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HETEROSIS AND COMBINING ABILITY ESTIMATES FOR EAR TRAITS AND GRAIN YIELD IN MAIZE HYBRIDS

Sultan Mahmood[1], Saad Imran Malik[1*] and Mozamil Hussain[2]

[1]*Department of Plant Breeding and Genetics, PMAS Arid Agriculture University Rawalpindi.*

[2]*Maize, Sorghum and Millet Programme, NARC, Park Road, Islamabad.*

ABSTRACT

To increase maize yields, exploitation of heterosis has been proven as highly effective and is widely used over the world to produce new and improved hybrids. Present study was undertaken to estimate combining ability and heterosis in maize hybrid combinations for ear traits, plant height and leaf area. Five inbred parents were crossed in a diallel fashion excluding reciprocals and fifteen genotypes including 10 hybrid combinations and 5 parents were tested during summer 2013. Statistical analysis revealed significant difference for kernel rows ear^{-1} ($P \leq 0.05$), and highly significant difference ($P \leq 0.01$) for days to silking, plant height, leaf area, kernels row^{-1}, 1000-kernel weight and grain yield. Hybrid $P_3 \times P_5$ and $P_3 \times P_4$ was marked as suitable for breeding early maturing hybrids due to negative heterosis values. High heterosis for plant height was recorded for $P_2 \times P_3$ with significant SCA effects. P_2 in combination with P_3, P_4 and P_5 showed significant SCA for greater leaf area, however, a significant positive heterosis was obtained only for $P_2 \times P_3$. Maximum numbers of kernel rows ear^{-1} were counted in hybrid $P_3 \times P_4$; nevertheless, hybrid $P_1 \times P_3$ exhibited the highest MPH while $P_3 \times P_4$ was the only combination to have significant BPH. On the other hand $P_1 \times P_4$ had the highest number of kernels row^{-1}. The highest 1000-kernel weight was obtained for the hybrid $P_2 \times P_3$ with highly significant heterosis and SCA. The grain yield remained highest in $P_2 \times P_3$ (4719 kg/ha) followed by $P_4 \times P_5$ (4616 kg/ha) and $P_3 \times P_4$ (4532 kg/ha). Hence the hybrid combination $P_2 \times P_3$ was marked as superior for the development of high yielding hybrids among 10 hybrids tested considering its significant and positive SCA for yield related traits and highest grain yield.

Keywords: Maize, *Zea mays*, heterosis, combining ability, diallel.

INTRODUCTION

Maize (*Zea mays* L.) is the most produced cereal grain in the world with a total global production of 1038 M-t in 2013-14, followed by rice (740 M-t) and wheat (720 M-t) (FAOSTAT, 2014). Maize is a source of calories in many African countries serving as a staple food for over 300 million people (La Rovere *et al*., 2011). In Pakistan it is third most important cereal crop with the annual grain production of 4.7 M-t (FAO, 2014). Maize is primarily used for animal and poultry feed in Pakistan which accounts for about 60% of the total production. Remaining 25% is used in the industry and a small fraction is used for human consumption (Pioneer, 2012). Increasing industrial demands and growing poultry and livestock sector in the country has raised maize demands more than ever today.

Historically, maize hybrids were first developed in 1920s and commercial cultivation was started in 1930s (Hayes, 1946; Crow, 1998; Duvick, 2005). To increase maize yield, exploiting the phenomenon of heterosis proved to be very effective and widely used over the world to significantly boost maize yields (Shull, 1948; Guo et al., 2014; Jiang et al., 2015; Oliveira et al., 2015). Useful heterosis is the superior performance of hybrids when compared to their parents (Elisa, 2001; Ding et al., 2014) and usually economic heterosis is commercial gain in yield over existing check hybrid cultivars. Since grain yield is a complex quantitative trait, this gain is indirectly achieved by improving yield-related traits with improves ear parameters, photosynthesis efficiency and response to fertilizer application along with better resistance to insect pests and diseases (Hirel, 2001; Jiang et al., 2015). The manifestation of heterosis is linked to specific combining ability (SCA) of inbred lines described by the performance of an inbred in a specific combination and characterized by non-additive gene action. On the other hand, general combining ability (GCA) is the overall performance of an inbred line in multiple crosses with other inbreds and is related to the

**Corresponding author:* e-mail: saad.malik@uaar.edu.pk

additive genetic effects (Bauman, 1981; Rodrigans et al., 2001; Moterle et al., 2011; Zhang et al., 2015). Sprague and Tatum (1942) elaborated for the first time the concept of general and specific combining ability. Both GCA and SCA are important in determining the improvement or decline in hybrid traits (Vieira et al., 2009).

