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HETEROTIC EFFECTS FOR YIELD RELATED ATTRIBUTES IN F_1 POPULATIONS OF MAIZE

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Abstract

Five white kernel maize inbred lines were crossed in a complete diallel fashion during spring season 2010 at Cereal Crops Research Institute (CCRI), Pirsabak - Nowshera, Khyber Pakhtunkhwa, Pakistan. The resulting 20 F_1 hybrids, five parental inbred lines and two checks (OPV 'Jalal' and 'Pioneer hybrid 30k08') were evaluated in field experiments during summer season 2011 at four different locations i.e., Cereal Crops Research Institute (CCRI), Nowshera, University of Haripur, Haripur, Agriculture Research Station (ARS), Baffa - Mansehra, and Agriculture Research Institute, Mingora - Swat, Khyber Pakhtunkhwa, Pakistan. All the experiments were laid out in a randomized complete block design with three replications with the objective to identify the suitable hybrid combinations on the basis of their genetic potential for commercial cultivation in Khyber Pakhtunkhwa. A Large number of F_1 hybrids revealed significant positive heterotic effects for grain yield and most of the yield contributing traits at Swat, followed by Baffa, Mansehra, Haripur and CCRI, Nowshera. Majority of the F_1 hybrids revealed significant positive mid and better parent heterotic effects for ear length, grain rows per ear, 1000-grain weight and grain yield at all the locations. For grain yield, F_1 hybrids like PSEV3 × FRHW-1 and PSEV3 × FRHW-2 at CCRI, FRHW-2 × FRHW-1 and SWAJK-1 × FRHW-1 at Haripur, FRHW-1 × SWAJK-1 at Mansehra and FRHW-2 × FRHW-3 and FRHW-1 × SWAJK-1 Mingora, Swat showed desirable and significant positive mid and better parents, economic and commercial heterosis. Therefore, these F_1 hybrids could be reliably recommended for cultivation in the tested locations and their use in the future breeding programs for developing high yielding maize genotypes.

Key words: Inbred lines, Diallel crosses, Mid & better parent heterosis, Economic & commercial heterosis, *Zea mays* L.

Introduction

Maize (*Zea mays* L.) is an important cereal crop of the world grown in irrigated and rainfed areas, and ranks third after wheat and rice (Gerpacio & Pingali, 2007). Maize utilizes solar radiations more efficiently than other cereals. It is an annual short day plant and belongs to family poaceae and tribe Maydeae. It is grown at an altitude of 3300 meters above sea level and from 50^0 N to 40^0S latitude in temperate, sub-tropical and tropical regions of the world (Iqbal, 2009). It can be grown on all types of soils ranging from sandy loam to clay loam. However, medium textured soil having pH values of 6.5 to 7.5 is the most suitable for its successful cultivation. Maize plant is monoecious and protandrous, and hot dry weather accelerates pollen shedding (Poehlman, 1977).

In Pakistan, maize is also third important cereal crop after wheat and rice (Hussain *et al*., 2011; Ali *et al*., 2018). Maize is cultivated as multipurpose crop for food, feed and fodder by the farming community, who largely lives in rural areas of Pakistan. The use of maize in Pakistan as direct human food is decreasing; however, its industrial use is increasing at a much faster rate. Currently in Pakistan, maize was grown on an area of 1.229 million hectares and total production was 5.702 million tones with average grain yield of 4.640 tons ha^{-1} (PBS, 2017-18). In Khyber Pakhtunkhwa province of Pakistan, after wheat, the maize is the second important summer cereal with an area of 0.451 million hectares and production of 0.865 million tons with average grain yield of 1.917 tons ha^{-1} (BS-PDP, 2016-17). In Khyber Pakhtunkhwa, more than 27% of the total cultivated area is cultivated by maize, which is second to wheat with total area of 42% (Iqbal *et al*., 2010; Ali *et al*., 2017). In the mountainous areas of Khyber Pakhtunkhwa, maize is utilized as an important staple food by the farming community as well as source of green and dry fodder for livestock (Iqbal *et al*., 2010; Khan *et al*., 2011).

Heterosis is a prerequisite for developing high yielding and economically viable maize hybrids. Production of such maize hybrids is largely dependent on a) ability of a breeder to exploit heterosis and b) knowledge of gene action involved in the expression of heterosis. Shull (1952) coined the term 'heterosis' which means the increase in vigor, size, speed of development, fruitfulness, resistance to biotic and abiotic stresses of the F_1 hybrids than their parental inbred lines. After that, many other maize breeders started working on hybrid vigor to benefit from that phenomenon. Mostly dominant gene action controls the inheritance of most maize characters, however, it is difficult to find out whether that dominance is partial to complete or in over-dominance range (Hallauer & Miranda, 1981; Ali *et al*., 2017, 2018). Generally, heterosis has been assessed in genetically different populations which mix-up the associations among dominance and gene frequency. Some previous studies revealed that heterozygosity of each parental pair is significantly associated with the general combining ability and not with specific combining ability. However, neither genetic diversity nor heterozygosity is a good indicator for predicting heterosis (Liu & Wu, 1998).

For more than a century, breeders all over the world are working on heterosis/hybrid vigor; however, basic causes that contribute to heterosis are still unclear (Coors & Pandey, 1999; Li *et al*., 2018). Despite the lack of clear understanding, literature acknowledges increase in vigor and productivity of many domesticated species by the successful utilization of heterosis (Springer & Stupar, 2007). Heterosis estimation is helpful in evaluation of parent's performance in hybrid combinations. Significant commercial heterosis was observed for all the drought tolerant traits such as soil-plant analyses development (SPAD) chlorophyll meter reading, specific leaf area, anthesis silking interval, carbon isotope discrimination and grain yield (Venkatesha *et al*., 2013). An increase in yield by 15% per year has been recorded by use of heterosis in maize F_1 hybrids (Duvick, 1999). Correlations of better parent heterosis with performance of parental genotypes and hybrids were of comparable magnitude which revealed that both inbred lines and hybrids are contributing to observed genotype-by-environment interactions for heterosis in maize (Li *et al*., 2018). In previous studies, 7 × 7 diallel hybrids were evaluated to find out heterosis and the performance of cross combinations in maize, and observed commercial heterosis ranged from -17.60 to 9.71%, -20.41 to 8.04%, -13.89 to 7.54% and -6.17 to 14.48% for grain yield, grains per ear, ear length and ear diameter, respectively (Amiruzzaman *et al*., 2010). Keeping in view the importance of hybrid vigor, an attempt was made to develop F_1 diallel hybrids so as to study their genetic potential at different locations of Khyber Pakhtunkhwa, Pakistan.

Materials and Methods

Plant material, design and procedure: Five white kernel maize inbred lines with distinct genetic make-up were crossed in a complete diallel fashion during spring season 2010 at Cereal Crops Research Institute (CCRI), Pirsabak - Nowshera, Khyber Pakhtunkhwa (Table 1). The resulting 20 F_1 hybrids, five parental inbred lines and two check genotypes (OPV 'Jalal' and 'Pioneer hybrid 30K08') were evaluated during summer season 2011 through field experiments at four different locations i.e., Cereal Crops Research Institute (CCRI), Pirsabak-Nowshera, Agricultural Research Institute (North) Mingora-Swat, Agricultural Research Station, Baffa - Mansehra, and the University of Haripur, Haripur- Khyber Pakhtunkhwa, Pakistan. All the experiments were laid out in a randomized complete block design (RCBD) with three replications at all the locations. Experimental sub-plots were comprised of four rows five meters long for all entries. Rows and plants spacing were kept 75 and 25 cm, respectively in all the experiments. Recommended cultural practices and inputs were uniformly applied to all the genotypes at all the locations to minimize the field environmental variations. From the central two rows, ten plants were randomly selected and used for recording the data for each character in each treatment, replication and location.

Measurement of traits: For ear length, ten randomly selected ears were measured in cm and averaged with a measuring tape. For grains rows per ear, ten ears in each subplot were randomly selected and number of grains rows per ear were counted and averaged. Random sample of 1000 grains were taken from final produce of each entry and their weight (g) was recorded by using electric balance. Grain yield of each genotype was calculated in kg after harvesting and adjusting fresh ear weight to 150 g kg^{-1} grain moisture by using following formula (Carangal *et al*., 1971).

$$\text{Grain yield (kg ha}^{-1}) = \frac{(100\text{-MC}) \times \text{FEW} \times \text{Shelling coefficient}}{(100\text{-}15) \times \text{Plot area}} \times 10{,}000$$

where;
MC= Moisture content (%) in grains at harvest
FEW = Fresh ear weight (kg) at harvest
Shelling coefficient = Shelling percentage/100

Table 1. Name and pedigree of parental inbred lines and their F_1 diallel hybrids.

