	-1.64*	0.00	-50.75	0.00
L11XT2	3.40	-2.53	-3.73**	-2.52**	-2.88**	-1.26	98.51	303.03**
L12XT1	19.68**	12.82	-2.90**	-1.68**	-3.30**	-1.68*	-50.75	0.00
L12XT2	29.52**	22.09**	-4.98**	-3.78**	-5.77**	-4.19**	-100.00	-100.00
L13XT1	10.38	4.05	-1.66*	-0.42	-2.47**	-0.84	-100.00	-100.00
L13XT2	10.02	3.71	-4.56**	-3.35**	-3.70**	-2.1**	98.51	303.03**
SE(d)	0.4	0.4	0.54	0.54	0.62	0.62	0.33	0.33

*=0.05 and **= 0.01 significant probability level. GY=Grail Yield, DA=Days to anthesis, DS= Days to silking, ASI=Anthesis silkinginterval, PH=Plant height, SE(d)=Standard error of difference

MPH and BPH for AD, SDis better to develop early maturity hybrids. In addition, to form short hybrid negative significant differences MPH,BPH are preferable for PH and EH.

Standard heterosis over the checks

Ten crosses showed highly significant heterosis over standard check (BH 546) for grain yield. The highest positive and significant heterosis of standard check of BH 546 and BH 547 for yield was observed from L1 × T2 cross. L1 × T2, L6 × T1 and L6 × T2 were the top three crosses that showed positive and significant standard heterosis for this trait over both checks. For grain yield, positive heterosis for this trait indicates increased yield advantage over the existing standard check. More than 40% of SH was recorded for two crosses over standard check (BH 546). This supports a similar result reported by Jiban (2018) that seven crosses showed more than 40% of SH. According to this author, the heterosis of more than 40% value in maize hybrid was considered best for commercial exploitation.In agreement with the present finding, several authors reported positive and negative significant SH for grain yield (Amiruzzaman *et al.*, 2010; Shushay, 2011; Melkamu, 2013; Ali *et al.*, 2014, Bello and Olawuyi, 2015, Toleraet *al.*, 2017).This is an indication that the majority of crosses mature earlier than checks.

All crosses revealed negative standard heterosis of both checks for days to anthesis except for L6 × T1. In addition to this, similar result was observed for days

Table 5.1 - Standard heterosis for grain yield, yield related and other traits of hybrids evaluated at Bako in the 2018 main season

Traits	PH		EH		PA		EA	
	SH%		SH%		SH%		SH%	
Crosses	BH 546	BH 547	BH 546	BH 547	BH 546	BH 547	BH 546	BH 547
L1XT1	2.24	5.17**	1.11	-7.14	0.00	-6.87	7.30	-6.37
L1XT2	0.56	3.45**	18.89**	9.18	0.00	-6.87	7.30	-6.37
L3XT1	3.91*	6.9**	6.67	-2.04	7.37	0.00	7.30	-6.37
L3XT2	-5.03**	-2.30	10.00	1.02	-7.83	-14.16*	-6.87	-18.73**
L4XT1	3.35	6.32**	3.33	-5.1	-15.67*	-21.46**	-28.33**	-37.45**
L4XT2	-4.47**	-1.72	6.67	-2.04	7.37	0.00	-6.87	-18.73**
L5XT1	-2.79	0.00	8.89*	0.00	0.00	-6.87	14.59	0.00
L5XT2	-11.17**	-8.62	-3.33	-11.22**	0.00	-6.87	21.46**	5.99
L6XT1	-4.47*	-1.72	6.67	-2.04	0.00	-6.87	0.00	-12.73
L6XT2	-0.56	2.30	21.11**	11.23**	0.00	-6.87	-14.16	-25.09**
L7XT1	-18.44**	-16.09**	-13.33**	-20.41**	23.04**	14.59*	28.76	12.36
L7XT2	-14.52**	-12.07**	-3.33	-11.22**	23.04**	14.59	0.00	-12.73
L8XT1	-8.38**	-5.75**	-2.22	-10.2**	15.21*	7.30	-14.16	-25.09**
L8XT2	-4.47*	-1.72	7.78	-1.02	15.21*	7.30	0.00	-12.73
L9XT1	-12.29**	-9.77**	-16.67**	-23.47**	29.03**	20.17**	0.00	-12.73
L9XT2	-8.38**	-5.75**	-1.11	-9.18	30.41**	21.46**	0.00	-12.73
L10XT1	-10.61**	-8.04**	-14.45**	-21.43**	15.21*	7.30	14.59	0.00
L10XT2	-6.14**	-3.45	1.11	-7.14	29.03**	20.17**	42.92**	24.72**
L11XT1	-2.23	0.58	8.89*	0.00	30.41**	21.46**	7.30	-6.37
L11XT2	-3.91*	-1.15	10.00*	1.02	23.04**	14.59*	21.46	5.99**
L12XT1	-3.91*	-1.15	-4.45	-12.25**	7.37	0.00	14.59	0.00
L12XT2	-4.47*	-1.72	13.33**	4.08	7.37	0.00	0.00	-12.73
L13XT1	1.12	4.02*	11.11**	2.04	0.00	-6.87	28.76**	12.36
L13XT2	-3.91*	-1.15	8.89*	0.00	30.41**	21.46**	14.59	0.00
SE(d)	5.37	5.37	6.38	6.38	0.15	0.15	0.18	0.18

