Standard Heterosis for Grain Yield and Yield Related Traits in Maize (*Zea mays* L.) Inbred Lines in Haramaya District, Eastern Ethiopia

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Abstract: Determination of heterosis in maize hybrids is necessary for identification of superior F_1 hybrids for breeding programs. Therefore, this study was conducted to estimate the amount of standard heterosis for grain yield and related traits in order to identify potential hybrid for future breeding schemes. Eight maize inbred lines were mated through a half diallel mating design (Griffing's Method IV, Model I). The resulting twenty-eight F_1 hybrids along with two standard checks (BHQPY 545 and MH 138) were evaluated using Alpha-Lattice Design with three replications during 2017/18 main cropping season at Haramaya University Research Site (Raare). Analysis of variance revealed significant variations for all traits indicating the existence of genetic variability. The result of heterosis estimation showed considerable amount of positive and negative heterosis for all traits studied. The highest percentage of standard heterosis for grain yield was manifested by the cross combinations L3 × L6 over BHQPY 545, and L3 × L6, L3 × L8, L2 × L5, L6 × L8, L1 × L4, L4 × L6 and L3×L4 over MH138 (greater than 20% yield advantage). The maximum positive and significant standard heterosis was recorded for L3 × L6, and L1 × L4 for 1000 kernel weight and number of kernels per row, respectively over the two checks BHQPY-545 and MH-138. The observed highest heterosis for grain yield and related traits indicated the possibility of increasing yield by exploiting heterotic potential of maize genotypes. The information generated by this study could be useful for researchers who need to develop high yielding maize hybrids. Hence the potential hybrids could be recommended for commercial use, after verifying the results by repeating the research over years and across locations.

Keywords: Crosses; F_1 hybrids; Maturity; Standard checks.

1. Introduction

Maize (*Zea mays* L.; 2n =20) is an important cereal crop to enhance food security and the demand for its grain is increasing every year (Abate *et al*., 2015), this is due to diverse uses, wide adaptability, and high yielding potential and genetic diversity. Considering the paramount importance of maize as a staple in the diets of many developing countries, particularly in Ethiopia the study intends to identify better performing crosses for the development of high yielding variety in eastern Ethiopia, to assure food security for maize producers and consumers while enhancing the sustainability of maize production. The exploitation of hybrid vigor can be instrumental in increasing seed yield (Nasim *et al.,* 2014) to come up with more advanced varieties than the existing ones in many aspects. In maize, several methods have been employed for the prediction of hybrid performance considering the cost and time which is required for field evaluation of hybrids. Selection of parents is the most important stage in any breeding programe to develop new genotypes having desirable characters. One of the methods to achieve this purpose is heterosis (Ilker *et al.,* 2010); Khan *et al.,* 2010; Siddiqi *et al*., 2012) since breeding strategies based on selection of hybrids require expected level of heterosis. Heterosis is important in breeding program especially for cross pollinated crop and is a great achievement to meet the world's food needs (Duvick, 1999). However, the definition of heterosis differs depending on the basis of comparison used.

Heterosis is the enhancement in size, growth, fertility and yield in progeny compared with their inbred parents (Thiemann *et al*., 2014; Jiban *et al*., 2018). The biological phenomenon of heterosis is described by the trait-specific performance of highly heterozygous F_1 hybrids with respect to the average (mid-parent) or high parent performance of their genetically distinct homozygous parents in measurable characters (Paschold *et al*., 2010). Similarly, heterosis is a phenomenon in which an F_1 hybrid of two genetically dissimilar parents shows superiority over the standard or commercial variety, which is often included in the trial as a check variety. It is also called economic heterosis or superiority over check variety. Therefore, a new maize hybrid must be superior to an existing

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commercial hybrid variety (i.e. check variety) for grain yield and other economic traits to be released as a commercial variety. Thus, determination of heterosis in reference to a standard check (standard heterosis) is required for commercialization of maize hybrids. So far, standard heterosis in maize has been extensively studied for different sets of new inbred lines developed/introduced and adapted at different times (Shushay, 2014; Reddy *et al*., 2015; Ziggiju *et al*., 2016; Natol *et al.,* 2017; Huiyong *et al*., 2018; Abiy *et al*., 2019).

The magnitude of heterosis provides information on extent of genetic diversity of parents in developing superior F_1s so as to exploit hybrid vigour and has direct bearing on the breeding methodology to be adapted for varietal improvement and their commercial utilization (Rajesh *et al*., 2014). The square of gene frequency difference between parental lines, pattern of distribution of dominance (ambi-directional or unidirectional) and genes are in dispersive or associated are also determinants of heterosis. According to Hallauer & Miranda (1988) the manifestation of heterosis depends on the genetic divergence of two parental varieties, also genetic divergence of the parents is inferred from the heterotic patterns manifested in a series of cross combination. Riday *et al.* (2003) suggested that in many cases heterosis can be accounted for by the interaction of genes controlling morphologically divergent traits between the parents. Hybrid breeders have always been interested in the selection of potential lines among the available parental lines which are expected to give heterotic hybrids to develop higher yielding, better performing hybrids. Therefore, the objective of the present study was to estimate the amount of standard heterosis in maize hybrids for grain yield and yield related traits in order to identify potential hybrid for future breeding schemes.

2. Materials and Methods

2.1. Description of Study Area

The study was conducted at Haramaya University main campus (Raare Research Site) in 2017/18 cropping season. The study area is located at an altitude of 2020 meters above sea level and lies at 9˚ 26' N latitude and 42˚3' E longitude. The area received an average annual rainfall of 727 mm during the 2018 main cropping season. The minimum and maximum mean annual temperatures during the cropping season were 8.99 ^{o}C and 25.15 ^{o}C, respectively (Haramaya University Weather Station, 2018).

