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Combining Ability and Heterotic Grouping in Maize (*Zea mays* L.) Inbred Lines for Yield and Yield Related Traits

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Abstract: A field experiment was conducted at Hawassa during 2015 cropping season to estimate combining ability of elite maize genotypes. Line x tester analysis involving 64 crosses was generated by crossing 32 selected maize inbred lines with two testers. The experiment was designed using alpha-lattice design with two replications. Analysis of variance showed that, mean squares of genotypes were significant for all traits except, ear position and cob per plant. Cross L31xT2 manifested highest mean grain yield (8.68 t/ha) and highest specific combining ability effect (1.85 t/ha). L8 exhibited the highest GCA whereas L32 exhibited the lowest GCA effect. Based on their mean grain yield, and SCA L31XT2, L8XT1, L26XT1, L23XT2, L12XT2, L16XT1, L23XT1, L21XT1, L21XT2, L8XT2 and L15XT2 are promising crosses that could go for across location testing or next steps in the breeding process.

Key words: Heteroticgrouping · Combining ability · Inbred lines · Yield

INTRODUCTION

Improving yield is the main objective of breeding programs in grain crops. Developing high yielding hybrids along with other favorable traits is receiving considerable attention to increase yield per unit area. Hybrid cultivars played a great role in increment of maize per unit area. Early in the development of hybrid maize, information of combining ability among maize germplasms is essential in maximizing the effectiveness of hybrid development [1]. Combining ability is one of the powerful tool to identify the best combiner parents in a series of its crosses and it provides information on the nature and magnitude of gene actions [2]. The two types of combining ability are: general combining ability (GCA) and specific combining ability (SCA). GCA is average performance of parents in a series of crosses and SCA designates those cases in which certain combinations perform relatively better or worse than would be expected on the basis of average performance of parents. Heterotic grouping is a group of related or unrelated genotypes from the same or different populations that indicate similar combining ability and heterotic response when crossed with testers from other genetically diverse germplasm groups [3].

Line x tester mating design is an efficient procedure as it allows the inclusion of a large number of entries, estimate combining ability, gene effects, male and female relationship, heterotic grouping and aid to select desirable parents and crosses [4]. The knowledge of combining ability is important to develop desired hybrids [5]. Thus, this study was carried out to estimate general and specific combining abilities of maize inbred lines for yield and yield related traits, to identify suitable parents for developing maize hybrids and to determine heterotic groups of inbred lines.

MATERIALS AND METHODS

Inbred lines (32) coded as L1, L2…L32 and two testers coded as T1 and T2 were crossed in line x tester mating scheme to generate 64 crosses [6]. Crosses were planted along with similarly maturing checks BHQPY-545 and BH-546 at Hawassa. Hawassa is situated at 7°4′N and 38°31′E latitude and longitude, respectively, at an altitude of 1700 m.a.s.l. in the central rift valley of Ethiopia. The experiment planted by using á-lattice design 6x11 arrangement [7] with two replications. Each block comprises of 11 units having 5.1 meter long and 9.75 meter width with the spacing of 0.75 meter between rows and

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0.30 meter between plants. All cultural practices performed as per required. Data like days to maturity (DM), field weight, seed moisture content and thousand kernel weight (TKW) were collected plot bases while data like plant height (PH), ear height (EH), ear length (EL), number of rows per ear (NRPE), ear diameter (ED) and number of kernels per row (NCPR) collected in plant bases. Biomass (BM) and grain yield (GY) calculated by using the following formula

$$\text{Grain yield (t ha}^{-1}\text{)} = \frac{Freshearweighx(100-MC)x0.8*17\ x\ 10{,}000}{nx\ 85\ x\ 3.85\ x\ 100\ kg}$$

where: MC =moisture content of grain at harvest, 0.8=shelling percentage, 85=standard moisture content of grain, n=number of plants harvested, 17=total number of plants in a plot, 10000 = Area of hectare in square meters

Data Analysis: Analyses of variance for all crosses were computed using SAS computer software.

