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**Research Article**

# Genetic analysis and Heterosis studies in 5×5 Diallel Crosses of Maize under the meteorological conditions of Rawalakot

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## Abstract
This experiment was performed to evaluate heterosis and combining ability of morphological traits in maize (*Zea mays* L.). The experiment was arranged in randomized complete block design (RCBD) with three replicates. Twenty maize hybrids were obtained by 5×5 complete diallel crosses in first year and were evaluated for plant attributes like plant height, ear height, ear leaf area, flag leaf area, days to 50% silking, days to 50% pollen shed, anthesis-silking interval (ASI), no. of leaves per plant, no. of branches per tassel, no. of kernel rows per ear and kernels per row, 1000-kernel weight, shelling percentage, grain plus biological yield per plant and harvest index in second year. Among the crosses NCEV-4 × NCEV-3 (462.70g) showed maximum 1000-kernel weight, followed by NCEV-3 × EV-70040 (451.33g), while highest grain yield per plant was recorded for NCEV-4 × NCEV-3 (152.97g), followed by NCEV-3 × EV-70040 (145.10g). Maximum and highly significant heterosis and heterobeltiosis was found in cross NCEV-1530-11 × HNG (70.49 and 67.54), followed by HNG × EV-70040 (65.57 and 56.39) and HNG × NCEV-1530-11 (64.14 and 61.3), rest of the crosses also showed positive and highly significant heterosis and heterobeltiosis for grain yield per plant. Among the parents NCEV-3 has best GCA for grain yield (4.30) while cross NCEV-3 × NCEV-4 has best SCA for grain yield per plant (18.10) and could be used in hybridization for yield improvement.

**Keywords**: Rawalakot; Genetic analysis; Heterosis studies



## Introduction
On the basis of production maize is 5th most important among all crops and 3rd in importance among cereals after wheat and rice. During 2019-2020, maize cultivated on 1.41 million hectare which was an increase of 2.9% than last year and production was 7.23 million ton. The maize contributes 2.9% to value addition in Agriculture and 0.6 % to GDP (Pakistan Bureau of Statistics, 2020). As compared to world, yield of maize in Pakistan is very low and Pakistan rank 41st position throughout the world. It is essential to increase the production of maize to fulfill the needs of food, feed and industrial raw material (Khan *et al.*, 2014).

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By exploiting heterosis increased yield can be obtained. The expression of heterosis is allied to SCA characterized by non- additive genetic effect and GCA related to the additive genetic effects (Zhang *et al*., 2015). For developing hybrids with desirable traits information about combining ability of parents and crosses is very important (Kage *et al*., 2013). Both GCA and SCA are important in determining the improvement or decline in hybrid traits (Vieira *et al*., 2009).

In comparison to other countries production per unit area is very low in Pakistan. Production in Azad Kashmir is lower than rest of the country. Yield per unit area is badly hampered by many environmental stresses. Rawalakot is a mountainous area and maize crop is cultivated under erratic climatic conditions. Climatic changes frequently affect the maize crop by decreasing yield. To increase yield, farmers rely on cultivation of hybrids. Hybrid seed is mostly introduced from the major growing areas of Punjab which is tried and tested under their climatic conditions. This seed is not acclimatized to mountainous region resulting in poor yield.

Hence a high yielding maize hybrid adopted to mountainous area of Rawalakot was required to increase the production of this area. Development of hybrid adopted to this area has not been reported yet, hence this research was conducted to assess the genetic potential of different genotypes of maize under Rawalakot conditions. To estimate the magnitude of heterosis and heterobeltiosis for the yield and yield components in maize and to determine combining ability in 5×5 diallel cross of maize.

## Methodology

The experiment was performed at the experimental fields of department of Plant Breeding and Molecular Genetics, University of Poonch Rawalakot. The material was comprised of 27 genotypes of maize germplasm that was obtained from National Agriculture Research Centre (NARC), Islamabad.