2.2. Experimental Materials

The planting materials were comprised of eight maize inbred lines which were crossed in 8×8 half diallel mating design (Griffing's Method IV, Model I) in 2017 at Haramaya University Crop Research Site (Raare) to produce twenty-eight F_1 hybrids. BHQPY-545 are medium maturing single cross hybrids released by Bako National Maize Research Project (BNMRP) for mid to high potential maize growing agro-ecologies of Ethiopia, while MH 138 is drought tolerant hybrid released by Melkassa Agricultural Research center, Ethiopia and was used as a standard check. The resulting 28 F_1 hybrids and two standard checks (BHQPY 545 and MH 138) were tested in the 2017/2018 cropping season at Haramaya University Crop Research Site (Raare). The lines were obtained from Haramaya University Maize Research Program. List and pedigrees of the inbred lines used in the dialle crosses are depicted in Table 1.

Table 1. Inbred lines used in the diallel cross.

Code	Inbred Lines Pedigree
L1	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-8-4-2-2-1-#-1-B-2
L2	[KIT/SNsyn[N3/TUX]]c1F1-##(GLS=2.5)-32-1-1-#/CML176BC1F1-12-1-3-4-2-#-2-B-1
L3	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-8-4-3-3-4-#-1-B-4
L4	[POOL9Ac7-SR(BC2)]FS48-1-1-1-1-1-#/CML144(BC2)-6-22-1-1-1-4-#-3-B-1
L5	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-8-4-3-2-2-#-1-B-1
L6	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-21-1-3-2-2-#-2-B-4
L7	[POOL9Ac7-SR(BC2)]FS59-2-2-1-1-#/CML144(BC1)F1-3-2-1-2-1-#-1-B-2
L8	[KIT/SNsyn[N3/TUX]]c1F1-##(GLS=2.5)-17-1-1-#/CML144(BC1)F1-5-1-2-1-1-#-2-B-1

2.3. Treatments and Experimental Design

The twenty-eight F_1 progenies derived from the diallel crosses and the two commercial hybrid checks were planted using alpha-lattice designs with three replications. In all cases, two rows per plots were used, where the length of each row was 5.1 m with the spacing of 0.75 m between rows and 0.30 m within rows. An alley of 1.5 m left between the blocks.

2.4. Procedure and Field Management

Two seeds were sown per hill to ensure enough stand, and then thinned to one plant per hill after two weeks of emergence (when seedlings were at a 3-4-leaf stage) to attain a population density of 44,444 plants per hectare. Urea and NPS fertilizers were applied at the rates of 140 kg/ha and 118 kg/ha, respectively. Urea was applied in 2 equal splits. The first half application was done at sowing along with NPS fertilizer and the second was applied at the knee-high growth stage of the crop. Moreover, all other necessary field management practices were carried out as per the recommendations for the study area and the crop.

2.5. Data Collection

Data on grain yield and yield related traits were collected on plot and individual plant bases. Characters were recorded on plant basis by taking five random plants. The average was taken as the mean of the treatment.

2.5.1. Data collected on plot basis

Days to anthesis (DA): This refers to the number of days taken from planting up to the date when 50% of the plants started pollen shedding.

Days to silking (DS): This is the number of days taken from planting to the date when 50% of the plants produced about 2-3cm long silk.

Anthesis-silking interval (ASI): was calculated as the difference between number of days to anthesis and number of days to silking (ASI = DA – DS).

Days to physiological maturity (DM): was recorded as the number of days after sowing to when 50% of the plants in the plot formed a black layer at the point of attachment of the kernel with the cob.

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

Grain moisture: Moisture content (%) in the grain was measured at harvesting by taking a sample of ears and shelling separately for each plot using a portable digital moisture tester.

Grain yield/plot (GY): Grain yield per plot adjusted to 12.5% of moisture content was recorded for each plot in kg/plot using the formula below.

$$\text{Adjusted grain yield (kg per plot} = \frac{\text{Field of weight (kg per plot)x } (100 - \text{MC})\text{x shelling } (\%)}{100 - 12.5)\text{ x Area harvested (plot size)}}$$

Where, MC = moisture content of grain at harvest.

$$\text{Shelling percentage} = \frac{\text{Grain weight}}{\text{Ear weight}} \text{ x } 100$$

Shelling percentages for normal ears usually average about 80% (80/100 = 0.8).

Grain yield/ha (GY): was obtained by converting the grain yield obtained per plot into a hectare basis.

Harvest index (HI): was calculated by dividing grain yield (kg ha^{-1}) by aboveground biomass yield (kg ha^{-1}) and expressed in percentage Donald (1962).

2.5.2. Data collected on plant basis

Ear height (EH): was measured from the ground level to the uppermost useful ear- bearing node of five randomly taken plants.

Plant height (PH): was measured from the soil surface to the tassel starts branching of five randomly taken plants.

Ear length (EL): was measured in centimeters from the base to the tip of ear.

Ear diameter (ED): was measured at the midsection along the ear length, as the average diameter of five randomly taken ears using a caliper.

Number of kernel rows per ear (NKRE): was recorded as the average number of kernels row per ear from five randomly taken ears.

Number of kernels per row (NKR): was counted and the average was recorded from five randomly taken ears.

2.6. Data Analyses

2.6.1 Analysis of variance

The data were subjected to simple analysis of variance (ANOVA) to see the existence of genetic variability whether there are differences between the tested genotypes using PROC GLM procedure of SAS, version 9.0 SAS (2002) before estimating standard heterosis.

2.6.2. Estimation of standard heterosis

Economic/ standard heterosis of the F_1 hybrids was estimated in percentage in relation to standard checks for traits that showed significant differences among crosses following the method suggested by Falconer and Mackay (1996):

$$SH (\%) = \left(\frac{F1-SV}{SV}\right) \times 100$$

Where, SH = standard heterosis, S_V = standard variety (for each check), F_1 = mean performance of F_1.

