Vol. 14(4), pp. 192-204, May 2020
DOI: 10.5897/AJPS2019.1839
Article Number: 4FA003C63780
ISSN 1996-0824

http://www.academicjournals.org/AJPS

ACADEMIC JOURNALS
expand your knowledge

African Journal of Plant Science

Full Length Research Paper

Standard heterosis and trait association of maize inbred lines using line x tester mating design in Ethiopia

Abenezer Abebe[1]*, Legesse Wolde[1] and Wosene Gebreselassie[2]

[1]Holetta Agricultural Research Center, Senior Maize Breeder, Ethiopia.
[2]Department of Horticulture and Plant Science, College of Agriculture and Veterinary Medicine, Jimma University, Ethiopia.

Received 28 May, 2019; Accepted 3 July, 2019

Maize is one of the high priority crops to feed the ever increasing population in Africa, however, its production limited by shortage of high yielding variety coupled with biotic and abiotic stresses. The study was initiated to evaluate the heterotic performances of the F_1 hybrids over the standard checks (Kolba and Jibat). Fifty entries consists 48 F_1 single crosses developed from 24 inbred lines and 2 testers using line x tester design and two commercial check hybrids used in the study. The experiment was conducted using alpha lattice design with two replications at Ambo and Holeta Agricultural Research Center. Analysis of variance revealed existence of significant genetic variation among genotypes for all studied traits except for plant aspect. Location x entry interaction for most of the traits was not significant which suggests hybrid performance was consistent across tested locations. The magnitude of standard heterosis over Kolba and Jibat for grain yield ranged from -40.31 (L13 x T1) to 32.44% (L23 x T1). Cross L23 x T1 exhibited maximum standard heterosis (32.44%) over Kolba and Jibat for grain yield followed by L11 x T1 (22.18%). Positive and significant genotypic, phenotypic correlation coefficient were recorded for yield with plant height (rg=48 and rp=40**), ear height, ear per plant, number of kernels per row, ears length, ear diameter and number of kernel rows per ear. Number of ears per plan (1.08) had the highest positive direct effect on grain yield followed by ear diameter (0.95), number of kernels per row and number of kernel rows per ear indicating the effectiveness of direct selection. Finally, crosses with high standard heterosis for yield and yield components could be used for developing high yielding maize hybrids in the future maize breeding program.**

Key words: Heterosis, Hybrid, correlation, path analysis.

INTRODUCTION

Maize (*Zea mays* L., 2n = 20) is a monoecious; C4 plant belongs to the tribe Maydeae of the family Poaceae. It is a tall, robust, annual, usually with a single dominant stem, although there may be few tillers in some genotypes and environments. Prasanna et al. (2001) noted that the crop is a vital source of calorie, protein and some important

*Corresponding author. E-mail: abenezerabebetefera@gmail.com, Tel.: +251913449020.

vitamins and minerals to billions of people world-wide, particularly in Africa, South America and Asia.

Approximately 88% of maize produced in Ethiopia is consumed as food, both as green and dry grain (Tsedeke et al., 2015).

Maize is cultivated globally as one of most important cereal crops and ranks third next to wheat and rice. CSA (2017) reported that in Ethiopia by 2016/2017 main cropping season out of the total grain crop area, 81.27% was under cereals of which maize share as large area as 16.98%, after tef (24%). Regarding total annual production, cereals contributed 87.42% in which maize ranked first 27.02% followed by teff and sorghum (CSA, 2017). The national average yield in Ethiopia is still as low as 3.675 t ha^{-1} (CSA, 2017) compared to that of the developed world of 10.96 t ha^{-1} (FAS, 2017) which implies the importance of increasing maize productivity as high national priority issue. The shortages of high yielding varieties or potential parent materials and the effect of biotic and abiotic stresses are the major constraints limiting maize production and productivity (Mosisa et al., 2012). This implies the need for developing high yielding maize varieties from suitable parents or crosses.

Hybrid varieties are the first generations (F1) from crosses between two pure lines, inbred lines, open pollinated varieties or other populations that are genetically dissimilar. 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). Feng et al. (2015) pointed out that understanding the magnitude of hybrid vigor (heterosis) helps us for effective selection of best combinations of parents for predicting breeding goal.

The efficiency of breeding programme depends mainly on the direction and magnitude of association between yield and its components and also the relative importance of each factor involved in contributing to grain yield (Jakhar et al., 2017). Munawar et al. (2013) noted estimation of trait association is important for the selection of favorable plant types for effective maize breeding programs. Mallikarjuna et al. (2011) and Zeeshan et al. (2013) also reported that correlation and path coefficient analysis were used to measure the level of relationships between the traits, give reliable and useful information on nature, extent and direction of selection. The path analysis provides the effective measures of direct and indirect causes of association and depicts the relative importance of each factor involved in contributing to the final product (Jakhar et al., 2017).

Heterosis and trait association has been studied in Ethiopia for different sets of new maize inbred lines (Dagne et al., 2007; Worku et al., 2008; Girma et al., 2015 and Tolera et al., 2017). Highland maize breeding program at Ambo Agricultural Research Center (AARC) in collaboration with CIMMYT recently developed crosses whose standard heterosis has not been studied. Hence, this study was conducted to evaluate the heterotic performances of the F_1 hybrids over the standard checks and trait association for yield and yield related traits.

MATERIALS AND METHODS

The experiment was conducted at Ambo and Holeta Agricultural Research Centers of the Ethiopian Institute of Agricultural Research (EIAR), Ethiopia during the main cropping season of May 2017 to December 2018. Holeta Agricultural research center (HARC) is located in West Showa zone of the Oromia region, 33 km west of Addis Ababa at 09° 04' 12" N and 38° 29' 45" E and an elevation of 2400 m.a.s.l. The center receives an average rainfall of 1102 mm per annum. The maximum and minimum temperatures of this site are 6 and 22°C, respectively. The center has nitosols and vertisols soil types with pH of 6.0 (Tamene et al., 2015).

Ambo Agricultural Research Center (AARC) is located in West Showa zone of the Oromia region, 114 km west of Addis Ababa at 8° 57' N latitude and 37° 51' E longitudes with an altitude of 2225 m.a.s.l. The site receives an average rainfall of 1115 mm. The maximum and minimum temperatures of this site are 11.7 and 25.4°C, respectively. The soil type of Ambo is clay (heavy vertisols) with a pH of 7.8 (Demissew, 2014).

Experimental materials

The experiment consisted of 50 maize entries which include 48 testcrosses and two hybrid checks (AMH853-Kolba and AMH851-Jibat). The testcrosses (48) were generated from crossing of 24 inbred lines (female parents) with two testers (male parents) in line x tester mating design during 2015/2016 cropping season at AARC. The inbred lines were developed at Ambo Agricultural Research Center from CYMMYT materials using ear-to-row selection and subsequent selfing until they attain homozygosity. The inbred line testers used for the formation of the testcrosses were FS59 (Tester 1) and FS67 (Tester 2) as shown in Table 1. The first tester was from heterotic group B, while the second was from heterotic group A. Ambo maize breeding program commonly uses these testers in the identification of promising inbred lines. The hybrid checks are commercial maize hybrids released for highland and sub-humid agro ecologies of Ethiopia. AMH851 (Jibat) and AMH853 (Kolba) are three-way cross hybrid varieties released by Ambo Agricultural Research Center, highland maize breeding program in 2011 and 2015, respectively. They take about 178 days for grain mature at Ambo and similar environments. Besides, hybrid checks are high yielding, tolerant/resistance to major maize disease in the country and well adapted to the altitude ranging from 1800-2600 m in the highland sub-humid agro-ecological conditions of the country (MoANR, 2016).

Experimental design and procedure

The experimental materials along with two hybrid checks were grown during the 2016/2017 main cropping season using alpha lattice design (Patterson and Williams, 1976) with two replications, 10 incomplete blocks and 5 plots per the incomplete blocks at both locations. Each entry was planted in a single row plot of 5.25 m length with a spacing of 75 cm between rows and 25 cm between plants. Seeds were planted with two seeds per hill and later thinned to one plant at four leaf stage.

Data collection and analysis

Data were collected days to 50% anthesis (AD), days to 50%

Table 1. List and pedigree of parents and hybrid checks used for the study.

