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Combining Ability Analysis in *Zea mays* L.

ANEES AHMAD† AND MUHAMMAD SALEEM
Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad–38040, Pakistan
†Corresponding author E-mail: an_datanet@hotmail.com

ABSTRACT

Both additive and non-additive gene effects played important role in genetic control of all the traits. The estimates of mean squares due to GCA were significant (P<0.05, 0.01) for all the traits except for growing degree days between tasseling and silking for F_1 and F_2 generation. Moreover, mean squares due to SCA were significant (P<0.01) for all the traits in both the generations. Mean squares for reciprocal effects were significant (P<0.01) for all the traits in both the generations except for growing degree days to reproductive phase, ratio of growing degree days to reproductive phase and vegetative phase, ear height, and kernel rows per ear in F_1 generation.

Key Words: Maize; GCA; SCA; Growing degree days; Heat units; Yield components; Grain yield

INTRODUCTION

If significant improvement in a plant trait is to be made through a breeding programme, knowledge of the relative contribution of the genetic components i.e., additive, dominance, epistasis, and linkage controlling the variation for that trait is an essential pre-requisite. The diallel analysis provides such information to formulate an appropriate programme for selecting and evaluating segregating generations. With a view to develop precocious maize varieties, Aulicino and Naranjo (1997) used two short-cycle testers with flint grain (the variety Gaspe and a selected inbred line) as pollinators in crosses with seven lines. F_1 hybrids were evaluated for number of grains per row, number of rows per ear, grain yield per plot, and heat units to tasseling and the best general combiners were identified. Giesbrecht (1960), Chase and Nanda (1967) and Bonaparte (1977) reported incomplete dominance for early flowering in maize. Additive genetic variance predominated for ear height and grain rows per ear in a diallel cross study of eight open-pollinated varieties (Qadri *et al.*, 1983). Sanghi *et al.* (1983) stressed on the importance of general combining ability (GCA) effects for days to tasseling, silking and maturity of eight early maturing composites (open-pollinated varieties). Results from a diallel analysis (Debnath *et al.*, 1988) involving nine inbreds showed the importance of non-additive gene effects in the inheritance of grain yield and 1000-grain weight and the equal importance of additive and non-additive effects for grain rows per ear and number of grains per row. Revilla *et al.* (1999) estimated GCA, specific combining ability (SCA) and reciprocal effects (RE) for plant height, pollen and silk date and kernel weight. Significant GCA was detected for all the traits, and SCA was significant for all the traits except kernel weight. Significant RE was detected for kernel weight and pollen and silk date. They concluded that the inbreds producing heavier kernels should be used as seed producing parents to obtain hybrids with better early vigor and earlier flowering dates.

Tarutina *et al.* (1990, 1991) found additive and dominant gene effects predominated over non-additive effects in control of kernels per row. Ivakhnenko and Klimov (1991) suggested that selection for number of grain rows would be the most effective. Debnath and Sarkar (1987) demonstrated complete dominance to over-dominance for all the traits except ear length and 1000-grain weight, which showed partial dominance to over dominance.

The information on the inheritance of growing degree days required for different physiological stages of maize growth is meager. Therefore, the present studies were conducted with the objective to investigate the genetic mechanisms involved in the inheritance of growing degree days to different physiological stages, yield and its components in maize. Moreover, estimates of specific combining ability are also important in hybrid breeding programs.

MATERIALS AND METHODS

The study was carried out in the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad. Six maize inbred lines i.e., T-232, FD-7, Mo-17, Pa-91, TZI-4001 and TZI-7103 were crossed in all possible combinations in a diallel fashion during Kharif 1996. The F_1s were sown and selfed in the coming planting season (Spring, 1997) to produce seed for F_2 generation. During Kharif 1997, F_1s, F_2s and parental inbred lines were sown according to a Randomized Complete Block Design with three replications. Two seeds of each entry were planted in each of 25 hills 20 cm apart in single row plots for F_1s and inbred lines while in ten-row plots for F_2s, keeping 75 cm row-to-row distance. After emergence each hill was thinned to single plant. The data were recorded on ten guarded plants for F_1 hybrids and inbred parents while 200 plants for F_2 generation for following traits:

