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Heterosis Studies in Line × Tester Crosses of Maize for Yield and its Component Traits in Maize (*Zea mays* L.) Across Locations

Bichewar Nagesh Dattatray[1*], B.V. Vara Prasad[1], M.V. Nagesh Kumar[2], N. Sunil[3], B. Mallaiah[4] and A. Meena[5]

[1]Department of Genetics and Plant Breeding,
College of Agriculture, PJTSAU, Hyderabad (Telangana), India.
[2]Department of Genetics and Plant Breeding,
Maize Research Centre, ARI, Rajendranagar, Hyderabad (Telangana), India.
[3]Department of Genetics and Plant Breeding,
IIMR-Winter Nursery Centre, ARI, Rajendranagar, Hyderabad (Telangana), India.
[4]Department of Plant Pathology,
AICRP-Maize, MRC, Rajendranagar, Hyderabad (Telangana), India.
[5]Department of Statistics & Mathematics,
College of Agriculture, PJTSAU, Hyderabad (Telangana), India.

(Corresponding author: Bichewar Nagesh Dattatray)*
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ABSTRACT: Heterosis is a quantifiable, trait-dependent and environment-specific phenotype, and the response of parental lines and their hybrids to environments resulted in various levels of heterosis hence, conformation of standard heterosis in maize hybrids is essential to exploit them commercially and thereupon uplifting their production potential. Therefore, the present study was designed in order to deduce the hybrid potential and useful heterosis to magnify the production and productivity of maize. Thirty single cross hybrids along with four standard checks were evaluated at three location using randomized block design during *rabi*, 2022-23. Analysis of variance due to mean square of genotype exhibit significant difference for all the studied traits indicating the presence of sufficient variation. Thirteen hybrids recorded the higher grain yield than the best check Bio 9544 and GP 329×GP 83, GP 82×GP 83 and PFSR 145×GP 69 were the top performers. Seven hybrids (GP 329×GP 83, GP 82×GP 83, PFSR 145×GP 69, GP 329×GP 86, PFSR 393×GP 107, GP 329×GP 107 and PFSR 204× GP 107) exhibited the significant and positive heterosis over the best check hybrid. Hybrid PFSR 393×GP 86 for ear length, GP 329×GP 69 for ear girth, GP 329×GP 86 for number of kernel per ear and number of kernel per row and PFSR 393×GP 83 for 100 grain weigh reported the significant heterosis in desirable direction over best checks. The hybrid GP 329×GP 83 had higher yield potential and found to be early in maturity indicating its significance in developing potential early maturing maize hybrid. The identified promising hybrids could be endorsed for future breeding programme following the conformation of results by repeating the research across locations.

Keywords: Useful heterosis, Hybrids, Checks.

INTRODUCTION

Maize (*Zea mays* L. 2n = 20) belonging to tribe *Maydeae*, of the grass family, *Poaceae*. Maize is the third most important crop in the world as well as in India after wheat and rice. The crop is cultivated in about 170 countries in an area of 193.7 Mha with production of 1147.7 Mt and an average productivity of 5754.7 kg/ha, which accounts for 37 per cent of total global grain production (FAOSTAT, 2020). In India, maize occupies an area of 9.26 Mha with 16.72 MT production and productivity of 3024 kg/ha. In Telangana, the crop shares 10.22 per cent of the area (2 lakh ha) under cultivation with the production of 6777 kg/ha (INDIASTAT, 2020-21).

Globally, maize is an important crop because of its diverse uses mainly as food (17%), feed (61%) and raw material for industrial uses (22%). It is estimated that the demand for maize will continue to increase in view of increasing demand in poultry and livestock sectors in the country and growing non-vegetarian population and changing food habits (India-Maize-Summit, Agri Vision 2022). Maize is used as raw material in many important industries viz., starch, oil, alcoholic beverages, food sweeteners, pharmaceuticals, cosmetics, textile, paper, film, tyre, food processing, packing and bio-fuel etc. for developing hundreds of industrial products. It also plays a key role in the Indian economy by contributing a significant share in global agricultural exports and imports. In 2019, according to the ITC Trade Map database the total export and import and export volume of maize in India was 312,389 and 379,000 metric tons, respectively.

Owing to its wide range of plasticity, maize is adaptable to diverse environments and offers tremendous scope for expansion to new areas and environments compared to many other crops. Over the years, maize has registered impressive production gains both at global and national levels and this could be attributed largely to successful adoption of single cross hybrid technology. However, to match the growing requirement of consumers across the globe, there is an urgent need to further improve the productivity level especially in developing nations including India. The production and productivity of maize enhance by using improved hybrid maize varieties accompanied with appropriate agronomic practices. As a result, gene action and hybrid vigor/heterosis can be used more effectively in breeding programs for the identification of advanced F1 hybrids and thereby enhance the productivity of the crop.

The term heterosis was coined by Shull (1914) and heterosis is the phenomenon in which the F_1 of two genetically dissimilar parents show increased vigour or size for various characters over the mid parent value (relative or mid parent heterosis) or over the better parent (heterobeltiosis) or over the standard check (standard heterosis). In practical plant breeding, superiority of F_1 over mid and better parent is of little value since it does not offer any advantage. However, the exploitation of hybrid would primarily depend on its performance in comparison to the best existing commercial hybrids/varieties (standard heterosis). The heterotic studies can provide the basis for the exploitation of valuable hybrid combinations in the future breeding programmes and their commercial utilization.

Therefore, the present investigation aimed at identifying the superior cross combinations generated by crossing 6 lines and 5 testers (L×T) belonging to different heterotic groups for grain yield and yield attributing traits.

MATERIAL AND METHODS

The present investigation was carried out during two crop seasons *kharif*, 2022 and *rabi*, 2022-23 on the experimental farm of Maize Research Centre, Rajendranagar, Hyderabad. The study area located at latitude of 17° 20' N, longitude of 78° 25' E and an altitude of 545 m above MSL. The area receives an average rainfall of 99.08 millimetres (3.9 inches) and has 107.27 rainy days (29.39% of the time) annually.