S. No.	Inbred lines	Code of inbred lines	Pedigree
1.	FRHW-22(F2)-5	FRHW-1	Male Parental Single cross of Babar
2.	FRHW-22(F2)-4-7	FRHW-2	Male Parental Single cross of Babar
3.	FRHW-20-4	FRHW-3	Female Parental Single cross of Babar
4.	PSEV3-120-2-2-2	PSEV3	Derived from white maize population PSEV3 (Base population of commercial OPV Jalal)
5.	SWAJK-6-6-3-6	SWAJK-1	Derived from open pollinated long duration variety Sarhad White

S. No.	F_1 hybrids	S. No.	F_1 hybrids
1.	FRHW-1× FRHW-2	11.	FRHW-3 × PSEV3
2.	FRHW-1 × FRHW-3	12.	FRHW-3 × SWAJK-1
3.	FRHW-1 × PSEV3	13.	PSEV3 × FRHW-1
4.	FRHW-1 × SWAJK-1	14.	PSEV3 × FRHW-2
5.	FRHW-2 × FRHW-1	15.	PSEV3 × FRHW-3
6.	FRHW-2 × FRHW-3	16.	PSEV3 × SWAJK-1
7.	FRHW-2 × PSEV3	17.	SWAJK-1 × FRHW-1
8.	FRHW-2 × SWAJK-1	18.	SWAJK-1 × FRHW-2
9.	FRHW-3 × FRHW-1	19.	SWAJK-1 × FRHW-3
10.	FRHW-3 × FRHW-2	20.	SWAJK-1 × PSEV3

Statistical analyses: Genotype by environment interaction analysis was carried out according to Gomez and Gomez (1984). Heterosis over mid-parent was calculated in terms of percent increase (+) or decrease (-) of the F_1 hybrids over its mid parent value at all the locations as suggested by Fehr (1987).

$$Heterosis\ \% = \frac{F_1 - MP}{MP} \times 100$$

Heterobeltiosis as coined by Fonseca (1965) was estimated in terms of percent increase or decrease of the F_1 hybrid over its better parent.

$$Heterobeltiosis\ \% = \frac{F_1 - BP}{BP} \times 100$$

Economic heterosis was also calculated by comparison of F_1 hybrids with existing commercial open pollinated variety 'OPV Jalal' using the following formula:

$$Economic\ Heterosis\ (\%) = \frac{\overline{F_1} - \overline{CV}}{\overline{CV}} \times 100$$

Commercial heterosis was also estimated with the help of following formula using commercial hybrid (CH) 'Pioneer 30K08' in comparison.

$$Commercial\ Heterosis\ (\%) = \frac{\overline{F_1} - \overline{CH}}{\overline{CH}} \times 100$$

Heterotic values for all the above four categories of heterosis were further subjected to 't' test to determine whether F_1 hybrid means were statistically different from their mid and better parents, check cultivar and hybrid. The 't' values were computed by the following formulas (Wynne *et al*., 1970).

't' for mid-parent heterosis $$t = \frac{F_1 - MP}{\sqrt{\frac{3}{2r}(EMS)}}$$

't' for better parent heterosis $$t = \frac{F_1 - BP}{\sqrt{\frac{2}{r}(EMS)}}$$

where
MP = Mid parent value of the particular F_1 hybrid
BP = Better parent value in the particular F_1 hybrid
EMS = Error mean square

The 't' values for economic and commercial heterosis were calculated by the following formulas (Falconer & Mackay, 1996).

t (Economics heterosis) = SH/SE(d)

t (Commercial heterosis) = CH/SE(d

$$SE\ (d)\ for\ EH\ or\ CH = \pm\ t = \sqrt{2Me/r}$$

where
SE(d) = Standard error
Me = Error mean square
r = Number of replications
t = Obtained value was tested against the tabulated t-value at error degree of freedom

Results and Discussion

According to combined analysis of variance, genotypes, environments (locations) and genotype by environment interaction effects revealed significant ($p \leq 0.01$) differences for all the studied traits (Table 2). In present study, the significance of genotypes, environments and genotype by environment interactions, authenticated that differences might be due to different genetic makeup of maize genotypes and their interaction with environments. Significant differences were found among the maize genotypes studied for yield related traits in diverse environments (Ahmad *et al*., 2011; EL-Hosary *et al*., 2014). Presence of significant differences among parents and crosses revealed the choice of exploitation of heterosis for all the trait in maize across the three locations (Panda *et al*., 2017). Previous studies revealed that significant differences were observed among maize hybrids for yield and yield components and concluded that these differences might be due to varied genetic background of the genotypes (Ali *et al*., 2007; Malik *et al*., 2010; Nzuve *et al*., 2014).

Ear length: Regarding mid and better parent heterosis for ear length at CCRI, all the F_1 hybrids manifested significant positive mid and better parent heterosis (Table 3). Significant positive mid parent heterosis ranged from 23.41% (PSEV3 × FRHW-1) to 77.83% (FRHW-3 × SWAJK-1) for ear length. Three other F_1 hybrids followed were; PSEV3 × FRHW-3 (65.01%), SWAJK-1 × FRHW-3 (63.20%) and FRHW-3 × FRHW-2 (61.86%). For better parent heterosis, the range was 8.86% (FRHW-1 × FRHW-2) to 73.63% (FRHW-3 × SWAJK-1) for ear length. Latter promising F_1 hybrid for ear diameter was followed by three other F_1 hybrids i.e., SWAJK-1 × FRHW-3 (59.34%), FRHW-3 × FRHW-2 (58.89%) and SWAJK-1 × FRHW-2 (58.79%). Economic heterosis for ear length was maximum in hybrid PSEV3 × FRHW-3 (12.93%) and that was followed by FRHW-3 × PSEV3 (7.48%) and FRHW-3 × SWAJK-1 (7.48%) and minimum and same value (2.04%) was recorded in two other F_1 hybrids i.e., FRHW-2 × FRHW-1 and PSEV3 × FRHW-1. In case of commercial heterosis, single F_1 hybrid PSEV3 × FRHW-3 (4.40%) showed increase in ear length than commercial check hybrid at CCRI.

Table 2. Mean squares for various traits in 5 × 5 F_1 diallel hybrids of maize evaluated at four locations.

Traits	Genotypes (G) (d.f. = 26)	Locations (L) (d.f. = 3)	Reps. within location (d.f. = 8)	G × L (d.f. = 78)	Error (d.f. = 208)	CV (%)
Ear length	59.879**	222.264**	3.740**	3.455**	0.496	4.29
Grain rows ear^{-1}	9.1805**	22.6874**	0.0931ns	1.7049**	0.1489	2.81
1000-grain weight	0.03745**	0.20166**	0.00155*	0.00328**	0.00071	8.57
Grain yield (kg ha^{-1})	5.750E+07**	2.303E+08**	329509ns	3591133**	179730	4.68

Table 3. Mid-, better parent, economic and commercial heterosis for ear length in 5 × 5 diallel crosses of maize at CCRI, Haripur, Mansehra and Swat, Pakistan.

F_1 Hybrids	Ear length															
	CCRI				Haripur				Mansehra				Swat			
	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)
FRHW-1 × FRHW-2	28.09**	8.86*	-4.76	-11.95**	3.43	-13.20**	-21.07**	-23.60**	28.39**	9.21**	-23.23**	-22.85**	28.06**	7.40*	-19.01**	-22.21**
FRHW-1 × FRHW-3	42.31**	19.13**	4.22	-3.65	26.40**	5.83*	-3.76	-6.84**	45.81**	23.71**	-13.04**	-12.61**	32.91**	11.21*	-16.14**	-19.45**
FRHW-1 × PSEV3	29.16**	22.08**	6.80*	-1.26	5.57*	3.90	-2.43	-5.56*	7.67**	-1.86	-16.18**	-15.77**	16.27**	14.13**	-10.65**	-14.18**
FRHW-1 × SWAJK-1	32.97**	13.53**	-0.68	-8.18*	14.98**	8.55**	-1.29	-4.46**	28.88**	25.96**	-7.26**	-6.80*	36.15**	28.29**	-3.25	-7.08**
FRHW-2 × FRHW-1	37.24**	16.64**	2.04	-5.66	18.24**	-0.77	-9.76**	-12.66**	37.86**	17.26**	-17.57**	-17.16**	33.60**	12.05**	-15.50**	-18.84**
FRHW-2 × FRHW-3	58.46**	55.56**	-4.76	-11.95**	37.05**	36.66**	-15.69**	-18.40**	63.66**	63.14**	-19.58**	-19.18**	51.07**	50.62**	-23.05**	-26.09**
FRHW-2 × PSEV3	34.96**	20.52**	-6.12	-13.21**	13.62**	-5.86*	-11.60**	-14.44**	17.41**	-7.41*	-20.93**	-20.53**	44.74**	19.59**	-6.38*	-10.08**
FRHW-2 × SWAJK-1	57.24**	56.37**	-3.20	-10.50**	38.90**	22.51**	-1.07	-4.24*	45.53**	21.48**	-10.56**	-10.11**	51.30**	33.58**	-10.89**	-14.41**
FRHW-3 × FRHW-1	41.20**	18.20**	3.40	-4.40	35.45**	13.41**	3.13	-0.18	36.09**	15.46**	-18.84**	-18.44**	38.77**	16.11**	-12.44**	-15.90**
FRHW-3 × FRHW-2	61.86**	58.89**	-2.72	-10.06**	47.10**	46.69**	-9.50**	-12.41**	52.58**	52.10**	-25.02**	-24.65**	49.26**	48.81**	-23.98**	-26.98**
FRHW-3 × PSEV3	57.06**	37.99**	7.48*	-0.63	22.42**	1.20	-4.97	-8.02**	42.54**	12.15**	-4.22*	-3.75	38.21**	13.93**	-10.81**	-14.33**
FRHW-3 × SWAJK-1	77.83**	73.63**	7.48*	-0.63	29.89**	14.28**	-7.72**	-10.68**	40.64**	17.10**	-13.78**	-13.35**	57.04**	38.29**	-7.75**	-11.39**
PSEV3 × FRHW-1	23.41**	16.64**	2.04	-5.66	14.78**	12.96**	6.08*	2.67	23.90**	12.94**	-3.55	-3.07	34.65**	32.18**	3.48	-0.61
PSEV3 × FRHW-2	48.95**	33.01**	3.61	-4.21	8.89**	-9.79**	-15.29**	-18.00**	28.59**	1.40	-13.40**	-12.97**	40.05**	15.72**	-9.41**	-12.99**
PSEV3 × FRHW-3	65.01**	44.98**	12.93**	4.40	26.79**	4.80*	-1.58	-4.74**	33.53**	5.06*	-10.28**	-9.83**	39.94**	15.36**	-9.69**	-13.26**
PSEV3 × SWAJK-1	28.66**	15.46*	-10.07**	-16.86**	19.23**	10.88**	4.13	0.78	18.86**	10.67**	-5.48*	-5.02*	20.48**	11.57**	-12.66**	-16.11**
SWAJK-1 × FRHW-1	42.08**	21.31**	6.12	-1.89	10.48**	4.29	-5.16*	-8.20**	38.00**	34.88**	-0.69	-0.20	24.75**	17.55**	-11.35**	-14.85**
SWAJK-1 × FRHW-2	59.67**	58.79**	-1.70	-9.12**	27.42**	12.38**	-9.24**	-12.16**	43.52**	19.80**	-11.79**	-11.35**	55.01**	36.85**	-8.71**	-12.31**
SWAJK-1 × FRHW-3	63.20**	59.34**	-1.36	-8.81**	38.41**	21.78**	-1.66	-4.81*	51.68**	26.29**	-7.01**	-6.55*	64.20**	44.60**	-3.54	-7.35**
SWAJK-1 × PSEV3	48.91**	33.62**	4.08	-3.77	-1.94	-8.81**	-14.36**	-17.11**	18.22**	10.07**	-5.99*	-5.53**	40.53**	30.14**	1.88	-2.14