The mathematical model used for the combining ability analysis is given as:

$$Y_{ijk}=\mu+r_k+l_i+t_j+(l\ x\ t)_{ij}+e_{ijk}$$

where; Y_{ijk}= the value of a character measured on i^{th} x j^{th} progeny in k^{th}replication, μ = general mean, r_k=effect of k^{th} replication, l_i = general combining ability (GCA) effects of i^{th} line, t_j = general combining ability (GCA) effect of the j^{th} tester, $(l\ x\ t)_{ij=}$ specific combining ability (SCA) of the i^{th}line and j^{th} tester, e_{ijk}= experimental error of ijk^{th} observation

Estimation of General Combining Ability Effects (GCA): Means of each cross were used for analysis of combining ability. For each trait, general combining ability (GCA) effects were estimated using the formula suggested by [8]. GCA of lines.

$$gi = \frac{Xi...}{tr} - \frac{X...}{lrt}$$

where; xi… total of i^{th} lines over testers, x…= grand total, l= number of lines, t= number of testers and r= number of replications

GCA of testers

$$gi = \frac{X.j.}{lr} - \frac{X...}{lrt}$$

where; x.j =total of the j^{th} tester over lines, x…= grand total, l= number of lines, j= number of testers and r= number of replication.

Estimation of Specific Combining Ability Effects (SCA): SCA effects was estimated as deviation of each cross mean from all hybrids mean adjusted for corresponding GCA of parents.

Specific combining ability of line x tester

$$Sij = \frac{Xij}{r} - \frac{Xi.}{tr} - \frac{Xj}{rl} + \frac{X...}{lrt}$$

where; xij= value of the j^{th} lines with i^{th} testers, Xi= total of i^{th} over all tester, xj..= total of j^{th} tester over all lines, x…= grand total crosses, l= number of lines, t= number of testers and r= number of replication.

Heterotic Grouping: Groupings of inbred lines were conducting based on SCA effect of crosses and mean grain yield performance. Inbred lines showing positive SCA effect and with greater or equal mean grain yield with tester (A) CML 159 were grouped under heterotic group “A”. Similarly, inbred lines displaying positive SCA effect with tester “B” and mean grain yield greater or equal to mean yield of the hybrid grouped under heterotic group “B” [9].

RESULTS AND DISCUSSION

Mean squares due to crosses were significant P<0.05 for days to maturity, number of rows per ear, number of kernel per row, ear length, grain yield, thousand-kernel weight and biomass. This indicates that, the crosses were sufficiently different from each other for these traits and hence, selection is possible to identify the most desirable crosses. In line with this finding, [10, 11] found significant different among crosses for yield and yield related traits. The mean square due to lines showed significant P<0.01 for traits like grain yield, thousand kernel weight, ear length and days to maturity (Table 1). Significant differences among lines indicate greater diversity in the parental lines. [12] found significance difference among GCA effects of lines in grain yield, days to maturity, plant height, ear height, ear length, number of rows per ear and number of kernels per row. Different authors [11, 12, 13] reported similar results. [14] found significant for all the traits studied in their study of Genetic dissection of heterosis and combining ability in castor (*Ricinus communis* L.) with line × tester analysis. The mean square

Table 1: Mean squares for yield and yield related traits in 64 testcrosses and 2 checks evaluated at Hawassa, 2015

Source variation	df	DM (days)	PH (cm)	EL (cm)	NRPC (no)	NCPR (no)	ED (cm)	TSW (g)	GY (t/ha)	BM (t/ha)
Crosses	63	15.4**	441.3 ns	5.67*	0.54*	13.9*	0.13 ns	4579**	3.00**	3.44**
Line (GCA)	31	11.9**	414.3 ns	7.23**	0.46**	13.5*	0.12 ns	5626**	2.96**	2.96*
Tester(GCA)	1	40.5**	30.0 ns	0.28 ns	0.002 ns	5.28 ns	0.48*	6684 ns	5.48 ns	2.01 ns
Line x Tester (SCA)	31	18.0**	481.6 ns	4.24 ns	0.6**	14.5*	0.13 ns	3464 ns	295.60**	3.97*
Error	60	3.82	290.34	3.01	0.32	8.55	0.09	50.0	1.58	1.42
Cv	2.01	9.44	12.53	5.50	9.17	7.33	20.34	27.02	22.01	

* and** significant at P < .05 and P < .01 respectively ns=non significance. DM=days to maturity, PH=plant eight, EL=ear length, NRPC=number of row per cob, NCPR=number of kernel per cob, ED= ear diameter, TSW= thousand kernel weight, GY=grain yield, BM=biomass, CPP=cob per plant.

due to testers showed significant difference at P<0.05 for days to maturity and ear diameter (Table 1). These results were consistent with [15]. In contrast to this finding [10, 16] reported significance difference between testers in grain yield and ear height of maize.