The material was sown during kharif-2019 according to augmented design and 5×5 complete diallel crosses including reciprocals were made. For crossing, two adjacent experiments were laid out in two different sowing dates at an interval of ten days for synchronization of pollination. Nine meter long rows were sown for each genotype, distance between rows was 75cm and between plants was 25cm. Ears of plants were bagged before the emergence of silk to control unnecessary cross-pollination. To collect pure pollen from male parents tassel bagging was done. Pollination was performed by dusting pollen collected in the pollen bag on the silk of the specific ear.

The hybrids along with parents were sown during kharif-2020 under RCBD with 3 replications. The distance between each row and plant was kept 75cm and 25cm. Sowing was done manually and nine meter long rows were sown for each genotype. All cultural practices were followed uniformly throughout the experiment. Urea and DAP fertilizers were applied at the rate of 140 kg N and 60 kg $P_2O_5$. The data regarding 16 quantitative parameters including plant and ear height, ear and flag leaf area, leaves/plant, branches/tassel, kernel rows/ear and kernels/row, 1000-kernels weight, grain and biological yield/plant, shelling percentage and harvest index was recorded from 10 randomly selected plants as under.

***Statistical analysis***

The significance of heterosis and heterobeltiosis was checked according to method given by Singh and Narayanam (2000).

Heterobeltiosis (%) = $\frac{F1-BP}{BP}\times 100$

Mid parent Heterosis (%) = $\frac{F1-MP}{MP}\times 100$

Where,

BP = mean value of better parent    MP = mean value of mid parent


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GCA and SCA are estimated by using the procedure given by Griffing (1956).

$u = \frac{1}{p^2} X..,$

$g_i = \frac{1}{2p}(X_{.i} + X_{i.}) - \frac{1}{p^2} X..,$

$s_{ij} = \frac{1}{2}(x_{ij} + x_{ji}) - \frac{1}{2p}(x_{i.} + x_{.i} + x_{j.} + x_{.j}) + \frac{1}{p^2} X..,$

$r_{ij} = \frac{1}{2}(x_{ij}\text{-}x_{ji})$

X.., = Total of all values, p = Number of parents, gi = GCA effect of ith line, $X_i$ = Total of ith line overall and replications, Sij = SCA of the cross between $i^{th}$ and $j^{th}$ line, Xij = Total of $(ij)^{th}$ combination over all replications and $r_{ij}$ = Reciprocal effect between $i^{th}$ and $j^{th}$ line.

## Result and Discussion

### Heterosis and heterobeltiosis for morphological traits of Maize

The increased performance of a $F_1$ than its parents is known as heterosis and its value would be negative or positive (Aguiar *et al.*, 2007). Yield of crop can be increased by exploiting heterosis in the form of greater vigor, increased productivity, early maturity and faster growth (Duvick, 1999). Better parent heterosis referred as improvement in performance of $F_1$ over its better parent in single or several traits (Yordanov, 1983). Heterosis and heterobeltiosis for 5×5 complete diallel crosses of maize for morphological traits i.e. plant and ear height, ear and flag leaf area, no. of leaves/plant, branches/tassel, kernel rows/ear, kernels/row, 1000-kernels weight, grain and biological yield/plant, shelling percentage and harvest index was calculated.

***Plant height***

Analysis revealed that all crosses showed positive heterosis as well as heterobeltiosis for plants height (Table 1). Maximum positive value of heterosis was reported for NCEV-4 × NCEV-3 (49.23%), followed by NCEV-3 × NCEV-1530-11 (44.12 %) and NCEV-1530-11 × HNG (40.95%), respectively. These hybrids also showed positive highly significant heterobeltiosis (Table 1). Hybrid NCEV-4 × NCEV-3 revealed highest positive significant heterosis (49.23%) along with significant positive heterobeltiosis (46.13%). With respect to plant height minimum positive heterosis was shown by EV-70040 × NCEV-4 (21.05%), NCEV-4 × EV-70040 (23.51%) and EV-70040 × HNG (24.46%) along with positive significant heterobeltiosis. These crosses showed better plant height than their parents. Karim *et al.* (2018) and Begum *et al.* (2018) also obtained similar results and observed significant positive levels of mid-parent heterosis for plant height in their studies.