MPH = Mid parent heterosis, HPH = High parent heterosis, EH = Economic heterosis, CH = Commercial heterosis

Regarding ear length at Haripur, 19 F_1 hybrids revealed positive heterotic effects over mid parent (Table 3). Highest mid parent heterotic performance (47.10%) was observed in F_1 hybrid FRHW-3 × FRHW-2 while minimum in F_1 hybrid FRHW-1 × FRHW-2 (3.43%). Former F_1 hybrid was tailed by three other hybrids such as, FRHW-2 × SWAJK-1 (38.90%), SWAJK-1 × FRHW-3 (38.41%) and FRHW-2 × FRHW-3 (37.05%). For better parent heterosis, 15 F_1 hybrids showed positive values for ear diameter ranging from 1.20% (FRHW-3 × PSEV3) to 46.69% (FRHW-3 × FRHW-2) for ear length. Two other F_1 hybrids like FRHW-2 × FRHW-3 (36.66%) and FRHW-2 × SWAJK-1 (22.51%) also revealed maximum heterobeltiosis. For ear length, three F_1 hybrids exhibited positive economic heterosis and maximum value was recorded in PSEV3 × FRHW-1 (6.08%) while minimum (3.13%) in hybrid FRHW-3 × FRHW-1. For commercial heterosis, two F_1 hybrids like PSEV3 × FRHW-1 (2.67%) and PSEV3 × SWAJK-1 (0.78%) exhibited positive heterotic effects and showed maximum ear length than commercial check hybrid at Haripur.

All the F_1 hybrids revealed significant positive mid parent heterosis for ear length at Mansehra (Table 3). Significant maximum mid parent heterosis was recorded in F_1 hybrid FRHW-2 × FRHW-3 (63.66%) while minimum in FRHW-1 × PSEV3 (7.67%). Four other F_1 hybrids viz., FRHW-3 × FRHW-2, SWAJK-1 × FRHW-3, FRHW-1 × FRHW-3 and FRHW-2 × SWAJK-1 also revealed incredible mid parent heterotic values of 52.58, 51.86, 45.81 and 45.53%, respectively for ear length. In view of better parent heterosis for ear length, 18 F_1 hybrids presumed positive heterotic effects varying from 1.40% (PSEV3 × FRHW-2) to 63.14% (FRHW-2 × FRHW-3). These promising F_1 hybrids were followed by two other F_1 hybrids FRHW-3 × FRHW-2 (52.10%) and SWAJK-1 × FRHW-1 (34.88%). In case of economic and commercial heterosis for ear length, none of the F_1 hybrids surpassed check cultivars at Mansehra.

At Swat, all the F_1 hybrids exhibited significant positive mid and better parent heterosis for ear length varying from 16.27% (FRHW-1 × PSEV3) to 64.20 (SWAJK-1 × FRHW-3) for mid and 7.40% (FRHW-1 × FRHW-2) to 50.62% (FRHW-2 × FRHW-3) for better parent heterosis (Table 3). Latter promising F_1 hybrid for mid parent heterosis was followed by three other F_1 hybrids FRHW-3 × SWAJK-1 (57.04%), SWAJK-1 × FRHW-2 (55.01%) and FRHW-2 × SWAJK-1 (51.30%). In case of heterobeltiosis, two other F_1 hybrids FRHW-3 × FRHW-2 (48.81%) and SWAJK-1 × FRHW-3 (44.60%) also showed promising performance for ear length. With respect to economic heterosis for ear length, two F_1 hybrids i.e., PSEV3 × FRHW-1 (3.48%) and SWAJK-1 × PSEV3 (1.88%) showed positive heterotic effects. Positive commercial heterosis was observed in none of the F_1 hybrids for ear length at Swat.

At CCRI and Swat, all the F1 hybrids, while 19 and 15 at Haripur and 20 and 18 F_1 hybrids at Mansehra surpassed the mid and better parents, respectively for ear length. In case of economic heterosis, 11, 3 and 2 F_1 hybrids at CCRI, Haripur and Swat and none of F_1 hybrid at Mansehra revealed positive values, respectively. In case of commercial heterosis, 1, 2 and 2 F_1 hybrids at CCRI, Haripur and Swat manifested positive heterotic effects, respectively. Previous studies revealed significant positive mid-parent heterosis ranging from 11.11 to 27.66%, 13.51 to 17.95%, 7.07 to 47.66%, 23.93 to 82.39% and 8.84 to 25.18% for ear length, grain rows per ear, 100-grain weight, grain yield per plant and harvest index, respectively in maize (Dhoot *et al*., 2017). Past studies revealed positive heterotic values for mid and better parents with greater genetic variability among maize F_1 populations for yield related traits (Ali *et al*., 2013; Gorgulho & Filho, 2001; Suba *et al*., 2001). Similarly, Rajesh *et al*., (2014), Shah *et al*., (2014), Bekele & Rao (2013) and Singh *et al*., (2013) findings also revealed mid, better and commercial heterosis for ear traits in maize F_1 hybrids.

Grain rows per ear: For grain rows per ear at CCRI, 19 F_1 hybrids revealed positive mid parent heterosis (Table 4). However, maximum heterotic effects were exhibited by F_1 hybrid PSEV3 × FRHW-2 (20.11%), followed by FRHW-3 × FRHW-1 (15.97%), SWAJK-1 × FRHW-2 (15.57%) and FRHW-3 × PSEV3 (14.29%), while minimum by FRHW-1 × PSEV3 (2.20%). Similarly, 13 F_1 hybrids showed positive heterobeltiosis ranging from 0.49% (PSEV3 × SWAJK-1) to 19.43% (PSEV3 × FRHW-2) for grain rows per ear. Latter promising F_1 hybrid was followed by two other F_1 hybrids FRHW-3 × PSEV3 (12.00%) and PSEV3 × FRHW-3 (11.43%). In view of economic heterosis for grain rows per ear, 15 F_1 hybrids manifested positive values and maximum by FRHW-1 × SWAJK-1 (17.33%), followed by SWAJK-1 × FRHW-2 (16.80%) and SWAJK-1 × FRHW-1 (15.20%), while minimum in PSEV3 × FRHW-1 (0.80%). For commercial heterosis, eight F_1 hybrids showed positive values ranging from 0.98% (SWAJK-1 × FRHW-3) to 7.84% (FRHW-1 × SWAJK-1) for grain rows per ear at CCRI.

Regarding mid parent heterosis for grain rows per ear at Haripur, all the F_1 hybrids revealed positive heterosis varying from 0.26% (PSEV3 × FRHW-2) to 21.11% (SWAJK-1 × FRHW-1) (Table 4). Three other F_1 hybrids such as, FRHW-2 × PSEV3, FRHW-1 × PSEV3 and FRHW-1 × SWAJK-1 also followed with values of 15.76%, 15.73% and 15.58%, respectively. For better parent heterosis, 19 F_1 hybrids revealed positive heterobeltiosis ranging from 1.52% (PSEV3 × FRHW-3) to 16.43% (SWAJK-1 × FRHW-1). Three other F_1 hybrids i.e., FRHW-1 × PSEV3 (13.61%), FRHW-1 × SWAJK-1 (11.11%) and PSEV3 × FRHW-1 (10.47%) also exhibited high percentages of better parent heterosis for said trait. In economic heterosis for grain rows per ear, F_1 hybrid SWAJK-1 × FRHW-1 (19.01%) revealed maximum heterotic effects, followed by FRHW-1 × SWAJK-1 (13.58%), FRHW-3 × SWAJK-1 (12.59%) and SWAJK-1 × FRHW-3 (11.60%) while minimum by FRHW-2 × FRHW-3 (2.22%). Nineteen F_1 hybrids were found superior than commercial hybrid for grain rows per ear, and maximum grain rows per ear were recorded in F_1 hybrid SWAJK-1 × FRHW-1 (22.65%) followed by three other hybrids FRHW-1 × SWAJK-1 (17.05%), FRHW-3 × SWAJK-1 (16.03%) and SWAJK-1 × FRHW-3 (15.01%). Minimum commercial heterosis for grain rows per ear was recorded in F_1 hybrid PSEV3 × FRHW-3 (2.29%) at Haripur.