For developing hybrids with desirable traits information about combining ability of parents and crosses is very important (Mohammad et al., 2006; Amir-uz-zaman et al., 2010; Khan et al., 2012; Kage et al., 2013). There are a number of studies with heterosis estimates and evaluation of the performance of diverse breeding materials *per se*. Temperate inbred lines have shown more significant effects of GCA for grain yield and yield related traits (da Silva et al., 2010). Due to negative effects of combining ability for days to pollen shedding, subtropical inbred lines happened to be usefulness in developing earliness in hybrids while tropical inbred lines are reported to have significant effects of GCA for days to pollen shedding (Malik et al., 2004a and b). Diallel analysis is a reliable and well known method of determining GCA and SCA effects for inbred lines in different crossing schemes (Griffing, 1956; Garcia et al., 1999; Larish and Brewbaker, 1999; Lee and Kannenberdg, 2003).

Hybrid maize has much higher yield potential as compared to open pollinated varieties (OPVs). As in the USA and other developed countries, hybrid maize seed industry is very much developed making maize the most productive cereal per unit area of land. Such efforts by breeders in Pakistan could be very fruitful to improve maize yield in the country by testing promising inbreds in hybrid combinations, their evaluation and identification of best crosses to develop and release commercial hybrid maize varieties.

MATERIALS AND METHODS

Experimental site and plant material

Experiment was conducted at the research area of Maize, Sorghum and Millet Program, National Agricultural Research Centre, Islamabad where the seed for inbred lines was also obtained. The seed for five inbred lines was sown in the March of the year 2013 and tested in *Kharif* season during summer of the same year.

Crossing plan

Inbred lines were grown under irrigation using standard cultural practices during spring 2013. The plants were spaced 25 cm while plant rows were 75 cm apart and 5 m long. The ears were bagged before the emergence of silks to prevent cross pollination and the pollens were collected in the Kraft paper bags for crossing. The inbreds and their hybrids were sown in *Kharif* of the same year in a randomized complete block design (RCBD) with three replications for data recording on several parameters. Similar row spacing and uniform cultural practices were undertaken.

Harvesting and data recording

The ears obtained after cross fertilization were manually harvested and dried under shade for two weeks before shelling. Seeds were harvested and grown next year for evaluation including five self-pollinated parental lines and 10 hybrids obtained by diallel fashion crossing of inbred lines excluding reciprocals. Data were recorded for days to 50% silking by counting the number of days from the date of germination when silks in 50% plant emerged out of the ears for every single entry in each replication. The plant height was measure in centimeters from the base of the stem to the lowest tassel branch. The leaf area was measured according to Payne et al. (1991). Kernel rows ear^{-1} were counted by selecting five random ears from each row. Kernels row^{-1} were counted by randomly selecting five ears and counting the numbers of kernels per row. Thousand-kernel weight (g) was obtained by counting 1000-seeds and allowing them to get dry to 15% moisture content. The seeds were weighted with the help of table top weighing balance. Grain yield was calculated by the following formula:

$$\text{Grain yield (GY)} = \frac{\text{FW} \times (100 - \text{MC}) \times 0.8 \times 10{,}000}{\text{Plot area} \times 85}$$

Where grain yield is in kg/ha, FW = Fresh weight of ears/plot, MC = Percent moisture content, 0.8 is the shelling percentage, 10,000 is the area in m^2 for one hectare and 85 is the factor for grains stored at 15% moisture content.