***Ear height***

Analysis revealed that all crosses showed positive heterosis as well as heterobeltiosis for ear height (Table 1). Maximum positive heterosis was reported for NCEV-4 × NCEV-3 (100%), followed by NCEV-1530-11 × HNG (94.72 %) and HNG × NCEV-1530-11 (88.45%), respectively. These hybrids also showed positive highly significant Heterobeltiosis (Table 1). Hybrid NCEV-4 × NCEV-3 revealed highest positive significant heterosis (100%) along with significant positive heterobeltiosis (90.83%). With respect to ear height minimum positive heterosis was shown by NCEV-4 × NCEV-1530-11 (23.1%), NCEV-3 × HNG (36.74%) and EV-70040 × NCEV-1530-11 (37.58%) along with positive significant heterobeltiosis. These hybrids response showed increased ear height as compared to their parents. These findings of high magnitude of better parent heterosis for ear height were in close conformity with those reported earlier Karim *et al.* (2018), Talukder *et al.* (2016) and Abuali *et al.* (2012).

***Ear leaf area***

Analysis revealed that all crosses showed positive heterosis as well as heterobeltiosis for ear leaf area (Table 1). Maximum positive heterosis was reported for NCEV-1530-11 × HNG (70.79%), followed by NCEV-3 × NCEV-1530-11 (62.79 %) and NCEV-1530-11 × NCEV-4 (62.16%), respectively. These hybrids also showed positive highly significant



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Heterobeltiosis (Table 1). Hybrid NCEV-1530-11 × HNG revealed highest positive significant heterosis (70.79%) along with significant positive heterobeltiosis (68.37%). With respect to ear leaf area minimum positive heterosis was shown by HNG × NCEV-4 (1.95%), EV-70040 × NCEV-4 (6.21%) and EV-70040 × HNG (8.94%) along with positive significant heterobeltiosis. Mahmood *et al.* (2016) reported the similar results.

***Flag leaf area***

Analysis revealed that all crosses showed positive heterosis as well as heterobeltiosis for flag leaf area (Table 1). Maximum positive heterosis was reported for NCEV-1530-11 × EV-70040 (78.79%), followed by HNG × NCEV-1530-11 (74.83 %) and NCEV-1530-11 × NCEV-4 (73.82%), respectively. These hybrids also showed positive highly significant Heterobeltiosis (Table 1). Hybrid NCEV-1530-11 × EV-70040revealed highest positive significant heterosis (78.79%) along with significant positive heterobeltiosis (72.92%). With respect to flag leaf area minimum positive heterosis was shown by HNG × NCEV-4 (3.18%) and NCEV-3 × NCEV-4 (5.69%) along with positive significant heterobeltiosis. Similar results for flag leaf area were reported by Karim *et al.* (2018) and Ali *et al.* (2013).

Table 1. Heterosis and Heterobeltiosis for some metric traits in a 5 × 5 diallel fashion of maize.