Table 4. Mid-, better parent, economic and commercial heterosis for grain rows ear^{-1} in 5 × 5 diallel crosses of maize at CCRI, Haripur, Mansehra and Swat, Pakistan.

F_1 Hybrids	Grain rows per ear															
	CCRI				Haripur				Mansehra				Swat			
	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)
FRHW-1 × FRHW-2	2.76	-1.59	-0.80	-8.82**	9.64**	6.40**	6.67**	9.92**	10.33**	5.29*	3.55*	15.87**	17.58**	2.65	-4.90*	2.65
FRHW-1 × FRHW-3	9.24**	3.17	4.00	-4.41*	12.60**	10.61**	8.15**	11.45**	9.18**	5.42*	1.18	13.23**	12.74**	10.05**	1.96	10.05**
FRHW-1 × PSEV3	2.20	-1.59	-0.80	-8.82**	15.73**	13.61**	7.16**	10.43**	26.92**	22.22**	9.22**	22.22**	9.84**	6.35**	-1.47	6.35**
FRHW-1 × SWAJK-1	11.39**	6.80**	17.33**	7.84**	15.58**	11.11**	13.58**	17.05**	27.89**	27.23**	14.89**	28.57**	16.16**	11.11**	12.75**	21.69**
FRHW-2 × FRHW-1	2.76	-1.59	-0.80	-8.82**	10.15**	6.90**	7.16**	10.43**	5.79**	0.96	-0.71	11.11**	16.36**	1.59	-5.88**	1.59
FRHW-2 × FRHW-3	13.78**	12.14**	3.47	-4.90*	3.24*	1.97	2.22	5.34*	1.22	0.00	-1.65	10.05**	19.63**	6.67**	-5.88**	1.59
FRHW-2 × PSEV3	7.47**	6.86**	-0.27	-8.33**	15.76**	10.34**	10.62**	13.99**	18.02**	8.65**	6.86**	19.58**	44.03**	29.38**	12.25**	21.16**
FRHW-2 × SWAJK-1	-0.26	-8.25**	0.80	-7.35**	5.37**	4.35**	6.67**	9.92**	7.77**	3.37*	1.65	13.76**	25.29**	5.31**	6.86**	15.34**
FRHW-3 × FRHW-1	15.97**	9.52**	10.40**	1.47	7.97**	6.06**	3.70	6.87**	5.61**	1.97	-2.13	9.52**	19.78**	16.93**	8.33**	16.93**
FRHW-3 × FRHW-2	4.99*	3.47	-4.53*	-12.25**	4.24**	2.96	3.21	6.36**	4.14**	2.88	1.18	13.23**	23.36**	10.00**	-2.94	4.76**
FRHW-3 × PSEV3	14.29**	12.00**	4.53*	-3.92*	10.99**	7.07**	4.69*	7.89**	3.70*	-3.45*	-7.33**	3.70	13.73**	12.78**	-0.49	7.41**
FRHW-3 × SWAJK-1	2.14	-7.28**	1.87	-6.37**	12.59**	10.14**	12.59**	16.03**	10.15**	6.90**	2.60	14.81**	13.18**	5.80**	7.35**	15.87**
PSEV3 × FRHW-1	3.85*	0.00	0.80	-7.35**	12.53**	10.47**	4.20*	7.38**	20.88**	16.40**	4.02*	16.40**	14.21**	10.58**	2.45	10.58**
PSEV3 × FRHW-2	20.11**	19.43**	11.47**	2.45	0.26	-4.43*	-4.20*	-1.27	8.09**	-0.48	-2.13	9.52**	54.09**	38.42**	20.10**	29.63**
PSEV3 × FRHW-3	13.70**	11.43**	4.00	-4.41*	5.24**	1.52	-0.74	2.29	14.29**	6.40**	2.13	14.29**	20.45**	19.44**	5.39*	13.76**
PSEV3 × SWAJK-1	8.66**	0.49	10.40**	1.47	9.97**	3.86*	6.17**	9.41**	27.32**	21.99**	10.17**	23.28**	6.77**	-0.97	0.49	8.47**
SWAJK-1 × FRHW-1	9.37**	4.85*	15.20**	5.88**	21.11**	16.43**	19.01**	22.65**	20.00**	19.37**	7.80**	20.63**	24.24**	18.84**	20.59**	30.16**
SWAJK-1 × FRHW-2	15.57**	6.31**	16.80**	7.35**	9.27**	8.21**	10.62**	13.99**	8.27**	3.85*	2.13	14.29**	33.33**	12.08**	13.73**	22.75**
SWAJK-1 × FRHW-3	10.16**	0.00	9.87**	0.98	11.60**	9.18**	11.60**	15.01**	14.72**	11.33**	6.86**	19.58**	10.08**	2.90	4.41*	12.70**
SWAJK-1 × PSEV3	9.19**	0.97	10.93**	1.96	9.97**	3.86*	6.17**	9.41**	18.03**	13.09**	2.13	14.29**	10.94**	2.90	4.41*	12.70**

MPH = Mid parent heterosis, HPH = High parent heterosis, EH = Economic heterosis, CH = Commercial heterosis

For grain rows per ear at Mansehra, all the F_1 hybrids had positive mid parent heterotic values (Table 4). Mid parent heterosis was ranging from 1.22% (FRHW-2 × FRHW-3) to 27.89% (FRHW-1 × SWAJK-1). However, high mid parent heterotic values of 27.32, 26.92 and 20.00% were also exhibited by three F_1 hybrids i.e., PSEV3 × SWAJK-1, FRHW-1 × PSEV3 and SWAJK-1 × FRHW-1, respectively. Regarding better parent heterosis, the heterotic effects ranged from 0.96% (FRHW-2 × FRHW-1) to 27.23% (FRHW-1 × SWAJK-1) for grain rows per ear. Latter best hybrid was also followed by three other F_1 hybrids viz., FRHW-1 × PSEV3, PSEV3 × SWAJK-1 and SWAJK-1 × FRHW-1 with heterotic values of 22.22, 21.99, and 19.37%, respectively. In economic heterosis for grain rows per ear, 15 F_1 hybrids showed positive values ranging from 1.18% (FRHW-1 × FRHW-3) to 14.89% (SWAJK-1 × FRHW-2). For commercial heterosis, all the F_1 hybrids exhibited significant positive values for grain rows per ear, ranging from 3.70% (FRHW-3 × PSEV3) to 28.57% (FRHW-1 × SWAJK-1). Latter best hybrid was followed by four other F_1 hybrids i.e., PSEV3 × SWAJK-1 (23.28%), FRHW-1 × PSEV3 (22.22%), FRHW-2 × PSEV3 (19.58%) and SWAJK-1 × FRHW-3 (19.58%) at Mansehra.

At Swat for grain rows per ear, all the F_1 hybrids showed significant positive mid-parent heterotic effects ranging from 6.77% (PSEV3 × SWAJK-1) to 54.09% (PSEV3 × FRHW-2) (Table 4). Latter hybrid was followed by three other F_1 hybrids FRHW-2 × PSEV3, SWAJK-1 × FRHW-2 and FRHW-2 × SWAJK-1 with values of 44.03, 33.33 and 25.29%, respectively. Better parent heterotic effects were recorded in 19 F_1 hybrids for grain rows per ear at Swat, and hybrid PSEV3 × FRHW-2 showed maximum high parent heterosis (38.42%), followed by FRHW-2 × PSEV3 (29.38%), PSEV3 × FRHW-3 (19.44%) and SWAJK-1 × FRHW-1 (18.84%) while PSEV3 × SWAJK-1 showed least better parent heterosis (0.49%). In economic heterosis, 14 F_1 hybrids exhibited positive values ranging from 1.59% (FRHW-2 × FRHW-3 and FRHW-2 × FRHW-1) to 30.16% (SWAJK-1 × FRHW-1). Latter F_1 hybrid was followed by three other F_1 hybrids i.e., PSEV3 × FRHW-2 (20.10%), SWAJK-1 × FRHW-2 (13.73%) and FRHW-2 × PSEV3 (12.25%). For commercial heterosis, all the F_1 hybrid revealed positive heterotic effects and maximum grain rows per ear were exhibited by F_1 hybrid SWAJK-1 × FRHW-1 (30.16) followed by PSEV3 × FRHW-2 (29.63%), SWAJK-1 × FRHW-2 (22.75%), FRHW-1 × SWAJK-1 (21.69%) and FRHW-2 × PSEV3 (21.16%) while minimum and same heterotic value (1.59%) was observed in two F_1 hybrids FRHW-2 × FRHW-3 and FRHW-2 × FRHW-1 at Swat.

All the 20 F_1 hybrids for mid parent, 13, 19, 17 and 19 for high parent, 15, 18, 15 and 14 for economic parent and 8, 19, 20 and 20 F_1 hybrids for commercial heterosis at CCRI, Haripur, Mansehra and Swat, respectively exhibited positive values for grain rows per ear. Present results for mid, better and commercial heterosis were in conformity with past findings as reported significant and varying magnitudes of heterosis in maize F_1 hybrids for grain rows per ear at diverse locations (Ali *et al*., 2014; Kumar *et al*., 2014; Shah *et al*., 2014). Significant positive heterosis was observed in F_1 hybrids for grain rows per ear and other yield related traits in maize at diverse locations (Bekele & Rao, 2013; Singh & Gupta, 2009; Matin *et al*., 2016).