S/N	Line code	Pedigree	
1	L1	(CML442*/OFP4)-B-4-2-2-B-B-B-#	
2	L2	(CML495*/OFP14)-7-1-5-1-1-B-B-#	
3	L3	(CML442*/OFP4)-B-17-1-1-B-B-B-#	
4	L4	(CML495*/OFP6)-B-27-1-1-B-#	
5	L5	(CML539*/OFP14)-2-1-1-2-2-B-B-#	
6	L6	(CML442*/OFP4)-B-17-5-1-B-B-B-#	
7	L7	(CML395*/OFP105)-1-1-1-1-1-B-B-#	
8	L8	(CML395*/OFP105)-1-2-3-1-1-B-B-#	
9	L9	CML539*/OFP1)-B-11-2-2-B-B-B-#	
10	L10	(CML444*/OFP23)-6-3-1-1-1-B-B-#	
11	L11	(LPSC7-F96-1-2-1-1-B-B-B*/OFP9)-3-2-1-1-1-B-B-#	
12	L12	(CML444*/OFP14)-3-2-4-1-2-B-B-#	
13	L13	(CML444*/OFP4)-B-4-1-1-B-B-B-#	
14	L14	(CML444*/OFP4)-B-6-1-1-B-B-B-#	
15	L15	(CML537*/OFP106)-6-1-3-1-2-B-B-#	
16	L16	(CML537*/OFP106)-7-1-2-1-2-B-B-#	
17	L17	(CML491*/OFP4)-B-10-1-2-B-B-B-#	
18	L18	CML546-#	
19	L19	([SYN-USAB2/SYN-ELIB2]-12-1-1-1-B*4-B-B-B*/OFP105)-4-2-1-1-2-B-B-#	
20	L20	([CML312/[TUxPSEQ]C1F2/P49-SR]F2-45-3-2-1-BB//INTA-F2-192-2-1-1-1-BBBB]-1-5-1-1-1-BBB-B-B-B*/OFP106)-1-2-2-2-1-B-B-#	
21	L21	([CML444/CML395//DTPWC8F31-1-1-2-2-BB]-4-2-2-1-2-BB-B-B-B*/OFP105)-1-4-3-3-2-B-B-#	
22	L22	([CML444/CML395//DTPWC8F31-1-1-2-2-BB]-4-2-2-1-2-BB-B-B-B*/OFP105)-2-1-1-2-1-B-B-#	
23	L23	(LPSC7-F71-1-2-1-2-B-B-B*/OFP2)-B-1-3-2-B-B-B-#	
24	L24	[CML444/CML395//DTPWC8F31-1-1-2-2-BB]-4-2-2-2-1-B*7-B-#	
25	T1	Tester	FS59
26	T2		FS67
27	-	Checks	JIBAT
28	-		KOLBA

Source: Ambo plant protection research center, highland maize breeding program (2017).

female flowering (SD), anthesis-silking interval (ASI), ear aspect (EA), plant aspect (PA), grain yield (GY), number of ears per plant (EPP) and thousand kernel weight (TKW) on plot basis. On plant basis data were collected on plant height (PH), ear height (EH), ear length (EL), ear diameter (ED), number of kernel rows per ear (KRPE) and number of kernels per row (KPR).

The data obtained for different traits from field measurements were organized and analyzed using SAS statistical package (SAS, 2014). Analysis of variance across location was conducted with PROC GLM procedure (SAS, 2014) by considering location, replication and blocks as random and entry/genotype as fixed factors with statement of RONDOM and TEST option.

Estimation of standard heterosis

Standard heterosis was calculated for traits that showed statistically significant differences among genotype based on the procedure suggested by Falconer and Mackay (1996).

$$\text{Standard heterosis (SH)} = \left(\frac{F1-SC}{SC}\right) x\ 100$$

Where; SH = standard Heterosis, F1 = mean value of the crosses, SC = mean value of standard checks. The significant difference for percentage of standard heterosis was tested by t-test. Standard error of difference for heterosis and t-value will be computed as follows;

$$\text{SE (d) for SE (d)} = \sqrt{\frac{2MSe}{r*loc}},\ t = \frac{F1-SC}{SE(d)}$$

Where, SE (d) is standard error of the difference, MSe =error mean (Paschal and Wilcox, 1975).

Correlation and path coefficient analysis

Phenotypic and genotypic correlations were estimated for the characters from variance of each character and the covariance components for each pair of characters (Comstock and Robinson, 1952; Miller et al., 1958). The analysis was performed using SAS 9.3 software package and test of significance of correlation coefficients were carried out comparing the computed values against table *r*

Table 2. Analysis of variance for yield and yield related traits of maize genotypes evaluated at Holeta and Ambo.

Trait	L, df=1	Rep(L)df=2	Blk(L*R) df=36	Ent df=49	Ent*L df=49	Error df=62	Mean±SE(m)	CV%
GY(kg)	8.38*	0.03	1.29	4.41*	2.63**	1.1	7.53± 0.52	13.9
AD(days)	14162.4**	24.23**	2.96	13.33**	2.77	3.18	104.52±0.89	1.71
SD(days)	18489.6**	19.34**	2.60	15.66**	2.51	3.31	105.15±0.91	1.73
ASI(days)	0.63**	0.001	0.005	0.007*	0.005	0.004	1.2± 0.03	5.52
PH(cm)	574.6**	779.0**	161.6	1631.89**	237.4*	139.1	251.07±5.9	4.70
EH(cm)	5724.5**	398.33**	45.04	943.11**	85.85*	54.64	136.66±3.7	5.41
EPO(%)	0.07**	0.0002	0.001	0.004**	0.0007	0.002	0.54±0.02	7.33
EPP(no)	1.49**	0.007	0.03	0.13**	0.05	0.03	1.70±0.09	10.18
EA(scale)	0.78*	0.91**	0.13	0.43**	0.19	0.13	3.12±0.18	11.56
PA(scale)	2.88**	0.75*	0.15	0.20	0.14	0.20	3.30±0.22	13.69
EL(cm)	1.69	8.82**	0.98	3.61**	1.21	0.81	15.47±0.45	5.82
ED(mm)	1.62**	0.004	0.03	0.10**	0.03**	0.03	4.32±0.09	3.84
KRPE(no)	10.76**	0.58	0.63*	1.21**	0.47	0.37	12.86±0.3	4.74
KPR(no)	19.22*	25.22**	7.43*	8.51**	6.50	4.22	32.3±1.03	6.37
TKW(gm)	193827.8**	27.26	743.1	3102.2**	1603.9*	947.3	305.0±15.39	10.09

**significant (0.01), *significant (0.05), L=location, Rep=replication, Blk=blocks, Ent= Entry, GY= grain yield, AD=anthesis days, SD=silking days, ASI=anthesis silking interval, PH=plant height, EH= ear height, EPO= ear position, EPP=ear per plant, EA=ear aspect, PA=plant aspect, EL=ear length, ED=ear diameter, KRPE=kernel rows per ear, KPR=kernels per row, TKW=thousand kernel weight.

values at 5 and 1% probability levels at n-2 degree of freedom (Fisher and Yates, 1963). Path coefficient analysis carried using the model and the formula which was adopted by Dewey and Lu (1959) the path and residual effect were computed. The residual effect, U $=\sqrt{1-R^2}$, $R^2 = \sum \mathrm{pij\ rij}$ Retherford and Choe (2011), rij = pij+ Σrikpkj, where, rij = mutual association between the independent character (i) and dependent character (j) as measured by the correlation coefficient, pij = component of direct effects of the independent character (i) on dependent character (j) as measured by the path coefficient and, ∑rikpkj = summation of components of indirect effect.

RESULTS AND DISCUSSION

The analysis of variance, standard heterosis, correlation and path coefficient analysis were conducted and the results are discussed below.

Analysis of variance

The analysis of variances for yield and yield related traits combined location are presented in Table 2. Significant differences were detected between the two locations for all of the studied traits except for ear length, indicating that the two locations differed in the environmental conditions to cause variation which agreed with the finding of Aly et al. (2011). Entry mean squares were significant (p<0.01 or p<0.05) for all traits except for plant aspect as shown in Table 2.

The significance differences obtained among the entries for almost all studied traits indicates the presence of high degree of genetic variation and had potential of making high yielding hybrids. Similarly, Dagne et al. (2010), Amiruzzaman et al. (2010), Amare et al. (2016) and Ziggiju et al. (2017) reported significant difference among genotypes for grain yield and yield related traits of different sets of maize genotypes. Mean squares of entry x location interaction for most of the studied traits were non-significant, suggesting the consistence in performance of genotypes from one location to another regarding these traits as illustrated in Table 2. On the other hand, variables like grain yield, plant and ear height, ear diameter and 1000 kernels weight showed significant entry x location interaction mean squares, disclosing entries differed in their performance from one location to another for these traits.

Similar to the current finding, Gudeta et al. (2015) found significant entry x location interaction for grain yield, 1000 kernels weight and ear height for different maize genotypes. Alake et al. (2008), Beyene et al. (2011) and Murtadha et al. (2016) also reported significant entry x location interaction effect for certain traits and referred to the presence of wide variability with regard to tested entry and locations. The result showed the location played significant role in the variation of these traits. If significant genotype x location interaction mean squares existed, different genes were involved in controlling the traits showing the inconsistency of the genes over locations (Dagne, 2008). The interaction of entry with location suggests further evaluation of the genotypes across more number of locations to remove environmental effect from computation genetic variance. Variation among locations, and single cross hybrids which interact more with environment would be responsible for the interaction of entry by location.