Estimation of General Combining Ability Effects: Estimates of GCA effects of the 32 lines and 2 testers are presented in Table 2. Line L8 exhibited the maximum GCA effect (1.97 t/ha) followed by L23 which exhibit (1.72 t/ha), whereas L32 exhibited the lowest GCA effect of all (-1.51 t/ha) followed by L2 which exhibit (-1.21 t/ha), the result revealed the existence of the best and poorest general combiners in the group of inbred lines studied, respectively. Inbred lines possesses good GCA effect were L2, L12, L21, L23 and L31 based on grain yield which could be utilized in maize grain yield improvement programs. Both positive and negative GCA effects reported for grain yield in maize by several investigators [15, 17, 18]. In contrast to the current finding [19] found non-significant GCA effects for grain yield in line x tester analysis of maize inbred lines. For days to maturity three lines L13, L18 and L27 showed negative GCA effects. Negative GCA effects indicate that they may be good sources of genes for earliness and positive GCA increases the tendency of late maturity. The current results are in general agreement with the findings of many researchers [13, 14, 20] reported significant positive and negative GCA effects for days to maturity. The GCA estimates ranged from -18.55 to 23.95cm in plant height. Among all lines, thirteen inbred lines showed positive GCA effects. Line L5 and L31 showed significant positive GCA effects indicating that these lines significantly contributed to taller plant stature. On the other hand, nineteen lines showed negative GCA effects. Line L15 showed significant negative GCA effects, indicating that these lines contributed to reduced plant stature in their crosses. None of the testers showed significant GCA effects in plant height. In line with the present finding [14, 20] found significant positive and negative GCA effects for plant height.

With respect to ear height, GCA estimate of lines ranged from -5.98 to 4.02cm (Table 2). Three lines L7, L11 and L30 showed negative and significant GCA effects, whereas, six lines L5, L8, L12, L17, L19 and L31 showed positive and significant GCA effect. L7 (-5.98cm), L11(-4.84cm) and L30 (-3.73cm) were good general combiners while L8 and L12 showed the highest GCA effects (4.02cm), which indicates the tendency to increase ear height.

The GCA estimates in ear length ranged from -3.26 to 2.89cm (Table 2). Four lines, (L8, L21, L23 and L26) showed positive and significant GCA effects. Positive GCA effect contributes to increased grain yield in its hybrid combinations. On the other hand, three lines (L8, L11 and L19) showed negative GCA effects.

The GCA estimates of number of rows per cob of parental lines ranged from -0.73 to 0.62 (Table 2). Three lines (L1, L9 and L28) showed positive and significant GCA effects. Similarly [14, 18] reported significant positive and negative GCA effects in ear height and number of rows per cob.

Positive GCA effect in number of rows per cob is very important yield parameter directly contributes to increased grain yield in its hybrid combinations. In contrast, six lines (L2, L6, L14, L19, L22 and L25) showed significant negative GCA effects (Table 2). Similarly, [15] reported significant positive and negative GCA effects in ear height and number of rows per cob.

The GCA estimates of inbred lines ranged from -2.87 to 4.78 in number of kernels per rows (Table 2). Two lines (L23 and L27) showed positive and significant GCA effects indicates good general combination for this trait and contributes to increased grain yield in its hybrid combinations. Hence, lines with high GCA effects for this trait can be suitable parents for hybrid formation as well as for inclusion in future breeding programs. Such parents contribute favorable alleles in the process of synthesis of new varieties. [21] reported similar result.