The differences in the magnitude of heterosis were tested following the procedure of Panse Sukhatme (1961). Standard error and critical difference were also computed as:

$$SE\ (d) = \frac{\sqrt{2MSe}}{r}$$

$$CD = SE\ (d) \times t$$

Where, SE (d) is standard error of the difference, MSe = error mean square from analysis of variance, r = the number of replications, CD = critical difference and t = value of t at error degree of freedom.

The test of significance of heterosis in relation to standard check was done by 't' test as suggested by Snedecor and Cochran (1967) as follows:

$$\text{Heterosis 't'} = \frac{\text{Mean of F1} - \text{standard check}}{\sqrt{\frac{2mse}{r}}}$$

The computed t-value was compared with the t-value at error degree of freedom corresponding to 5 or 1% level of significance.

3. Results and Discussion

3.1. Analysis of Variance (ANOVA)

The analysis of variance (ANOVA) revealed that the twenty-eight F_1 hybrids and the two standard checks showed significant differences for yield and yield related traits as well as disease reaction (Table 2). Genotypes significantly (p<0.01) differed for grain yield and yield related traits, namely, grain yield, biomass yield, days to anthesis, days to silking, plant and ear height, ear rot, plant aspect, ear aspect, common rust (*Puccinia sorghi*), days to maturity, thousand kernel weight, kernels per row, and *Turccicum* leaf blight (TLB). The existence of significant differences indicates the presence of inherent (genetic) variation among the materials evaluated, which makes selection possible for further breeding program (Dan *et al.,* 2018). In addition, ear length, ear diameter, kernel rows per ear, anthesis silking interval and harvest index showed significant (P<0.05) differences (Table-2). The results also highlight the presence of sufficient genetic variability among the genotypes. The presence of variability among the genotypes for character of interest enables the breeder to conduct appropriate selection of the most desirable cross combinations. These results are in line with the results reported by Bullo and Dagne (2016) and Matin *et al.* (2017).

Table 2. Analysis of variance due to mean square of genotypes for grain yield and related traits evaluated at Haramaya, Eastern Ethiopia, during the 2017/18 main cropping season.

Source of variation	df	Mean squares [a]									
		GY (t/ha)	DT (day)	DS (day)	ASI (day)	PS (scale)	ET (scale)	PA (scale)	PH (cm)	EH (cm)	EA (scale)
Rep	2	5.03	3.34	4.57	0.28*	0.09	0.03	0.03	112.83	198.28	0.01
Blk/(Rep)	10	1.26	0.87	1.69	0.05	0.04	0.04	0.08	141.15	37.1	0.05
Genotypes	29	6.80**	9.55**	8.40**	0.15*	0.11**	0.13**	0.17**	1212.08**	401.90**	0.73**
Error	48	1.75	1.08	1.19	0.08	0.03	0.06	0.05	192.26	65.18	0.08

Table 2. *Continued*

Source of variation	df	Mean squares [a]									
		EPP (#)	DM (day)	EL (cm)	ED (cm)	NKR (#)	NKRE (#)	TKW (g)	BY (t/ha)	ER (#)	HI (%)
Rep	2	0.02	1.42	1.41	0.09	3.83	2.44	1277.02	39.63	1.28**	25.54
Blk(Rep)	10	0.01	0.77	5.66	0.19	3.54	4.03	3644.99	7.45	0.19	14.62
Genotypes	29	0.18**	97.97**	9.38*	0.77*	30.04**	8.33*	10491.39**	48.58**	0.53**	39.56*
Error	48	0.02	0.69	5.29	0.45	4.17	4.63	4056.71	17.09	0.23	20.93

Note: [a] *GY = grain yield; BM = biomass yield; DA = days to anthesis; ED = ear diameter; EH = ear height; EL = ear length; EPP = number of ear per plant; NKR = number of kernels per row; PH = plant height; NKRE = number of kernel rows per ear; DS = number of days to silking; TKW = thousand kernels weight; DM = days to maturity; PA = plant aspect; EA = ear aspect; HC = husk cover; ASI = anthesis silking interval; HI = harvest index; ER = ear rot; ET = Turccicum leaf blight and PS = Puccinia sorghi (rust).** = Significant at P<0.01 level of probability and * = Significant at P<0.05 level of probability*

3.2. Mean Performance of Genotypes

The mean performances of the crosses are presented in Table 3. Among the crosses, the best yield was obtained from the cross L3×L6 while the least was L1×L5. The top four high yielding hybrids are obtained from the crosses L3×L6, L3×L8, L2×L5, and L6×L8 which exhibited higher mean value of grain yield relative to one of the best checks BHQPY-545. In addition, the mean value of the twenty crosses showed higher grain yields than the total average grain yield and out-yielded the grand mean of the second checkMH-138. Higher mean performances of these crosses over the standard checks indicate the possibility of obtaining a better commercial variety to enhance grain yield in maize. These results agree with the findings of Shushay (2014) and Girma *et al.* (2015) who reported significant mean performance of grain yield and related traits over the best hybrid check (BHQPY-545) in the study of combining ability of maize inbred lines for grain yield and yield related traits. Berhanu (2009) also reported greater range in grain yield among test crosses of maize inbred lines evaluated at Bako, Hawassa and Jimma Research Centers.

The highest mean value of thousand kernel weight was obtained from the cross L3×L6 while the lowest in L1×L5 with the average value of 360.4 g. Similarly, the highest mean value of harvest index retained from L2×L8 while the lowest for L3×L4 with the mean value of 40.44. Among all, the crosses L6×L8 and L3×L5 are late mature hybrids whereas L4×L6 are early mature hybrid which are desirable for the development of early maturing varieties for moisture stress environments since earliness are desirable to increase water use efficiency.