Standard heterosis

The estimates of standard heterosis over the standard checks were computed for combined data of grain yield and yield related traits that showed significant difference among genotypes as shown in Table 3. The magnitude of standard heterosis over Kolba and Jibat for grain yield ranged from -40.31 (L13 x T1) to 32.44% (L23 x T1). The cross L23 x T1 (32.44%) exhibited maximum standard heterosis for grain yield followed by L11 x T1 (22.18%). Nine crosses showed negative significant standard heterosis over the best hybrid check (Kolba) for grain yield, while two crosses revealed positive and significant standard heterosis. Several scholars Amiruzzaman et al. 2010, Kustanto et al. 2012, Hiremath et al. 2013, Melkamu et al. 2013, Habtamu 2015, Bitew 2016, Gemechu et al. 2017 and Ziggiju et al. 2017 reported positive and negative significant standard heterosis for grain yield. High level of heterosis observed in the current study could be mainly because of the involvement of more distant related inbred lines. Fato (2010) and Hallauer and Miranda (1988) also suggested that full exploitation of heterosis requires crossing of distantly related materials. The crosses with higher grain yield standard heterosis. Natol (2017) also found that crosses with high standard heterosis also had good specific combining ability. In contrast, Kumar et al. (2014) reported crosses with good specific combining ability effects, but non-significant standard heterosis for grain yield. The difference in these findings might be due to the influence of environmental factors and tested materials.

The standard heterosis for days to 50% anthesis, days to 50% silking and anthesis silking interval ranged from 0 to 8.75%, -1.21 to 8.11% and 1.68 to -13.14%, respectively as illustrated in Table 3a. The current study found none of crosses with significant standard heterosis for days to 50% anthesis and silking towards the desirable direction, which was in agreement with the findings of Dufera et al. (2018). This states the lack of genetic divergence among crosses for selection of early flowering materials; however, Ram et al. (2015), Patil et al. (2017) and Natol et al. (2017) found negative and significant standard heterosis for days to 50% anthesis and suggested that earliness is a desirable character. For anthesis-silking interval, crosses L6 x T1, L9 x T2, L11 x T2, L12 x T2, L19 x T2 and L22 x T1 revealed negative and significant standard heterosis with respective values of -6.99, -10.38, -8.09, -11.58, -10.38 and -9.22%. Negative heterosis for anthesis-silking interval is desirable as it is indicated in pollen shedding and silk receptive synchronization, thereby increasing seed set.

The magnitude of standard heterosis for plant height ranged from -19.96 (L18 x T2) to 13.15% (L5 x T1) and for ear height ranged from -24.18 (L23 x T2 and L24 x T2) to 36.78% (L12 x T2) as shown in Table 3b. Ten crosses had positive and significant heterosis, while 22 crosses showed negative and significant standard heterosis for plant height over the best standard checks, respectively. For ear height, 9 and 27 crosses had positive and negative significant standard heterosis over the best standard checks, respectively. Various workers (Melkamu et al., 2013; Melkamu, 2014; Hailegebrial et al., 2015; Natol, 2017) also found positive and negative significant standard heterosis for plant and ear height. So, crosses with shorter plant and ear height over the standard checks are desirable for lodging resistance and mechanical harvesting. Natol et al. (2017) and Yazachew et al. (2017) also suggested negative standard heterosis for plant and ear height is in desirable; however, Sharma et al. (2017) reported the desirability of for ear height negative standard heterosis, while for plant height either negative or positive. Hence, the negative heterosis for plant and ear height is desirable to enable the selection of effective shorter plant, with reduction of lodging.

Estimate of standard heterosis ranged from -18.80 (L8 x T2) to 48.57% (L23 x T1) for number of ear per plant, -23.47(L9 x T2) to 21% (L15 x T2) for ear length and -13.54 (L7 x T2) to 9.36% (L10 x T1) for ear diameter. The positive standard heterosis for these traits is in a desirable direction. For number of ears per plant, 26 crosses showed positive and significant standard heterosis over hybrid standard checks. Regarding ear length, only L15 x T1 cross showed positive and significant standard heterosis over Kolba. Shushay (2014) and Arsode et al. (2017) for number of ears per plant, Raghu et al. (2011) and Asif et al. (2014) for ear length found comparable results to the current findings. Though ear diameter revealed significantly positive and negative standard heterosis, none of the crosses had wider ear diameter than the best standard checks (Kolba). The positive standard heterosis for number of ear per plant and ear length indicates possibilities of breeding maize for increasing number of ears per plant and ear length thereby improve grain yield.

Standard heterosis for number of kernel rows per ear, number of kernels per row and 1000 kernel weight varied from -8.02 (L21 x T2) to 13.52% (L11 x T1), -17.04 (L9 x T2) to 5.77% (L15 x T1) and -33.76 (L19 x T1) to 27.64% (L21 x T2), respectively. For number of kernels row per ear, 12 crosses exhibited positive and significant standard heterosis over best hybrid check (Kolb) as shown in Table 3c. Maximum positive standard heterosis for number of kernel rows per ear was recorded for cross L11 x T1 (13.52%) followed by L20 x T1 (12.16%). This indicates increased number of kernel rows per ear as compared to the standard checks would be increase grain yield. As to the number of kernels per row and 1000 kernel weight, none of the crosses had positive and significant standard heterosis over the standard checks. This signifies the non-availability of variation among genotypes investigated for these traits. But, Reddy and Jabeen (2016), Gemechu et al. (2017) and Patil et al. (2017) found positive and negative and significant standard heterosis for number of kernels per row and 1000 kernel weight and indicated the possibility of exploitation of the crosses for commercial release. According to Singh (2015), heterosis was positively correlated with genetic distance and specific combining ability. In line with this, crosses with higher

Table 3a. Standard heterosis of 48 testcrosses and two commercial checks hybrids for yield and yield related traits for combined data, 2017.

S/N	Entry	GY (%)		AD (%)		SD (%)		ASI (%)	
		Kolba	Jibat	Kolba	Jibat	Kolba	Jibat	Kolba	Jibat
1	L1xT1	4.89	6.29	0.98	2.75*	0.73	1.97	-0.93	-2.68
2	L1xT2	-0.16	1.17	0.74	2.50	-0.73	0.49	-5.91*	-7.57**
3	L2xT1	10.41	11.89	3.19*	5.00**	2.18	3.44**	-3.85	-5.54*
4	L2xT2	-24.85*	-23.84*	0.49	2.25	0.24	1.47	-0.93	-2.68
5	L3xT1	-29.51**	-28.57*	5.41**	7.25**	6.07**	7.37**	2.67	0.85
6	L3xT2	-11.31	-10.13	5.41**	7.25**	4.85**	6.14**	-1.88	-3.61
7	L4xT1	-1.74	-0.42	0.74	2.50	1.21	2.46	1.80	0.00
8	L4xT2	-7.39	-6.16	0.98	2.75*	0.00	1.23	-3.85	-5.54*
9	L5xT1	12.86	14.36	0.25	2.00	0.49	1.72	0.91	-0.87
10	L5xT2	-3.76	-2.48	0.00	1.75	-0.73	0.49	-2.85	-4.57
11	L6xT1	0.10	1.43	2.46	4.25**	0.73	1.97	-6.99**	-8.63**
12	L6xT2	-22.60*	-21.56*	1.97	3.75**	0.73	1.97	-4.87*	-6.55*
13	L7xT1	-17.94	-16.84	4.91**	6.75**	5.58**	6.88**	2.67	0.85
14	L7xT2	-10.77	-9.58	6.14**	8.00*	4.85**	6.14**	-4.87*	-6.55*
15	L8xT1	15.69	17.23	2.95	4.75**	3.64**	4.91**	2.67	0.85
16	L8xT2	-21.89*	-20.85*	2.46	4.25**	1.94	3.19*	-1.88	-3.61
17	L9xT1	8.94	10.39	0.00	1.75	0.00	1.23	0.00	-1.76
18	L9xT2	-4.28	-3.00	1.23	3.00*	-1.21	0.00	-10.38**	-11.96**
19	L10xT1	0.10	1.43	5.41**	7.25**	5.34**	6.63**	0.00	-1.76
20	L10xT2	9.93	11.40	3.44**	5.25**	2.18	3.44**	-4.87*	-6.55*
21	L11xT1	22.18*	23.81*	4.67**	6.50**	4.61**	5.90**	0.00	-1.76
22	L11xT2	10.09	11.56	4.18**	6.00**	2.18	3.44**	-8.09**	-9.71**
23	L12xT1	9.71	11.17	5.65**	7.50**	4.37**	5.65**	-4.87*	-6.55*
24	L12xT2	-7.30	-6.06	3.93**	5.75**	1.21	2.46	-11.58**	-13.14**
25	L13xT1	-40.31**	-39.51*	6.88**	8.75**	6.80**	8.11**	0.00	-1.76
26	L13xT2	-6.88	-5.64	2.70*	4.50**	1.70	2.95*	0.00	-5.54
27	L14xT1	12.83	14.33	5.16**	7.00**	5.10**	6.39**	-3.85	-1.76
28	L14xT2	-10.58	-9.38	5.16**	7.00**	4.61**	5.90**	0.00	-3.61
29	L15xT1	16.36	17.92	4.18**	6.00**	3.88**	5.16**	-1.88	-2.68
30	L15xT2	14.05	15.57	2.21	4.00**	2.18	3.44**	-0.93	-1.76
31	L16xT1	13.85	15.37	0.49	2.25	0.00	1.23	0.00	-3.61
32	L16xT2	-20.06*	-18.99	3.93**	5.75**	2.67*	3.93**	-1.88	-6.55*
33	L17xT1	-9.19	-7.98	1.72	3.50**	1.46	2.70*	-4.87*	-2.68
34	L17xT2	0.61	1.95	1.72	3.50**	7.52**	8.85**	-0.93	-1.76
35	L18xT1	-2.44	-1.14	0.74	2.50	1.70	2.95*	0.00	1.69
36	L18xT2	-22.40*	-21.37*	1.97	3.75**	-0.49	0.74	3.52	-11.96**
37	L19xT1	-13.60	-12.44	1.97	3.75**	1.70	2.95*	-10.38**	-2.68
38	L19xT2	-21.73*	-20.68*	3.19*	5.00**	2.43	3.69**	-0.93	-4.57
39	L20xT1	7.91	9.35	1.72	3.50**	1.70	2.95*	-2.85	-1.76
40	L20xT2	-7.75	-6.51	3.44**	5.25**	1.94	3.19**	0.00	-7.57*
41	L21xT1	-21.28*	-20.23*	4.91**	6.75**	4.61**	5.90**	-5.91*	-2.68
42	L21xT2	-15.33	-14.20	1.23	3.00	-0.97	0.25	-0.93	-10.82**
43	L22xT1	-3.44	-2.15	5.65**	7.50**	5.34**	6.63**	-9.22**	-2.68
44	L22xT2	-7.07	-5.83	3.19*	5.00**	2.43	3.69**	-0.93	-4.57
45	L23xT1	30.70**	32.44**	1.72	3.50**	0.97	2.21	-2.85	-4.57
46	L23xT2	5.46	6.87	1.97	3.75**	1.21	2.46	-2.85	-4.57
47	L24xT1	-2.80	-1.50	1.72	3.50**	1.94	3.19*	-2.85	-0.87
48	L24xT2	10.09	11.56	2.95*	4.75**	1.21	2.70*	0.91	-8.63**
SE(d)		0.75		1.25		1.29		0.91	