The 6 inbred lines (Group A) were designated as a female and 5 testers (Group B) designated as a male were crossed in Line × Tester mating system during *kharif*, 2022. The experimentalunitsconsistedofsixrowsof4mlength plots, with a spacing of 0.6m×0.2m. Three staggered sowings of the male testers were undertaken at an interval of 4 days to ensure synchronization of flowering with female lines and to produce adequate crossed seeds.

A panel of 30 experimental single-cross hybrids were evaluated for eleven quantitative traits alongwith 4checks (NK 6240, Hitech 5160, Hitech 5106 and Bio 9544) across three locations (Rajendranagar, Karimnagar and Madhira) during *rabi*, 2022-23. The seed material was sown in a Randomized Block Design with three replications following a spacing 0.6m×0.2m. All the recommended package of practices for specific site were followed to maintain proper crop stand.

The data was recorded on five randomly selected plants in each entry for parameters such as plant height (cm), ear height(cm), earl ength (cm), eargirth(cm), number of kernel rows per ear, number of kernel sperrow, 100 seed weight (g) whereas, days to 50 % tasseling, days to 50 % silking, days to maturity and grain yield were recorded on a plot basis.

Statistical Analysis. Economic/standard heterosis, the superiority of the F1 hybrid over the standard commercial hybrid variety, expressed as a percentage. The data recorded for 11 quantitative traits for 30 single crosses and 4 checks across three locations was recorded and magnitude of heterosis was estimated in relation to standard checks for traits that showed significant differences among crosses following the method suggested by Virmani *et al*. (1982).

$$SH = \frac{\overline{F_1} - \overline{S.C.}}{\overline{S.C.}} \times 100$$

Where, SH - Standard heterosis

$\overline{F_1}$ = Mean of F_1

$\overline{S.C.}$ = Mean of standard check value.

RESULTS AND DISCUSSION

A pooled analysis of variance for eleven quantitative traits of 34 maize genotypes (30 hybrids and 4 checks) revealed a significant variability for genotype and environment. The Genotype-Environment Interaction (GEI) effect was found significant for most of the traits indicating the presence of considerable variation among the studied genotypes for yield and yield attributing traits (Table 1). These findings are in accordance with Oliveira *et al*. (2019); Amzeri *et al*. (2020); Arunkumar *et al*. (2020); Shrestha *et al*. (2021); Mostafavi and Saremi-Rad (2021); Liu *et al*. (2022).

Mean performance of 30 single crosses along with four checks for eleven quantitative traits was recorded over three locations and presented in Table 2. Among all hybrids, the lowest grain yield was recorded for PFSR 145×GP 83 (10361.25 kg ha^{-1}) and the highest value was observed for GP 239×GP 83 (12772.2 kg ha^{-1}). Thirteen hybrids (PFSR 393×GP 83, PFSR 393×GP 86, PFSR 393×GP 107, PFSR 204× GP 107, GP 329×GP 69, GP 329×GP 83, GP 329×GP 86, GP 329×GP 107, GP 327× GP 36, GP 327× GP 107, PFSR 145×GP 69, PFSR 145×GP 86 and GP 82×GP 83) recorded the higher grain yield than the best check Bio 9544 (12061.0 kg ha^{-1}). Therefore, these high performing crosses than the standard check indicates the possibility of obtaining better commercial variety and thereby enhance the production and productivity of maize. These results are in accordance with the earlier findings of Meena *et al*. (2016); Sserumaga *et al*. (2016); Oyekunle *et al*. (2017); Meseka *et al*. (2018); Shrestha *et al*. (2019) ; Rezende *et al*. (2020). PFSR 393×GP 36 (47 days) were found to be earliest and GP 329×GP 86 (59 days) was reported to be late among all hybrids in 50% tasseling. The hybrids exhibited the range of 50 days (PFSR 393×GP 36, PFSR 393×GP 107 and PFSR 204×GP 36) to 60 days (PFSR 204×GP 69, PFSR 204×GP 86, GP 329×GP 86 and GP 327×GP 36) for days to 50% silking. Seven crosses (PFSR 393×GP 36, PFSR 393×GP 69, PFSR 393×GP 107, PFSR 204× GP 36, GP 329 × GP 83, PFSR 145×GP 86 and GP 82 × GP 83) showed early tasseling and silking than the best check Hi-Tech-5106 (53 and 55 days, respectively) hence, these genotypes can be further tested extensively for the development of potential early maturing hybrids. These results are in accordance with Ghimire and Timsina (2015); Oyekunle *et al*. (2017); Mesaka *et al*. (2018); Kandel and Shrestha (2020). Hybrids exhibited a range from 86 days (PFSR 393×GP 36 and PFSR 204× GP 36) to 107 days (GP 327× GP 36) for days to maturity. Twelve hybrids (PFSR 393×GP 36, PFSR 393×GP 107, PFSR 204× GP 36, GP 329×GP 69, GP 329×GP 83, GP 329×GP 107, GP 327× GP 83, GP 327× GP 86, PFSR 145×GP 36, PFSR 145×GP 69, PFSR 145×GP 86 and GP 82×GP 83) were earlier in days to maturity than the best check Bio 9544 (98 days).