- Growing degree days to tasseling (vegetative phase)
- Growing degree days to silking

- Growing degree days to maturity
- Growing degree days between tasseling and silking
- Growing degree days between tasseling and maturity (reproductive phase)
- Ratio of growing degree days to reproductive phase and vegetative phase
- Plant height (cm)
- Ear height (cm)
- Kernel rows per ear
- Kernels per row
- 1000 kernel weight (g)
- Grain yield per plant (g)

Daily maximum and minimum temperatures were recorded to calculate the growing degree days for different physiological stages according to Gilmore and Rogers (1958) and Cross and Zuber (1972). The data on all the parameters for the parents, F_1 and F_2 generations, were subjected to the analysis of variance according to Steel and Torrie (1980). Griffing's (1956) method I model II technique was used to estimate GCA of the parents and SCA effects for F_1 and F_2 generations.

RESULTS AND DISCUSSION

The mean squares due to GCA, SCA and RE, and components of variance are presented in Tables I and II, respectively. The estimates of mean squares due to GCA were significant (P<0.05, 0.01) for all the traits except for growing degree days between tasseling and silking (GDDTS) for F_1 and F_2 generation. Sanghi *et al.* (1983) stressed on the importance of GCA effects for days to tasseling, silking and maturity of eight early maturing composites (open-pollinated varieties). Kimani (1984) reported highly significant GCA effects for yield, actual grain filling period duration, rows/ear and plant height. Mean squares due to SCA were significant (P<0.01) for all the traits in both the generations. The significance of GCA and SCA indicated that both additive and non-additive gene effects were important for the control of these characters (Prasad *et al.*, 1988).

Qadri *et al.* (1983) also found significant GCA and SCA for ear height and grain rows per ear, and Revilla *et al.* (1999) reported significant GCA for plant height, pollen and silk date and kernel weight, and significant SCA for all theses traits except for kernel weight. Beck *et al.* (1990) found significant SCA for ear height. The situation was little bit different for RE i.e. mean squares were significant (P<0.01) for all the traits in both the generations except for growing degree days to reproductive phase (GDDREP), ratio of growing degree days to reproductive phase and vegetative phase (GDD R/V), ear height and kernel rows per ear in F_1 generation. Shieh *et al.* (1991), and Revilla *et al.* (1999) found significant RE for days to tasseling and silking and kernel weight. They concluded that the inbreds producing heavier kernels should be used as seed producing parents to obtain hybrids with better early vigor and earlier flowering dates. Lin and Chen (1986) revealed significant cytoplasmic effects for all characters except days to harvest and 100-grain weight.

The relative importance of GCA and SCA is usually judged from the ratio $2\sigma^2{g} / 2\sigma^2{g} + \sigma^2{s}$, as suggested by Baker (1978). Closer the ratio to unity, greater the importance of GCA alone. The estimates of this ratio in present studies were in no case near unity (Table II), indicating that both GCA and SCA accounted for genetic variability. Similar results have already been reported by Prasad *et al.* (1988), Naspolini *et al.* (1981) and Dhillon and Singh (1977). The magnitude of mean squares due to GCA was higher than that of mean squares due to SCA (Table I) for growing degree days to tasseling (GDDTA), silking (GDDSL), reproductive phase (GDDREP), GDD R/V, maturity (GDDMT), kernel rows per ear and 1000-kernel weight (g). This was indicative of the share of additive

Table I. Mean squares due to general and specific combining ability (GCA and SCA), and reciprocal effects (RE) for various traits of maize (*Zea mays* L.) in 6 x 6 diallel cross experiment