1000-grain weight: At CCRI, all the F_1 hybrids showed significant positive mid and better parents heterosis and heterobeltiosis for 1000-grain weight (Table 5). The F_1 hybrid FRHW-3 × FRHW-2 revealed highest values of 64.71% and 47.37% over their mid and better parental inbred lines, respectively. Similarly the F_1 hybrid FRHW-1 × SWAJK-1 manifested the lowest values for mid parent (18.03%) and better parent (9.09%) heterosis for 1000-grain weight. Three other F_1 hybrids i.e., FRHW-3 × PSEV3 (63.16%), PSEV3 × FRHW-3 (56.14%) and FRHW-3 × FRHW-1 (54.46%) showed mid parent heterosis. F_1 hybrids PSEV3 × FRHW-1 (37.68%), FRHW-3 × FRHW-1 (36.84%) and FRHW-2 × FRHW-3 (36.84%) revealed better parent heterosis for 1000-grain weight. Two F_1 hybrids showed positive but similar values for economic as well as commercial heterosis i.e., PSEV3 × FRHW-1 (2.15%) and SWAJK-1 × PSEV3 (1.08%) for 1000-grain weight at CCRI.

For 1000-grain weight, all the F_1 hybrids revealed significant positive heterosis and heterobeltiosis at Haripur (Table 5). Mid parent heterotic effects varied from 61.49% (SWAJK-1 × FRHW-3) to 126.60% (FRHW-2 × FRHW-1), while 32.91% (FRHW-1 × SWAJK-1) to 95.65% (PSEV3 × SWAJK-1) for better parent. Three other F_1 hybrids i.e., FRHW-1 × FRHW-2 (115.96%), PSEV3 × FRHW-1 (10.13%) and SWAJK-1 × PSEV3 (103.31%) for mid parent and three SWAJK-1 × PSEV3 (94.30%), FRHW-2 × FRHW-1 (7.50%) and FRHW-3 × PSEV3 (74.31%) for high parent heterosis also revealed high heterotic effects for 1000-grain weight. In light of economic heterosis, four F_1 hybrids manifested positive values in which two were significant and varied from 2.47% (FRHW-3 × SWAJK-1) to 26.34% (SWAJK-1 × PSEV3) for 1000-grain weight. Four F_1 hybrids displayed positive values for commercial heterosis in which two reached to the significance level and ranging from 0.48% (FRHW-3 × SWAJK-1) to 23.89% (SWAJK-1 × PSEV3) for 1000-grain weight at Haripur.

At Mansehra, heterosis and heterobeltiosis for 1000-grain weight revealed positive effects for all the F_1 hybrids (Table 5). For mid parent heterosis, all the F_1 hybrids reached the significance level, while in case of better parent heterosis, 17 F_1 hybrids showed significant positive values. F_1 hybrid FRHW-3 × PSEV3 displayed the highest percentage (70.86%) of mid parent heterosis, followed by F_1 hybrids FRHW-2 × FRHW-1, SWAJK-1 × FRHW-3 and FRHW-2 × FRHW-3 with heterotic values of 66.67%, 66.67% and 60.32%, respectively for 1000-grain weight. F_1 hybrid PSEV3 × FRHW-1 revealed the lowest value (22.70%) for mid parent heterosis. For better parent heterosis, the F_1 hybrid FRHW-2 × FRHW-1 (66.67%) exhibited highest value while PSEV3 × FRHW-1 (6.38%) showed lowest percentage. Three other F_1 hybrids i.e., FRHW-1 × FRHW-2 (50.72%), FRHW-2 × FRHW-3 (46.38%) and FRHW-3 × FRHW-2 (39.13%) for better parents, also manifested values of high magnitudes for 1000-grain weight. For economic heterosis, four F_1 hybrids revealed positive values, and highest value (4.88%) is revealed by FRHW-3 × PSEV3, while lowest value (1.63%) by SWAJK-1 × FRHW-3 for 1000-grain weight. For commercial heterosis, none of the F_1 hybrids manifested positive values for 1000-grain weight at Mansehra.

Table 5. Mid-, better parent, economic and commercial heterosis for 1000-grain weight in 5 × 5 diallel crosses of maize at CCRI, Haripur, Mansehra and Swat, Pakistan.

F_1 Hybrids	1000-grain weight															
	CCRI				Haripur				Mansehra				Swat			
	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)
FRHW-1 × FRHW-2	27.43**	26.32**	-22.58**	-22.58**	115.96**	69.17**	-16.46**	-18.08**	50.72**	50.72**	-15.45**	-21.21**	53.13**	40.00**	-16.95*	-22.63**
FRHW-1 × FRHW-3	48.51**	33.93**	-19.35**	-19.35**	91.23**	57.97**	-10.29*	-12.03*	39.68**	27.54**	-28.46**	-33.33**	42.86**	36.84**	-26.55**	-31.58**
FRHW-1 × PSEV3	29.60**	17.39*	-12.90*	-12.90*	76.92**	43.75**	-14.81**	-16.46**	57.06**	36.17**	4.07	-3.03	38.70**	4.02	2.26	-4.74
FRHW-1 × SWAJK-1	18.03*	9.09	-22.58**	-22.58**	69.35**	32.91**	-13.58**	-15.25**	25.93**	9.68	-17.07**	-22.73**	29.96**	-1.76	-5.65	-12.11*
FRHW-2 × FRHW-1	25.66**	24.56**	-23.66**	-23.66**	126.60**	77.50**	-12.35*	-14.04**	66.67**	66.67**	-6.50	-12.88**	64.58**	50.48**	-10.73	-16.84**
FRHW-2 × FRHW-3	52.94**	36.84**	-16.13*	-16.13*	79.66**	53.62**	-12.76*	-14.45**	60.32**	46.38**	-17.89**	-23.48**	63.00**	55.24**	-7.91	-14.21*
FRHW-2 × PSEV3	39.68**	27.54**	-5.38	-5.38	91.74**	61.11**	-4.53	-6.38	36.20**	18.09**	-9.76	-15.91**	48.39**	18.97**	16.95*	8.95
FRHW-2 × SWAJK-1	25.20**	16.67*	-17.20**	-17.20**	75.78**	42.41**	-7.41	-9.20*	23.46**	7.53	-18.70**	-24.24**	19.56**	-3.29	-7.12	-13.47
FRHW-3 × FRHW-1	54.46**	36.84**	-16.13*	-16.13*	102.63**	67.39**	-4.94	-6.78	44.44**	31.88**	-26.02**	-31.06**	43.96**	37.89**	-25.99**	-31.05**
FRHW-3 × FRHW-2	64.71**	47.37**	-9.68	-9.68	88.14**	60.87**	-8.64	-10.41*	52.38**	39.13**	-21.95**	-27.27**	71.00**	62.86**	-3.39	-10.00
FRHW-3 × PSEV3	63.16**	34.78**	0.00	0.00	78.01**	74.31**	3.29	1.29	70.86**	37.23**	4.88	-2.27	32.34**	2.30	0.56	-6.32
FRHW-3 × SWAJK-1	47.75**	24.24**	-11.83*	-11.83*	68.24**	57.59**	2.47	0.48	52.00**	22.58**	-7.32	-13.64**	37.36**	7.06	2.82	-4.21
PSEV3 × FRHW-1	52.00**	37.68**	2.15	2.15	105.13**	66.67**	-1.23	-3.15	22.70**	6.38	-18.70**	-24.24**	48.66**	11.49	9.60	2.11
PSEV3 × FRHW-2	39.68**	27.54**	-5.38	-5.38	85.12**	55.56**	-7.82	-9.60*	25.15**	8.51	-17.07**	-22.73**	25.45**	0.57	-1.13	-7.89
PSEV3 × FRHW-3	56.14**	28.99**	-4.30	-4.30	68.09**	64.58**	-2.47	-4.36	40.40**	12.77**	-13.82**	-19.70**	42.01**	9.77	7.91	0.53
PSEV3 × SWAJK-1	24.44**	21.74**	-9.68	-9.68	78.81**	95.65**	11.11*	8.96**	35.83**	35.11**	3.25	-3.79	19.77**	18.39**	16.38*	8.42
SWAJK-1 × FRHW-1	18.03*	9.09	-22.58**	-22.58**	79.84**	41.14**	-8.23	-10.01*	43.21**	24.73**	-5.69	-12.12**	36.19**	2.94	-1.13	-7.89
SWAJK-1 × FRHW-2	18.70**	10.61	-21.51**	-21.51**	77.34**	43.67**	-6.58	-8.39	33.33**	16.13**	-12.20*	-18.18**	35.56**	9.65	5.31	-1.89
SWAJK-1 × FRHW-3	40.54**	18.18*	-16.13*	-16.13*	61.49**	51.27**	-1.65	-3.55	66.67**	34.41**	1.63	-5.30	19.25**	-7.06	-10.73	-16.84**
SWAJK-1 × PSEV3	39.26**	36.23**	1.08	1.08	103.31**	94.30**	26.34**	23.89**	17.65**	17.02**	-10.57*	-16.67**	27.91**	26.44**	24.29**	15.79**

MPH = Mid parent heterosis, HPH = High parent heterosis, EH = Economic heterosis, CH = Commercial heterosis

For 1000-grain weight, at Swat, mid parent heterosis was significant positive for all the F_1 hybrids ranging from 19.25% (SWAJK-1 × FRHW-3) to 71.00% (FRHW-3 × FRHW-2) (Table 5). Latter promising F_1 hybrid was followed by three other F_1 hybrids i.e., FRHW-2 × FRHW-1 (64.58%), FRHW-2 × FRHW-3 (63.00%) andFRHW-1 × FRHW-2 (53.13%). In case of better parent heterosis for 1000-grain weight, 17 F_1 hybrids manifested positive values in which 12 reached at significance level, and ranged from 0.57% (PSEV3 × FRHW-2) to 62.86% (FRHW-3 × FRHW-2). Latter promising F_1 hybrid was followed by three other F_1 hybrids i.e., FRHW-2 × FRHW-3, FRHW-2 × FRHW-1 and FRHW-1 × FRHW-2 with heterotic values of 55.24, 50.48 and 40.00%, respectively. In economic heterosis for 1000-grain weight**,** nine F_1 hybrids showed positive values in which four were significant and F_1 hybrid SWAJK-1 × PSEV3 (24.29%) revealed highest value for economic heterosis followed by FRHW-2 × PSEV3 (16.95%) and PSEV3 × SWAJK-1 (16.38%). Minimum value for economic heterosis (0.56%) was observed in F_1 hybrid FRHW-3 × PSEV3. For commercial heterosis, five F_1 hybrids depicted positive values in which two achieved significance and varying from 0.53 (PSEV3 × FRHW-3) to 15.79% (SWAJK-1 × PSEV3) for 1000-grain weight at Swat.