The highest mean value of number of kernel per row was obtained from L1×L4, while the least number of kernels per row was for L6×L8. Higher number of kernel row per ear was recorded from standard check BHQPY 545, while the lowest number of kernel row per ear recorded from the cross L3×L4. The higher number of kernel per row and kernel row per ear are desirable to enhance grain yield of maize as the two traits are directly correlated with grain yield.

The highest number of ear per plant was recorded from L3×L6; and the lowest was from L4×L5. This indicated that L3×L6 was prolific as compared to the standard check BHQPY-545, thus which will be used for the next breeding activity to enhance grain yield. Among all the genotypes tested, L3×L8 attained the maximum ear length while L3×L7 was genotypes with shortest ear length. Similarly, higher ear diameter was obtained from the check (BHQPY 545) while the lowest retained from L3×L4. Maize genotypes with longer ear length and wide ear diameter may have inherent genetic potential to enhance grain yield.

The cross L6×L8 that were late in anthesis and silking could be used as sources of genes for development of late maturing hybrids. Conversely, the crosses L4×L6 which had shorter days to flowering could be regarded as early maturing types. Early maturing types of crosses are appropriate in area with short rainy season so as to escape moisture stress encountering during grain filling stage or late in the season.

Anthesis-silking interval (ASI) is the most important trait in determining drought tolerance. Moreover, the crosses which exhibited low anthesis-silking interval (L1×L2, L1×L3, L1×L5, L1×L6, L1×L7, L1×L8, L2×L3, L2×L4, L2×L5, L2×L6, L3×4, L3×L5) indicates that the cross had short gaps between days to anthesis and silking, which are desirable characters for good seed setting and drought tolerance. On the other hand, if the gap between days to anthesis and silking is large, the viability of pollen would be reduced and abnormal fertilization might take place or fertilization may not happen consequently, which leads to yield lose. The result was in line with the report of Bolafios and Edmeades (1996).

Table 3. Mean performance of maize genotypes for grain yield and yield related traits at Haramaya, Eastern Ethiopia, during the 2017/18 main cropping season.

Crosses	Traits considered [a]							
	GY (t/ha)	HI (%)	DT (day)	DS (day)	ASI (day)	NKR (#)	NKRE (#)	TKW (g)
L1×L2	5.91	44.14	79.00	82.00	3.00	40.87	11.89	309.70
L1×L3	6.29	39.54	80.00	83.00	3.00	37.00	11.61	330.32
L1×L4	9.18	44.48	77.33	80.67	3.33	44.07	14.98	448.42
L1×L5	3.97	36.60	82.33	85.33	3.00	36.00	12.41	226.00
L1×L6	8.74	45.08	77.67	80.67	3.00	41.20	14.13	326.50
L1×L7	7.75	36.84	78.00	81.00	3.00	41.47	11.36	306.53
L1×L8	7.24	46.63	79.33	82.33	3.00	42.53	16.23	321.48
L2×L3	8.47	45.07	82.00	85.00	3.00	38.73	12.90	384.20
L2×L4	7.97	41.20	78.67	81.67	3.00	41.13	14.29	346.77
L2×L5	9.33	41.22	80.00	83.00	3.00	37.67	13.39	417.22
L2×L6	7.29	40.18	80.33	83.33	3.00	40.87	12.94	380.29
L2×L7	8.07	45.22	78.33	81.33	3.00	41.07	13.09	332.90
L2×L8	8.02	47.26	80.00	83.67	3.67	41.27	14.69	382.11
L3×L4	9.12	33.84	77.67	80.67	3.00	41.27	9.59	421.20
L3×L5	7.95	44.07	78.00	81.00	3.00	41.73	13.17	365.97
L3×L6	11.19	40.35	77.00	80.67	3.67	39.93	11.20	472.42
L3×L7	6.60	38.61	81.00	84.00	3.00	40.13	11.05	293.85
L3×L8	9.99	39.18	78.00	81.00	3.00	42.13	16.02	393.84
L4×L5	4.86	39.73	82.33	85.33	3.00	34.53	13.84	234.84
L4×L6	9.15	39.24	76.33	79.67	3.33	37.53	12.34	359.37
L4×L7	7.80	37.51	78.67	81.67	3.00	42.20	11.70	325.38
L4×L8	6.08	38.72	78.33	81.33	3.00	41.50	11.85	284.59
L5×L6	7.69	37.14	77.67	80.67	3.00	42.47	11.15	400.91
L5×L7	7.41	35.82	79.67	82.67	3.00	43.20	13.03	381.44
L5×L8	8.80	37.26	77.33	80.67	3.33	38.93	12.39	451.34
L6×L7	8.95	37.37	78.33	81.33	3.00	38.40	13.14	370.82
L6×L8	9.31	35.60	83.33	86.67	3.33	28.47	12.32	403.03
L7×L8	8.75	38.51	80.33	83.33	3.00	38.53	11.27	319.92
BHQPY	9.28	46.19	78.67	83.00	3.67	37.70	17.04	375.67
MH138	7.50	40.53	78.00	81.00	3.00	37.67	13.42	305.20
CV	16.60	11.31	1.26	1.25	9.02	5.16	16.62	17.67
LSD	2.17	7.51	1.64	1.69	0.46	3.35	3.53	104.00
Max.	11.19	47.26	83.33	86.67	3.67	44.07	17.04	472.42
Mean	7.96	40.44	79.12	82.26	3.11	39.67	12.95	360.40
Min.	3.97	33.84	76.33	79.67	3.00	28.47	9.59	226.00