Heterosis and combining ability analysis

Combining ability was estimated according to Griffing's Method-II (Fixed Model) (Griffing,

1956) while reciprocal crosses were excluded in this study. The data were subjected to statistical analysis using Statistix 8.1 and diallel analysis package in MSTAT-C.

Heterosis was calculated as described by Haullauer and Miranda, 1988.

$$\text{Midparent (MP)heterosis (\%)} = \frac{(\text{F1} - \text{MP})}{\text{MP}} \times 100$$

$$\text{Better parent (BP) heterosis (\%)} = \frac{\text{F1} - \text{BP}}{\text{BP}} \times 100$$

RESULTS AND DISCUSSION

Analyses of variance showed significant difference ($P \leq 0.05$) for kernel rows ear^{-1} and highly significant difference ($P \leq 0.01$) for days to 50% silking, plant height, leaf area, kernels row^{-1}, 1000-kernel weight and grain yield (Table 1). The difference between replications was recorded as non-significant for all parameters under study.

Similarly, mean square values from the ANOVA performed for GCA effects showed highly significant difference ($P \leq 0.01$) among inbred lines for plant height, leaf area, kernels row^{-1} and grain yield while days to 50% silking and 1000-kernel weight exhibited significant difference ($P \leq 0.05$) and difference for kernel rows ear^{-1} was found as non-significant (Table 2). Considering SCA effects, highly significant difference ($P \leq 0.01$) was observed among hybrids for days to 50% silking, plant height, kernels row^{-1}, 1000-kernel weight and grain yield (Table 2), while the difference for leaf area and kernel rows ear^{-1} was significant at $P \leq 0.05$ (Table 2)

Heterosis and combining ability effects for days to 50% silking

Days required to 50% silking by all the genotypes were significantly different (Table 1). The results revealed that among the F_1 from the crosses, $P_3 \times P_5$ showed highly significant SCA of -4.67 for days to 50% silking and took 58 days to reach silking stage compared to its parental lines P_3 (64 days) and P_5 (67 days). This suggests that $P_3 \times P_5$ cross is a good combination for early maturity hybrid breeding. P_3 showed negative and significant value of 0.93 for GCA effect which means this parent had a diminishing effect on days taken to 50% silking. This suggests that P_3 can be a good choice for developing early maturing hybrids. Estimation of heterosis showed that hybrid $P_3 \times P_5$ has -17.53% MPH and -12.77% BPH values (Table 5). Hence this hybrid combination is marked as suitable for early maturity hybrid breeding. Likewise, hybrid $P_3 \times P_4$ also exhibited -12.32% MPH and -5.23% BPH (Table 5). Considering highly significant negative SCA effects of -4.67 for $P_3 \times P_5$ (Table 4), the combination is identified as suitable for early maturity hybrid breeding.

Heterosis and combining ability effects for plant height

Plant height varied significantly ($P \leq 0.01$) among all hybrids and their parental lines (Table 1). The highest value for plant height was recorded in hybrid $P_2 \times P_3$ (136.47 cm), while the lowest value was measured for $P_2 \times P_2$ (74.09 cm). Statistical analysis for combining ability (both GCA and SCA) showed highly significant difference for plant height (Table 2). P_1 and P_2 gave negative values suggesting that these parents are not good combiner for increased plant height (Table 3). P_3 and P_5 both had positive and highly significant value for GCA suggesting that these two inbred parents are good combiners for increasing plant height (Table 3) which may be good to increase fodder production but might have reduced lodging resistance. Like GCA, the effects of SCA were also highly significant for most of the hybrid combinations (Table 4). Hybrid $P_2 \times P_3$ showed the highest and significant SCA (34.53) for greater plant height which proves this combination to be the best for this trait (Table 4). Likewise, highly significant heterotic effects were seen for $P_2 \times P_3$ with 67.37% MPH and 53.36% BPH (Table 5). Similarly, significant and positive heterosis was recorded for plant height in $P_3 \times P_4$ (Table 5) with highly significant SCA effects of 10.88 (Table 4).