The plant height is an important trait in maize cultivation as low plant height is attributed to its high drought tolerance capacity, lowers the transpiration rate and ultimately reduce moisture stress during drought. For the reason, the hybrids (PFSR 393×GP 83, PFSR 204×GP 69, PFSR 204× GP 83, GP 327× GP 83, PFSR 145×GP 83, PFSR 145×GP 86, GP 82×GP 69 and GP 82×GP 86) recorded plant height less than the best check NK 6240 (172.7 cm) indicating the tendency of hybrids to be used in drought tolerant variety development. The plant height in hybrids ranged from 164.1 cm (PFSR 145×GP 83) to 185.0 cm (PFSR 393×GP 86). Hybrids exhibited the mean value ranged from 69.7 cm (GP 82×GP 86) to 85.4 cm (PFSR 204× GP 36) for ear height. Two hybrids namely GP 82×GP 69 and GP 82×GP 86 recorded the lower ear height than the best commercial check NK 6240 (73.6 cm). The lowest ear length observed was 18.6 cm (PFSR 145×GP 83) and the highest ear length recorded was 21.7 cm (GP 329×GP 107). Fifteen hybrids (PFSR 393×GP 83, PFSR 393×GP 86, PFSR 393×GP 107, PFSR 204× GP 83, PFSR 204× GP 107, GP 329×GP 83, GP 329×GP 86, GP 329×GP 107, GP 327× GP 36, GP 327× GP 107, PFSR 145×GP 36, PFSR 145×GP 69, PFSR 145×GP 86, GP 82×GP 36 and GP 82×GP 69) recorded ear length greater than best check Bio 9544 (20.6 cm). Similar results for plant height, ear height and ear length were reported by Ghimire and Timsina (2015); Meena *et al*. (2016). The lowest ear girth was recorded by the hybrid PFSR 204× GP 83 (13.7 cm) whereas, the highest ear girth was observed for GP 329×GP 69 (15.8 cm). Ten hybrids (PFSR 393×GP 69, PFSR 393×GP 83, PFSR 393×GP 107, GP 329×GP 69, GP 329×GP 86, PFSR 145×GP 36, PFSR 145×GP 69, GP 82×GP 69, GP 82×GP 83 and GP 82×GP 107) exhibited more ear girth than the best check hybrid Hi-Tech-5106 (15.2 cm). These results are in agreement with the findings of Meena *et al*. (2016).

The lowest number of kernels per ear was recorded by the hybrid PFSR 204 × GP 86 (353) and the highest value for the trait was recorded for GP 329×GP 86 (613). Eight hybrids (PFSR 393×GP 83, PFSR 393×GP 86, GP 329×GP 69, GP 329×GP 83, GP 329×GP 86, GP 329×GP 107, GP 82×GP 83 and GP 82×GP 107) exhibited higher value than the best check NK 6240 (484) for number of kernels per ear. Mean for number of kernels per row ranged from 30 (PFSR 145×GP 83) to 37 kernels (GP 329×GP 86). Ten hybrids (PFSR 393×GP 69, PFSR 393×GP 83, PFSR 393×GP 86, PFSR 204× GP 36, PFSR 204× GP 86, GP 329×GP 69, GP 329×GP 86, GP 329×GP 107, GP 327× GP 107 and PFSR 145×GP 86) showed the higher value for number of kernels per row than the best check hybrid Hi-Tech-5160 (34). 100 kernel weight was found lowest for the hybrid GP329×GP 36 (30.0g) and highest value recorded for PFSR 393×GP 83 (38.2 g). Ten hybrids (PFSR 393×GP 83, PFSR 393×GP 86, PFSR 204× GP 107, GP 329×GP 69, GP 329×GP 83, GP 329×GP 86, GP 329×GP 107, GP 327× GP 107, PFSR 145×GP 69 and PFSR 145×GP 86) recorded the higher value for 100 grain weight as compared to the best check Hi-Tech-5160 (33.5 g). Similar results were reported by Meena *et al*. (2016) for ear girth, number of kernels per row and 100 kernel weight.

Information on heterosis of maize germplasm is essential in increasing the efficiency of hybrid development. In the present study, standard heterosis of hybrids for eleven quantitative characters over the best check for the respective characters are presented in Tables 3. Results revealed the significant difference among genotypes. However, the magnitude and direction of heterosis in F1 hybrids varied from character to character, and from cross to cross (Table 3). The overall results indicated that positive and negative significant standard heterosis was observed in some of the crosses compared with the standard check (NK 6240, Hitech 5160, Hitech 5106 and Bio 9544) for the respective trait. This indicates the presence of considerable amount of heterosis for improving grain yield and yield related traits.

Grain yield: Grain yield improvement is the main concern in any plant breeding programme. Commercial production of newly developed hybrids cannot be achievable, if it is not performed better than standard commercial check. Positive and significant heterosis is desirable for grain yield as it indicates increased grain yield potential over the existing standard check. The heterosis for grain yield over the best check Bio 9544 varied from -12.19 (PFSR 145×GP 83) to 8.25 (GP 329×GP 83).Significant and positive heterosis for grain yield over the best check Bio 9544 was observed for seven hybrids (GP 329×GP 83, GP 82×GP 83, PFSR 145×GP 69, GP 329×GP 86, PFSR 393×GP 107, GP 329×GP 107 and PFSR 204× GP 107). Positive heterosis is desirable for this trait and these hybrids was found to exhibit 4-6% yield advantage than the best available check Bio 9544. The crosses which exhibited higher grain yield than the standard checks are desirable for the improvement of maize grain yield by exploiting maximum heterosis. Sharma *et al*. (2017); Karim *et al*. (2018); Ambikabathy *et al*. (2019); Kumar *et al*. (2019); Chaurasia *et al*. (2020); Onejeme *et al*. (2020);

Mogesse and Zeleke (2022) also reported significant and positive standard heterosis for grain yield over respective checks.

Days to 50% tasseling: Heterosis in the negative direction is desirable for this trait which depicts the earliness of the crosses. The hybrids showed the range of heterosis for days to 50% tasseling from -9.84 (PFSR 393×GP 36) to 11.43 (GP 329×GP 86). Six crosses (PFSR 393×GP 36, PFSR 393×GP 107, PFSR 204× GP 36, GP 329×GP 83, PFSR 145×GP 86 and GP 82×GP 83) exhibited significant and negative heterosis over the best check Hi-Tech-5106. Similar results for negative heterosis of this trait were reported by Reddy *et al*. (2015); Bello and Olawuyi (2015); Hoque *et al*. (2016); Patil *et al*. (2017); Sharma *et al*. (2017); Karim *et al*. (2018); Darshan and Marker (2019); Keimeso *et al*. (2020); Onejeme *et al*. (2020); Chaurasia *et al*. (2020).