Table 3a. Contd.

LSD(0.05)	1.17	1.94	2.58	1.82
LSD(0.01)	1.41	2.34	3.43	2.41

**significant (0.01), *significant (0.05), LSD used to compare two heterosis value, GY=grain yield, AD=anthesis days, SD=silking days, ASI=anthesis silking interval.

Table 3b. Standard heterosis of 48 testcrosses and two commercial checks hybrids for yield and yield related traits for combined data, 2017.

S/N	Entry	EL (%)		ED (%)		KRPE (%)		KPR (%)		TKW (%)	
		Kolba	Jibat	Kolba	Jibat	Kolba	Jibat	Kolba	Jibat	Kolba	Jibat
1	L1xT1	-17.34**	-10.49*	-7.15**	-0.53	1.34	-0.02	-14.54**	-13.68**	-22.13**	-6.52
2	L1xT2	-12.75**	-5.52	-9.99**	-3.57	2.70	1.32	-10.53*	-9.62*	-17.89**	-1.43
3	L2xT1	-6.64	1.09	-5.79*	0.94	2.72	1.34	-0.75	0.25	-32.92**	-19.47**
4	L2xT2	-11.48**	-4.14	-8.96**	-2.46	4.03	2.64	0.51	1.52	-13.39*	3.97
5	L3xT1	-6.38	1.38	-9.99**	-3.57	6.73	5.30	-5.77	-4.81	-20.93**	-5.08
6	L3xT2	-10.71**	-3.32	-5.95*	0.76	8.11*	6.66	-12.53**	-11.65**	-14.38*	2.78
7	L4xT1	-0.77	7.46	1.26	8.48**	12.14**	10.64**	3.26	4.30	-16.02**	0.81
8	L4xT2	0.26	8.57*	-5.79*	0.94	2.70	1.32	2.51	3.54	-14.39*	2.76
9	L5xT1	-3.32	4.69	-5.30*	1.46	0.00	-1.34	-1.00	0.00	-14.26*	2.93
10	L5xT2	-3.57	4.43	-4.92	1.87	-1.36	-2.68	-4.01	-3.04	-17.75**	-1.27
11	L6xT1	-7.15	0.55	-3.17	3.74	6.75	5.32	-3.76	-2.79	-22.25**	-6.66
12	L6xT2	-8.68*	-1.11	-4.10	2.75	8.09*	6.64	-4.26	-3.30	-15.75**	1.14
13	L7xT1	2.56	11.06*	-8.25**	-1.70	8.09*	6.64	-3.01	-2.03	-31.78**	-18.10*
14	L7xT2	-0.51	7.74	-13.54**	-7.37**	1.34	-0.02	1.50	2.53	-26.49**	-11.76
15	L8xT1	1.03	9.40*	-5.52*	1.23	12.14**	10.64**	1.26	2.28	-19.18**	-2.98
16	L8xT2	0.28	8.59*	-5.30*	1.46	4.03	2.64	-1.76	-0.77	-3.99	15.25*
17	L9xT1	-7.39	0.28	-6.01*	0.70	6.75	5.32	-4.26	-3.30	-30.86**	-17.00**
18	L9xT2	-23.47**	-17.12**	-4.21	2.63	5.39	3.98	-17.04**	-16.21**	-17.04**	-0.41
19	L10xT1	-5.62	2.20	2.08	9.36**	9.46**	8.00*	-0.50	0.50	-13.83*	3.45
20	L10xT2	5.88	14.65**	-1.64	5.38	6.75	5.32	1.00	2.02	-15.38*	1.58
21	L11xT1	-18.37**	-11.60**	0.00	7.14*	13.52**	12.00**	-11.28**	-10.39*	-12.72*	4.77
22	L11xT2	-8.92*	-1.38	-2.73	4.21	2.68	1.30	1.26	2.28	-3.10	16.32*
23	L12xT1	-2.02	6.10	-0.33	6.79*	9.44**	7.98*	-0.25	0.76	-9.68	8.43
24	L12xT2	0.26	8.57*	-6.12*	0.59	-1.36	-2.68	3.01	4.05	-7.45	11.10
25	L13xT1	-18.09**	-11.30**	-1.64	5.38	6.75	5.32	-3.51	-2.54	-30.00**	-15.97*
27	L14xT1	7.13	16.01**	-2.68	4.27	9.46**	8.00**	4.26	5.31	-26.79**	-12.12
28	L14xT2	-6.37	1.39	-3.66	3.22	6.75	5.32	-7.52	-6.59	-13.22*	4.17
29	L15xT1	2.82	11.34**	-4.81	1.99	10.78**	9.30**	4.51	5.57	-27.65**	-13.15
30	L15xT2	11.74**	21.00**	-4.31	2.52	4.05	2.66	2.00	3.03	-17.22**	-0.63
31	L16xT1	-5.88	1.92	-5.84*	0.88	2.68	1.30	-3.01	-2.03	-18.33**	-1.96
32	L16xT2	-9.95*	-2.49	-9.72**	-3.28	-4.05	-5.34	-7.26	-6.33	-23.25**	-7.87
33	L17xT1	-1.27	6.91	-9.45**	-2.98	1.34	-0.02	-3.01	-2.04	-19.24**	-3.06
34	L17xT2	-10.96**	-3.58	-9.07**	-2.57	-2.72	-4.02	-9.52*	-8.61*	-7.05	11.58
35	L18xT1	-3.05	4.99	-1.31	5.73*	5.39	3.98	2.51	3.55	-20.32**	-4.35
36	L18xT2	-5.60	2.22	-5.63*	1.11	2.70	1.32	-6.02	-5.07	-14.65*	2.46
37	L19xT1	-9.93*	-2.47	-7.92**	-1.35	6.75	5.32	1.50	2.53	-33.76**	-20.48**
38	L19xT2	-11.46**	-4.13	-12.51**	-6.26*	2.70	1.32	-10.03*	-9.12*	-18.55**	-2.23
39	L20xT1	-3.83	4.14	-1.97	5.03	12.16**	10.66**	3.00	4.04	-16.80**	-0.12
40	L20xT2	-1.78	6.36	-1.04	6.03*	9.44**	7.98*	-2.50	-1.52	-8.32	10.05
41	L21xT1	-8.40*	-0.81	-0.16	6.96*	5.39	3.98	-10.78*	-9.88*	3.09	23.75**
42	L21xT2	-1.78	6.36	-5.79*	0.94	-6.77	-8.02*	-1.76	-0.77	6.33	27.64**

Table 3b. Contd.

43	L22xT1	-3.31	4.71	-9.72**	-3.28	5.39	3.98	-5.76	-4.81	-11.70	6.00
44	L22xT2	-4.33	3.60	-10.81**	-4.45	-5.43	-6.70*	-3.26	-2.29	-8.89	9.37
45	L23xT1	-5.60	2.22	-8.52**	-1.99	1.34	-0.02	-3.50	-2.53	-17.07**	-0.45
46	L23xT2	-7.65	0.00	-9.07**	-2.57	5.41	4.00	2.51	3.55	-14.33*	2.84
47	L24xT1	2.05	10.51*	-11.74**	-5.44	-1.36	-2.68	-0.25	0.76	-19.76**	-3.68
48	L24xT2	-2.80	5.25	-7.21**	-0.59	5.37	3.96	2.51	3.54	-8.21	10.19
SE(d)		0.64		0.12		0.42		1.45		21.76	
LSD(0.05)		1.28		0.24		0.65		2.25		43.51	
LSD(0.01)		1.70		0.32		0.78		2.71		57.84	

**significant (0.01), *significant (0.05), EL=ear length, ED=ear diameter, KRPE=kernel rows per ear, KPR=kernels per row, TKW=thousand kernel weight.