Table 3. *Continued*

Crosses	Traits considered [a]								
	PS (scale)	ET (scale)	EL (cm)	PH (cm)	EH (cm)	ED (cm)	ER (#)	DM (day)	EPP (#)
L1×L2	1.50	2.00	17.32	198.33	93.33	4.24	1.74	161.67	1.03
L1×L3	1.50	1.83	14.65	170.00	70.00	3.98	1.43	160.33	1.02
L1×L4	1.00	1.33	19.50	211.67	101.67	4.86	1.10	167.67	1.53
L1×L5	1.50	1.50	15.26	185.00	83.33	3.88	1.56	161.00	1.10
L1×L6	1.33	1.50	17.69	203.33	90.00	4.31	1.00	168.33	1.50
L1×L7	1.50	1.50	15.30	198.33	93.33	3.97	1.17	156.00	1.03
L1×L8	1.50	1.50	19.03	196.67	96.67	5.20	1.56	160.00	1.05
L2×L3	1.50	1.50	19.21	180.00	83.33	4.59	1.00	165.33	1.28
L2×L4	1.67	1.67	16.55	200.00	90.00	4.64	2.18	163.00	1.16
L2×L5	1.33	1.33	19.94	211.67	105.00	4.83	1.39	168.00	1.15
L2×L6	1.67	1.67	18.10	195.00	96.67	3.77	1.95	160.33	1.05
L2×L7	1.50	1.50	18.63	203.33	101.67	4.58	1.44	160.67	1.02
L2×L8	1.50	1.67	19.21	190.00	96.67	4.92	1.55	160.67	1.02
L3×L4	1.50	1.50	14.49	178.33	88.33	3.42	1.10	168.33	1.14
L3×L5	1.17	1.33	18.65	190.00	100.00	4.89	1.65	170.33	1.28
L3×L6	1.00	1.50	17.49	215.00	98.33	4.35	2.41	170.00	1.82
L3×L7	1.50	1.50	14.43	201.67	103.33	3.84	1.17	168.33	1.12
L3×L8	1.17	1.17	19.97	221.67	115.00	5.39	1.87	169.67	1.42
L4×L5	1.50	1.50	19.16	183.33	80.00	4.83	1.72	163.67	1.00
L4×L6	1.33	1.33	16.74	210.00	98.33	4.16	1.17	141.67	1.23
L4×L7	1.50	1.67	18.05	196.67	95.00	4.43	1.44	167.67	1.11
L4×L8	1.50	1.50	16.03	218.33	108.33	4.10	2.08	164.67	1.11
L5×L6	1.50	1.83	17.59	206.67	101.67	4.09	1.57	164.33	1.07
L5×L7	1.50	1.50	18.80	191.67	95.00	4.63	1.10	168.33	1.01
L5×L8	1.17	1.17	18.56	200.00	108.33	4.63	1.00	164.67	1.55
L6×L7	1.33	1.67	18.13	198.33	100.00	4.72	1.64	169.33	1.35
L6×L8	1.83	1.83	16.29	125.00	60.00	4.51	1.60	170.33	1.01
L7×L8	1.67	2.00	14.47	151.67	85.00	3.67	1.00	163.67	1.63
BHQPY	1.17	1.33	19.74	203.33	101.67	5.67	1.00	169.00	1.79
MH138	1.50	1.67	16.11	160.00	78.33	4.24	1.01	163.33	1.36
CV	12.47	15.38	13.14	7.18	8.59	15.07	33.28	0.51	12.48
LSD	0.29	0.39	3.77	22.76	13.25	1.10	0.78	0.78	0.25
Max.	1.83	2.00	19.97	221.67	115.00	5.67	2.41	170.33	1.82
Mean	1.43	1.55	17.50	193.17	93.94	4.44	1.45	164.34	1.23
Min.	1.00	1.17	14.43	125.00	60.00	3.42	1.00	141.67	1.00

Note: [a] *GY = grain yield; BM = biomass yield; DA = number of days to anthesis; NKR = number of kernels per row; NKRE = Number of kernel rows per ear; DS = days to silking; TKW = thousand kernels weight; ASI = anthesis silking interval; HI = harvest index; EH = ear height; EL = ear length; EPP =number of ear per plant; PH = plant height; DM = days to maturity; ED = ear diameter; EL = ear length; ER = ear rot; ET= Turciccum leaf blight and PS = Puccinia sorgi (rust). ** = Significant at P<0.01 level of probability; * = Significant at P<0.05 level of probability.*

The crosses L6×L8, L7×L8, L1×L2, L4×L5, L2×L3 which have shorter plant height and medium ear placement, which are desirable for lodging resistance and to apply necessary management practices, whereas hybrids that were longer in ear and plant heights such as L3×L8, L4×L8 could be used as sources of genes for development of longer statured varieties to harvest high biomass yield that could be used as animal feed, fencing and source of fuel for resource poor farmers.

The F_1 crosses namely L1×L6, L2×L3, L6×L8, and L7×L8 display lower ear rot severity score. These show there are promising materials that are less affected by ear rot. Based on their yield and overall performance, these materials could be advanced to advanced stages of trials to confirm their performance across locations and years. The low severity *Turcicum* leaf blight was recorded for L3×L8, L5×L8; while the higher was recorded from L1×L2, L7×L8. Generally, the TLB severity varied from low to moderate level. In the case of *Puccinia sorghi* (common rust), the lowest severity was observed from L1×L4, L3×L6 and the highest was from L6×L8.

3.3. Estimation of Standard Heterosis

In the present study, the magnitude and direction of heterosis in F_1 hybrids varied from character to character, and from cross to cross (Table 4). The estimates of heterosis over the best standard check showed significant differences among genotypes for grain yield and yield related traits. Thus, positive, and negative significant standard heterosis was observed in most of the genotypes compared with the two standard checks (BHQPY-545 and MH-138). This indicates the presence of considerable amount of heterosis for improving grain yield and yield related traits including disease reaction. These results are comparable with the reports of Mahantesh (2006) and Shushay (2014) who reported varying degree of heterosis for grain yield and its related traits in maize.