Days to 50% silking: The hybrids showed the heterosis for days to 50% silking in the range of -10.27 (PFSR 393×GP 36) to 9.37 (GP 329×GP 86). Six crosses (PFSR 393×GP 36, PFSR 393×GP 107, PFSR 204× GP 36, GP 329×GP 83, PFSR 145×GP 86 and GP 82×GP 83) reported the significant and negative standard heterosis over the best check Hi-Tech-5106. Bello and Olawuyi (2015); Lekha *et al*. (2015); Reddy *et al*. (2015); Hoque *et al*. (2016); Sharma *et al*. (2017); Karim *et al*. (2018); Kumar *et al*. (2019); Darshan and Marker (2019); Keimeso *et al*. (2020); Onejeme *et al*. (2020); Chaurasia *et al*. (2020) also reported similar results for days to 50% silking.

Days to maturity: The lowest heterosis was reported for hybrid GP 329× GP 83 (-10.77) and highest value of heterosis was observed for hybrid GP 327× GP 36 (14.21). Six hybrids (PFSR 393×GP 36, PFSR 393×GP 107, PFSR 204× GP 36, GP 329× GP 83, PFSR 145×GP 86 and GP 82× GP 83) exhibited significant and negative heterosis for days to maturity over the best check hybrid Bio 9544. These results are in agreement with the findings of Reddy *et al*. (2015); Ahmad (2015); Hoque *et al*. (2016); Sharma *et al*. (2017); Kumar *et al*. (2019); Darshan and Marker (2019); Chaurasia *et al*. (2020).

Plant height: Significant negative heterosis is desirable for plant height as it enables the selection of short stature plant providing lodging resistance and ease in mechanical harvesting. The range of heterosis for plant height lied between -4.98 (PFSR 145×GP 83) and 7.1 (PFSR 393×GP 86). Heterosis for plant height was low and none of the crosses showed significant and negative heterosis for the trait over the best check NK 6240. Whereas, six hybrids (PFSR 145×GP 83, GP 82×GP 69, PFSR 393×GP 83, PFSR 204× GP 83, GP 327× GP 83 and PFSR 145×GP 86) reported negative heterosis on par with the best check NK 6240. These results are similar with the findings of Rajitha *et al*. (2014); Karim *et al*. (2018).

Ear height: The lowest value for the heterosis was observed for the hybrid GP 82×GP 86 (-5.3) whereas, the highest value reported by the hybrid PFSR 204× GP 36 (15.93). Two hybrids (GP 82×GP 69 and GP 82×GP 86) showed negative heterosis on par with the best check NK 6240 for ear height (Table 3). Bello and Olawuyi (2015); Ofori *et al*. (2015); Dorina and Viorica (2015); Karim *et al*. (2018) also observed low hetrosis for ear height.

Ear length: Hybrids with longer ear length are desirable to enhance grain yield hence, significant positive heterosis is desirable for this trait.Four hybrids (PFSR 393×GP 86, GP 329×GP 83, GP 329×GP 107 and PFSR 145×GP 36) reported positive and significant standard heterosis for the trait ear length over the best check Bio 9544. The lowest value for heterosis over best check for ear length was observed for hybrid PFSR 145×GP 83 (-5.26) while, the highest value recorded for PFSR 393×GP 86 (11.88). Significant positive heterosis for ear length was also reported by Zeleke Habtamu (2015); Ali *et al*. (2019); Abebe *et al*. (2020) ; Mogesse and Zeleke (2022).

Ear girth: The heterosis over best check Hi-Tech-5106 for ear girth ranged from -10.28 (PFSR 204× GP 83) to 3.5 (GP 329×GP 69). Ten hybrids (PFSR 393×GP 69, PFSR 393×GP 83, PFSR 393×GP 107, GP 329×GP 69, GP 329×GP 86, PFSR 145×GP 36, PFSR 145×GP 69, GP 82×GP 69, GP 82×GP 83 and GP 82×GP 107) were found to exhibit positive heterosis on par with the best check Hi-Tech-5106. Similar results for the low level of heterosis for ear girth were reported by Zeleke Habtamu (2015); Ofori *et al*. (2015); Keimeso *et al*. (2020). Hybrids with wide ear diameter indicated that they have inherent genetic potential for wider ear diameter, and thus desirable to enhance grain yield.

Number of kernels per ear: The highest number of kernels per ear are desirable to enhance grain yield as they are directly correlated. The heterosis for number of kernels per ear over the best check varied from -13.29 (PFSR 145×GP 83) to 26.05 (GP 329×GP 86). Six hybrids (PFSR 393×GP 83, GP 329×GP 69, GP 329×GP 83, GP 329×GP 86, GP 329×GP 107 and GP 82×GP 83) reported significant and positive heterosis for number of kernels per ear over the best check NK 6240.

Number of kernels per row: Kernel number per row was one of the most important trait that determines yield, which can be used as direct selection criteria for yield heterosis. Significant and positive heterosis for number of kernels per row was exhibited by two crosses GP 329×GP 69 and GP 329×GP 86 over the best check Hi-Tech-5160. The range of the standard heterosis for number of kernels per row lied between -9.93 (PFSR 393×GP 107) to 10.43 (GP 329×GP 86). The current results were in consonance with the findings of Ruswandi *et al*. (2015); Abebe *et al*. (2020); Mogesse and Zeleke (2022) for number of kernel per row.

100 grain weight: The lowest value of standard heterosis for 100 grain weight was reported by hybrid PFSR 145×GP 83 (-11.06) while, the highest value was observed for PFSR 393×GP 83 (7.7). The hybrids PFSR 393×GP 83, GP 329×GP 86, PFSR 204× GP 107 and GP 329×GP 83 exhibited significant and positive standard heterosis for 100 grain weight over the best check hybrid Hi-Tech-5160 hence, these hybrids are desirable to enhance grain yield.