Heterosis and combining ability effects for leaf area

All genotypes showed statistically significant difference ($P \leq 0.01$) for leaf area. Hybrid obtained by the cross $P_2 \times P_3$ had the highest leaf area (244.47 cm^2) despite parental line P_2 had a lowest value of 143.44 cm^2. The GCA effects were significant for P_1 and P_5 only (Table 3) while P_2 in combination with P_3, P_4 and P_5 showed significant SCA (Table 4). Overall, a significant and positive heterosis was obtained only for $P_2 \times P_3$ regarding leaf area with 51.87% MPH and 36.83% BPH, hence, regarded as the best hybrid for greater leaf area in the crosses tested (Table 5). Since, leaf area is directly correlated with increased biomass and grain filling with more photosynthates, the inbred combination identified could be a valuable source for yield increase in hybrid combinations.

Heterosis and combining ability effects for number of kernel rows ear^{-1}

Statistical analysis showed significant difference regarding the number of kernel rows per ear ($P \leq 0.05$) (Table 1). Maximum numbers of kernel rows (14.8) were observed in hybrid $P_3 \times P_4$. None of the parents showed significant effect of GCA (Table 2). Among all specific combinations, four hybrids had significant SCA effects for this trait. Based on these estimates, $P_1 \times P_2$ was highlighted as the best combination with significant positive SCA effects (Table 4) and highly significant 15.26% MPH (Table 5). Hybrid $P_1 \times P_3$ showed the highest value for MPH and $P_3 \times P_4$ was the only combination to have significant BPH (Table 5). These data suggest that P_1 may be a good parent choice for increasing kernel rows in maize in certain specific combinations mentioned.

Heterosis and combining ability effects for number of kernels row^{-1}

The data for number of kernels row^{-1} showed significant statistical difference when hybrids and their parents were compared (Table 1). Highest average number of kernels produced on a row was measured in the hybrid combination $P_1 \times P_4$ and was calculated as 29.0 kernels row^{-1}. Statistical analysis of GCA and SCA revealed highly significant difference for number of kernels row^{-1} (Table 2), while significant and positive GCA effects were only recorded for P_4, hence regarded as a good general combiner for this trait (Table 3). SCA effects for number of kernels row^{-1} remained positive and highly significant for four hybrids evaluated (Table 4). Hybrid $P_1 \times P_2$ gave negative value showing an undesired combination, while $P_2 \times P_3$ yielded significant and positive SCA effects (Table 4). Among 10 hybrids tested, six hybrids showed highly significant and positive MPH and only two hybrids showed significant and positive BPH (Table 5). Hybrid $P_1 \times P_3$ was marked as the best with 52.81% MPH and 49.45% BPH for this parameter (Table 5).

Heterosis and combining ability effects for 1000-kernel weight

Highly significant difference was recorded for this trait when means were compared by the ANOVA. The highest 1000-kernel weight was recorded for the hybrid $P_2 \times P_3$ (230 g) while inbred P_1 had the lowest value of 126.3 g. Highly significant but negative value for GCA was obtained only in P_1 while rest of the parental lines showed non-significant GCA effects (Table 3). Hence, P_1 was identified as a poor general combiner for 1000-kernel weight (Table 3). Results of SCA also varied for all hybrid combinations tested. Hybrid $P_2 \times P_3$ showed highly significant and positive SCA for 1000-kernel weight suggesting it as the best combination amongst 10 hybrids for this trait. On the other hand, hybrid $P_2 \times P_4$ showed negative SCA value suggesting this combination results in reduced kernel weight and ultimately grain yield (Table 4). The results for heterosis remained highly significant in certain crosses (Table 5). Out of the 10 hybrids tested, eight hybrids showed significant and positive heterosis for 1000-kernel weight. Hybrid $P_4 \times P_5$ had the highest and highly significant BPH of 41.21% (Table 5). Hybrid $P_2 \times P_3$ was designated as a cross with highly significant mid-parent and better-parent heterotic effects with 46.34% MPH and 36.09% BPH (Table 5).