| Crosses | Plant height | | Ear height | | Ear leaf area | | flag leaf area | |
|---|---|---|---|---|---|---|---|---|
| | MPH | BPH | MPH | BPH | MPH | BPH | MPH | BPH |
| HNG × NCEV-4 | 33.11** | 31.4** | 57.15** | 55.26** | 1.95** | 1.7** | 3.18** | 1.9** |
| HNG × NCEV-3 | 34.23** | 35.44** | 87.09** | 80.55** | 35.14** | 32.85** | 12.05** | 10.15** |
| HNG × EV-70040 | 27.11** | 17.65** | 63.14** | 58.21** | 41.34** | 39.34** | 42.43** | 41.89** |
| HNG × NCEV-1530-11 | 40.34** | 39.43** | 88.45** | 80.39** | 60.75** | 60.3** | 74.83** | 71.85** |
| NCEV-4 × HNG | 29.88** | 28.21** | 47.67** | 45.92** | 32.03** | 31.7** | 40.07** | 38.86** |
| NCEV-4 × NCEV-3 | 49.23** | 46.13** | 100** | 90.83** | 40.95** | 41.61** | 34.55** | 33.41** |
| NCEV-4 × EV-70040 | 23.51** | 16.88** | 85.3** | 81.8** | 26.79** | 26.12** | 46.45** | 42.82** |
| NCEV-4 × NCEV-1530-11 | 39.1** | 36.44** | 23.1** | 19.24** | 31.64** | 30.13** | 23.85** | 22.8** |
| NCEV-3 × HNG | 30.39** | 26.13** | 36.74** | 32.09** | 15.88** | 13.91** | 7.18** | 5.43** |
| NCEV-3 × NCEV-4 | 33.23** | 30.44** | 51.22** | 44.4** | 34.38** | 32.42** | 5.69** | 4.79** |
| NCEV-3 × EV-70040 | 29.16** | 24.76** | 59.3** | 49.4** | 31.07** | 28.49** | 21.94** | 17.93** |
| NCEV-3 × NCEV-1530-11 | 44.12** | 38.46** | 71.41** | 58.78** | 62.79** | 62.31** | 51.34** | 51.34** |
| EV-70040 × NCEV-4 | 21.05** | 14.55** | 38.8** | 36.18** | 6.21** | 5.65** | 6.78** | 4.13** |
| EV-70040 × NCEV-3 | 24.46** | 20.21** | 83** | 71.82** | 42.97** | 40.15** | 6.41** | 2.92** |
| EV-70040 × HNG | 24.46** | 16.35** | 63.15** | 58.2** | 8.94** | 8.64** | 44.67** | 42.32** |
| EV-70040 × NCEV-1530-11 | 30.12** | 20.91** | 37.58** | 35.79** | 45.31** | 42.86** | 52.13** | 47.13** |
| NCEV-1530-11 × HNG | 40.95** | 40.03** | 94.72** | 86.44** | 70.79** | 68.37** | 49.75** | 47.2** |
| NCEV-1530-11 × NCEV-4 | 38.09** | 35.45** | 48.02** | 43.38** | 62.16** | 66.24** | 73.82** | 72.34** |
| NCEV-1530-11 × NCEV-3 | 32.58** | 27.37** | 67.32** | 54.78** | 26.45** | 26.08** | 11.92** | 11.92** |
| NCEV-1530-11 × EV-70040 | 30.51** | 21.27** | 53.7** | 51.72** | 23.05** | 20.97** | 78.79** | 72.92** |

***Days to 50% pollen shed***

Analysis revealed that some crosses showed positive heterosis as well as heterobeltiosis for days to 50% pollen shed (Table 2). Maximum positive heterosis was reported for NCEV-3 × EV-70040 (13.79%), followed by EV-70040 × NCEV-1530-11 (12.29%) and NCEV-1530-11 × EV-70040 (12%), respectively. These hybrids also showed positive highly significant Heterobeltiosis (Table 2). Hybrid NCEV-3 × EV-70040 revealed highest positive significant heterosis (13.79%) along with significant positive heterobeltiosis (13.24%). For days to 50% pollen shed minimum heterosis was shown by NCEV-4 × NCEV-1530-11 (-1.16%) and NCEV-4 × EV-70040 (-1.16%).

***Days to 50% silking***

Analysis revealed that some crosses showed positive heterosis as well as heterobeltiosis for days to 50% silking (Table 2). Maximum positive heterosis was reported for NCEV-3 ×


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EV-70040 (14.13%), followed by EV-70040 × NCEV-1530-11 (10.42%) and NCEV-1530-11 × EV-70040 (10.15%), respectively. These hybrids also showed positive highly significant Heterobeltiosis (Table 2). Hybrid NCEV-3 × EV-70040 revealed highest positive significant heterosis (14.13%) along with significant positive heterobeltiosis (12.61%). For days to 50% silking minimum heterosis was shown by NCEV-4 × NCEV-1530-11 (-2.08%) and NCEV-4 × EV-70040 (-1.58%). Similar heterosis for days to 50% pollen shed was reported earlier in maize by Karim *et al.* (2018) and Begum *et al.* (2018).