The GCA of inbred lines ranged from -0.33 to 0.31cm in ear diameter (Table 2). Three lines L8, L13 and L23 showed positive and significant GCA effects to the

Table 2: Estimates of general combining ability effects for grain yield and yield related traits of maize lines and tester studied in line x tester crosses at Hawassa 2015

Lines	DM	PH (cm)	EH (cm)	EL (cm)	NRPC	NKPR	ED (cm)	TKW (g)	GY (t/ha)
L1	-0.42	-5.55	-1.98	-0.39	0.87**	-0.67	0.04	-2.70	-0.01
L2	2.33	-12.55	-1.23	-1.22	-0.33*	-1.77	-0.07	-1.45	-1.21**
L3	1.08	-13.05	-1.98	-0.68	0.17	0.63	-0.13	-30.20**	-0.32
L4	-0.67	-2.05	0.27	0.27	-0.03	1.98	-0.08	-8.95*	0.08
L5	-0.17	23.45*	3.52*	0.80	-0.28	-0.97	0.16	21.05**	0.51
L6	1.83	-8.05	-1.98	-3.26**	-0.33*	-2.82	-0.24*	-66.45**	-0.52
L7	-0.17	-5.55	-5.98*	-0.41	-0.23	-1.87	0.00	-21.45**	-0.54*
L8	1.83	16.95	4.02*	2.29**	0.27	1.93	0.31*	39.80**	1.97**
L9	0.58	-11.05	-1.73	-1.70	0.32*	-1.67	-0.14	-30.20**	-0.77*
L10	2.83	-7.05	-1.23	0.27	0.27	0.93	-0.09	-28.95**	-0.41
L11	5.08	-18.55*	-4.48*	-2.12**	-0.03	-1.47	-0.15	-33.95**	-0.72**
L12	-2.42	16.45	4.02*	1.19	0.02	1.78	0.20	41.05**	1.23**
L13	-0.92	-0.05	1.02	0.24	0.17	0.78	0.26*	49.80**	0.35
L14	1.58	3.45	0.27	-1.39	-0.38*	-0.97	-0.24*	-23.95**	-0.98**
L15	-2.42	3.45	0.52	-0.27	0.27	-0.47	0.13	9.80*	0.43
L16	-1.17	-2.05	1.02	0.65	-0.08	0.48	0.18	6.05	0.40
L17	0.83	4.45	3.52*	1.16	0.32	0.18	0.18	24.80**	-0.77**
L18	-0.67	7.45	-0.23	0.24	0.27	-2.62	0.08	21.05**	0.32
L19	-0.17	2.45	3.77*	-1.65*	-0.38*	-1.27	-0.16	-38.95**	-0.19
L21	-3.42	1.45	-2.48	2.44**	0.17	0.98	0.18	49.80**	1.36**
L22	-0.67	-2.05	2.52	0.73	-0.43*	-0.07	-0.01	-7.70*	-0.0001
L23	-2.17	10.95	0.27	2.89**	-0.03	3.23*	0.28*	116.05**	1.72**
L24	-0.42	-9.55	1.27	-0.46	-0.23	-1.62	-0.33**	-28.95**	0.49
L25	0.08	-4.05	-0.98	-0.24	-0.73**	-2.12	-0.05	29.80**	-0.64*
L26	-0.17	5.95	-0.23	1.91*	0.07	1.18	-0.08	41.05**	0.20
L27	-2.17	-1.55	-1.23	-0.31	0.17	4.78**	-0.13	-33.95**	-0.60*
L28	-0.67	3.45	0.27	0.54	0.62*	1.03	0.14	-12.70**	0.08
L29	-0.92	-2.05	-0.98	-1.14	-0.03	-1.02	-0.14	-25.20**	-0.93**
L30	0.33	-6.55	-3.73*	-0.29	-0.13	0.73	0.03	-12.70**	0.25
L31	1.33	23.95*	3.77*	0.89	-0.03	2.73	0.09	28.55**	1.48**
L32	-0.17	-10.55	1.02	-0.77	-0.23	-2.87	-0.03	-20.20**	-1.51**
SE (m±)	0.84	6.90	2.89	0.61	0.19	1.07	0.09	2.50	0.19
SE (gi – gj) lines	1.38	12.05	6.06	1.23	0.40	2.07	0.21	5.00	0.84
Tester 1	0.56	-0.48	-0.88	0.05	-0.02	-0.20	0.06	7.2**	0.21**
Tester 2	-0.56	0.48	0.88	-0.05	0.02	0.20	-0.06	-7.2**	-0.21**
SE m±	0.24	2.13	1.07	0.22	0.07	0.37	0.04	0.88	149.26
SE (gi – gj) testers	0.35	3.01	1.51	0.31	0.10	0.52	0.05	1.25	0.211

SE (m±)= standard error of mean, SE (gi – gj) lines =standard error of difference in lines, SE (gi – gj) testers = standard error of difference in testers **highly significant P < .01 * significant (P= 0.05)

desirable direction and contribute to increased grain yield in its hybrid combinations. Four lines L6, L14, L20 and L24 showed significant and negative SCA effects (Table 2). [22] also reported significant positive and negative ear diameter.