Heterosis and combining ability effects for grain yield (kg/ha)

A highly significant difference for grain yield was observed in hybrid combinations as well as the inbreds under investigation ($P \leq 0.01$) (Table 1). Hybrid $P_2 \times P_3$ gave the highest estimated grain yield of 4719 kg/ha followed by $P_4 \times P_5$ (4616 kg/ha), $P_3 \times P_4$ (4532 kg/ha) and $P_1 \times P_4$ (4506. GCA for grain yield remained highly significant for P_4 and significant but negative for P_1 while other inbred lines did not show significant GCA effects (Table 3). These data suggests that P_4 is a good general combiner for higher grain yield while P_1 is a poor general combiner.

SCA effects were positive and highly significant for $P_1 \times P_4$, $P_2 \times P_3$, $P_3 \times P_4$, $P_4 \times P_5$ (Table 4). Hybrid $P_2 \times P_3$ was regarded as the best combination for high grain yield with highest 61.24% MPH and 34.31% BPH (Table 5). Specifically, this combination showed the highest and highly significant SCA (1184.72) increasing the worth of this combination for higher grain yield in hybrid combination. Significant negative SCA was exhibited by the hybrid $P_2 \times P_4$ which suggests it unsuitability for hybrid development for high grain yield (Table 4). Considering MPH, four hybrid combinations showed high heterosis, while in view of better parent heterosis, only two hybrids showed high heterotic values (Table 5). Hybrid $P_4 \times P_5$ showed the highest and significant BPH of 35.2% and 52.32% MPH (Table 5). This hybrid combination also had highly significant and positive SCA (915.98). As mentioned, hybrid $P_2 \times P_3$ due to its high heterosis, can be further used for the development of high yielding hybrids. Rest of the hybrids did not show significant heterosis so the lines in specific combinations for these hybrids cannot be regarded as useful.

The inbred line development is a tedious job with 6-7 cycles of self-pollination followed by an extensive and rigorous selection. Majority of the lines are discarded in 3rd or 4th selection cycle and only a few are carried further for SCA and GCA estimates along with the measurement of heterotic effects in cross combinations. Hence, the hybrid breeding program completely relies on the quality and performance of inbred lines *per se* which is evaluated by manual crossing and field trials for agronomic performance. There are a number of studies carried out for such purposes with different results obtained for diverse breeding materials and crosses (Larish and Brewbaker, 1999; Katna et al., 2005; Uddin et al., 2006; Devi et al., 2007; Kage et al., 2013). Different scientists obtained diversified results for the material tested, hence such studies are important for the evaluation of inbred lines in specific hybrid breeding programs and identification of those inbreds which have high and significant SCA in specific hybrid combinations and give significant heterosis over the better parent to increase maize yield in the growing demands for poultry and livestock sector of the country.

Table 1: Mean square values from the analyses of variance for grain yield and related traits of maize hybrids.

Source of variation	DF	Days to silking	Plant Height (cm)	Leaf area (cm^2)	Kernel rows ear^{-1}	Kernels rows^{-1}	1000-kernel weight (g)	Grain yield (t-ha^{-1})
Genotypes	14	18.01**	10.31**	2564**	1.81*	5.92**	2632.4**	1981.1**
Replications	2	4.5^{ns}	155.62^{ns}	6078^{ns}	0.152^{ns}	2.14^{ns}	846.0^{ns}	245.4^{ns}
Error		125.7	78.8	900.1	0.90	7.02	632.34	474.8
CV (%)		3.4	8.2	15.4	7.0	11.1	13.8	20.0

** Significant at $P \leq 0.01$, *Significant at $P \leq 0.05$, ^{ns}Non-significant

Table 2: Mean square values for GCA and SCA effects in maize inbred lines and their hybrid combinations for grain yield and related traits.

Source of variation	DF	Days to 50% silking	Plant height (cm)	Leaf area (cm^2)	Kernel rows ear^{-1}	Kernels rows^{-1}	1000 kernel weight (g)	Grain yield (kg-ha^{-1})
GCA	4	5.7*	267.2**	1321.3**	0.33^{ns}	10.52**	629.7*	653061**
SCA	9	6.1**	272.4**	667.9*	0.71*	15.16**	976.6**	663269**

** Significant at $P \leq 0.01$, *Significant at $P \leq 0.05$, ^{ns}Non-significant

Table 3: Estimated GCA effects for grain yield and related traits for each parental line.