***Anthesis-silking interval***

Analysis revealed that all crosses showed negative heterosis as well as heterobeltiosis for anthesis-silking interval except NCEV-4 × NCEV-3 (Table 2). Maximum heterosis was reported for NCEV-4 × NCEV-3 (5.26%), followed by NCEV-1530-11 × NCEV-3 (-0.06%) and HNG × NCEV-4 (-8.5%), respectively. Hybrid NCEV-4 × NCEV-3 revealed highest positive significant heterosis (5.26%) along with significant heterobeltiosis (-10.31%). For anthesis-silking interval minimum heterosis was shown by NCEV-1530-11 × EV-70040 (-45.27%) and EV-70040 × NCEV-1530-11 (-35.39%) along with highly significant heterobeltiosis.

***Number of leaves per plant***

Analysis revealed that all crosses showed positive heterosis as well as heterobeltiosis for this parameter. Maximum positive heterotic value was reported for NCEV-3 × NCEV-1530-11 (64.8%), followed by EV-70040 × NCEV-1530-11 (53.13 %) and NCEV-1530-11 × NCEV-4 (53.13%), respectively. These hybrids also showed positive highly significant Heterobeltiosis (Table 2). Hybrid NCEV-3 × NCEV-1530-11 revealed highest positive significant heterosis as well as heterobeltiosis (64.8%) and (60.31%) respectively. Minimum positive heterosis was shown by NCEV-3 × EV-70040 (18.38%) and NCEV-1530-11 × NCEV-3 (25.22%) along with positive significant heterobeltiosis. These hybrids response showed increased number of leaves per plant as compared to their parents.

***Number of branches per tassel***

Analysis revealed that all crosses showed positive heterosis as well as heterobeltiosis for no. of branches per tassel (Table 3). Maximum positive heterosis was reported for NCEV-4 × NCEV-3 (92.77%), followed by NCEV-3 × HNG (86.44 %) and HNG × NCEV-4 (77.72%), respectively. These hybrids also showed positive highly significant Heterobeltiosis (Table 3). Hybrid NCEV-4 × NCEV-3 revealed highest positive significant heterosis (92.77%) and heterobeltiosis (85%). Minimum positive heterosis was shown by NCEV-4 × NCEV-1530-11 (11.77%) and HNG × NCEV-1530-11 (20.81%) along with positive significant heterobeltiosis.

***Number of kernel rows per ear***

Analysis revealed that all crosses showed positive heterosis as well as heterobeltiosis for no. of kernel rows per ear (Table 3). Maximum heterosis was reported for NCEV-3 × NCEV-1530-11 (66.97%), followed by NCEV-4 × NCEV-3 (62.63%) and NCEV-1530-11 × EV-70040 (58.77%), respectively. These hybrids also showed positive highly significant Heterobeltiosis (Table 3). Hybrid NCEV-3 × NCEV-1530-11 revealed highest significant heterosis (66.97%) along with significant positive heterobeltiosis (66.14%). Minimum heterosis was shown by EV-70040 × NCEV-4 (25.82%) and NCEV-3 × HNG (27.09%) along with positive significant heterobeltiosis. Mahmood *et al.* (2016) and Abuali *et al.* (2012) were in close agreement with the present findings.

***Number of kernels per row***

Analysis revealed that all crosses showed positive heterosis as well as heterobeltiosis for no. of kernels per row (Table 3). Maximum heterosis was reported for NCEV-4 × NCEV-3 (100%), followed by NCEV-1530-11 × EV-70040 (87.53%) and NCEV-3 × NCEV-1530-11 (86.57%), respectively. These hybrids also showed positive highly significant Heterobeltiosis (Table 3). Hybrid NCEV-4 × NCEV-3 revealed highest significant



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heterosis (100%) along with significant positive heterobeltiosis (98.38%). Minimum heterosis was shown by NCEV-3 × HNG (26.62%) and HNG × NCEV-4 (29.95%) along with positive significant heterobeltiosis. Mahmood *et al.* (2016), Kage *et al.* (2013) and Ali *et al.* (2013) found similar results.