Traits	F_1 Generation				F_2 Generation			
	GCA (df=5)	SCA (df=15)	RE (df=15)	Error (df=70)	GCA (df=5)	SCA (df=15)	RE (df=15)	Error (df=70)
Growing degree days to tasseling (vegetative phase)	2817.72**	1634.65**	570.65**	117.45	239.79 *	4389.72**	874.66**	83.10
Growing degree days to silking	3944.36**	2434.34**	693.71**	87.96	591.26**	2759.41**	564.27**	73.35
Growing degree days between tasseling and silking	199.99 NS	517.49**	253.75**	93.06	124.18 NS	544.41**	338.10**	87.25
Growing degree days between tasseling and maturity (reproductive phase)	2682.86**	1575.70**	633.19 NS	359.95	1420.71**	1550.77**	2629.82**	201.49
Ratio of growing degree days to reproductive phase and vegetative phase	0.0015**	0.0014**	0.0006 NS	0.0004	0.0009**	.0.0022**	0.0024**	0.0002
Growing degree days to maturity	5298.05**	2602.15**	846.90**	85.21	1475.46**	6223.42**	1863.87**	161.67
Plant height (cm)	159.90**	506.16**	56.20**	15.71	46.55**	128.58**	145.86**	11.97
Ear height (cm)	80.30**	126.68**	12.61 NS	13.21	21.20**	33.69**	45.97**	6.29
Kernel rows per ear	2.78**	1.86**	0.61 NS	0.41	0.87 *	1.54**	1.11**	0.27
Kernels per row	19.79**	31.57**	6.79**	0.27	14.39**	11.81**	8.31**	0.21
1000-Kernel weight (g)	1664.64**	1234.84**	139.07**	9.34	536.28**	759.84**	767.41**	14.58
Grain yield per plant (g)	249.12**	905.90**	479.34**	31.68	145.49**	201.24**	172.42**	15.45

NS, *, **, denote non-significant, significant (P<0.05) and highly significant (P<0.01), respectively

Table II Estimates of components of variance for various traits of maize (*Zea mays* L.) in 6 x 6 diallel cross experiment

Traits	F1 Generation			F2 Generation		
	$\sigma^2 g$	$\sigma^2 s$	$\frac{2\sigma^2 g}{2\sigma^2 g + \sigma^2 s}$	$\sigma^2 g$	$\sigma^2 s$	$\frac{2\sigma^2 g}{2\sigma^2 g + \sigma^2 s}$
Growing degree days to tasseling (vegetative phase)	102.67	880.95	0.19	-334.25	2500.62	-0.36
Growing degree days to silking	132.14	1362.41	0.16	-173.46	1559.65	-0.29
Growing degree days between tasseling and silking	-25.32	246.45	-0.26	-33.79	265.45	-0.34
Growing degree days between tasseling and maturity (reproductive phase)	95.53	705.92	0.21	-7.21	783.45	-0.02
Ratio of growing degree days to reproductive phase and vegetative phase	0.00002	0.0006	0.06	-0.0001	0.0011	-0.22
Growing degree days to maturity	231.42	1451.45	0.24	-379.37	3519.73	-0.27
Plant height (cm)	-27.54	284.78	-0.24	-6.52	67.71	-0.24
Ear height (cm)	-3.56	65.88	-0.12	-0.97	15.91	-0.14
Kernel rows per ear	0.08	0.84	0.16	-0.05	0.74	-0.16
Kernels per row	-0.90	18.17	-0.11	0.25	6.74	0.07
1000-Kernel weight (g)	39.11	711.59	0.10	-16.63	432.73	-0.08
Grain yield per plant (g)	-52.38	507.61	-0.26	-4.15	107.88	-0.08

Table III. Estimates of general combining ability effects for various traits of maize (*Zea mays* L.) in 6 x 6 diallel cross experiment