Parents	Days to 50% silking	Plant height (cm)	Leaf area (cm^2)	Kernel rows ear^{-1}	Kernels rows^{-1}	1000-kernel weight (g)	Grain yield (t-ha^{-1})
P1	-0.44 ^{ns}	-6.6**	-17.96**	-0.3 ^{ns}	-1.41*	-16.5**	-352.41*
P2	1.04*	-6.17**	-11.31 ^{ns}	0.14 ^{ns}	0.03 ^{ns}	7.27 ^{ns}	119.96 ^{ns}
P3	-0.96*	5.14**	8.37 ^{ns}	0.14 ^{ns}	0.1 ^{ns}	1.98 ^{ns}	-26.41 ^{ns}
P4	-0.53 ^{ns}	1.04 ^{ns}	7.63 ^{ns}	0.18 ^{ns}	1.9 *	5.17 ^{ns}	445.97**
P5	0.9*	6.6**	13.28*	-0.16 ^{ns}	-0.62 ^{ns}	2.08 ^{ns}	-187.1 ^{ns}

** Significant at $P \leq 0.01$, *Significant at $P \leq 0.05$, ^{ns}Non-significant

Table 4: Estimated SCA effects for grain yield and related traits in hybrid combinations.

Hybrids	Days to 50% silking	Plant height (cm)	Leaf area (cm^2)	Kernel rows ear^{-1}	Kernels rows^{-1}	1000 kernel weight (g)	Grain yield (t-ha^{-1})
1 × 2	-1.33*	-6.18**	4.0 ^{ns}	1.17**	-1.58**	12.54 ^{ns}	-244.42 ^{ns}
1 × 3	0.67 ^{ns}	3.98 ^{ns}	4.19 ^{ns}	1.05**	4.54**	7.83 ^{ns}	254.27 ^{ns}
1 × 4	0.9 ^{ns}	12.52**	13.0 ^{ns}	0.47 ^{ns}	4.54 ^{ns}	19.3*	971.39**
1 × 5	0.81 ^{ns}	9.02**	-11.5 ^{ns}	-0.46 ^{ns}	0.0 ^{ns}	5.73 ^{ns}	-176.55 ^{ns}
2 × 3	-1.81**	34.53**	52.67**	-0.13 ^{ns}	4.83**	38.73**	1184.72**
2 × 4	0.1 ^{ns}	0.22 ^{ns}	-26.0**	-0.05 ^{ns}	-3.17**	-13.13*	-719.57**
2 × 5	-1.33*	4.51 ^{ns}	27.6**	-0.17 ^{ns}	-0.17 ^{ns}	16.97*	113.9 ^{ns}
3 × 4	-1.24	10.88**	10.8 ^{ns}	0.9**	1.29 ^{ns}	24.16**	671.25**
3 × 5	-4.67**	-0.84 ^{ns}	-1.9 ^{ns}	-0.23 ^{ns}	1.28 ^{ns}	10.59 ^{ns}	-14.47 ^{ns}
4 × 5	-1.1*	-2.44 ^{ns}	1.1 ^{ns}	0.59*	3.02**	35.73**	915.98**

** Significant at $P \leq 0.01$, *Significant at $P \leq 0.05$, ^{ns}Non-significant

Table 5: Mid-parent heterosis (MPH) and better parent heterosis (BPH) for grain yield and related traits.