***1000-kernel weight***

Analysis showed positive heterosis as well as heterobeltiosis for 1000-kernel weight. Maximum heterosis regarding 1000-kernel weight was reported for NCEV-4 × NCEV-3 (80.47%), followed by NCEV-3 × NCEV-1530-11 (74.46%) and HNG × NCEV-1530-11 (69.68%), respectively. These hybrids also showed positive highly significant Heterobeltiosis (Table 3). Hybrid NCEV-4 × NCEV-3 revealed highest significant heterosis (80.47%) along with significant positive heterobeltiosis (77.28%). For 1000-kernel weight minimum heterosis was shown by EV-70040 × NCEV-3 (38.1%) and EV-70040 × HNG (39.09%) along with positive significant heterobeltiosis.

***Shelling percentage***

Analysis revealed that all crosses showed positive heterosis as well as heterobeltiosis for shelling percentage except NCEV-3 × NCEV-1530-11 (Table 4). Maximum heterosis regarding shelling percentage was reported for NCEV-1530-11 × HNG (14.1%), followed by NCEV-1530-11 × EV-70040 (13.33%) and NCEV-4 × HNG (12.51%), respectively. These hybrids also showed positive highly significant Heterobeltiosis (Table 4). Hybrid NCEV-1530-11 × HNG revealed highest significant heterosis (14.1%) along with significant positive heterobeltiosis (12.97%). Similar magnitudes of heterosis have been observed in the past studies for shelling percentage by Ali *et al.* (2013) and Abuali *et al.* (2012).

Table 2. Heterosis and Heterobeltiosis for some metric traits in a 5 × 5 diallel fashion of maize.

| Crosses | Days to 50% Pollen Shed | | Days to 50% Silking | | Anthesis Silking Interval | | No. of leaves per plant | |
|---|---|---|---|---|---|---|---|---|
| | MPH | BPH | MPH | BPH | MPH | BPH | MPH | BPH |
| HNG × NCEV-4 | 3.81** | 3.78** | 2.8** | 2.49** | -8.5** | -17.94** | 44.76** | 41.31** |
| HNG × NCEV-3 | 2.87** | 2.3** | 2.16** | 1.44* | -29.94** | -33.87** | 52.24** | 42.53** |
| HNG × EV-70040 | 11.44** | 10.28** | 10.13** | 9.51** | -4.76** | -17.7** | 44.76** | 41.31** |
| HNG × NCEV-1530-11 | 3** | 1.98** | 1.97** | 1.45* | -33.33** | -42.39** | 32.81** | 27.68** |
| NCEV-4 × HNG | 9.76** | 9.73** | 9.23** | 8.9** | -8.5** | -17.94** | 41.1** | 37.74** |
| NCEV-4 × NCEV-3 | -0.76NS | -1.12NS | -0.59NS | -1.57** | 5.26** | -10.31** | 41.15** | 35.22** |
| NCEV-4 × EV-70040 | -1.16* | -2.16** | -1.58** | -2.42** | -14.16** | -17.7** | 28.21** | 28.21** |
| NCEV-4 × NCEV-1530-11 | -1.16* | -2.11** | -2.08** | -2.87** | -28.33** | -31.28** | 50.79** | 48.44** |
| NCEV-3 × HNG | 9.5** | 8.9** | 9.6** | 8.83** | -14.37** | -19.21** | 51.43** | 41.77** |
| NCEV-3 × NCEV-4 | 9.71** | 9.14** | 8.5** | 7.87** | -17.37** | -29.6** | 38.53** | 32.72** |
| NCEV-3 × EV-70040 | 13.79** | 13.24** | 14.13** | 12.61** | -21.5** | -35.39** | 18.38** | 13.41** |
| NCEV-3 × NCEV-1530-11 | 8.54** | 8.06** | 7.37** | 7.72** | -16.5** | -31.28** | 64.8** | 60.31** |
| EV-70040 × NCEV-4 | 8.49** | 7.39** | 7.18** | 6.85** | -14.16** | -17.7** | 42.86** | 42.86** |
| EV-70040 × NCEV-3 | 8.51** | 7.65** | 7.89** | 7.75** | -16.5** | -31.28** | 46.5** | 40.35** |
| EV-70040 × HNG | 8.64** | 7.51** | 7.9** | 7.29** | -15.71** | -27.16** | 48.41** | 44.88** |
| EV-70040 × NCEV-1530-11 | 12.29** | 12.24** | 10.42** | 10.37** | -35.39** | -35.39** | 53.13** | 50.75** |
| NCEV-1530-11 × HNG | 5.95** | 4.93** | 5.36** | 4.82** | -12.86** | -24.7** | 42.41** | 36.91** |
| NCEV-1530-11 × NCEV-4 | 7.65** | 6.6** | 6.36** | 5.51** | -24.03** | -27.16** | 53.13** | 50.75** |
| NCEV-1530-11 × NCEV-3 | 11.9** | 9.84** | 9.74** | 9.64** | -0.06NS | -0.23NS | 25.22** | 21.81** |
| NCEV-1530-11 × EV-70040 | 12** | 11.96** | 10.15** | 10.1** | -45.27** | -45.27** | 48.48** | 46.14** |