Parents	GDDTA	GDDSL	GDDTS	GDDREP	GDD R/V	GDDMT	PHT	EHT	KR/E	K/R	KW	YLD
						F1 Generation						
T-232	-17.03	-15.13	2.08	6.31	0.002	-6.27	-5.34	-2.98	-0.20	-1.47	-6.76	-8.15
FD-7	-17.60	-25.06	-7.38	-29.69	-0.016	-39.41	-3.48	-2.43	0.52	-0.001	1.52	2.59
Mo-17	-3.26	-3.18	0.17	6.16	0.005	3.89	3.71	2.63	-0.04	-0.69	12.49	2.81
Pa-91	16.79	17.25	0.45	-0.14	0.005	10.89	2.94	3.21	-0.59	-0.11	8.83	1.39
TZI-4001	16.02	21.28	4.93	6.49	-0.004	13.95	0.32	-1.04	-0.32	-0.08	3.84	-2.48
TZI-7103	5.08	4.83	-0.26	10.87	0.007	16.96	1.85	0.60	0.63	2.36	-19.92	3.83
SE (g_i)	2.86	2.47	2.54	4.99	0.004	2.43	1.04	0.96	0.17	0.14	0.81	1.48
CD (g_i)	5.70	4.94	5.08	9.98	0.007	4.86	2.09	1.91	0.34	0.27	1.61	2.96
CD ($g_i - g_j$)	8.84	7.65	7.86	15.47	0.011	7.53	3.23	2.96	0.52	0.42	2.49	4.59
Parents						**F2 Generation**						
T-232	-1.82	-2.45	-0.54	0.96	0.016	-0.96	-1.86	1.15	-0.02	0.40	10.85	5.47
FD-7	2.50	-0.26	-2.76	-19.79	-0.011	-17.28	-2.11	-2.10	-0.24	-0.32	0.62	-2.65
Mo-17	0.31	4.70	4.08	7.96	0.007	8.58	-1.06	0.01	0.37	-0.94	-4.34	-2.15
Pa-91	-7.77	-11.84	-4.07	0.51	-0.012	-7.26	2.69	0.01	0.04	-1.30	-2.81	-3.31
TZI-4001	5.10	8.35	3.27	-1.22	-0.005	3.85	0.72	-0.69	-0.35	0.43	3.73	-0.20
TZI-7103	1.74	1.51	0.01	11.58	0.005	13.07	1.61	1.62	0.20	1.73	-8.05	2.84
SE (g_i)	2.40	2.26	2.46	3.74	0.005	3.35	0.91	0.66	0.14	0.12	1.01	1.04
CD (g_i)	4.80	4.51	4.92	7.47	0.010	6.69	1.82	1.32	0.27	0.24	2.01	2.07
CD ($g_i - g_j$)	7.43	6.98	7.62	11.57	0.016	10.37	2.82	2.05	0.42	0.37	3.11	3.20

effects of genes in the control of these traits (Lin & Chen, 1986; El Hefnawy & El Zeir, 1991; Choudhary *et al.*, 2000). In a study of diallel cross of six inbred lines, Newton and Eagles (1991) estimated high GCA than SCA for days to silking, days to physiological maturity and grain filling duration (reproductive phase). Mahmoud *et al.* (1990) derived information that genetic variances for plant height, 100-grain weight and yield were non-additive. Debnath *et al.* (1988) also showed the importance of non-additive gene effects in the inheritance of grain yield and 1000-grain weight. Crossa *et al.* (1990) determined that non-additive gene effects were more important in controlling yield. For plant height, additive gene effects accounted for more of the variation among populations, possibly plant height was more subject to selection in these populations. Combining ability estimates vary with type (inbred lines, open-pollinated populations, synthetics, etc) and combination (different sets of inbred lines/varieties) of experimental material, environmental conditions and different generations.

General combining ability (GCA). A perusal of GCA effects (Table III) revealed the transcendency of the inbred parent TZI-7103 for half of the traits including grain yield per plant in both the generations followed by Mo-17, TZI-4001, Pa-91 and T-232. These parents have good potential to be used as components of synthetics and composites of maize. Cosmin *et al.* (1991) have also reported high GCA effects for yield in Mo-17.

Specific combining ability (SCA). A careful examination of Table IV disclosed that eight crosses exhibited negative and seven positive SCA effects for GDDTA ranging from –44.09 (T-232 X M0-17) to 38.59 (Mo-17 X Pa-91) in F_1 generation and –56.35 (Mo-17 X TZI-4001) to 70.47 (FD-7 X Mo-17) in F_2 generation. Similarly, the range for SCA effects for GDDSL was -54.08 (T-232 X M0-17) to 47.27

Table IV. Estimates of specific combining ability effects for various traits of maize (*Zea mays* L.) in 6 x 6 diallel cross experiment