*=0.05 and **= 0.01 significant probability level. EH= EH=Ear height, PA=plant aspect,EA= Ear aspect SE(d)=Standard error of difference

to silking; except no heterosis for one cross over BH 547. This indicated that majority of the crosses matured earlier than the checks. Seventeen and fourteen crosses displayed highly significant negative SH over both checks for AD. Negative SH for these traits directly contributed to earliness, short number of days between Anthesis and silking, short plant stature, which is resistant to lodging, and firm husk cover, which prevents ear from rotting and external damage. EL, ED, NRPE and TSW are important yield components. L1 × T2 showed positive and significant SH for EL over both checks, NKPR only for BH547, TSW for BH 546 and significant and negative for NRPE for BH547.

Gadad (2003), Amiruzzamanet *al.* (2010) and Shushay (2014,; Ziggiju *et al.* (2016) and Tolera *et al.* (2017) had also found similar heterosis effect for number of kernel rows per ear in their study on combining ability and heterosis for yield and component characters in maize. The highest positive and significant standard heterosis for thousand kernel weight over BH 546 were obtained from crosses L4 × T2 followed by L13 × T2 and L1 × T2. None of crosses showed negative SH over BH 546 (check). Whereas, the lowest positive and significant SH for this trait was obtained from L8 × T1 followed L7 × T1. Usually, SH in a positive direction are desirable for grain yield and yield components like thousand kernel weight, ear length, number of rows per ear plant, ear height and number of ears per plant. On other hand, SH in a negative direction is desirable for traits like days to Anthesis, silking and maturity, Anthesis-silking interval, ear position.

Table 5.2 - Standard heterosis for grain yield, yield related and other traits of hybrids evaluated at Bako in the 2018 main season