Table 3c. Standard heterosis of 48 testcrosses and two commercial checks hybrids for yield and yield related traits for combined data, 2017.

S/N	Entry	EL (%)		ED (%)		KRPE (%)		KPR (%)		TKW (%)	
		Kolba	Jibat	Kolba	Jibat	Kolba	Jibat	Kolba	Jibat	Kolba	Jibat
1	L1xT1	-17.34**	-10.49*	-7.15**	-0.53	1.34	-0.02	-14.54**	-13.68**	-22.13**	-6.52
2	L1xT2	-12.75**	-5.52	-9.99**	-3.57	2.70	1.32	-10.53*	-9.62*	-17.89**	-1.43
3	L2xT1	-6.64	1.09	-5.79*	0.94	2.72	1.34	-0.75	0.25	-32.92**	-19.47**
4	L2xT2	-11.48**	-4.14	-8.96**	-2.46	4.03	2.64	0.51	1.52	-13.39*	3.97
5	L3xT1	-6.38	1.38	-9.99**	-3.57	6.73	5.30	-5.77	-4.81	-20.93**	-5.08
6	L3xT2	-10.71**	-3.32	-5.95*	0.76	8.11*	6.66	-12.53**	-11.65**	-14.38*	2.78
7	L4xT1	-0.77	7.46	1.26	8.48**	12.14**	10.64**	3.26	4.30	-16.02**	0.81
8	L4xT2	0.26	8.57*	-5.79*	0.94	2.70	1.32	2.51	3.54	-14.39*	2.76
9	L5xT1	-3.32	4.69	-5.30*	1.46	0.00	-1.34	-1.00	0.00	-14.26*	2.93
10	L5xT2	-3.57	4.43	-4.92	1.87	-1.36	-2.68	-4.01	-3.04	-17.75**	-1.27
11	L6xT1	-7.15	0.55	-3.17	3.74	6.75	5.32	-3.76	-2.79	-22.25**	-6.66
12	L6xT2	-8.68*	-1.11	-4.10	2.75	8.09*	6.64	-4.26	-3.30	-15.75**	1.14
13	L7xT1	2.56	11.06*	-8.25**	-1.70	8.09*	6.64	-3.01	-2.03	-31.78**	-18.10*
14	L7xT2	-0.51	7.74	-13.54**	-7.37**	1.34	-0.02	1.50	2.53	-26.49**	-11.76
15	L8xT1	1.03	9.40*	-5.52*	1.23	12.14**	10.64**	1.26	2.28	-19.18**	-2.98
16	L8xT2	0.28	8.59*	-5.30*	1.46	4.03	2.64	-1.76	-0.77	-3.99	15.25*
17	L9xT1	-7.39	0.28	-6.01*	0.70	6.75	5.32	-4.26	-3.30	-30.86**	-17.00**
18	L9xT2	-23.47**	-17.12**	-4.21	2.63	5.39	3.98	-17.04**	-16.21**	-17.04**	-0.41
19	L10xT1	-5.62	2.20	2.08	9.36**	9.46**	8.00*	-0.50	0.50	-13.83*	3.45
20	L10xT2	5.88	14.65**	-1.64	5.38	6.75	5.32	1.00	2.02	-15.38*	1.58
21	L11xT1	-18.37**	-11.60**	0.00	7.14*	13.52**	12.00**	-11.28**	-10.39*	-12.72*	4.77
22	L11xT2	-8.92*	-1.38	-2.73	4.21	2.68	1.30	1.26	2.28	-3.10	16.32*
23	L12xT1	-2.02	6.10	-0.33	6.79*	9.44**	7.98*	-0.25	0.76	-9.68	8.43
24	L12xT2	0.26	8.57*	-6.12*	0.59	-1.36	-2.68	3.01	4.05	-7.45	11.10
25	L13xT1	-18.09**	-11.30**	-1.64	5.38	6.75	5.32	-3.51	-2.54	-30.00**	-15.97*
27	L14xT1	7.13	16.01**	-2.68	4.27	9.46**	8.00**	4.26	5.31	-26.79**	-12.12
28	L14xT2	-6.37	1.39	-3.66	3.22	6.75	5.32	-7.52	-6.59	-13.22*	4.17
29	L15xT1	2.82	11.34**	-4.81	1.99	10.78**	9.30**	4.51	5.57	-27.65**	-13.15
30	L15xT2	11.74**	21.00**	-4.31	2.52	4.05	2.66	2.00	3.03	-17.22**	-0.63
31	L16xT1	-5.88	1.92	-5.84*	0.88	2.68	1.30	-3.01	-2.03	-18.33**	-1.96
32	L16xT2	-9.95*	-2.49	-9.72**	-3.28	-4.05	-5.34	-7.26	-6.33	-23.25**	-7.87
33	L17xT1	-1.27	6.91	-9.45**	-2.98	1.34	-0.02	-3.01	-2.04	-19.24**	-3.06
34	L17xT2	-10.96**	-3.58	-9.07**	-2.57	-2.72	-4.02	-9.52*	-8.61*	-7.05	11.58
35	L18xT1	-3.05	4.99	-1.31	5.73*	5.39	3.98	2.51	3.55	-20.32**	-4.35

Table 3c. Contd.

36	L18xT2	-5.60	2.22	-5.63*	1.11	2.70	1.32	-6.02	-5.07	-14.65*	2.46
37	L19xT1	-9.93*	-2.47	-7.92**	-1.35	6.75	5.32	1.50	2.53	-33.76**	-20.48**
38	L19xT2	-11.46**	-4.13	-12.51**	-6.26*	2.70	1.32	-10.03*	-9.12*	-18.55**	-2.23
39	L20xT1	-3.83	4.14	-1.97	5.03	12.16**	10.66**	3.00	4.04	-16.80**	-0.12
40	L20xT2	-1.78	6.36	-1.04	6.03*	9.44**	7.98*	-2.50	-1.52	-8.32	10.05
41	L21xT1	-8.40*	-0.81	-0.16	6.96*	5.39	3.98	-10.78*	-9.88*	3.09	23.75**
42	L21xT2	-1.78	6.36	-5.79*	0.94	-6.77	-8.02*	-1.76	-0.77	6.33	27.64**
43	L22xT1	-3.31	4.71	-9.72**	-3.28	5.39	3.98	-5.76	-4.81	-11.70	6.00
44	L22xT2	-4.33	3.60	-10.81**	-4.45	-5.43	-6.70*	-3.26	-2.29	-8.89	9.37
45	L23xT1	-5.60	2.22	-8.52**	-1.99	1.34	-0.02	-3.50	-2.53	-17.07**	-0.45
46	L23xT2	-7.65	0.00	-9.07**	-2.57	5.41	4.00	2.51	3.55	-14.33*	2.84
47	L24xT1	2.05	10.51*	-11.74**	-5.44	-1.36	-2.68	-0.25	0.76	-19.76**	-3.68
48	L24xT2	-2.80	5.25	-7.21**	-0.59	5.37	3.96	2.51	3.54	-8.21	10.19
SE(d)		0.64		0.12		0.42		1.45		21.76	
LSD(0.05)		1.28		0.24		0.65		2.25		43.51	
LSD(0.01)		1.70		0.32		0.78		2.71		57.84	

**significant (0.01), *significant (0.05), EL=ear length, ED=ear diameter, KRPE=kernel rows per ear, KPR=kernels per row, TKW=thousand kernel weight.

standard heterosis for certain traits could be the result of divergent inbred lines and higher *sca* effects. Heterosis over standard checks helps in either a hybrid variety would be accepted or rejected for commercial cultivation. Ram et al. (2015) suggested that over 20% of standard heterosis has high commercial value. L23 x T1 and L11 x T1 crosses proved to be outstanding in grain yield over the best hybrid check (Kolba) with standard heterosis value of 30.70 and 22.18%, respectively. Devi and Singh (2011) suggested that appearance of crosses could be predicted based on the relationship between mean of grain yield, heterosis and specific combining ability. The best performing crosses might indicate the recovery of vigor that was lost during inbreeding as functional gene often absent. These crosses also had high per se performance and positive *sca* effects. Hence, they are ready for further evaluation in different location and commercial use. Furthermore, for traits with inferior performance in these crosses, breeders may improve via accumulation of favorable alleles from other good performing crosses for the trait of interest.

Correlation and path coefficients

Genotypic and phenotypic correlations among significant traits for F_1 hybrids analyzed from the combined data over the two locations shown in Table 4. Ratner (2009) categorized the Pearson correlation coefficient as weak, moderate and strong for values ranging from 0 to ±0.29, ±0.3 to ±0.69 and ±0.7 to ±1.0, respectively. Grain yield exhibited positive and significant genotypic and phenotypic correlations with plant height, ear height, ears per plant and number of kernels per row as shown in Table 4. The results are in accordance to the finding of Pavan et al. (2011), Kumer et al. (2014), Hailegebrial et al. (2015), and Pandey et al. (2017). In contrast, Zorana et al. (2011) and Silva et al. (2016) reported negative of correlations for grain yield with plant and ear height.