Crosses	GDDTA	GDDSL	GDDTS	GDDRE	GDD	GDDMT	PHT	EHT	KR/E	K/R	KW	YLD
						F_1 Generation						
T-232 X FD-7	-4.43	-16.33	-11.89	24.17	0.003	15.10	15.84	9.90	1.76	0.36	-11.48	7.14
T-232 X Mo-17	-44.09	-54.08	-9.58	-18.71	0.011	-60.97	7.98	3.01	-0.69	5.22	0.94	8.57
T-232 X Pa-91	10.60	12.54	1.40	5.96	-0.012	6.23	0.26	3.76	0.54	2.47	20.29	15.65
T-232 X TZI-4001	24.47	20.87	-3.18	-9.30	-0.048	26.97	11.37	3.84	-0.74	-1.89	-2.46	-13.50
T-232 X TZI-7103	-2.17	-16.51	-13.96	3.30	-0.029	3.08	2.84	-3.96	-0.35	-1.00	-6.38	4.78
FD-7 X Mo-17	-9.92	-15.97	-6.19	4.93	-0.024	-5.94	0.62	-4.05	-0.41	-1.75	9.84	-4.52
FD-7 X Pa-91	37.05	47.27	10.81	-3.00	-0.027	39.23	3.23	4.37	0.15	0.17	17.52	7.10
FD-7 X TZI-4001	-12.69	-19.42	-6.74	-23.04	-0.015	-26.83	11.51	3.12	0.87	1.47	3.17	15.72
FD-7 X TZI-7103	-26.78	-35.51	-8.68	37.33	0.036	9.50	3.82	-0.02	-1.07	0.19	17.57	-0.07
Mo-17 X Pa-91	38.59	17.57	-20.71	6.12	-0.021	36.44	9.20	5.65	-0.30	3.53	17.21	28.35
Mo-17 X TZI-4001	6.08	1.33	-4.65	52.90	0.025	54.02	10.48	5.07	-1.24	1.17	2.99	-6.80
Mo-17 X TZI-7103	4.79	5.32	0.49	-23.99	-0.036	-13.29	1.45	5.09	0.15	-1.11	20.36	5.78
Pa-91 X TZI-4001	-22.14	-23.87	-1.50	-17.31	0.013	-17.06	-2.91	-1.69	-0.32	3.58	28.98	17.47
Pa-91 X TZI-7103	21.06	17.24	-5.01	30.96	-0.017	24.14	5.40	2.51	-0.30	2.14	-2.52	-2.43
TZI- X TZI-7103	-18.66	-24.50	-5.57	-44.25	0.008	-47.29	8.18	6.09	1.09	3.61	1.79	21.13
CD (S_{ij})	13.01	11.26	11.58	22.77	0.017	11.08	4.76	4.36	0.77	0.62	1.61	6.75
CD ($S_{ij} – S_{ik}$)	19.76	17.10	17.59	34.59	0.025	16.83	7.23	6.63	1.17	0.95	5.57	10.26
CD ($S_{ij} – S_{kl}$)	17.67	15.29	15.73	30.94	0.022	15.05	6.46	5.93	1.05	0.85	4.98	9.18
Crosses						**F_2 Generation**						
T- X FD-7	-3.42	-9.26	-7.18	0.96	0.021	-1.13	8.39	3.69	-0.26	0.35	-17.88	-8.65
T-232 X Mo-17	16.08	2.04	-14.41	29.99	0.071	46.45	4.67	-1.76	-0.20	2.63	-9.59	1.59
T-232 X Pa-91	49.52	46.99	-1.68	20.70	-0.001	69.33	-2.75	6.24	0.13	1.49	37.98	17.37
T-232 X TZI-4001	32.40	18.65	-12.82	-39.45	-0.026	-7.96	4.22	0.77	-0.15	0.10	12.32	1.85
T-232 X TZI-7103	-9.83	-14.86	-4.60	-44.76	0.004	-54.99	2.17	0.63	0.63	0.30	-9.61	4.39
FD-7 X Mo-17	70.47	59.00	-11.49	21.38	0.010	91.87	-2.42	1.82	-0.32	-1.15	14.19	-0.57
FD-7 X Pa-91	32.18	24.39	-6.83	-12.70	-0.025	18.52	5.33	-2.01	0.35	-0.62	15.82	4.92
FD-7 X TZI-4001	8.30	24.61	16.95	-13.52	-0.010	-5.85	2.47	-1.32	0.41	-1.01	-10.18	-4.43
FD-7 X TZI-7103	-13.99	-17.38	-3.17	36.76	0.049	22.57	-4.58	-3.45	-1.15	-1.82	9.95	-9.71
Mo-17 X Pa-91	9.01	-0.99	-10.25	-19.58	-0.023	-10.32	-0.39	-3.95	-0.59	0.66	0.55	-1.14
Mo-17 X TZI-4001	-56.35	-53.02	3.68	-9.01	0.039	-65.69	-4.92	0.74	-0.20	2.60	-9.78	1.90
Mo-17 X TZI-7103	33.47	34.65	1.39	-25.23	-0.022	7.99	-5.31	-2.57	-1.09	-2.20	-0.59	-13.65
Pa-91 X TZI-4001	12.18	7.62	-5.09	28.36	0.001	41.69	-3.67	-3.76	-0.20	2.46	-15.98	-2.34
Pa-91 X TZI-7103	3.23	6.31	1.55	-20.06	0.010	-15.27	-12.39	-3.57	0.57	1.49	-3.06	4.59
TZI- X TZI-7103	28.77	2.43	-25.63	30.74	-0.021	58.71	12.75	5.46	-1.04	0.77	34.98	8.25
CD (S_{ij})	10.94	10.28	11.21	17.03	0.023	15.26	4.15	3.01	0.62	0.55	4.58	4.72
CD ($S_{ij} – S_{ik}$)	16.62	15.61	17.03	25.88	0.035	23.18	6.31	4.57	0.94	0.83	6.96	7.17
CD ($S_{ij} – S_{kl}$)	14.86	13.96	15.23	23.15	0.031	20.73	5.64	4.09	0.84	0.74	6.23	6.41