Table 3. Heterosis and Heterobeltiosis for some metric traits in a 5 × 5 diallel fashion of maize.

| Crosses | No. of branches per tassel | | No. of kernel rows per ear | | No. of kernels per row | | 1000-kernel weight | |
|---|---|---|---|---|---|---|---|---|
| | MPH | BPH | MPH | BPH | MPH | BPH | MPH | BPH |
| HNG × NCEV-4 | 77.72** | 76.29** | 30.68** | 29.44** | 29.95** | 26.76** | 42.02** | 39.58** |
| HNG × NCEV-3 | 57.63** | 52.46** | 51.72** | 49.08** | 60.54** | 57.85** | 67.29** | 61.56** |
| HNG × EV-70040 | 65.37** | 64.03** | 45.27** | 44.09** | 48.77** | 42.86** | 52.64** | 42.67** |
| HNG × NCEV-1530-11 | 20.81** | 19.84** | 50** | 48.12** | 52.28** | 50.58** | 69.68** | 68.62** |
| NCEV-4 × HNG | 30.08** | 29.03** | 26.27** | 25.07** | 38.32** | 34.92** | 42.95** | 38.06** |
| NCEV-4 × NCEV-3 | 92.77** | 85** | 62.63** | 58.31** | 100** | 98.38** | 80.47** | 77.28** |
| NCEV-4 × EV-70040 | 29.03** | 29.03** | 46.74** | 46.53** | 39.22** | 37** | 46.72** | 39.4** |
| NCEV-4 × NCEV-1530-11 | 11.77** | 11.77** | 29.42** | 26.59** | 54.61** | 52.48** | 67.39** | 63.51** |
| NCEV-3 × HNG | 86.44** | 80.32** | 27.09** | 24.88** | 26.62** | 24.5** | 50.49** | 45.34** |
| NCEV-3 × NCEV-4 | 62.52** | 55.97** | 50.93** | 46.91** | 46.64** | 45.45** | 55.53** | 50.03** |
| NCEV-3 × EV-70040 | 68.07** | 61.29** | 58.57** | 54.57** | 74.63** | 70.48** | 66.95** | 61.38** |
| NCEV-3 × NCEV-1530-11 | 44.03** | 38.22** | 66.97** | 66.14** | 86.57** | 85.5** | 74.46** | 67.47** |
| EV-70040 × NCEV-4 | 35.97** | 35.97** | 25.82** | 25.64** | 43.57** | 41.29** | 44.19** | 36.99** |
| EV-70040 × NCEV-3 | 41.68** | 35.97** | 42.94** | 39.33** | 47.95** | 44.43** | 38.1** | 33.49** |
| EV-70040 × HNG | 37.07** | 35.97** | 30.58** | 29.2** | 31.07** | 25.86** | 39.09** | 30** |
| EV-70040 × NCEV-1530-11 | 38.23** | 38.23** | 50.41** | 47.33** | 53.2** | 48.71** | 50.32** | 39.69** |
| NCEV-1530-11 × HNG | 20.81** | 19.84** | 50.29** | 48.4** | 57.39** | 55.64** | 66.5** | 65.47** |
| NCEV-1530-11 × NCEV-4 | 29.03** | 29.03** | 50.49** | 47.2** | 47.98** | 45.94** | 61.7** | 57.95** |
| NCEV-1530-11 × NCEV-3 | 40** | 30.55** | 52.69** | 51.94** | 58.76** | 57.85** | 64.79** | 58.19** |
| NCEV-1530-11 × EV-70040 | 29.03** | 29.03** | 58.77** | 55.52** | 87.53** | 82.05** | 64.98** | 53.31** |