Tall plant with higher ear placement increases grain yield due to high number of leaves possessed and stem reserve mobilization which is in agreement with the findings of Zeeshan et al. (2013) and Al-Tabbal and Al-Fraihat (2012). Moreover, ear length, ear diameter and number of kernel rows per ear showed positive significant genotypic and phenotypic correlation with grain yield, which is in conformity to the findings of Izzam et al. (2017) and Wuhaib et al. (2017). Positive genotypic correlations for these traits imply the presence of moderate inherent relationship, thereby discloses the improvement of maize grain yield was linked with the selection for these traits. Grain yield exhibited negative and significant genotypic and phenotypic correlation with days to 50% anthesis and silking, anthesis silking interval which is analogous to the findings of Raghu et al. (2011), Munawar et al. (2013), Kumer et al. (2014) and Pandey et al. (2017). On the contrary, Dagne (2008) and Dar et al. (2015) found positive and significant phenotypic correlations for grain yield with days to 50% anthesis and silking. The negative genotypic association of days to flowering with grain yield implies that these traits are not co-inherited together with grain yield. Narrow anthesis silking interval period would increase grain yield due to the synchronization of pollen shedding and silking emergence.

Highly significant positive genotypic and phenotypic correlations observed between days to 50% anthesis and

Table 4. Genotype (above diagonal) and phenotype (below diagonal) correlation coefficients for yield and yield related traits of 48 hybrids evaluated across two locations, 2017.

Trait	GY	AD	SD	ASI	PH	EH	EPO	EPP	EL	ED	KRPE	KPR	TKW
GY	1.00	-0.21**	-0.14*	0.25**	0.48**	0.37**	0.02	0.56**	0.24**	0.20**	0.22**	0.38**	-0.03
AD	-0.17*	1.00	0.91**	-0.19*	-0.07	0.08	0.30**	-0.06	0.04	0.08	0.33**	-0.06	-0.08
SD	-0.18*	0.99**	1.00	0.49	0.08	0.20**	0.31**	-0.01	0.05	0.04	0.33**	-0.06	-0.14*
ASI	-0.14*	0.59**	0.58**	1.00	0.26**	0.23**	0.09	0.07	0.04	-0.05	0.08	-0.02	-0.12
PH	0.40**	-0.08	-0.07	-0.01	1.00	0.90**	0.34**	0.26**	0.14*	0.35**	0.33	0.15*	-0.23**
EH	0.32**	-0.24**	-0.23**	-0.17*	0.81**	1.00	0.72**	0.13	0.11	0.38**	0.33**	0.09	-0.01
EPO	0.04	-0.33**	-0.34**	-0.29**	0.16*	0.65**	1.00	-0.12	0.03	0.25**	0.19**	-0.03	-0.03
EPP	0.44**	0.29**	0.27**	0.20**	0.20**	0.05	-0.18*	1.00	-0.12	-0.30**	-0.01	-0.05	-0.24*
EL	0.17*	0.06	0.07	0.09	0.08	0.03	-0.04	-0.07	1.00	0.06	0.04	0.72**	0.05
ED	0.20**	-0.34**	-0.33**	-0.33**	0.23**	0.33**	0.25**	-0.31**	-0.23**	1.00	0.52	0.15*	0.25**
KRPE	0.21**	0.30**	0.27**	0.12	0.18*	0.15*	0.02	0.08	-0.21**	0.28**	1.00	0.14*	-0.28**
KPR	0.33**	-0.10	-0.12	-0.05	0.08	0.11	0.09	-0.14*	0.02	0.09	0.38**	1.00	-0.08
TKW	0.18*	-0.58**	-0.58**	0.1	-0.05	0.05	0.14	-0.29**	-0.14*	0.43**	-0.25**	0.04	1.00

**Significant (p<0.01), *significant (p<0.05), GY=grain yield, AD=anthesis days, SD=silking days, ASI=anthesis silking interval, PH=plant height, EH=ear height, EPO =ear position, EPP=ear per plant, EA=ear aspect, EL=ear length, ED=ear diameter, KRPE=kernel rows per ear, KPR=kernels per rows, TKW=thousand kernels weight.

silking (rg=0.91**, rp=0.99**) are in conformity to the findings of Nataraj et al. (2014), Hailegebrial et al. (2015) and Hussain et al. (2016). This infers jointly improvement of these traits could be possible due to positive genotypic correlation. Negative and significant genotypic and phenotypic correlations obtained between days to 50% silking and 1000 kernel weight are in agreement with the finding of Kumar et al. (2014). In contrast, Nataraj et al. (2014) and Varaprasad et al. (2016) found positive and significant genotypic and phenotypic correlation for days to 50% silking with 1000 kernel weight. Such differences might be attributed to the differences in locations used and the genetic make-up of studied materials (Iqbal et al., 2011). Based on the current findings, early silking could be responsible for timely pollination and grain filling thereby increase weight of kernels. Zhou et al. (2017) confirmed that climate variation from silking to maturity were the main factors affecting kernel weight.

Plant and ear height had positive and significant genotypic correlation with ear position, ear diameter and number of kernel rows per ear, which indicates that increase in plant and ear height would simultaneously increase these traits. These results support the findings of Mathew (2015) and Prasad and Shivani (2017). Number of ear per plant had negatively significant genotypic and phenotypic correlation with ear diameter, number of kernel rows per row and 1000 kernel weight which confirms the finding of Ziggiju et al. (2015). Eleweanya et al. (2005) suggested that positive associations among traits indicate positive responses in the levels of one character when the other is selected, while the negative signify the reverse situation. Magnitudes of genotypic correlations were relatively higher than phenotypic one for most of studied traits which indicates presence of greater inherent relationship among the traits which allows simultaneous improvement of these traits. Hallauer et al. (2010) noted the more importance of genetic correlation as it represents the heritable fraction of parent characters to progeny.

Estimates of direct and indirect effects towards grain yield for individual traits with significant correlation are presented in Table 5. Lenka and Mishra (1973) categorized the path coefficient into negligible (0.00-0.09), low (0.1-0.19), moderate (0.2-0.29), high (0.3-1) and very high (>1). Based on this, days to 50% silking, number of ears per plant, ear diameter, number of kernels per row and number of kernel rows per ear exerted higher positive direct effect towards grain yield. Similar findings were reported by Rafiq et al. (2010) and Raghu et al. (2011) for number of kernels per row and ear diameter, Pavan et al. (2011) for days to 50% silking and number of kernel rows per ear and Reddy and Jabeen (2016) for number of ear per plant.

Though plant height and ear length had positive genotypic correlation, they exerted negative direct effect towards grain yield. Similar results were reported by Selvaraj and Nagarajan (2011) for plant height, Zarei et al. (2012) for days to 50% anthesis and Bullo (2015) for ear length. In contrast, Praveen (2013), Poudel et al. (2016) and Varaprasad et al. (2016) found that days to 50% anthesis, plant height and ear length with positive direct effect. Positive higher indirect effect on grain yield was obtained from days to 50% silking via days to 50% anthesis, ear diameter via number of kernel rows per ear, plant height, ear height, and number of kernels per row via ear length and number of kernel rows per ear. Satyanvesh (2016) also found positive indirect effect from number of kernels per row through ear length and number of kernel rows per ear. Furthermore, higher, negative indirect effects on grain yield noted for days to 50% anthesis via days to

Table 5. Direct (diagonal) and indirect effect of genotypic path coefficient among yield and yield related traits of 50 maize hybrids evaluated at two locations, 2017.

TRAITT	AD	SD	ASI	PH	EH	EPP	EL	ED	KRE	KPR	RGY
AD	-0.50	0.48	0.01	0.01	0.03	-0.03	0.00	0.07	-0.24	-0.02	-0.19
SD	-0.45	0.52	0.00	-0.04	0.06	-0.08	0.00	0.11	-0.33	0.05	-0.16
ASI	0.09	-0.04	-0.04	-0.03	0.03	-0.04	-0.01	-0.11	0.06	-0.14	-0.25
PH	0.02	0.07	0.00	-0.30	0.22	0.28	-0.01	0.35	-0.25	0.13	0.52
EH	-0.06	0.12	0.00	0.26	0.25	0.15	0.00	0.36	-0.25	0.08	0.38
EPP	0.01	-0.04	0.00	-0.08	0.03	1.08	0.00	-0.29	0.02	-0.18	0.57
EL	-0.01	0.06	-0.01	-0.05	0.03	-0.14	-0.04	0.06	-0.04	0.36	0.22
ED	-0.04	0.06	0.01	-0.11	0.09	-0.32	0.00	0.95	-0.38	-0.06	0.20
KRPE	-0.17	0.25	0.00	-0.10	0.09	-0.03	0.00	0.52	0.70	0.37	0.22
KPR	0.01	0.03	0.01	-0.04	0.02	-0.21	0.21	-0.06	-0.28	0.92	0.38

Residual effect (U) = 0.22.