(FD-7 X Pa-91) in F_1 generation and –53.02 (Mo-17 X TZI-4001) to 59.00 (FD-7 X Mo-17) in F_2 generation. Parent line Mo-17 played an important role in the expression of SCA effects for these traits. For GDDTS, cross combination FD-7 X Pa-91 was at the top (10.81) and cross Mo-17 X Pa-91 was at the bottom (-20.71) in F_1 generation and crosses FD-7 X TZI-4001 and TZI-4001 X TZI-7103 got the same position in F_2 generation. Twelve out of 15 crosses showed negative SCA effects in F_1 generation and 11 out of 15 in F_2 generation.

The maximum SCA effects for GDDREP were recorded for hybrid combinations Mo-17 X TZI-4001 and FD-7 X TZI-7103 in F_1 and F_2 generation, respectively. Eight crosses exhibited positive SCA effects in F_1 generation and seven in F_2 generation. A total of nine crosses appeared to have negative SCA effects for GDD R/V in F_1 generation. The least estimate was observed with the cross T-232 X TZI-4001 (-0.048) and the highest value (0.036) was associated with the cross FD-7 X TZI-7103. In F_2 generation the corresponding positions were held with the crosses T-232 X TZI-4001 (-0.026) and T-232 X Mo-17 (0.071). T-232 X Mo-17 was proved to be the earliest maturing cross (-60.97) while Mo-17 X TZI-4001 took the maximum growing degree days (54.02) to mature in F_1 generation while in F_2 generation cross combinations Mo-17 X TZI-4001 and FD-7 X Mo-17 (Table IV) were early and late maturing, respectively.

For plant height cross combinations T-232 X FD-7 and PA-91 X TZI-4001 exhibited the maximum and minimum SCA effects, respectively in F_1 generation and crosses TZI-4001 X TZI-7103 and Pa-91 X TZI-7103 showed the maximum and minimum SCA effects, respectively in F_2 generation. Cross combinations T-232 X FD-7 and FD-7 X Mo-17 exhibited the maximum and minimum SCA effects, respectively for ear height in F_1 generation and crosses T-232 X Pa-91 and Pa-91 X Mo-17 showed the maximum and minimum SCA effects, respectively in F_2 generation. Six out of 15 crosses showed positive SCA effects for kernel rows per ear with cross combination T-232 X FD-7 on one extreme (positive) and cross FD-7 X Mo-17 on the other extreme (negative) in F_1 generation. The position of the crosses was different in F_2 generation. Cross T-232 X TZI-

Table V. Estimates of reciprocal effects for various traits of maize (*Zea mays* L.) in 6 x 6 diallel cross experiment