Mostly significant positive mid and better parent heterotic effects were recorded for 1000-grain weight at all the locations. For economic and commercial heterosis, two each at CCRI, four each at Haripur, four and zero at Mansehra and nine and five F_1 hybrids at Swat, respectively were superior for 1000-grain weight against their respective checks. Regarding mid and better parent heterosis, varying level of heterosis for grain weight was also advocated in maize F_1 hybrids studied at diverse locations (Abuali *et al*., 2012; Aghaei *et al*., 2012; Amanullah *et al*., 2011; Suba *et al*., 2001). Whereas, Kumar *et al*., (2014), Ali *et al*., (2014), Bekele & Rao (2013) and Singh *et al*., (2013) also recorded positive heterosis over mid, better and commercial parent for 1000-grain weight in maize F_1 populations. Previous studies on heterosis indicated the expression of standard heterosis and heterobeltiosis in numerous maize hybrids for majority of the traits including 1000-grain weight in both desirable and undesirable direction (Sharma *et al*., 2017).

Grain yield (kg ha^{-1}): For grain yield at CCRI, all the F_1 hybrids manifested significant positive mid and better parent heterosis (Table 6). Mid parent heterosis was ranging from 37.95% (PSEV3 × SWAJK-1) to 144.25% (PSEV3 × FRHW-1). Latter promising F_1 hybrid was followed by four other high yielding hybrids PSEV3 × FRHW-3 (131.78%), FRHW-3 × PSEV3 (118.60%), FRHW-2 × PSEV3 (103.32%) and FRHW-1 × FRHW-3 (100.35%). For better parent heterosis, F_1 hybrid PSEV3 × FRHW-1 (122.32%) exhibited significant positive heterotic effects for grain yield, followed by four other high yielding F_1 hybrids PSEV3 × FRHW-3 (120.89%), FRHW-3 × PSEV3 (108.32%), FRHW-2 × PSEV3 (93.03%) and FRHW-1 × FRHW-3 (90.89%). For economic heterosis, 12 F_1 hybrids revealed positive values, in which 11 achieved significance for grain yield and maximum grain yield was recorded in F_1 hybrid PSEV3 × FRHW-1 (25.63%), followed by three hybrids PSEV3 × FRHW-3 (24.82%), FRHW-2 × PSEV3 (21.36%) and SWAJK-1 × FRHW-2 (19.94%). Minimum heterotic value of 5.74% was recorded in F_1 hybrid PSEV3 × FRHW-2. In case of commercial heterosis, none of the F_1 hybrids out yielded the commercial check hybrid in grain yield at CCRI.

All the F_1 hybrids revealed significant positive heterosis over mid and better parents at Haripur (Table 6). Highest mid parent heterotic performance (197.40%) was observed in F_1 hybrid FRHW-2 × FRHW-1 while minimum (42.29%) in SWAJK-1 × FRHW-3. Former promising F_1 hybrid was followed by five other high yielding hybrids i.e., FRHW-2 × FRHW-3 (162.19%), SWAJK-1 × FRHW-1 (160.08%), PSEV3 × FRHW-1 (159.46%), FRHW-1 × FRHW-2 (147.51%) and FRHW-2 × PSEV3 (147.411%). In better parent heterosis for grain yield, the range was 28.49% (SWAJK-1 × FRHW-3) to 173.87% (FRHW-2 × FRHW-1) and latter hybrid was followed by three other F_1 hybrids i.e., FRHW-1 × FRHW-2 (127.97%), FRHW-2 × FRHW-3 (99.47%) and PSEV3 × FRHW-1 (97.05%). For economic heterosis, two F_1 hybrids i.e., SWAJK-1 × FRHW-1 (12.24%) and PSEV3 × FRHW-1 (9.17%) exhibited significant positive values and proved to be high yielding than check cultivar (Jalal). For commercial heterosis, none of the F_1 hybrids exhibited positive heterotic value for grain yield at Haripur.

At Mansehra, all the F_1 hybrids manifested significant positive effects for mid and better parent heterosis for grain yield (Table 6). Maximum mid parent heterosis was recorded in PSEV3 × SWAJK-1 (197.66%) while minimum in FRHW-1 × FRHW-2 (55.93%). Four other F_1 hybrids i.e., FRHW-1 × FRHW-2, FRHW-1 × SWAJK-1, SWAJK-1 × PSEV3 and FRHW-3 × PSEV3 also followed and revealed desirable mid parent heterosis of 175.56, 175.02, 145.82 and 141.28%, respectively. In better parent heterosis for grain yield, the range was 41.55% (FRHW-1 × FRHW-2) to 150.79% (FRHW-1 × SWAJK-1) and latter promising F_1 hybrid was followed by three other high yielding F_1 hybrids i.e., FRHW-1 × FRHW-2 (138.40%), PSEV3 × SWAJK-1 (138.38%) and SWAJK-1 × FRHW-3 (120.90%). In case of economic heterosis, eight F_1 hybrids revealed positive heterotic values in which six gain significance and ranging from 0.65% (FRHW-2 × FRHW-3) to 34.05% (FRHW-1 × SWAJK-1). In commercial heterosis for grain yield, nine F_1 hybrids revealed positive heterotic values, in which six achieved significance for grain yield and varying from 1.21% (SWAJK-1 × FRHW-2) to 36.99% (FRHW-1 × SWAJK-1). The latter high yielding F_1 hybrid was also followed by two other F_1 hybrids i.e., PSEV3 × SWAJK-1 (30.21%) and SWAJK-1 × FRHW-3 (20.66%) for grain yield at Mansehra.

Table 6. Mid-, better parent, economic and commercial heterosis for grain yield in 5 × 5 diallel crosses of maize at CCRI, Haripur, Mansehra and Swat, Pakistan.

F_1 Hybrids	Grain yield (kg ha^{-1})															
	CCRI				Haripur				Mansehra				Swat			
	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)	MPH (%)	HPH (%)	EH (%)	CH (%)
FRHW-1 × FRHW-2	56.85**	36.25**	-14.34**	-41.81**	147.51**	127.93**	-34.47**	-43.18**	55.93**	41.55**	-23.58**	-21.90**	84.59**	71.90**	-13.01**	-20.95**
FRHW-1 × FRHW-3	100.35**	90.89**	-2.27	-33.61**	109.67**	69.79**	-21.22**	-31.69**	116.08**	113.58**	-3.72	-1.61	123.56**	94.82**	-1.41	-10.40**
FRHW-1 × PSEV3	66.13**	51.21**	-14.56**	-41.96**	88.30**	43.01**	-20.77**	-31.31**	121.72**	91.83**	-15.53**	-13.68**	54.10**	39.88**	-13.19**	-21.11**
FRHW-1 × SWAJK-1	64.20**	38.69**	-6.73	-36.64**	106.60**	54.90**	-10.84**	-22.70**	175.02**	150.79**	34.05**	36.99**	114.03**	89.61**	24.33**	12.98**
FRHW-2 × FRHW-1	57.48**	36.80**	-13.99**	-41.57**	197.40**	173.87**	-21.26**	-31.73**	86.56**	69.36**	-8.56**	-6.56*	98.57**	84.92**	-6.41*	-14.96**
FRHW-2 × FRHW-3	88.94**	71.40**	7.76	-26.79**	162.19**	99.47**	-7.45*	-19.75**	103.19**	86.42**	0.65	2.85	151.25**	133.82**	2.06	-7.25**
FRHW-2 × PSEV3	103.32**	93.03**	21.36**	-17.56**	147.41**	77.74**	-1.53	-14.62**	125.38**	79.81**	-2.92	-0.79	97.10**	67.86**	4.18	-5.33*
FRHW-2 × SWAJK-1	71.68**	66.08**	11.70**	-24.12**	123.74**	58.90**	-8.53**	-20.70**	79.99**	79.09**	-3.31	-1.19	78.91**	49.01**	-2.29	-11.21**
FRHW-3 × FRHW-1	91.64**	82.58**	-6.52	-36.50**	131.52**	87.49**	-13.01**	-24.57**	101.44**	99.10**	-10.25**	-8.28**	103.66**	77.48**	-10.18**	-18.38**
FRHW-3 × FRHW-2	88.13**	70.66**	7.30	-27.11**	137.60**	80.76**	-16.13**	-27.28**	68.71**	54.79**	-16.43**	-14.60**	112.14**	97.42**	-13.82**	-21.69**
FRHW-3 × PSEV3	118.60**	108.32**	17.72**	-20.03**	78.45**	63.95**	-9.17**	-21.25**	141.28**	106.70**	-6.82*	-4.78	116.27**	73.64**	7.77**	-2.07
FRHW-3 × SWAJK-1	90.24**	67.53**	12.67**	-23.46**	91.32**	72.77**	-0.55	-13.78**	105.95**	89.82**	1.46	3.68	72.06**	35.36**	-11.25**	-19.35**
PSEV3 × FRHW-1	144.25**	122.32**	25.63**	-14.66**	159.46**	97.05**	9.17**	-5.34*	175.56**	138.40**	4.98*	7.28*	80.74**	64.06**	1.82	-7.47**
PSEV3 × FRHW-2	77.16**	68.19**	5.74	-28.17**	103.86**	46.46**	-18.86**	-29.65**	89.78**	51.41**	-18.25**	-16.46**	83.78**	56.52**	-2.86	-11.73**
PSEV3 × FRHW-3	131.78**	120.89**	24.82**	-15.21**	84.65**	69.65**	-6.01*	-18.51**	140.55**	106.08**	-7.10*	-5.07	83.47**	47.31**	-8.58**	-16.93**
PSEV3 × SWAJK-1	37.95**	26.93**	-14.64**	-42.01**	66.07**	62.96**	-6.20*	-18.67**	197.66**	138.38**	27.42**	30.21**	81.93**	77.06**	16.10**	5.50*
SWAJK-1 × FRHW-1	68.05**	41.94**	-4.54	-35.15**	160.08**	94.99**	12.24**	-2.69	132.68**	112.18**	13.41**	15.90**	88.32**	66.84**	9.40**	-0.59
SWAJK-1 × FRHW-2	84.35**	78.34**	19.94**	-18.52**	138.78**	69.59**	-2.38	-15.36**	84.37**	83.45**	-0.96	1.21	70.17**	41.73**	-7.07**	-15.55**
SWAJK-1 × FRHW-3	86.54**	64.27**	10.48**	-24.95**	42.29**	28.49**	-26.04**	-35.87**	139.67**	120.90**	18.07**	20.66**	98.12**	55.86**	2.20	-7.13**
SWAJK-1 × PSEV3	77.66**	63.47**	9.94*	-25.32**	69.23**	66.06**	-4.41	-17.12**	145.82**	96.86**	5.23*	7.53*	56.08**	51.91**	-0.39	-9.49**