50% silking, number of ear per plant through ear diameter, and number of kernels per row via days to 50% silking. The contrasting findings could be due to the difference of materials and environments encountered. Finally, number of ear per plant, ear diameter, number of kernel rows per ear, number of kernels per rows and ear height excreted positive direct effect and they are good indicators in indirect selection for higher grain yield.

Residual effect, determines how best the causal variables (anthesis days, silking days, anthesis silking interval, plant height, ear height, ear per plant, ear length, ear diameter, number of kernel rows per ear and kernels per row). Its estimate of 0.22 indicated that the causal variables explained about 78% of the variability in grain yield and only 22% of the variability remained unexplored.

CONCLUSION

The estimation of standard heterosis identified various crosses revealed greater standard heterosis for more than one trait. Crosses L23 x T1 and L11 x T1 revealed higher standard heterosis for grain yield per hectare as compared to Kolba and Jibat hybrid checks and they also had positive higher standard heterosis for number of ear per plant and number of kernel rows per ear. This indicates the possibility of developing three ways cross hybrid varieties using these crosses as parent.

According to the results, in order to bring an effective improvement of grain yield, more attention should be given for traits such as ear diameter, number of kernels per row and number of kernel rows per ear which showed high positive phenotypic and genotypic correlation coefficients with a considerable direct and indirect effect on grain yield. Further evaluation of these and other hybrids at more locations and over years is advisable to confirm the promising results observed in present study. Finally, it may be concluded that the information from this study could be valuable for researchers who intend to develop high yielding varieties of maize.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

The authors express heartfelt gratitude to Holetta Agricultural Research Center maize breeding staffs for hosting the trials and collecting the data. Appreciation is also extended to Ethiopian Institute of Agricultural Research for financial support.

REFERENCES

Alake O, K Ojo, A Oduwaye and A Adekoya (2008). Genetic Variability and Correlation Studies in Yield and Yield Related Characters of Tropical Maize (*Zea Mays* L.). ASSET: An International Journal 8(1):14-27.

Al-Tabbal A, Al-Fraihat H (2012). Genetic Variation, Heritability, Phenotypic and Genotypic Correlation Studies for Yield and Yield Components in Promising Barley Genotypes. Journal of Agricultural Science 4(3):193.

Amare S, Dagne W, Sintayehu A (2016). Test Cross Performance and Combining Ability of Elite Highland Maize (*Zea Mays* L.) Inbred Lines At Jimma, South West Ethiopia. International Journal of Trend in Research and Development 3(2):13-26.

Amiruzzaman M, Islam MA, Hassan L, Rohman MM (2010). Combining Ability and Heterosis for Yield and Component Characters in Maize. Academic Journal of Plant Sciences 3(2):79-84.

Arsode P, Krishna KM, Sunil N, Sree V, Charan AR (2017).Combining Ability and Heterosis Studies for Grain Yield and Its Components in Hybrids of Quality Protein Maize (*Zea Mays* L.). International Journal of Current Microbiology and Applied Sciences 6(12): 2538-2545.

Asif A, Liaqat S, Shah KA, Shamsur R (2014). Heterosis for Grain Yield and Its Attributing Components in Maize Variety Azam Using Line x Tester Analysis Method. Academia Journal of Agricultural Research 2(11):225-230.

Beyene Y, Mugo S, Gakunga J, Karaya H, Mutinda C, Tefera T, Njoka S, Chepkesis D, Shuma JM, Tende R (2011). Combining ability of maize (*Zea mays* L.) inbred lines resistant to stem borers. African Journal of Biotechnology 10(23):4759-4766.

Bitew T (2016). Heterosis and Combining Ability of Mid Altitude Maize (*Zea Mays* L.) Inbred Lines for Grain Yield, Yield Related Traits and Reaction to Turcicum Leaf Blight (*Exserohilum Turcicum Leonard and Suggs*). Msc Thesis Presented to the School of Graduate Studies of Haramaya University. 115 p.

Bullo N (2015).Correlation and Path Coefficients Analysis Studies among Yield and Yield Related Traits of Quality ProteinMaize (QPM) Inbred Lines. International Journal of Plant Breeding and Crop Science 1(2): 006-017.

Central Statistical Agency (CSA) (2017). Agricultural Sample Survey 2016/2017: Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season) Volume I. Statistical Bulletin, Addis Ababa, Ethiopia 195(2):183-195.

Comstock E, Robinson F (1952). Genetic Parameters, Their Estimation and Significance. Proceeding 6th Intercropping, Grassland Congress pp. 284-291.

Dagne WB, Vivek S, Birhanu T, Koste A, Mosisa W, Legesse W (2010). Combining Ability and Heterotic Relationships Between CIMMYT and Ethiopian Maize Inbred Lines. Ethiopian Journal of Agricultural Sciences 21(1-2):82-93.

Dagne W (2008). Genotypic Variability and Combining Ability Of Quality Protein Maize Inbred Lines Under Stress And Optimal Conditions. PhD Dissertation Presented at University of the Free State, South Africa. 300 p.

Dagne W, Habtamu Z, Labuschagne MT, Temam H, Singh H (2007). Heterosis and Combining Ability for Grain Yield and Its Components in Selected Maize Inbred Lines. South African Journal of Plant and Soil 24(3):133-137.

Dar ZA, Lone AA, Alaie BA, Ali G, Gazal A, Gulzar S, Yousuf N (2015). Correlation Studies in Temperate Maize (*Zea Mays* L.) Inbred Lines. Plant Archives 15(2):1191-1194.

Demissew A (2014). Genetic diversity and combining ability of selected quality protein maize (QPM) inbred lines adapted to the highland agro-ecology of Ethiopia. PhD dissertation presented at University of KwaZulu-Natal, Republic of South Africa.178 p.

Devi P, Singh NK (2011). Heterosis, Molecular Diversity, Combining Ability and Their Interrelationship in Short Duration Maize (*Zea Mays* L.)Across The Environments. Euphytica 178(1):71-81.

Dewey R, Lu H (1959). A Correlation and Path Coefficient Analysis of Components of Crested Wheat Grass Seed Production. Agronomy Journal 51(9): 515-518.

Dufera T, Bulti T, Girum A (2018). Heterosis and Combining Ability Analysis of Quality Protein Maize (*Zea Mays* L.) Inbred Lines Adapted to Mid-Altitude Sub-Humid Agro-Ecology Of Ethiopia. African Journal of Plant Science 12(3):47-57.

Duvick DN (1999). Heterosis: feeding people and protecting natural resources. In: Coors JG, Pandey S, eds. The Genetics and Exploitation of Heterosis in New York: Crop Science Society of America pp. 19-30.

Falconer D, Mackay T (1996). Introduction to Quantitative Genetics.*4th* eds*.* Benjamin Cummings*,* England 247 p.

Fato P (2010). Investigation of Heterotic Patterns and Genetic Analysis of Downy Mildew Resistance in Mozambican Lowland Maize (*Zea Mays* L.) Germplasm. PhD Dissertation Presented University of Kwazulu-Natal, South Africa 146 p.

Feng S, Chen X, Wu S, Chen X (2015). Recent Advances in Understanding Plant Heterosis. Agricultural Sciences 6(09):1033.

Foreign Agricultural Service (FAS) (2017). World Agricultural Production Circular Series WAP 07-17, pp. 1-29.

Gemechu N, Leta T, Sentayehu A (2017). Standard Heterosis of the Selected Maize (*Zea Mays* L.)Inbred Lines Hybrids for Grain Yield and Yield Component. Journal of Biology, Agriculture and Healthcare 7(15):51-58.

Girma H, Sentayehu A, Berhanu T, Temesgen M (2015). Test Cross Performance and Combining Ability of Maize (*Zea Mays* L.) Inbred Lines at Bako, Western Ethiopia. Global Journal of Science Frontier Research 15(4):1-24.

Habtamu Z (2015). Heterosis and Combining Ability for Grain Yield and Yield Component Traits of Maize in Eastern Ethiopia. Science, Technology and Arts Research Journal 4(3): 32-37.

Hailegebrial K, Getachew A, Legesse W, Yemane T (2015). Correlation and Path Coefficient Analysis of Grain Yield And Yield Related Traits In Maize (*Zea Mays* L.) Hybrids, At Bako, Ethiopia. Journal of Biology, Agriculture and Healthcare 5(15):44-52.

Hallauer R, Miranda B (1988). Quantitative Genetics in Maize Breeding. Iowa State Univ, Press 468 p.

Hallauer R, Carena M, Miranda F (2010).Testers and Combining Ability. Springer, New York, NY. 423 p.

Hiremath N, Shantakumar G, Adiger S, Gangashetty P (2013). Heterosis Breeding for Maturity, Yield and Quality Characters in Maize (*Zea Mays* L.). Molecular Plant Breeding 4(6):44-49.

Hussain N, Rehman B, Faizal K (2016). Phenotypic and Genotypic Association between Maturity and Yield Traits in Maize Hybrids (*Zea Mays* L.). African Journal of Agriculture and Food Security 4(3):157-160.

Izzam A, Sohail H, Shahzad A, Hussain Q (2017). Genetic Variability and Correlation Studies for Morphological and Yield Traits in Maize (*Zea Mays* L.). Pure and Applied Biology 6(4):1234-1243.