Crosses	GDDTA	GDDSL	GDDTS	GDDRE	GDD	GDDMT	PHT	EHT	KR/E	K/R	KW	YLD
						F_1 Generation						
FD-7 X T-232	4.07	4.35	0.13	-18.43	-0.040	-14.21	1.00	1.00	-0.33	2.00	-8.38	0.69
Mo-17 X T-232	4.22	-11.53	-15.83	-29.89	0.007	-25.59	2.67	1.17	0.001	0.83	-1.45	1.68
Pa-91 X T-232	-28.79	-24.81	4.01	-18.38	0.013	-27.23	-3.83	-1.50	0.002	1.00	-19.27	-5.25
TZI-4001 X T-232	8.48	12.45	4.22	-18.23	-0.028	-10.00	-15.67	-4.00	0.33	0.67	1.20	4.51
TZI-7103 X T-232	-46.05	-25.36	20.73	-5.43	-0.028	-57.53	4.33	-0.83	0.33	5.67	1.25	35.79
Mo-17 X FD-7	12.35	16.66	3.93	-16.43	0.007	-3.70	-1.83	2.67	1.00	1.33	2.08	14.28
Pa-91 X FD-7	-4.31	0.001	4.17	-29.78	-0.013	-33.94	1.00	1.67	1.00	-0.83	3.33	7.47
TZI-4001 X FD-7	-4.17	-13.05	-8.98	-3.43	0.083	-7.50	0.67	0.17	0.001	0.50	1.27	2.49
TZI-7103 X FD-7	-20.87	-28.18	-6.84	11.07	0.052	-10.28	3.50	0.33	0.33	0.33	0.93	4.25
Pa-91 X Mo-17	-11.57	-16.06	-4.08	-21.78	-0.028	-13.14	4.83	5.00	-1.33	-2.17	-12.57	-41.47
TZI-4001 X Mo-17	11.98	3.84	-8.61	0.67	-0.005	-7.50	-0.50	0.17	0.001	0.50	0.57	2.22
TZI-7103 X Mo-17	0.24	-8.61	-8.56	17.13	0.032	17.08	6.00	5.50	0.33	0.67	19.90	14.93
TZI-4001 X Pa-91	4.31	-24.81	-28.98	-14.44	-0.050	-10.28	-2.33	-1.00	-0.33	0.50	0.55	-1.45
TZI-7103 X Pa-91	12.13	-0.14	-11.38	-19.81	0.017	-6.71	-3.50	2.50	0.002	0.50	-3.75	-0.59
TZI-7103 X TZI-4001	12.54	37.86	25.41	-12.51	-0.003	0.001	-6.33	0.83	-0.33	2.00	3.15	5.42
CD (r_{ij})	15.30	13.24	13.62	26.79	0.019	13.03	5.60	5.13	0.91	0.74	4.32	7.95
CD ($r_{ij} – r_{kl}$)	21.64	21.64	19.26	37.83	0.027	18.43	7.92	7.26	1.29	1.04	6.10	11.24
Crosses						**F_2 Generation**						
FD-7 X T-232	12.31	12.08	0.55	-45.51	-0.017	-33.98	-1.17	0.001	-0.33	2.50	-5.55	2.22
Mo-17 X T-232	-29.62	-36.57	-8.38	-12.20	-0.027	-40.38	5.50	7.33	1.67	0.83	7.85	17.21
Pa-91 X T-232	-4.26	-8.15	-3.80	15.47	0.003	11.06	1.50	1.33	-0.33	0.33	1.38	-1.17
TZI- X T-232	0.001	0.002	0.001	-41.25	-0.018	-41.25	-14.50	-6.50	1.00	-6.00	-6.07	-13.22
TZI- X T-232	28.18	40.36	12.44	-17.64	0.028	10.28	0.33	0.33	-0.33	-0.50	15.85	8.00
Mo-17 X FD-7	11.94	0.001	-12.87	20.25	-0.020	33.12	-1.83	1.00	0.001	-0.33	0.47	-0.76
Pa-91 X FD-7	8.70	12.27	3.57	-80.71	-0.022	-0.01	-12.33	0.17	0.33	-2.50	-27.97	-15.31
TZI- X FD-7	-45.44	-16.30	29.20	79.39	0.0001	33.89	1.50	5.17	-0.67	-0.17	28.87	5.43
TZI- X FD-7	-45.36	-16.15	28.70	34.53	0.023	-10.33	-4.67	-3.00	0.33	0.33	-11.72	-0.59
Pa-91 X Mo-17	7.96	0.001	-7.92	-31.53	-0.005	-23.62	4.00	3.00	0.001	0.50	-17.97	-7.01
TZI- X Mo-17	12.78	7.86	-4.72	8.24	-0.007	20.64	4.50	-4.00	0.67	0.17	-3.95	3.46
TZI- X Mo-17	0.09	0.003	0.74	43.33	0.013	42.53	22.00	12.00	-0.33	-0.67	50.75	14.00
TZI- X Pa-91	0.002	-12.27	-12.27	-64.00	-0.013	-64.00	-3.50	-0.17	-0.33	1.67	-24.68	-7.23
TZI- X Pa-91	-12.31	-4.12	7.41	14.95	-0.020	3.43	-2.33	-1.00	1.67	0.001	-9.85	6.46
TZI- X TZI-4001	0.001	12.27	12.27	-3.47	-0.015	-3.47	-11.50	-6.33	0.33	3.00	-0.07	11.67
CD (r_{ij})	12.87	12.09	13.19	20.04	0.027	17.95	4.87	3.54	0.73	0.64	5.39	5.55
CD ($r_{ij} – r_{kl}$)	18.20	17.10	18.65	28.35	0.038	25.39	6.91	5.01	1.03	0.91	7.63	7.85