Table 4. Estimates of standard heterosis for yield and yield related trait of maize inbred lines evaluated at Haramaya, Eastern Ethiopia, during the 2017/18 main cropping season.

Crosses	Traits per inbred lines tested [a]							
	GY		EL		NKR		NKRE	
	BHQPY545	MH138	BHQPY545	MH138	BHQPY545	MH138	BHQPY545	MH138
L1×L4	-1.08	22.40*	-1.22	21.04*	16.90**	16.99**	-12.09	11.62
L1×L6	-5.82	16.53*	-10.39	9.81	9.28	9.37*	-17.08	5.29
L1×L7	-16.49*	3.33	-22.49*	-5.03	10.00*	10.09*	-33.33**	-15.35
L2×L3	-8.73	12.93	-2.68	19.24	2.73	2.81	-24.30*	-3.87
L2×L4	-14.12*	6.27	-16.16*	2.73	9.10*	9.19*	-16.14	6.48
L2×L5	0.54	24.40*	1.01	23.77*	-0.08	0.00	-21.42*	-0.22
L2×L7	-13.04*	7.60	-5.62	15.64	8.94*	9.03*	-23.18*	-2.46
L2×L8	-13.58*	6.93	-2.68	19.24	9.47*	9.56*	-13.79	9.46
L3×L4	-1.72	21.60*	-26.60**	-10.06	9.47*	9.56*	-43.72**	-28.54*
L3×L5	-14.33*	6.00	-5.52	15.77	10.69*	10.78*	-22.71*	-1.86
L3×L6	20.58**	49.20**	-11.40	8.57	5.92	6.00	-34.27**	-16.54
L3×L8	7.65	33.20**	1.17	23.96*	11.75*	11.84**	-5.99	19.37
L4×L6	-1.40	22.00*	-15.20	3.91	-0.45	-0.37	-27.58*	-8.05
L4×L7	-15.95*	4.00	-8.56	12.04	11.94**	12.03**	-31.34**	-12.82
L5×L6	-17.13*	2.53	-10.89	9.19	12.65**	12.74**	-34.57**	-16.92
L5×L8	-5.17	17.33*	-5.98	15.21	3.26	3.34	-27.29*	-7.68
L6×L7	-3.56	19.33	-8.16	12.54	1.86	1.94	-22.89*	-2.09
L6×L8	0.32	24.13*	-17.48*	1.12	-24.48**	-24.42**	-27.70*	-8.20
L7×L8	-5.71	16.67*	-26.70**	-10.18	2.20	2.28	-33.86**	-16.02
SE(d)	0.71	0.71	1.88	1.88	1.67	1.67	1.76	1.76
CD5%	1.19	1.19	3.16	3.16	2.80	2.80	2.96	2.96
CD1%	1.71	1.71	4.53	4.53	4.03	4.03	4.25	4.25

Table 4. *Continued*

Crosses	Traits per inbred lines tested [a]							
	DT		DS		PH		EH	
	BHQPY545	MH138	BHQPY545	MH138	BHQPY545	MH138	BHQPY545	MH138
L1×L4	-1.70	-0.86	-2.81*	-0.41	4.100	32.29**	0.00	29.80**
L1×L6	-1.27	-0.42	-2.81*	-0.41	0.000	27.08**	-11.48*	14.90*
L1×L7	-0.85	0.00	-2.41*	0.00	-2.460	23.96**	-8.20	19.15*
L2×L3	4.23**	5.13**	2.41*	4.94**	-11.47*	12.50*	-18.04**	6.38
L2×L4	0.00	0.86	-1.61	0.82	-1.640	25.00**	-11.48*	14.90*
L2×L5	1.69	2.56*	0.00	2.47**	4.100	32.29**	3.28	34.05**
L2×L7	-0.43	0.42	-2.01	0.41	0.000	27.08**	0.00	29.80**
L2×L8	1.69	2.56*	0.80	3.29	-6.560	18.75**	-4.92	23.41**
L3×L4	-1.27	-0.42	-2.81*	-0.41	-12.30*	11.460	-13.12*	12.77
L3×L5	-0.85	0.00	-2.41*	0.00	-6.560	18.75*	-1.64	27.67**
L3×L6	-2.12	-1.28	-2.81*	-0.41	5.740	34.38**	-3.29	25.53**
L3×L8	-0.85	0.00	-2.41*	0.00	9.020	38.54**	13.11*	46.81**
L4×L6	-2.97**	-2.14	-4.01**	-1.64	3.280	31.25**	-3.29	25.53**
L4×L7	0.00	0.86	-1.61	0.82	-3.280	22.92**	-6.56	21.28**
L5×L6	-1.27	-0.42	-2.81*	-0.41	1.640	29.17**	0.00	29.80**
L5×L8	-1.70	-0.86	-2.81*	-0.41	-1.640	25.00**	6.55	38.30**
L6×L7	-0.43	0.42	-2.01	0.41	-2.460	23.96**	-1.64	27.67**
L6×L8	5.92**	6.83**	4.42**	7.00**	-38.52**	-21.88**	-40.99**	-23.40**
L7×L8	2.11	2.99**	0.40	2.88**	-25.41**	-5.21**	-16.40**	8.52
SE(d)	0.85	0.85	0.89	0.89	11.32	11.32	6.59	6.59
CD5%	1.43	1.43	1.49	1.49	19.01	19.01	11.06	11.06
CD1%	2.05	2.05	2.15	2.15	27.30	27.30	15.90	15.90