Jakhar S, Singh R, Kumar A (2017). Studies on Path Coefficient Analysis in Maize (*Zea Mays* L.) for Grain Yield and Its Attributes. International Journal of Current Microbiology and Applied Sciences 6(4):2851-2856.

Kumar V, Singh SK, Bhati PK, Sharma A, Sharma SK, Mahajan V (2014). Correlation, Path and Genetic Diversity Analysis in Maize (*Zea Mays* L.). Environment and Ecology 33(2A): 971-975.

Kustanto H, Sugiharto A, Basuki N, Kasno A (2012). Study on Heterosis and Genetic Distance of S_6 Inbred Lines of Maize. Journal of Agriculture and Food Technology 2:118-125.

Lenka D, Misra B (1973). Path-Coefficient Analysis of Yield in Rice Varieties. Indian Journal of Agricultural Sciences 43(4):376-379.

Mallikarjuna N, Chandrashekhar H, Shashibhaskar M, Prahalada G (2011).Genetic Variability and Correlation Studies for Yield and Related Characters in Single Cross Hybrids of Maize (*Zea Mays* L.). Current Biotica 5(2):157-163.

Mathew I (2015). Combining Ability, Genetic Gains and Path Coefficient Analyses of Maize Hybrids Developed From Maize Streak Virus and Downy Mildew Resistant Recombinant Inbred Lines. PhD Dissertation Presented at University of Kwazulu-Natal, Pietermaritzburg, South Africa. 154 p.

Melkamu E, Tadsse D, Yigzaw D (2013).Combing Ability, Gene Action and Heterosis Estimation in Quality Protein Maize. International Journal of Scientific and Research Publications 3(6):1-17.

MoANR (2016). Plant Variety Release, Protection and Seed Quality Control Directorate, Crop Variety Register 19:318.

Mosisa W, Twumasi-Afriyie S, Legesse W, Birhanu T, Girma D, Gezehagn B, Dange W, Prasanna B (2012). Meeting the Challenges of Global Climate Change and Food Security through Innovative Maize Research. Proceedings of 3rd National Maize Workshop of Ethiopia, April 18-20, Institute of Agricultural Research.

Munawar M, Shahbaz M, Hammad G, Yasir M (2013).Correlation and Path Analysis of Grain Yield Components in Exotic Maize (*Zea Mays* L.) Hybrids. International Journal of Sciences: Basic And Applied Research 12(1):22-27.

Nataraj V, Shahi J, Agarwal V (2014).Correlation and Path Analysis in Certain Inbred Genotypes of Maize (*Zea Mays* L.) at Varanasi. International Journal of Innovative Research and Development 3(1):14-17.

Natol B (2017). Combining Ability and Heterotic Grouping in Maize (*Zea Mays* L .) Inbred Lines for Yield and Yield Related Traits. World Journal of Agricultural Sciences 13(6):212-219.

Natol B, Birhanu A, Mandefro N (2017). Standard Heterosis of Maize (*Zea mays* L.) Inbred Lines for Grain Yieldand Yield Related Traits at Southern Ethiopia, *American-* American-Eurasian Journal of Agricultural and Environmental Sciences 17(3):257-264.

Pandey Y, Vyas P, Kumar J, Singh L, Singh C, Yadav C (2017). Heritability, Correlation and Path Coefficient Analysis for Determining Interrelationships among Grain Yield and Related Characters in Maize (*Zea Mays* L.). International Journal of Pure and Applied Bioscience 5(2):595-603.

Paschal E, Wilcox J (1975). Heterosis and Combining Ability in Exotic Soybean Germplasm. Crop Science 15(3):344-349.

Patil B, Ahamed M, Babu D (2017). Heterosis Studies for Yield and Yield Component Characters in Maize (*Zea mays* L.). International Journal of Agriculture, Environment and Bioresearch 10(4):449-455.

Patterson H, Williams E (1976). A New Class of Resolvable Incomplete

Block Designs. Biometrika 63(1): 83-92.
Pavan R, Lohithaswa C, Wali C, Prakash G, Shekara G (2011).Correlation and Path Coefficient Analysis of Grain Yield and Yield Contributing Traits in Single Cross Hybrids of Maize (*Zea Mays* L.). Electronic Journal of Plant Breeding 2(2):253-257.
Poudel M, Poudel H, Shrestha J (2016). Path Analysis for Agro-Morphological Traits in Maize. International Journal of Graduate Researcha Review 2(2):32-37.
Prasad B, Shivani D (2017). Correlation and Path Analysis in Maize (*Zea Mays* L.). Journal of Genetics, Genomics and Plant Breeding 1(2):1-7.
Prasanna B, Vasal S, Kasahun B, Singh N (2001). Quality Protein Maize. Current Science 81(10):1308-1319.
Rafiq M, Rafique M, Hussain A, Altaf A (2010). Studies on Heritability, Correlation and Path Analysis in Maize (*Zea Mays* L.). Journal of Agricultural Research 48(1):35-38.
Raghu B, Suresh J, Kumar S, Saidaiah P (2011). Character Association and Path Analysis in Maize (*Zea Mays* L.). Madras Agricultural Journal 98(3):7-9.
Ram L, Singh R, Singh S, Srivastava R (2015). Heterosis and Combining Ability Studies for Quality Protein Maize. Ekin Journal of Crop Breeding and Genetics 2:8-25.
Ratner B (2009). The Correlation Coefficient: Its Values Range Between+ 1/− 1, or Do They? Journal of Targeting, Measurement and Analysis for Marketing 17(2): 139-142.
Reddy R, Jabeen F (2016). Narrow Sense Heritability, Correlation and Path Analysis in Maize (*Zea Mays* L.). SABRAO Journal of Breeding and Genetics 48(2):120-126.
Retherford R, Choe M (2011). Statistical Models for Causal Analysis. John Wiley And Sons, New York, 258p.
SAS Institute (2014). Statistical Analysis System Version 9.3, SAS Institute, Inc., Cary, NC, USA.
Satyanvesh B (2016). Studies on Line x Tester Analysis of Yield and Yield Contributing Traits in Maize (*Zea Mays* L.). MSc Thesis Presented at Professor Jayashankar Telangana State Agricultural University 130 p.
Selvaraj C, Nagarajan P (2011). Interrelationship and Path-Coefficient Studies for Qualitative Traits, Grain Yield and other Yield Attributes Among Maize (*Zea Mays* L.). International Journal of Plant Breeding and Genetics 5(3):209-223.
Sharma P, Kamboj M, Singh N, Chand M (2017).Heterosis for Grain Yield and Quality Traits in Maize (*Zea Mays* L.). International Journal of Pure & Applied Bioscience 5(5): 241-248.
Shushay W (2014). Standard Heterosis of Maize (*Zea Mays* L.) Inbred Lines for Grain Yield and Yield Related Traits in Central Rift Valley of Ethiopia. Journal of Biology, Agriculture and Healthcare 4(23):31-37.
Silva T, Moro G, Moro F, Santos D, Buzinaro R (2016). Correlation and Path Analysis of Agronomic and Morphological Traits in Maize. Revista Ciência Agronômica 47(2):351-357.
Singh P (2015). Genetic Distance, Heterosis And Combing Ability Studies In Maize For Predicting F1 Hybrid Performance. SABRAO Journal of Breeding and Genetics 47 (1):21-28.
Tamene T, Gemechu K, Hussein M (2015). Genetic progresses from over three decades of faba bean (*Vicia faba* L.) breeding in Ethiopia. Australian Journal of Crop Science 9(1):41-48.
Tolera K, Mosisa W, Habtamu Z (2017). Combining Ability and Heterotic Orientation of Mid-Altitude Sub-Humid Tropical Maize Inbred Lines For Grain Yield and Related Traits. African Journal of Plant Science 11(6):229-239.
Tsedeke A, Bekele Sh, Abebe M, Dagne W, Yilma K, Kindie T, Menale K, Gezahegne B, Berhanu T, Tolera K (2015). Factors That Transformed Maize Productivity in Ethiopia. Food Security 7(5):965-981.
Yazachew G, Pangirayi B, Beatrice E (2017). General and Specific Combining Ability Studies of Selected Tropical White Maize Inbred Lines for Yield And Yield Related Traits. International Journal of Agricultural Science and Research 7(2):381-396.
Zarei B, Kahrizi D, Aboughadaresh P, Sadeghi F (2012). Correlation and Path Coefficient Analysis for Determining Interrelationships among Grain Yield and Related Characters in Corn Hybrids. International Journal of Agriculture and Crop Sciences 4(20):1519-152.
Zeeshan M, Ahsan M, Arshad W, Ali S, Hussain M and Khan M (2013). Estimate of Correlated Responses for Some Polygenic Parameters in Yellow Maize (*Zea Mays* L.) Hybrids. International Journal of Advanced Research 1(5):24-29.
Ziggiju M, Habtamu Z, Legesse W (2017). Ethiopian Standard Heterosis of Pipeline Maize (*Zea Mays* L.) Hybrids for Grain Yield and Yield Related Traits. International Journal of Plant Breeding and Genetics 4(1):249-255.