The GCA effects of inbred lines ranged from -66.45 to 116.05g in thousand-kernel weight (Table 2). Lines L23, L13 and L21 were good general combiners while L6, L19 and L20 were poor combiners for thousand-kernel weight (Table 2). Lines with positive GCA effect could have vital potential for genetic improvement of this trait in breeding programs.

Tester 1 is best combiner for plant height (-0.48), ear height (0.88), ear length (0.05), ear diameter (0.06), thousand kernels weight (7.20), grain yield (0.21) while Tester 2 is best combiner for days to maturity (-0.56), number of kernels per row (0.02) and number of rows per cob (0.2) (Table 2)[10] found best combiner tester for thousand kernels [23] reported best combiner tester for grain yield, number of rows per cob and ear length.

Estimation of Specific Combining Ability Effects: With respect to grain yield, both positive and negative significant estimates of SCA effects observed among

Table 3: Specific combining ability effects for 64 crosses in respect of thirteen traits tested at Hawassa 2015 cropping season

Crosses	DM (days)	PH (cm)	EH (cm)	EL (cm)	NRPC (no)	NCPC (no)	ED (cm)	TSW (g)	GY (t/ha)
L1xT1	0.44	7.98	6.88	0.87	-0.58	-0.30	-0.20	-0.90	0.07
L1xT2	-0.44	-7.98	-6.88	-0.87	0.58	0.30	0.20	0.90	-0.07
L2xT1	-0.81	-29.0**	-11.63*	-1.46	-0.38	-1.10	-0.08	-12.15*	-0.10
L2xT2	0.81	29.0**	11.63*	1.46	0.38	1.10	0.08	12.15*	0.10
L3XT1	-1.06	-0.52	-2.13	0.30	-0.08	0.80	0.09	-23.4**	-0.21
L3XT2	1.06	0.52	2.13	-0.30	0.08	-0.80	-0.09	23.4**	0.21
L4XT1	1.19	4.48	3.38	-0.05	0.02	-0.15	-0.06	-2.15	-0.29
L4XT2	-1.19	-4.48	-3.38	0.05	-0.02	0.15	0.06	2.15	0.29
L5XT1	-1.81	-15.02*	-3.13	-1.64	0.27	0.10	-0.06	-39.7**	-0.21
L5XT2	1.81	15.02*	3.13	1.64	-0.27	-0.10	0.06	39.7**	0.21
L6XT1	0.69	8.48	7.88	1.45	0.02	0.55	0.19	17.9**	1.24**
L6XT2	-0.69	-8.48	-7.88	-1.45	-0.02	-0.55	-0.19	-17.9**	-1.24**
L7XT1	-1.31	-9.02	3.88	-0.80	-0.88*	-3.20	-0.14	-22.2**	-0.86*
L7XT2	1.31	9.02	-3.88	0.80	0.88*	3.20	0.14	22.2**	0.86*
L8XT1	-0.81	11.48	5.88	-0.09	0.22	1.10	0.08	-5.90	0.52
L8XT2	0.81	-11.48	-5.88	0.09	-0.22	-1.10	-0.08	5.90	-0.52
L9XT1	1.44	7.48	-5.63	0.44	0.67	0.00	0.08	31.6**	0.54
L9XT2	-1.44	-7.48	5.63	-0.44	-0.67	0.00	-0.08	-31.6**	-0.54