Table 1: Pooled analysis of variance for eleven quantitative traits of 34 maize genotypes.

	Source of variation			
	Genotypes	Environments	Gen. × Env.	Pooled error
Degree of freedom	33	2	66	99
Characters	**Mean sum of squares**			
Days to 50% tasseling	70.66**	34.82**	4.23**	1.92
Days to 50% silking	71.37**	29.51**	3.85**	1.82
Days to maturity	160.08**	39.12**	22.61**	6.63
Plant height (cm)	2336.00**	523.45*	131.92	126.70
Ear height (cm)	328.44**	41.19	50.15*	34.70
Ear length (cm)	73.35**	7.09*	2.17	1.83
Ear girth (cm)	17.53**	0.043	1.01	0.88
Number of Kernel per ear	78784.09**	2006.40	921.85	927.30
Number of kernels per row	137.05**	24.43**	6.85*	4.39
100 kernel weight (g)	97.78**	28.04**	12.24**	4.58
Grain yield (kg ha^{-1})	60861178.27**	6413170.14**	1086171.23**	324344.13

*Significance at 5% probability, **significance at 1% probability

Table 2: Mean performance of 34 genotypes for eleven quantitative traits across three locations.

Sr. No.	Genotypes	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (cm)	Number of Kernel per ear	Number of kernels per row	100-kernel weight (g)	Grain-yield ((kg ha-1)
	Hybrids											
1.	PFSR 393×GP 36	47	50	86	174.7	81.0	19.8	14.7	451	31	32.3	11510.4
2.	PFSR 393×GP 69	52	54	103	175.5	77.8	19.5	15.3	463	35	30.9	11736.2
3.	PFSR 393×GP 83	57	59	102	168.2	80.2	21.1	15.5	534	36	38.2	12173
4.	PFSR 393×GP 86	58	60	103	185.0	85.1	21.1	14.7	497	35	33.9	12258.9
5.	PFSR 393×GP 107	48	50	87	178.7	79.8	20.7	15.3	436	31	30.4	12651.7
6.	PFSR 204× GP 36	48	50	86	182.7	85.4	20.0	14.6	458	35	32.2	11574.7
7.	PFSR 204× GP 69	57	60	104	171.5	79.0	19.2	14.5	437	33	30.8	11638.8
8.	PFSR 204× GP 83	57	59	102	168.6	79.9	20.8	13.7	451	31	31.2	10917.2
9.	PFSR 204× GP 86	58	60	101	177.2	81.2	20.3	14.9	353	35	30.2	11939.3
10.	PFSR 204× GP 107	55	57	100	183.3	82.8	21.1	14.4	454	33	35.5	12479.1
11.	GP 329×GP 36	54	57	98	181.5	80.6	19.1	15.2	439	32	30	10802.9
12.	GP 329×GP 69	57	59	96	177.5	81.6	20.5	15.8	536	36	34.2	12421.6
13.	GP 329×GP 83	48	50	87	177.4	78.6	21.3	15.1	529	34	36.2	12772.2
14.	GP 329×GP 86	59	60	100	180.3	76.6	21.2	15.7	613	37	36.5	12693.4
15.	GP 329×GP 107	53	56	96	180.8	81.4	21.7	15.1	541	35	34.9	12579.0
16.	GP 327×GP 36	58	60	107	182.3	82.8	21.3	15	471	34	32.2	12259.2
17.	GP 327×GP 69	57	59	98	178.9	79.0	20.6	13.8	454	33	32.4	12024.3
18.	GP 327× GP 83	54	57	95	170.0	81.4	19.2	15.2	435	33	30.9	11344.1
19.	GP 327× GP 86	55	57	96	176.3	80.9	20.1	15	461	33	32.7	11913.5
20.	GP 327× GP 107	55	57	100	177.2	83.0	21.3	14.8	463	35	34.3	12108.5
21.	PFSR 145×GP 36	55	57	96	178.5	76.7	20.9	15.3	467	33	33	11928.9
22.	PFSR 145×GP 69	55	58	97	173.9	78.6	20.6	15.3	423	33	35	12697.4
23.	PFSR 145×GP 83	57	59	99	164.1	75.6	18.6	14.2	420	30	30.1	10361.3
24.	PFSR 145×GP 86	48	50	88	171.0	75.4	21.3	14.7	466	35	35.4	12164.4
25.	PFSR 145×GP 107	54	57	100	177.3	74.2	20.1	15.1	436	32	32	11764.5
26.	GP 82×GP 36	58	60	99	177.5	78.2	21.0	15.1	470	33	32.4	11603.0
27.	GP 82×GP 69	54	55	102	167.2	72.0	20.7	15.3	452	32	33.4	11642.6
28.	GP 82×GP 83	49	52	91	182.2	84.6	20.4	15.4	555	34	33.1	12711.8
29.	GP 82×GP 86	57	59	104	172.1	69.7	19.9	14.5	448	32	31.4	10714.8
30	GP 82×GP 107	54	57	103	180.8	83.2	20.2	15.3	488	33	31.6	11063.2
Range	**Minimum**	47	50	86	164.1	69.7	18.6	13.7	353	30	30	10361.3
	Maximum	59	60	107	185.0	85.4	21.7	15.8	613	37	38.2	12772.2
	Checks											
1.	NK 6240	54	56	102	172.7	73.6	19.9	14.6	484	33	29.3	11501.7
2.	Hi-Tech-5160	56	58	101	174.2	84.9	20.4	14.9	446	34	33.5	11572.1
3.	Hi-Tech-5106	53	55	99	176.7	76.0	19.6	15.2	474	30	30.1	11159.8
4.	Bio 9544	54	56	98	181.9	80.8	20.6	15.1	465	33	33.1	12061
	Minimum	53	55	98	172.7	73.6	19.6	14.6	446	30	29.3	11159.8
	Maximum	56	58	102	181.9	84.9	20.6	15.2	484	34	33.5	12061
	CV	3.0	2.0	2.0	4.6	6.5	5.1	4.2	8.0	6.0	7.3	7.3
	SEM	1.0	1.0	1.0	4.4	2.8	0.5	0.3	18.0	1.0	1.3	425.4
	CD@ 5%	2.0	1.0	3.0	12.5	8.1	1.5	0.9	50.0	3.0	3.6	1,197.8

CV- Coefficient of Variation**, SEM-** Standard Error Meanand **CD-** Critical Difference

Table 3: Estimation of standard heterosis for 11 quantitative traits across three locations.