7103 got the maximum SCA effect while FD-7 X TZI-7103 exhibited minimum SCA effect.

For kernels per row, cross combination T-232 X Mo-17 was at the top (5.22) and cross T-232 X TZI-4001 was at the bottom (-1.89) in F_1 generation and crosses T-232 X Mo-17 (2.63) and Mo-17 X TZI-7103 (-2.20) got the same position in F_2 generation. Eleven out of 15 crosses showed positive SCA effects in F_1 generation and 10 out of 15 in F_2 generation. Cross combinations Pa-91 X TZI-4001 and T-232 X FD-7 exhibited the maximum and minimum SCA effects, respectively for 1000-kernel weight in F_1 generation and crosses T-232 X Pa-91 and T-232 X FD-7 showed the maximum and minimum SCA effects, respectively in F_2 generation. For grain yield per plant in F_1 generation, cross Mo-17 X Pa-91 (28.35) got the highest SCA effect followed by TZI-4001 X TZI-7103 (21.13). These crosses were between good (Mo-17, TZI-7103) and poor (Pa-91, TZI-4001) general combiners. Cross T-232 X TZI-4001 with lowest SCA effect (-13.50) was a combination of poor X poor general combiners. There is a clear influence of GCA of the two parents on SCA of a particular cross. Therefore, equal attention should be paid for selecting the parents with high GCA effect for having high SCA effects of the crosses (Zhang & Wang, 1991). According to Zieger (1988), the best hybrids (with high SCA) had at least one parent and often both with significant and high GCA effects. However, in F_2 generation, a poor X poor combination (T-232 X TZI-4001) yielded maximum SCA effect and good X good combiner (Mo-17 X TZI-7103) resulted in minimum SCA effect.

Reciprocal effects (RE). The scrutiny of reciprocal effects (Table V) divulged the superiority of the cross combinations, TZI-7103 X TZI-4001 for GDDTA and GDDSL, TZI-7103 X Mo-17 for GDDREP, GDDMT, plant height, ear height and 1000-kernel weight, TZI-7103 X TZI-4001 for GDDTS, TZI-4001 X FD-7 for GDD R/V, Mo-17 X FD-7 and Pa-91 X FD-7 for kernel rows per ear, TZI-7103 X T-232 for kernel per row and grain yield per plant in F_1 generation and the ascendancy of the crosses, TZI-7103 X T-232 for GDDTA, GDDSL and GDD R/V, TZI-4001 X FD-7 for GDDREP and GDDTS, TZI-7103 X Mo-17 for GDDMT, plant height, ear height and 1000-kernel weight, TZI-7103 X TZI-4001 for kernels per row and Mo-17 X T-232 for kernel rows per ear and grain yield per plant in F_2 generation.

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