L10XT1	4.69**	2.48	2.38	-0.17	0.22	0.00	-0.31*	-17.2**	-0.97*
L10XT2	-4.69**	-2.48	-2.38	0.17	-0.22	0.00	0.31*	17.2**	0.97*
L11XT1	4.44**	3.98	-1.13	1.03	-0.48	0.70	0.24	57.9**	0.82*
L11XT2	-4.44**	-3.98	1.13	-1.03	0.48	-0.70	-0.24	-57.9**	-0.82*
L12XT1	3.44*	1.98	1.88	-0.35	0.07	-1.85	0.01	-4.65	-0.42
L12XT2	-3.44*	-1.98	-1.88	0.35	-0.07	1.85	-0.01	4.65	0.42
L13XT1	2.44	-7.52	-2.13	-0.90	0.52	0.45	-0.04	-40.9**	0.49
L13XT2	-2.44	7.52	2.13	0.90	-0.52	-0.45	0.04	40.9**	-0.49
L14XT1	-0.06	13.98	-1.63	1.24	-0.33	2.40	0.24	55.4*	0.70
L14XT2	0.06	-13.98	1.63	-1.24	0.33	-2.40	-0.24	-55.4*	-0.70
L15XT1	-2.06	-9.02	-4.13	-0.73	0.42	-2.90	-0.03	-13.4*	-1.03**
L15XT2	2.06	9.02	4.13	0.73	-0.42	2.90	0.03	13.4*	1.03**
L16XT1	0.19	-5.52	-6.13	0.77	-0.03	0.75	0.10	45.4**	0.88*
L16XT2	-0.19	5.52	6.13	-0.77	0.03	-0.75	-0.10	-45.4**	-0.88*
L17XT1	0.19	7.98	-1.13	1.13	0.37	2.55	0.35*	39.1**	1.71**
L17XT2	-0.19	-7.98	1.13	-1.13	-0.37	-2.55	-0.35*	-39.1**	-1.71**
L18XT1	-3.81*	-2.02	2.38	0.10	-0.18	1.55	0.01	-27.2**	-0.56
L18XT2	3.81*	2.02	-2.38	-0.10	0.18	-1.55	-0.01	27.2**	0.56
L19XT1	-0.31	-14.02*	-15.63**	0.13	0.37	-0.90	0.10	0.35	-0.30
L19XT2	0.31	14.02*	15.63**	-0.13	-0.37	0.90	-0.10	-0.35	0.30
L20XT1	0.69	8.48	1.88	1.25	-0.13	1.15	-0.03	14.1*	0.72
L20XT2	-0.69	-8.48	-1.88	-1.25	0.13	-1.15	0.03	-14.1*	-0.72
L21XT1	-2.56	-4.02	6.88	-1.34	0.32	-1.05	0.07	11.60*	-0.20
L21XT2	2.56	4.02	-6.88	1.34	-0.32	1.05	-0.07	-11.60*	0.20
L22XT1	-0.81	3.48	0.88	1.46	0.12	2.70	0.21	49.1**	0.83*
L22XT2	0.81	-3.48	-0.88	-1.46	-0.12	-2.70	-0.21	-49.1**	-0.83*
L23XT1	-2.31	3.48	1.38	-1.35	0.52	-3.30	-0.37*	-39.7**	-0.48
L23XT2	2.31	-3.48	-1.38	1.35	-0.52	3.30	0.37*	39.7**	0.48
L24XT1	-2.56	2.98	2.38	-0.58	-0.28	-1.35	0.07	-27.2**	-0.88*
L24XT2	2.56	-2.98	-2.38	0.58	0.28	1.35	-0.07	27.2**	0.88*
L25XT1	1.44	-3.52	-1.13	-1.68	0.22	-4.05*	-0.29	-15.9**	-1.25**
L25XT2	-1.44	3.52	1.13	1.68	-0.22	4.05*	0.29	15.9**	1.25**
L26XT1	-2.81	27.5**	8.38	0.95	0.42	3.05	0.29	30.4**	1.74**
L26XT2	2.81	-27.5**	-8.38	-0.95	-0.42	-3.05	-0.29	-30.4**	-1.74**
L27XT1	2.69	9.98	2.38	-0.25	-0.08	-1.15	-0.01	5.35	-0.73
L27XT2	-2.69	-9.98	-2.38	0.25	0.08	1.15	0.01	-5.35	0.73
L28XT1	-1.81	4.98	4.38	1.50	-0.53	3.30	-0.20	1.60	0.39
L28XT2	1.81	-4.98	-4.38	-1.50	0.53	-3.30	0.20	-1.60	-0.39