Hybrids	Days to 50% silking		Plant height		Leaf area		Kernel rows ear^{-1}		Kernels rows^{-1}		1000-kernel weight		Grain yield	
	MPH%	**BPH%**	**MPH%**	**BPH%**	**MPH%**	**BPH%**	**MPH%**	**BPH%**	**MPH%**	**BPH%**	**MPH%**	**BPH%**	**MPH%**	**BPH%**
1 × 2	1.38^{ns}	-5.64 ^{ns}	8.98^{ns}	4.88 ^{ns}	14.23 ^{ns}	10.39 ^{ns}	15.26**	8.42^{ns}	1.29^{ns}	-12.74^{ns}	25.51*	9.66^{ns}	1.38^{ns}	-15.64^{ns}
1 × 3	4.9 ^{ns}	1.71 ^{ns}	24.78**	18.56*	14.01 ^{ns}	6.01 ^{ns}	16.04**	10.71^{ns}	52.81**	49.45**	29.08*	20.64^{ns}	41.91^{ns}	41.71^{ns}
1 × 4	6.81 ^{ns}	2.01 ^{ns}	25.95**	16.39*	9.13 ^{ns}	-5.55 ^{ns}	12.06*	7.18^{ns}	37.01**	16.31^{ns}	33.02*	19.25^{ns}	56.81**	32.01^{ns}
1 × 5	9.41 ^{ns}	2.93 ^{ns}	17.17*	0.85 ^{ns}	-2.77 ^{ns}	-16.47 ^{ns}	0.26^{ns}	-5.47^{ns}	15.24^{ns}	6.13^{ns}	24.70^{ns}	14.29^{ns}	9.41^{ns}	2.93^{ns}
2 × 3	-11.24**	-4.31*	67.37**	53.36**	51.87**	36.83*	3.52^{ns}	1.98^{ns}	36.91**	20.22*	46.34**	36.09**	61.24**	34.31*
2 × 4	-5.09 ^{ns}	-6.44 ^{ns}	16.36*	3.82 ^{ns}	-6.53 ^{ns}	-21.39 ^{ns}	4.79^{ns}	2.97^{ns}	-7.21 ^{ns}	-8.82^{ns}	10.46^{ns}	7.30^{ns}	-5.09^{ns}	-6.44 ^{ns}
2 × 5	3.22 ^{ns}	-0.74 ^{ns}	16.57*	-2.83 ^{ns}	25.43*	4.73 ^{ns}	-0.25^{ns}	-0.50^{ns}	3.73^{ns}	-3.60^{ns}	29.94*	23.27^{ns}	13.22^{ns}	-0.74^{ns}
3× 4	-12.32**	-5.23 ^{ns}	30.86**	27.07**	14.00 ^{ns}	5.48 ^{ns}	13.55*	13.27*	26.43**	9.36^{ns}	40.04**	33.89*	57.53**	32.77^{ns}
3 × 5	-17.53**	-12.77*	13.85*	2.54 ^{ns}	9.30 ^{ns}	0.30 ^{ns}	0.76^{ns}	-0.50^{ns}	27.27**	19.68^{ns}	32.44*	29.67*	28.84^{ns}	21.37^{ns}
4 × 5	8.84 ^{ns}	1.37 ^{ns}	5.27 ^{ns}	-2.59 ^{ns}	2.26 ^{ns}	1.36 ^{ns}	7.58^{ns}	5.97^{ns}	23.98**	13.37^{ns}	44.69**	41.21**	52.32**	35.2 *

** Significant at $P \leq 0.01$, *Significant at $P \leq 0.05$, ^{ns}Non-significant

CONCLUSION

Our results highlighted that none of a single hybrid was superior for all of traits and that hybrid superiority varied for each individual trait evaluated. The hybrid combination $P_2 \times P_3$ was marked as the best with highest heterotic effects regarding high yield among 10 hybrids tested considering its significant and positive SCA for yield related traits and highest grain yield. The cross combinations $P_3 \times P_5$ and $P_3 \times P_4$ were found suitable for the development of early maturity varieties while highest kernel rows ear^{-1} were obtained in the hybrid $P_3 \times P_4$ which is an important character having a positive correlation with grain yield. The hybrids $P_1 \times P_4$ yielded the highest number of kernels row^{-1} while $P_1 \times P_3$ combination was marked as the best for high heterotic effects for the said trait. The highest heterosis for 1000-kernel weight was obtained for $P_2 \times P_3$ along with a highly significant and positive SCA effects for this trait. The cross combinations presented in this study can be used for the improvement of specific traits highlighted in this study and further development of hybrid cultivars according to the needs of the farmers.

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