MPH = Mid parent heterosis, HPH = High parent heterosis, EH = Economic heterosis, CH = Commercial heterosis

At Swat, all the F_1 hybrids exhibited significant positive mid and better parent heterosis for grain yield (Table 6). Mid parent heterosis was varying from 54.10% (FRHW-1 × PSEV3) to 151.25 (FRHW-2 × FRHW-3). Latter promising F_1 hybrid was followed by four other F_1 hybrids FRHW-1 × FRHW-3 (123.56%), FRHW-3 × PSEV3 (116.27%) and FRHW-1 × SWAJK-1 (114.03%). In case of better parent heterosis for grain yield, the range was 35.36% (FRHW-3 × SWAJK-1) to 133.82% (FRHW-2 × FRHW-3) and latter high yielding F_1 hybrid was followed by three other F_1 hybrids i.e., FRHW-3 × FRHW-2 (97.42%), FRHW-1 × FRHW-3 (94.82%) and FRHW-1 × SWAJK-1 (89.61%). In economic heterosis for grain yield, eight F_1 hybrids showed positive values, in which five were significant. Maximum economic heterosis was recorded in F_1 hybrid FRHW-1 × SWAJK-1 (24.33%), followed by PSEV3 × SWAJK-1 (16.10%) and SWAJK-1 × FRHW-1 (9.49%) while minimum in FRHW-1 × FRHW-2 (1.82%). Significant positive commercial heterosis was observed in two F_1 hybrids i.e., FRHW-1 × SWAJK-1 (12.98%) and PSEV3 × SWAJK-1 (5.50%) for grain yield at Swat.

Regarding mid and better parent heterosis, all the F_1 hybrids surpassed mid and better parent inbred lines for grain yield. However, twelve, two, eight and eight F_1 hybrids at CCRI, Haripur, Mansehra and Swat, respectively out yielded the check OPV in grain yield. For commercial heterosis, nine and two F_1 hybrids at Mansehra and Swat, respectively showed positive values, while at CCRI and Haripur all the F_1 hybrids showed negative heterotic effects. Corroborating results for grain yield indicating heterotic effects of varying magnitudes in different cross combinations of maize F_1 hybrids have been reported (Springer & Stupar, 2007; Abdel-Moneam *et al*., 2009; Amanullah *et al*., 2011; Ikramullah *et al*., 2011; Abuali *et al*., 2012; Ali *et al*., 2013; Singh, 2015). Previous studies revealed that one-third of the populations exhibited better performance for grain yield, and mid-parent heterosis in the appropriate mega-environment and possessed great potential for further improvement and utilization in maize (Zhang *et al*., 2017). Commercial positive heterosis in various maize F_1 hybrids studied in diverse environments was also confirmed by Amiruzzaman *et al*., (2010), Singh *et al*., (2012), Izhar & Chakraborty (2013), Nethra *et al*., (2013) and Rajesh *et al*., (2014). Similarly, different levels of mid, better and commercial heterosis were also reported in maize F_1 hybrids for grain yield in the past studies (Singh *et al*., 2013; Kumar *et al*., 2014; Ali *et al*., 2014).

In majority of the crops, heterosis works as a vital tool for improvement in production of F_1 hybrids. Therefore, in production of best F_1 hybrids, it is crucial to have comprehensive evidences about the desired parental combiners in breeding program that can bare a high degree heterotic response. An intensive research work have been conducted on heterosis in many crops, but so for the causes which contribute to heterosis are not too much clear (Coors & Pandey, 1999). In spite of this deficiency of understanding, breeders throughout the world have effectively utilized heterosis to increase the vigor and productivity of many domesticated crop species (Springer & Stupar, 2007). An increase in yield by 15% per year has been recorded by use of heterosis in F_1 hybrids (Duvick, 1999). Therefore, the present findings could better help and guide the plant breeders in recommending maize genotypes for some specific areas, and to use the tested breeding material in future breeding program so as to develop high yielding maize cultivars and hybrids.

Conclusion

Large number of the F_1 hybrids revealed significant positive heterotic effects for grain yield and most of the yield contributing traits at Swat followed by Mansehra, Haripur and CCRI. For grain yield, maximum mid-, better parent and economic heterotic effects were manifested by F_1 hybrids PSEV3 × FRHW-1 at CCRI, FRHW-2 × FRHW-1 for mid and better parents, and SWAJK-1 × FRHW-1 for economic heterosis at Haripur. At Mansehra, the promising F_1 hybrids were PSEV3 × SWAJK-1 and FRHW-1 × SWAJK-1 for grain yield. For grain yield at other locations, the F_1 hybrid FRHW-2 × FRHW-3 for mid and better parents at Swat, and FRHW-1 × SWAJK-1 exhibited maximum economic and commercial heterotic effects at Mansehra and Swat.

References

Abdel-Moneam, M.A., A.N. Attia, M.I. El-Emery and E.A. Fayed. 2009. Combining ability and heterosis for some agronomic traits in crosses of maize. *Pak. J. Biol. Sci*., 12(5): 433-438.

Abuali, A.I., A.A. Abdelmulla, M.M. Khalafalla. A.E. Idris and A.M. Osman. 2012. Combining ability and heterosis for yield and yield components in maize. *Aust. J. Basic Appl. Sci*., 6(10): 36-41.

Aghaei, Sh.S., Aharizad, M.R. Shiri and S.A. Mohammadi. 2012. Average heterosis of maize hybrids under terminal water stress at Moghan region. *Ann. Biol. Res*., 3(12): 5462-5465.

Ahmad, S.Q., S. Khan, M. Ghaffar and F. Ahmad. 2011. Genetic diversity analysis for yield and other parameters in maize (*Zea mays* L.) genotypes. *Asian J. Agric. Sci*., 3(5): 385-388.

Ali, F., K.R. Zahid, F. Shah, R. Gul, Q. Pan, Hira, G. Mustafa, Y. Jamal, H. Khan and H. Ullah. 2013. Heterosis and early generation testing is a pivotal method for production of hybrid. *Aust. J. Crop Sci*., 7(11): 1728-1736.

Ali, G., A.C. Rather, A. Ishfaq, S.A. Dar, S.A. Wani and M.N. Khan. 2007. Gene action for grain yield and its attributes in maize (*Zea mays* L.). *Int. J. Agric. Sci*., 3(2): 278-281.

Ali, M.J., M. Saleem, G. Abbas, H. Raza, M.S. Iqbal, K. Hussain and M.N. Akhtar. 2014. Estimation of gene action for grain yield and its components in maize in bred lines. *Standard Sci. Res. Essays*., 2(5): 220-227.

Ali, S., N.U. Khan, I.H. Khalil, M. Iqbal, S. Gul, S. Ahmed, N. Ali, M. Sajjad, K. Afridi, I. Ali and S.M. Khan. 2017. Environment effects for earliness and grain yield traits in F_1 diallel populations of maize (*Zea mays* L.). *J. Sci. Food Agric*., 97: 4408-4418.

Ali, S., N.U. Khan, R. Gul, I. Naz, R. Goher, N. Ali, S.A. Khan, I. Hussain, M. Saeed and M. Saeed. 2018. Genetic analysis for earliness and yield traits in maize. *Pak. J. Bot*., 50(4): 1395-1405.

Amanullah, S. Jehan, M. Mansoor and M.A. Khan. 2011. Heterosis studies in diallel crosses of maize. *Sarhad J. Agric*., 27(2): 207-211.