Table 3: Continued

Crosses	DM (days)	PH (cm)	EH (cm)	EL (cm)	NRPC (no)	NCPC (no)	ED (cm)	TSW (g)	GY (t/ha)
L29XT1	-1.06	-0.52	-1.13	0.26	0.02	2.75	-0.15	-13.4*	-0.07
L29XT2	1.06	0.52	1.13	-0.26	-0.02	-2.75	0.15	13.4*	0.07
L30XT1	0.19	-1.02	-4.63	1.03	0.42	-0.60	0.18	21.6**	0.67
L30XT2	-0.19	1.02	4.63	-1.03	-0.42	0.60	-0.18	-21.6**	-0.67
L31XT1	1.69	-22.5**	-8.63	-0.95	-0.88*	-0.80	-0.10	-29.65**	-1.85**
L31XT2	-1.69	22.5**	8.63	0.95	0.88*	0.80	0.10	29.65**	1.85**
L32XT1	0.19	-8.02	6.88	-1.61	-0.28	-1.30	-0.24	-45.9**	-0.90*
L32XT2	-0.19	8.02	-6.88	1.61	0.28	1.30	0.24	45.9**	0.90*
SE(m±)	1.19	9.76	4.09	0.87	0.27	1.51	0.12	3.54	0.27
SE(Sij –Skl)	1.95	17.04	8.57	1.73	0.57	2.92	0.30	7.07	1.19

SE (m) = standard error of mean, SE (S_{ij}-S_{kl}) = standard error of difference

crosses. Estimation of SCA effects in crosses ranged from -1.85 to 1.85 t ha^{-1} (Table 3). Crosses L6xT1, L15xT2, L17xT1, L25xT2, L26xT1 and L31xT1) were best specific combiners while crosses like L6xT2, L15xT1, L17xT2, L25xT1, L26xT2 and L31xT2 were poor specific combiners. Best combiner crosses in estimation of SCA to use in maize improvement program. A current finding is pact with the report of [10, 11]. For days to maturity, estimates of SCA effects ranged from (-4.69 to 4.69 days) (Table 3). Four crosses L10xT1, L11xT1, L12xT1, L18xT2 and four crosses L1xT2, L11xT2, L12xT2 and L18xT1 had significantly positive and negative SCA effects difference respectively. Significant negative SCA effects in days to maturity indicate that these crosses were good specific combiners and were effective if exploited to develop early maturing maize varieties. In agreement with current study [13] reported significant positive and negative estimates of SCA effects for days to maturity. Estimates of SCA effects in plant height crosses L2xT2 (29cm) and L2xT1 (-29cm) were good and poor specific combiners, respectively (Table 3). A cross with highest negative SCA effect is advantageous in case of lodging resistance development [24, 25] reported significant positive and negative SCA effects in maize.

For ear height crosses, L19xT2 (15.63cm) best specific combiner while cross L19xT1 (-15.63cm) poor specific combiner (Table 3). Positive SCA effects in ear height (ear placement) causes lodging while negative SCA effect increases animal attack, which could ultimately affect the quantity and quality of final grain yield. Likewise [10, 26] reported significant negative and positive estimates of SCA effects. The estimates of SCA effects for crosses in number of row per cob ranged from -0.88 to 0.88 (Table 3). Crosses with significant positive SCA effects were (L7xT2, and L31xT2) were good specific combiners, while crosses with significant negative SCA effects (L7xT1 and L31xT1) were poor specific combiners for number of row per cob (Table 3).

For number of kernels per row estimates of SCA effects ranged from -4.05 to 4.05 (Table 3). Cross with significant positive SCA effects (L25xT1) were good specific combiner. Similarly [10] reported significant positive and negative SCA effect for number of kernels per row.

Estimates of SCA effects for ear diameter ranged from -0.37 to 0.37cm. Six crosses showed significant estimates of SCA effects (Table 3). Good specific combiner was L23xT2, while the poorest was L23xT2 cross. Crosses with positive and significant SCA effects L10xT2, L17xT1 and L23xT2 had desirable trait for this trait. In agreement with current finding [27] found significant positive and negative SCA effects in maize ear diameter. Estimates of SCA effects for thousand-kernel weight of crosses ranged from -57.9 to 57.9g (Table 3). Fifty crosses exhibited significant estimates of SCA effects (Table 3). Good specific combiner was L11xT1, while the poorest cross was L11xT2. Crosses with positive and significant SCA effects for this trait are desirable as this trait directly contributes to grain yield of maize [28] reported significant positive and negative SCA effects for thousand-kernel weigh.