Sr. No.	Genotypes	Days to 50% tasseling (Hi-Tech-5106)	Days to 50% silking (Hi-Tech-5106)	Days to maturity (Bio 9544)	Plant height (cm) (NK 6240)	Ear height (cm) (NK 6240)	Ear length (cm) (Bio 9544)	Ear girth (cm) (Hi-Tech-5106)	Number of Kernel per ear (NK 6240)	Number of kernels per row (Hi-Tech-5160)	100-kernel weight (g) (Hi-Tech-5160)	Grain-yield ((kg ha^{-1}) (Bio 9544)
1.	PFSR 393×GP 36	-9.84	-10.27 **	-7.99 **	1.12	10.05*	-4.2	-3.72	-7.17	-9.83 **	-8.98 *	-2.45
2.	PFSR 393×GP 69	-0.63	-1.81	9.95 **	1.58	5.7	-8.89 *	0.22	-2.27	4.07	-7.11*	-0.53
3.	PFSR 393×GP 83	7.94**	6.95 **	8.35 **	-2.66	8.87	2.5	1.53	10.19 **	4.17	7.70 *	3.17
4.	PFSR 393×GP 86	9.84**	9.06 **	9.77 **	7.1	15.62**	6.46*	-3.5	2.28	4.17	0.89	3.9
5.	PFSR 393×GP 107	-9.21**	-9.67 **	-7.10 **	3.43	8.37	2.58	0.22	-10.23 **	-9.93 **	-9.97 *	7.23 *
6.	PFSR 204× GP 36	-9.52**	-9.67 **	-8.53 **	5.75	15.93**	-5.17	-4.16	-3	3.97	-3.55	-1.9
7.	PFSR 204× GP 69	9.21**	8.16 **	10.30 **	-0.73	7.24	-2.34	-4.6	-9.66 *	-2.68	-8.59 *	-1.36
8.	PFSR 204× GP 83	8.57**	7.55 **	8.17 **	-2.39	8.56	3.15	-10.28 **	-7.27	-7.65 *	-5.13*	-7.47 *
9.	PFSR 204× GP 86	9.84**	8.76 **	7.46 **	2.57	10.23*	-0.97	-2.41	-4.44	3.57	-7.4*	1.19
10.	PFSR 204× GP 107	4.76**	3.32 *	6.93 **	6.12	12.40**	-2.26	-5.25	-6.56	-0.79	6.22*	5.76 *
11.	GP 329×GP 36	3.17*	3.02 *	4.09 *	5.06	9.51*	-7.43	-0.44	-9.75 **	-3.77	-7.90 *	-8.44 **
12.	GP 329×GP 69	8.89**	7.55 **	2.49	2.74	10.77*	0.65	3.5	8.44 *	6.75*	3.65	5.28
13.	GP 329×GP 83	-9.52**	-9.42**	-10.77**	2.72	6.75	6.14*	-0.66	8.88 *	1.19	5.13*	8.25 **
14.	GP 329×GP 86	11.43**	9.37 **	6.68 **	4.36	4.12	2.58	3.06	26.05 **	10.43 **	5.43*	7.58 **
15.	GP 329×GP 107	1.27	0.6	1.95	4.69	10.55*	6.3*	-0.88	15.40 **	3.18	1.48	6.61 *
16.	GP 327×GP 36	10.79**	9.06 **	14.21 **	5.52	12.40**	3.23	-1.75	-2.84	2.18	-2.37	3.9
17.	GP 327×GP 69	9.21**	7.55 **	4.26 **	3.57	7.29	-0.16	-9.41 *	-6.5	-2.28	-3.65	1.91
18.	GP 327× GP 83	3.17*	3.02 *	0.89	-1.56	10.55*	-8.72 *	-0.44	-10.49 **	-2.18	-7.4*	-3.86
19.	GP 327× GP 86	4.13**	3.63 *	1.78	2.08	9.87*	-1.29	-1.53	3.88	-1.09	-3.36	0.97
20.	GP 327× GP 107	4.76**	3.32 *	6.75 **	2.59	12.68**	3.07	-3.06	-4.79	4.07	2.27	2.62
21.	PFSR 145×GP 36	4.13**	2.72	1.78	3.3	4.16	4.68*	0.66	-3.85	-2.58	-4.94	1.1
22.	PFSR 145×GP 69	5.40**	4.53 **	6.39 **	0.68	6.79	-3.39	0.22	-10.86 **	-2.98	4.34	7.61 **
23.	PFSR 145×GP 83	8.89**	7.25 **	5.51 **	-4.98	2.67	-9.85 *	-7.00	-13.29 **	-9.63 **	-11.06 **	-12.19 **
24.	PFSR 145×GP 86	-7.94**	-8.76 **	-6.75 **	-1.00	2.40	3.07	-3.5	-4.2	4.77	3.46	3.1
25.	PFSR 145×GP 107	2.22	2.42	2.31	2.64	0.72	-2.58	-0.66	-10.21 **	-3.57	-5.63*	-0.29
26.	GP 82×GP 36	9.52 **	8.76 **	5.33 **	2.74	6.25	1.13	-0.66	-5.01	-1.29	-3.65	-1.66
27.	GP 82×GP 69	3.17 *	0.3	9.06 **	-3.22	-2.26	-0.81	0.44	-7.11	-4.57	-2.27	-1.33
28.	GP 82×GP 83	-6.67**	-5.80**	-6.67**	5.5	14.89 **	-4.52*	1.09	14.26 **	-1.39	-2.27	7.74 **
29.	GP 82×GP 86	7.94 **	7.25 **	11.19 **	-0.39	-5.3	-3.39	-5.03	-7.79 *	-5.96	-7.21	-9.19 **
30.	GP 82×GP 107	2.86	3.63 *	9.24 **	4.65	12.95 **	-3.72	0.66	1.75	-1.59	-4.74	-6.24 *