Amiruzzaman, M., M.A. Islam, L. Hassan and M.M. Rohman. 2010. Combining ability and heterosis for yield and component characters in maize. *Acad. J. Plant Sci*., 3(2): 79-84.

Bekele, A. and T.N. Rao. 2013. Heterosis study for grain yield, protein and oil improvement in selected genotypes of maize (*Zea mays* L.). *J. Plant Sci*., 1(4): 57-63.

BS-PDP. 2016-17. Bureau of Statistics, Planning and Development Department (BS-PDP), Government of Khyber Pakhtunkhwa, Pakistan.

Carangal, V.R., S.M. Ali, A.F. Koble, E.H. Rinke and J.C. Sentz. 1971. Comparison of S_1 with testcross evaluation for recurrent selection in maize. *Crop Sci*., 11: 658-661.

Coors, J.G. and S. Pandey. 1999. Genetics and exploitation of heterosis in crops. *Am. Soc. Agron. Crop Sci. Soc. America,* Madison, WI, USA.

Dhoot, M., R.B. Dubey, K.D. Ameta, R. Dhoot, R. Kumar and V.K. Badaya. 2017. Estimation of heterosis for grain yield and architectural traits in yellow seeded maize (*Zea mays* L.). *Int. J. Curr. Microbiol. Appl. Sci*., 6(7): 4536-4542.

Duvick, D.N. 1999. Commercial strategies for exploitation of heterosis. In: J.G. Coors and S. Pandey (Eds.). The Genetics and Exploitation of Heterosis in Crops. ASA, CSS, and SSSA, Madison, Wisconsin, USA, pp. 19-29.

EL-Hosary, A.A., M.E.M. EL-Badawy, T.A.E. Saafan, A.A.A. El Hosary and I.A.A. Hussein. 2014. Evaluation of diallel maize crosses for physiological and chemical traits under drought stress. *Minufiya J. Agric. Res*., 24(1): 43-63.

Falconer, D.S. and T.F.C. Mackay. 1996. Introduction to Quantitative Genetics, 4th ed. Longman Scientific and Technical, London, UK.

Fehr, W.R. 1987. Principles of Cultivar Development. Theory and Technique. Macmillan Pub. Comp. Inc. New York, pp. 115-119.

Fonseca, S.M. 1965. Heterosis, heterobeltiosis, diallel analysis and gene action in crosses of *Triticum aestivum* L. Ph.D. Thesis, Purdue Univ., USA.

Gerpacio, V.R. and P.L. Pingali. 2007. Tropical and Sub-tropical Maize in Asia: Production System, Constraints and Research Priorities, CIMMYT, Mexico, ISBN: 978-970-648-155-9, pp. 93.

Gomez, K.A. and A.A. Gomez. 1984. Statistical procedures for agricultural research. John Wiley and Sons Inc., 2nd (ed.) New York, USA.

Gorgulho, E.P. and J.B.M. Filho. 2001. Evaluation of maize varieties in the partial diallel-mating scheme. *Bragantia, Campinas,* 60(I): 1-8.

Hallauer, A.R. and J.B. Miranda. 1981. Quantitative genetics in maize breeding. Iowa State Univ. Press. Ames. IA, USA.

Hussain, N., M.Y. Khan and M.S. Baloch. 2011. Screening of maize varieties for grain yield at Dera Ismail Khan. *J. Anim. Plant Sci*., 21(3): 626-628.

Ikramullah, I.H. Khalil, M. Noor and M.K.N. Shah. 2011. Heterotic effects for yield and protein content in white quality protein maize. *Sarhad J. Agric*., 27(3): 403-409.

Iqbal, M. 2009. Genetic analysis of maturity and yield attributes in subtropical maize. Ph.D. Dissertation, The University of Agriculture, Peshawar - Pakistan.

Iqbal, M., K. Khan, H. Rahman, I.H. Khalil, H. Sher and J. Bakht. 2010. Heterosis for morphological traits in subtropical maize (*Zea mays* L.). *Maydica*, 55: 41-48.

Izhar, T. and M. Chakraborty. 2013. Combining ability and heterosis for grain yield and its components in maize inbreds over environments. *Afr. J. Agri. Res*., 8(25): 3276-3280.

Khan, K., H. Sher and M. Iqbal and F. Al-Qurainy. 2011. Development and release of indigenous maize hybrids to enhance maize yield in Khyber Pakhtunkhwa province of Pakistan. *Afr. J. Agric. Res*., 6(16): 3789-3792.

Kumar, G.P., Y. Prashanth, V.N. Reddy, S.S. Kumar and P.V. Rao. 2014. Heterosis for grain yield and its component traits in maize (*Zea mays* L.). *Int. J. Pure Appl. Biosci*., 2(1): 106-111.

Li, Z., L. Coffey, J. Garfin, N.D. Miller, M.R. White, E.P. Spalding, N. Leon, S.M. Kaeppler, P.S. Schnable, N.M. Springer and C.N. Hirsch. 2018. Genotype-by-environment interactions affecting heterosis in maize. *PLoS ONE,* 13(1): e0191321.

Liu, X.C. and J.L. Wu. 1998. SSR heterotic patterns of parents for making and predicting heterosis. *Mol. Breed*., 4: 263-268.

Malik, H.N., I. Ara, M. Naeem, M. Hussain, M.H. Munawwar and M. Yousaf. 2010. Comparison of open pollinated varieties and newly developed hybrids for yield and yield contributing traits in maize. *Pak. J. Agric. Res*., 23(1-2): 37-41.

Matin, M.Q.I., M.G. Rasul, A.K.M.A. Islam, M.A.K. Mian, N.A. Ivy and J.U. Ahmed. 2016. Combining ability and heterosis in maize (*Zea mays* L.). *Am. J. Bio-Sci*., 4(6): 84-90.

Nethra H., G. Shantakumar, S. Adiger, L. Malkannavar and P. Gangashetty. 2013. Heterosis breeding for maturity, yield and quality characters in maize (*Zea mays* L.). *Mol. Plant Breed*., 4(6): 44-49.

Nzuve, F., S. Githiri, D.M. Mukunya and J. Gethi. 2014. Genetic variability and correlation studies of grain yield and related agronomic traits in maize. *J. Agric. Sci*., 6(9): 166-176.

Panda, S., M.C. Wali, R.M. Kachapur and S.I. Harlapur. 2017. Combining ability and heterosis analysis of single cross hybrids of maize (*Zea mays* L.). *Int. J. Curr. Microbiol. Appl. Sci*., 6(10): 2608-2618.

PBS 2017-18. Year Book, Pakistan Bureau of Statistics (PBS), Govt. of Pakistan, Islamabad, Pakistan.

Poehlman, J.M. 1977. Breeding Field Crops. 2nd. The AVI Publish. Co. Inc. Westport, CT, USA.

Rajesh, V., S.S. Kumar, V.N. Reddy and A.S. Sankar. 2014. Heterosis studies for grain yield and its component traits in single cross hybrids of maize (*Zea mays* L.). *Int. J. Plant, Anim. Environ. Sci*., 4(1): 304-306.

Shah, L., H. Rahman, A. Ali, K.A. Shah and A. Khan. 2014. Heterotic effects for grain yield and related traits in maize variety Azam. *ARPN J. Agric. Biol. Sci*., 9(6): 200-205.

Sharma, P., M.C. Kamboj, N. Singh and M. Chand. 2017. Heterosis for grain yield and quality traits in maize (*Zea mays* L.). *Int. J. Pure, Appl. Biosci*., 5(5): 241-248.

Shull, G.H. 1952. Beginnings of the heterosis concept. P. 14-48. John W. Gowen (ed). Heterosis, Iowa State College Press. Ames.

Singh, A., J.P. Shahi and D.M. Langade. 2013. Appraisal of heterosis for yield and yield attributing components in maize (*Zea mays* L.). *Bio-life*., 1(3): 123-129.

Singh, P. 2015. Genetic distance, heterosis and combing ability studies in maize for predicting F_1 hybrid performance. *SABRAO J. Breed. Genet*., 47(1): 21-28.

Singh, P.K., A.K. Singh, J.P. Shahi and R. Ranjan. 2012. Combining ability and heterosis in quality protein maize. *The Bioscan*, 7(2): 337-340.

Singh, S.B. and B.B. Gupta. 2009. Heterotic expression and combining ability analysis for yield and its components in maize (*Zea mays* L.) inbreds. *J. Progress. Agric*., 9(2): 184-191.

Springer, N.M. and R.M. Stupar. 2007. Allelic variation and heterosis in maize: How do two halves make more than a whole? *Genome Res*., 17: 264-275.

Suba, D.D., T.T. Suba and A.B. Pop. 2001. Genetic study of the yield constituents of the maize single cross Andreea. *Tehnice Fundulea*, 68(1): 19-25.

Venkatesha, K.T., H. Shivanna, M. Asif and K.V. Kumar. 2013. Heterosis studies for drought tolerant and grain yield traits in maize (*Zea mays* L.). *Int. J. Agric. Sci*., 9(1): 242-247.

Wynne, J.C., D.A. Emery and P.M. Rice. 1970. I. Combining ability estimates in *Arachis hypogeae* L. 11. Field performance of F_1 hybrids. *Crop Sci*., 10(6): 713-715.

Zhang, X., H. Yong, Z. Zhou, C. Zhang, M. Lu, Q. Sun, L. Zhang, M. Li . D. Zhang, J. Weng, Z. Hao, S. Zhang, Z. Wang and X. Li. 2017. Heterosis and combining ability of seven maize germplasm populations. *Euphytica*, 213(45): 1-11.

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