Traits	NPRE		NKPR		EL		ED		TSW	
	SH%		SH%		SH%		SH%		SH%	
Crosses	BH 546	BH 547	BH 546	BH 547	BH 546	BH 547	BH 546	BH 547	BH 546	BH 547
L1XT1	-2.68	-3.58	4.18	20.24**	7.28**	24.25**	-1.04	-6.84	28.27**	-7.82
L1XT2	-8.04	-8.89**	-3.70	11.15**	6.88**	23.78**	-4.36	-9.96	44.07**	3.53
L3XT1	2.68	1.73	-3.55	11.32**	0.46	16.34**	-0.41	-6.25	18.59**	-14.78**
L3XT2	-9.78	-10.62	-3.70	11.15**	4.75	21.32**	-5.19	-10.74	34.56**	-3.30
L4XT1	-3.55	-4.45*	-1.45	13.74**	4.10	20.56**	2.70	-3.32	21.58**	-12.63**
L4XT2	-13.4**	-14.2**	-5.80	8.73**	1.47	17.52**	-9.75	-15.04	46.46**	5.25
L5XT1	4.49*	3.52	-10.63*	3.15**	-8.8**	5.62**	2.07	-3.91	20.86**	-13.15**
L5XT2	-0.87	-1.79	-10.94*	2.79**	-6.17**	8.67**	4.98	-1.17	41.72**	1.85**
L6XT1	-1.74	-2.65	-5.00	9.65**	-8.6**	5.86*	6.43	0.2	25.18**	-10.04**
L6XT2	-5.36**	-6.24**	-7.42	6.86**	-3.39	11.89**	5.81	-0.39	35.81**	-2.40**
L7XT1	-4.42*	-5.31*	-12.56**	0.92	-8.45**	6.03*	1.24	-4.69	18.08**	-15.14**
L7XT2	-15.14**	-15.93**	-4.35	10.4**	-0.51	15.23	-3.94	-9.57	38.54**	-0.44
L8XT1	-4.42*	-5.31**	-0.80	14.5**	-6.27**	8.55**	3.11	-2.93	15.42**	-17.06**
L8XT2	-14.27**	-15.06**	-1.62	13.55**	5.87*	22.61**	-2.07	-7.81	37.21**	-1.40
L9XT1	-8.91**	-9.75**	-11.28	2.4**	-9.26**	5.1	-3.11	-8.79	20.71**	-13.26**
L9XT2	-11.59**	-12.41**	-38.82**	-29.38**	-2.73	12.65	-3.32	-8.98	39.96**	0.58
L10XT1	-3.55	-4.45*	-8.53	5.58**	-3.24	12.07	0.21	-5.66	9.09	-21.6
L10XT2	-5.34*	-6.22**	-11.91	1.67	-4.50	10.6**	-1.45	-7.23	31.07**	-5.81
L11XT1	-13.4**	-14.2**	-1.76	13.38**	-14.87**	-1.41	1.66	-4.30	7.80	-22.53
L11XT2	-20.56**	-21.3**	-9.83*	4.07**	-3.59	11.66**	-7.05	-12.5	30.15	-6.47
L12XT1	-2.68	-3.58	-16.26**	-3.35**	-20.74**	-8.2**	-2.28	-8.01	20.72**	-13.25**
L12XT2	-12.46**	-13.27**	-17.56**	-4.85**	-16.59**	-3.4	-1.45	-7.23	32.24**	-4.97
L13XT1	-1.74	-2.65	-12.56*	0.92	-5.77*	9.14**	1.24	-4.69	28.82**	-7.43
L13XT2	-9.78**	-10.62**	-3.07	11.88**	7.74**	24.78**	-7.26	-12.7	46.41**	5.21
SE(d)	0.32	0.32	2.02	2.02	0.47	0.47	0.07	0.07	12.82	12.82

*=0.05 and **= 0.01 significant probability level. EL=Ear length, ED = Ear Diameter, TKW=Thousand kernel *=0.05 and **= 0.01 significant probability level. EL=Ear length, ED = Ear Diameter, TKW=Thousand kernel weight, NRPE=Row per ear, SE(d)=Standard error of difference.

Conclusions and recommendations

Traits like thousand kernel weight, ear length, ear diameter, number of row per ear and number of kernels per ear, which expressed positive heterosis of MP and BP, are good for selection and granted for grain yield. While negative significant differences of MPH, BPH, SH for AD and SD are better to develop mature earlier hybrid; whereas PH and EH are better for formation of short hybrids. The highest positive and significant heterosis of standard check of BH 546 for grain yield resulted from crosses L1 × T2 and for BH 547 the highest positive and significant of heterosis recorded from L1 × T2, respectively. L1 × T2, L6 × T1 and L6 × T2 were the top three crosses that showed positive and significant standard heterosis for this trait over both checks. Generally, from this research study we recommend firstly, Inbred lines displayed high positive percentage heterosis for grain yield over best standard checks and should promote advanced yield trial. Secondly, maize breeders can use inbred lines that showed highest positive heterosis over BP and MP for grain yield to improve yields; whereas negative heterosis is recommended for AD and SD to develop early maturing hybrids.

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