*Significance at 5% probability, **significance at 1% probability

CONCLUSIONS

The phenomenon of heterosis in maize is important for identification and development of promising hybrids in breeding program. PFSR 393×GP 36 recorded the lowest mean value for the earliness traits, indicating the significance of this hybrids in development of early maturing variety. Similarly, PFSR 145×GP 83 recorded the lowest plant height thus useful for developing short stature lodging tolerant hybrids. On the other hand, GP 329×GP 86 recorded the higher mean value for most of the yield attributing traits whereas, the hybrid GP 329×GP 83 recorded highest mean for grain yield among all hybrids.

The hybrid PFSR 393×GP 36 and GP 329×GP 83 recorded the lowest heterosis for flowering traits and days to maturity respectively. PFSR 145×GP 83 and GP 82×GP 86 recorded the lowest heterosis for plant and ear height respectively. Hybrid PFSR 393×GP 86 for ear length, GP 329×GP 69 for ear girth, GP 329×GP 86 for number of kernel per ear and number of kernel per row, PFSR 393×GP 83 for 100 grain weight and GP 329×GP 83 for grain yield recorded the highest heterosis in desirable direction indicated their potential for exploiting hybrid vigour in breeding programme and might be used for obtaining high yielding maize hybrids. The hybrid GP 329×GP 83 can be tested extensively for the development of potential early maturing hybrids.

FUTURE SCOPE

The heterotic studies in respect of yield will be useful for identification of genotypes with high hybrid vigour which can be exploited in further breeding programmes to develop elite genotypes with high yield potential.

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REFERENCES

Abebe, A., Wolde, L. and Gebreselassie, W. (2020). Standard heterosis and trait association of maize inbred lines using line x tester mating design in Ethiopia. *African Journal of Plant Science*, *14*, 192-204.

Ahmad, D. M. (2015). Heterosis studies in single crosses of inbred lines in maize (*Zea mays* L.). *Electronic Journal of Plant Breeding*, *6,* 1073-1077.

Ali, S.A.R.D.A.R., Khan, N. U., Gul, S., Goher, R.A.B.I.A., Naz, I.S.H.R.A.T., Khan, S. A., Ali, N., Saeed, M., Hussain, I., Khan, S. M. and Ali, I. (2019). Heterotic effects for yield related attributes in F1 populations of maize. *Pakistan Journal of Botany*, *51,* 1675-1686.

Ambikabathy, A., Selvam, N. J., Selvi, D. T., Dhasarathan, M., Vairam, N., Renganathan, V. and Vanniarajan, C. (2019). Determination of combining ability and heterosis for yield and yield related traits in maize hybrids based on line× tester analysis. *Research Journal of Agricultural Sciences*, *10,* 215-220.

Amzeri, A., Daryono, B. S. and Syafii, M. (2020). Genotype by environment and stability analyses of dryland maize hybrids. *SABRAO Journal of Breeding and Genetics*, *52*, 355-368.

Arunkumar, B., Gangapp, E., Ramesh, S., Savithramma, D. L., Nagaraju, N. and Lokesha, R. (2020). Stability Analysis of Maize (*Zea mays* L.) Hybrids for Grain Yield and Its Attributing Traits using Eberhart and Russel Model. *Current Journal of Applied Science and Technology*, *39,* 52-63.

Bello, O. B. and Olawuyi, O. J. (2015). Gene action, heterosis, correlation and regression estimates in developing hybrid cultivars in maize. *Tropical Agriculture*, *92*, 102-117.

Chaurasia, N. K., Nirala, R. B. P. and Singh, B. (2020). Combining ability and heterosis studies in maize (*Zea mays* L.) under kharif season. *International Journal of Current Microbiology and Applied Sciences*, *9,* 2576-2586.

Darshan, S. S. and Marker, S. (2019). Heterosis and combining ability for grain yield and its component characters in quality protein maize (*Zea mays* L.) hybrids. *Electronic Journal of Plant Breeding*, *10,* 111-118.

Dorina, B. and Viorica, U. (2015). The evaluation of heterosis for Romanian maize germplasm. *Pakistan Journal of Botany*, *47*, 2387-2390.

FAOSTAT (2020). *Food outlook. Biannual reports on global food markets*. 104.

Ghimire, B. and Timsina, D. (2015). Analysis of yield and yield attributing traits of maize genotypes in Chitwan, Nepal. *World Journal of Agricultural Research*, *3,* 153-162.

Hoque, M., Akhter, F., Kadir, M., Begum, H. A. and Ahmed, S. (2016). Study on combining ability and heterosis for earliness and short statured plant in maize. *Bangladesh Journal of Agricultural Research*, *41*, 365-376.

India-Maize-Summit, AgriVision 2022. *https://agriculturepost.com/tag/india-maize-summit/*

INDIASTAT. 2020-21. *http://www.indiastat.com/maize/production/area*.

Kandel, B. P. and Shrestha, K. (2020). Performance evaluation of maize hybrids in inner-plains of Nepal. *Heliyon*, *6*.

Karim, A. N. M. S., Ahmed, S., Akhi, A. H., Talukder, M. Z. A. and Mujahidi, T. A. (2018). Combining ability and heterosis study in maize (*Zea mays* L.) Hybrids at different environments in Bangladesh. *Bangladesh Journal of Agricultural Research*, *43,* 125-134.

Keimeso, Z., Abakemal, D. and Gebreselassie, W. (2020). Heterosis and combining ability of highland adapted maize (*Zea mays*. L) DH lines for desirable agronomic traits. *African Journal of Plant Science*, *14*, 121-133.