Heterotic Groups: The results exhibited that, from thirty-two inbred lines, twelve inbred lines viz, L6, L8, L11, L13, L16, L17, L20, L22, L26, L28 and L30 were showing positive SCA effects, exhibiting negative SCA effects with CML 159 and grain yield greater than the mean grain yield when crossed to CML144. On the other hand fourteen inbred lines viz. L4, L5, L7, L10, L12, L15, L18, L19, L21, L23, L24, L25, L27 and L31 showed positive SCA effects, exhibited negative SCA effects with CML 144 and grain yield greater than the mean yield of lines when crossed to CML 159 (Table 4). Six inbred lines viz. L2, L3, L9, L14, L29 and L32 showed non-significant SCA and yield less than the mean grain yield when crossed to both testers were classified as C group (Table 4) [29] classified inbred lines

Table 4: Heterotic grouping of Lines corresponding to testers

Lines	CML144 (group "B")	SCA	CML159 (group "A")	SCA	Heterotic group
L1	5.74	0.07	5.19	-0.07	B
L2	4.45	-0.1	4.24	0.1	C
L3	5.24	-0.21	5.25	0.21	C
L4	5.56	-0.29	5.73	0.29	A
L5	6.06	-0.21	6.07	0.21	A
L6	6.49	1.24**	3.59	-1.24**	B
L7	4.37	-0.86*	5.67	0.86*	A
L8	8.25	0.52	6.81	-0.52	B
L9	5.53	0.54	4.03	-0.54	C
L10	4.39	-0.97*	5.92	0.97*	A
L11	5.86	0.82*	3.81	-0.82*	B
L12	6.58	-0.42	7.00	0.42	A
L13	6.61	0.49	5.22	-0.49	B
L14	5.49	0.7	3.67	-0.7	C
L15	5.17	-1.03**	6.82	1.03**	A
L16	7.04	0.88*	4.88	-0.88*	B
L17	6.71	1.71**	2.88	-1.71**	B
L18	5.53	-0.56	6.23	0.56	A
L19	5.27	-0.3	5.46	0.3	A
L20	5.79	0.72	3.93	-0.72	B
L21	6.93	-0.2	6.91	0.2	A
L22	6.60	0.83*	4.52	-0.83*	B
L23	7.00	-0.48	7.56	0.48	A
L24	5.37	-0.88*	6.72	0.88*	A
L25	3.88	-1.25**	5.97	1.25**	A
L26	7.70	1.74**	3.82	-1.74**	B
L27	4.44	-0.73	5.48	0.73	A
L28	6.24	0.39	5.04	-0.39	B
L29	4.77	-0.07	4.49	0.07	C
L30	6.69	0.67	4.94	-0.67	B
L31	5.39	-1.85**	8.68	1.85**	A
L32	3.36	-0.90*	4.75	0.90*	C
mean	5.77		5.35		

* and ** significant at (P=0.05 and 0.01) respectively

into different heterotic groups based on mean grain yield and estimation of SCA effects. Similarly [30] were classified ten inbred lines in to three main groups A, B and AB heterotic groups based on SCA of grain yield and mean grain yield.

CONCLUSION

The current study revealed the presence of considerable amount of variability among crosses and lines. These permit us to select promising lines and hybrids for future use. SCA variance played greater role in controlling most of the studied characters. The significant differences among hybrids and lines for most traits indicate the possibility of selection for improvement of yield and yield related traits. Inbred lines identified for desirable GCA effects were L1, L8, L9, L21, L23, L27 and L28 in the studied traits. For grain yield, inbred lines L8 and L23 were the best general combiners. These lines also showed positive and highly significant GCA effects for ear length, ear diameter and thousand-kernel weight. These lines can possibly be used to develop high yielding and early maturing synthetic variety. Five crosses viz., L31XT2, L26XT1, L17XT1, L25XT2 and L6XT1 have shown high positive SCA effects for grain yield involving parents of positive GCA effects can be exploited for the development of single cross hybrids. The results of the current study identified inbred lines with positive GCA that can be used for (open pollinated varieties) OPV development and potential crosses with reasonable SCA that can be advanced to the next stage of breeding program. In addition, the information from this study may possibly be useful for researchers who would like to advance these breeding materials.

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