Table 4. *Continued*

Crosses	Traits per inbred lines tested [a]					
	TKW		EPP		DM	
	BHQPY545	MH138	BHQPY545	MH138	BHQPY545	MH138
L1×L4	19.37	46.93**	-14.53*	12.50	-0.79*	2.66**
L1×L6	-13.09	6.98	-16.20*	10.29	-0.40	3.06**
L1×L7	-18.40	0.44	-42.46**	-24.26**	-7.69**	-4.49**
L2×L3	2.27	25.88	-28.4**	-5.88	-2.17**	1.22**
L2×L4	-7.69	13.62	-35.20**	-14.71*	-3.55**	-0.20
L2×L5	11.06	36.70*	-35.75**	-15.44*	-0.59	2.86**
L2×L7	-11.38	9.08	-43.02**	-25.00**	-4.93**	-1.63**
L2×L8	1.71	25.20	-43.02**	-25.00**	-4.93**	-1.63**
L3×L4	12.12	38.01*	-36.31**	-16.18*	-0.40	3.06**
L3×L5	-2.58	19.91	-28.49**	-5.88	0.79*	4.29**
L3×L6	25.75**	54.79**	1.68	33.82**	0.59	4.08**
L3×L8	4.84	29.04*	-20.67**	4.41	0.40	3.88**
L4×L6	-4.34	17.75	-31.28**	-9.56	-16.17**	-13.26**
L4×L7	-13.39	6.61	-37.99**	-18.38*	-0.79*	2.66**
L5×L6	6.72	31.36*	-40.22**	-21.32*	-2.76**	0.61
L5×L8	20.14	47.88**	-13.41*	13.97*	-2.56**	0.82*
L6×L7	-1.29	21.50	-24.58**	-0.74	0.20	3.67**
L6×L8	7.28	32.05*	-43.58**	-25.74**	0.79*	4.29**
L7×L8	-14.84	4.82	-8.94	19.85*	-3.15**	0.21
SE(d)	52.00	52.00	0.12	0.12	0.68	0.68
CD5%	87.31	87.31	0.20	0.20	1.14	1.14
CD1%	125.42	125.42	0.29	0.29	1.64	1.64

Note: [a] *GY = grain yield; EL= ear length; NKR = number of kernels per row; NKRE = number of kernel rows per ear; DA = days to anthesis; EH = ear height; PH = plant height; DS = days to silking; EPP = number of ear per plant; TKW = thousand kernels weight; DM = days to maturity; SE (d) = standard error difference and CD = critical difference. ** = significant at P<0.01 level of probability; * = significant at P<0.05 level of probability.*

Number of ear per plant: The estimated heterosis of crosses over BHQPY-545 and MH-138 for number of ear per plant varied from -43.58% to 1.68%; and -25.00% to 33.82%, respectively. Twenty-six crosses showed significantly lower number of ear per plant than BHQPY-545 while only one of the crosses (L3×L6) showed higher number of ear per plant than BHQPY-545. This indicates that this cross is highly prolific than the better standard check could be used to enhance grain yield. On the other hand, nine hybrids showed significantly lower number of ear per plant than MH-138 while three of the crosses showed significantly higher thousand kernel weights than MH-138.

Days to maturity: The estimated heterosis crosses over BHQPY-545 and MH-138 for days to maturity varied from -16.17% to 0.79 % and -13.26% to 4.29%, respectively. Eighteen hybrids revealed significantly earlier than BHQPY-545, which are desirable for the development of early maturing varieties than the checks and to adjust cropping pattern. However, two crosses showed significantly late maturity than the check BHQPY-545. On the other hand, nine hybrids revealed significantly lower days to maturity than MH-138, which are desirable for the development of early maturing varieties to escape drought or terminal moister stress and frost while fifteen hybrids showed significantly higher days to maturity than MH-138.

Plant height: Standard heterosis estimates of crosses over the two commercial checks for plant height ranged from -38.52% to 9.02 % and -21.88% to 38.54%, respectively. Among all the crosses, L1×L3, L3×L4, L6×L8 and L7× L8 showed significantly lower plant height than BHQPY-545 while none of the crosses showed significantly higher plant height than BHQPY-545. On the other hand, two hybrids (L6×L8 and L7×L8) showed significantly lower plant height than MH-138 while twenty-four hybrids showed significantly higher plant height than MH-138. Generally, negative heterosis for plant height is desirable for breeding short statured hybrids and implied that these hybrids would resist lodging and mature earlier. On the other hand, the crosses which showed significantly higher plant height gave higher grain yield, which could be attributed to high photosynthetic products accumulation during long period for grain filling. These results agreed with the findings of Shushay (2014); Reddy *et al.* (2015); Matin *et al.* (2017); and Natol *et al.* (2017) who reported both negative and positive values of standard heterosis for plant height.

Ear height: Standard heterosis of crosses over the two standard checks for ear height ranged from -40.99% to 13.11% and 23.40% to 46.81%, respectably. Among the tested genotypes, nine hybrids exhibited significantly lower ear placement than BHQPY-545 while only one hybrid (L3×L8) showed significantly higher ear placement than BHQPY-545. On the other hand, one cross (L6×L8) showed significantly lower ear height than MH-138 while twenty-one crosses showed significantly higher ear height than MH-138 (Table 4). Generally, plant and ear heights are the major concern to maize breeders since plants with increased ear and plant heights are vulnerable to lodging and hence to yield reduction. On the contrary, low plant and ear height are desirable to reduce lodging problems in maize and for ease of mechanized operations. Therefore, the variability existed in the tested crosses could help in the improvement of these traits.

Ear length: Heterosis estimates of crosses over the two standard checks for ear length ranged from -26.90% to 1.17% and -10.43% to 23.96%, respectively. Nine of the crosses showed significantly lower ear length compared to BHQPY- 545, while none of the cross showed significantly higher ear length than BHQPY-545. Conversely, the crosses L1×L4, L2×L5 and L3×L8 showed significantly higher ear length than MH-138 while none of the cross showed significantly lower ear length compared to MH-138 (Table 4). Longer ears are desirable and can result in higher grain yield. These results agree with the finding of Dhoot *et al.* (2017) who reported that none of the hybrid exhibited positive significant economic heterosis for ear length. On the contrary, Natol *et al.* (2017) reported both negative and positive values of standard heterosis for ear length.