Kumar, S., Chandel, U., Guleria, S. K. and Devlash, R. (2019). Combining ability and heterosis for yield contributing and quality traits in medium maturing inbred lines of maize (*Zea mays* L.) using line x tester. *International Journal of Chemical Studies*, *7*, 2027-2034.

Lekha, R. A. M., Singh, R., Singh, S. K. and Srivastava, R. P. (2015). Heterosis and combining ability studies for quality protein maize. *Ekin Journal of Crop Breeding and Genetics*, *1*, 8-25.

Liu, C., Ma, C., Lu, J. and Ye, Z. (2022). Yield Stability Analysis in Maize Hybrids of Southwest China under Genotype by Environment Interaction Using GGE Biplot. *Agronomy*, *12*, 1189-1200.

Meena, M.K., Singh, R. and Meena, H.P. (2016). Genetic variability, heritability and genetic advance studies in newly developed maize genotypes (*Zea mays* L.). *The Bioscan*, *11*, 1787-1791.

Meseka, S., Menkir, A., Bossey, B. and Mengesha, W. (2018). Performance assessment of drought tolerant maize hybrids under combined drought and heat stress. *Agronomy*, *8*, 274.

Mogesse, W. and Zeleke, H. (2022). Hybrid Performance and Standard Heterosis of Maize (*Zea mays* L.) for Grain Yield and Yield Related Trait in Eastern Ethiopia. *American Journal of BioScience*, *10*, 44-50.

Mostafavi, K. and Saremi-Rad, A. (2021). Genotype-Environment Interaction Study in Corn Genotypes Using additive main effects and multiplicative interaction method and GGE-biplot Method. *Journal of Crop Production*, *14*, 1-12.

Ofori, A. P., Ofori, K., Obeng-Antwi, K., Tengan, K. M. L. and Badu-Apraku, B. (2015). Combining ability and heterosis estimate of extra-early quality protein maize (QPM) single cross hybrids. *Journal of Plant Breeding and Crop Science*, *7,* 87-93.

Oliveira, T. R. A. D., Carvalho, H. W. L. D., Oliveira, G. H. F., Costa, E. F. N., Gravina, G. D. A., Santos, R. D. D. and Carvalho, J.L.S.D. (2019). Hybrid maize selection through GGE biplot analysis. *Bragantia*, 78, 166-174.

Onejeme, F. C., Okporie, E.O. and Eze, C. E. (2020). Combining Ability and Heterosis in Diallel Analysis of Maize (*Zea mays* L.) Lines. *International Annals of Science*, *9,* 188-200.

Oyekunle, M., Haruna, A., Badu Apraku, B., Usman, I.S., Mani, H., Ado, S. G., Olaoye, G., Obeng-Antwi, K., Abdulmalik, R. O. and Ahmed, H. O. (2017). Assessment of early-maturing maize hybrids and testing sites using GGE biplot analysis. *Crop Science*, *57*, 2942-2950.

Patil, B. S., Ahamed, M. L. and Babu, D. R. (2017). Heterosis studies for yield and yield component characters in maize (*Zea mays* L.). *International Journal of Agriculture, Environment and Biotechnology*, *10,* 449-455.

Rajitha, A., Babu, D. R., Lal, A. M. and Rao, V. S. (2014). Heterosis and combining ability for grain yield and yield component traits in maize (*Zea mays* L.). *Electronic Journal of Plant Breeding*, *5,* 378-384.

Reddy, V. R., Jabeen, F. and Sudarshan, M. R. (2015). Heterosis studies in diallel crosses of maize for yield and yield attributing traits in maize (*Zea mays* L.) over locations. *International Journal of Agriculture, Environment and Biotechnology*, *8,* 271-283.

Rezende, W. S., Beyene, Y., Mugo, S., Ndou, E., Gowda, M., Sserumaga, J. P., Asea, G., Ngolinda, I., Jumbo, M., Oikeh, S. O. and Olsen, M. (2020). Performance and yield stability of maize hybrids in stress-prone environments in eastern Africa. *The crop Journal*, *8*, 107-118.

Ruswandi, D., Supriatna, J., Makkulawu, A. T., Waluyo, B., Marta, H., Suryadi, E. and Ruswandi, S. (2015). Determination of combining ability and heterosis of grain yield components for maize mutants based on line × tester analysis. *Asian Journal of Crop Science*, *7*, 19-33.

Sharma, P., Kamboj, M. C., Singh, N. and Chand, M. (2017). Heterosis for grain yield and quality traits in maize (*Zea mays* L.). *Indian Journal of Pure and Applied Biosciences*, *5*, 241-248.

Shrestha, J. (2019). Performance evaluation of maize in Jumla district of Nepal: from yielding perspective. *International Journal of Applied Biology*, *3*, 35-45.

Shrestha, J., Subedi, S., Acharya, R., Sharma, S. and Subedi, M. (2021). Grain yield stability of maize (*Zea mays* L.) hybrids using ammi model and GGE Biplot analysis. *SAARC Journal of Agriculture*, *19*, 107-121.

Shull, G. H. (1914). Duplicate genes for capsule-form in Bursa bursa-pastoris. *Z Indukt Abstamm Vererbungsl*, *12*, 97-149.

Sserumaga, J. P., Oikeh, S. O., Mugo, S., Asea, G., Otim, M., Beyene, Y., Abalo, G. and Kikafunda, J. (2016). Genotype by environment interactions and agronomic performance of doubled haploids testcross maize (*Zea mays* L.) hybrids. *Euphytica*, *207*, 353-365.

Virmani, S., Aquino, R.C. and Khush, G. S. (1982). Heterosis breeding in rice (*Oryza sativa* L.). *Theoretical and Applied Genetics*, *63,* 373-380.

Zeleke, H. (2015). Heterosis and combining ability for grain yield and yield component traits of maize in eastern Ethiopia. *Science, Technology and Arts Research Journal*, *4*, 32-37.

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