Number of kernels row per ear: The estimated heterosis of crosses over the two standard checks for number of kernels row per ear ranged from -35.15% to -4.75% and -28.54% to 20.94%, respectively. Twenty-one of the crosses showed significantly lower number of kernels row per ear than BHQPY545 while none of the crosses showed significantly higher number of kernels row per ear than BHQPY545. Conversely, only one cross showed significantly lower number of kernel row per ear than MH-138 while none of the crosses showed significantly higher number of kernels row per ear than MH-138. These results were comparable with the finding of Dhoot *et al.* (2017) who reported none of the tested hybrids exhibited positive significant economic heterosis for kernel row per ear. On the contrary, Amiruzzaman (2010) reported both significant negative and positive values of standard heterosis for kernel row per ear.

Number of kernels per row: Standard heterosis of crosses over BHQPY-545 and MH-138 for number of kernels per row ranged from -24.48% to 16.90% and -24.42% to 16.99%, respectively. Among the genotypes, fourteen crosses showed significantly higher number of kernels per row compared to BHQPY-545 while only two crosses showed significantly lower number of kernels per row than BHQPY-545. On the other hand, sixteen crosses showed significantly higher number of kernel per row compared to MH-138 while only one cross showed significantly lower number of kernels per row than MH-138. These results agree with the findings of Reddy *et al.* (2015); and Natol *et al.* (2017) who reported both negative and positive values of standard heterosis for number of kernel per row.

Thousand kernel weight: The estimated heterosis of crosses over the two standard checks for thousand kernel weight varied from -39.84% to 25.75% and -25.95% to 54.79%, respectively. Among all two crosses showed significantly lower thousand kernel weight than BHQPY-545 while only one cross showed significantly higher thousand kernel weights than BHQPY-545. On the contrary, eight hybrids showed significantly higher thousand kernel weights than MH-138 while none of the crosses showed significantly lower thousand kernel weights than MH-138 (Table 4). These results agree with the findings of Amiruzzaman (2010), Shushay (2014), Reddy *et al.* (2015); Ziggiju *et al.* (2016); Matin *et al.* (2017) and Natol *et al.* (2017) who reported both negative and positive values of standard heterosis for thousand kernel weight.

Grain yield: Standard heterosis of crosses over the two standard checks for grain yield ranged from -57.22% to 20.58% and -47.07% to 49.20%, respectively. Among the crosses, L3×L6 showed significantly higher grain yield compared to BHQPY-545 whereas sixteen hybrids showed significantly lower grain yield than BHQPY-545. On the other hand, ten hybrids exhibited significantly higher grain yield compared to MH-138 while five crosses showed significantly lower grain yield than MH-138(Table 4). Crosses which showed higher grain yield than the commercial standard checks are desirable for the improvement of maize grain yield by exploiting maximum heterosis. Presence of positive and significant standard heterosis for grain yield was reported by Berhanu (2009) and Tajwar and Chakraborty (2013). Similarly, Amiruzzaman (2013), Melkamu (2013), Shushay (2014), Girma *et al.* (2015), Matin *et al.* (2017) and Natol *et al.* (2017) found significant positive and negative values of standard heterosis for grain yield.

Days to tasseling: Heterosis estimates of crosses over the two standard checks for days to tasseling ranged from -2.97% to 4.65 % and -2.14% to 6.83%, respectively. Thirteen hybrids showed significantly lower days to tasseling than BHQPY-545 which are desirable to develop early maturing hybrids while five crosses showed significantly higher days to tasseling than BHQPY-545. On the other hand, seven hybrids revealed non-significant negative value of standard heterosis for days to tasseling over MH-138 while ten hybrids showed significantly higher days to tasseling than MH-138.

Days to silking: The estimated heterosis of crosses over the two standard checks for days to silking varied from -4.01% to 4.42 % and-1.64% to 7.0%, respectively. Among the crosses, ten showed significantly lower days to silking than BHQPY-545 towards the desired direction while only four crosses showed significantly higher days to silking than BHQPY-545 towards undesirable direction. On the other hand, seven hybrids revealed non-significant and negative value of standard heterosis for days to silking over MH-138 while nine hybrids showed significantly higher days to silking than MH-138. Negative and significant standard heterosis for days to silking indicates that earlier silking is directly correlated with early maturity; and the reverse holds true for the positive heterosis.

4. Conclusions

The results of this study demonstrated that promising standard heterosis for grain yield was recorded for crosses L3×L6, L3×L8 over BHQPY 545. Crosses L3×L6, L1×L4, L1×L6, L2×L5, L3×L4, L3×L8, L4×L6, L5×L8, L6×L8, and L7×L8 showed positive and significant standard heterosis for grain yield over MH-138, indicating the presence of high magnitude of standard heterosis over commercial checks which could be used in the maize breeding program to exploit the hybrid vigor.

The crosses L1×L7, L2×L7, L2×L8 and L4×L8 are earlier than commercial check which could be useful for breeders in developing early maturing variety. In addition, maximum positive and significant standard heterosis was recorded for L3 × L6 and L1 × L4 for 1000 kernel weight and number of kernels per row, respectively, over BHQPY-545 and MH-138. These results indicate the possibility of obtaining high yielding commercial varieties with many desirable traits after confirming the results by repeating the research over years and across locations and thereby help in accelerating the rate of adoption of maize hybrids in the eastern Ethiopia. In general, the information generated from this study could be valuable for researchers who intend to develop high yielding varieties of maize. Therefore, future research should have to be directed towards the development of three-way crosses or double cross by selecting other good inbred lines as the third parent to improve the productivity of the crop.

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