Table 4. Heterosis and Heterobeltiosis for some metric traits in a 5 × 5 diallel fashion of maize.

| Crosses | Shelling Percentage | | Grain Yield per Plant | | Biological Yield per Plant | | Harvest Index | |
|---|---|---|---|---|---|---|---|---|
| | MPH | BPH | MPH | BPH | MPH | BPH | MPH | BPH |
| HNG × NCEV-4 | 3.67** | 1.73** | 22.88** | 19.24** | 11.56** | 5.31** | 9.75** | 6.97** |
| HNG × NCEV-3 | 7.67** | 5.9** | 63.98** | 55.32** | 49.49** | 41.32** | 9.78** | 9.59** |
| HNG × EV-70040 | 10.85** | 10.52** | 65.57** | 56.39** | 51.22** | 41.35** | 9.47** | 8.24** |
| HNG × NCEV-1530-11 | 9.12** | 8.04** | 64.14** | 61.3** | 43.77** | 38.45** | 13.94** | 11.62** |
| NCEV-4 × HNG | 12.51** | 8.3** | 35.13** | 31.13** | 14.11** | 7.72** | 17.28** | 14.3** |
| NCEV-4 × NCEV-3 | 12.06** | 8.18** | 59.25** | 55.32** | 58.03** | 57.8** | 9.66** | 7.06** |
| NCEV-4 × EV-70040 | 4.71** | 3.05** | 40.18** | 36.33** | 25.03** | 23.72** | 11.84** | 10.22** |
| NCEV-4 × NCEV-1530-11 | 11.4** | 10.4** | 58.32** | 56.29** | 43.68** | 40.73** | 8.89** | 8.33** |
| NCEV-3 × HNG | 1.51** | $-0.45^{NS}$ | 50.49** | 42.54** | 39.94** | 27.6** | 7.79** | 7.61** |
| NCEV-3 × NCEV-4 | 8.94** | 5.16** | 49.32** | 45.63** | 32.79** | 32.59** | 12.49** | 9.82** |
| NCEV-3 × EV-70040 | 5.62** | 3.58** | 59.74** | 59.28** | 48.03** | 46.27** | 7.73** | 6.7** |
| NCEV-3 × NCEV-1530-11 | 2.51** | $-0.16^{NS}$ | 62.51** | 56.53** | 50.09** | 47.22** | 8.31** | 6.28** |
| EV-70040 × NCEV-4 | 4.93** | 3.26** | 49.02** | 44.93** | 31.66** | 30.28** | 12.13** | 10.5** |
| EV-70040 × NCEV-3 | 10.44** | 8.3** | 42.49** | 42.07** | 31.05** | 29.49** | 8.52** | 7.48** |
| EV-70040 × HNG | 2.54** | 2.23** | 52.09** | 43.66** | 33.22** | 24.52** | 14.04** | 12.76** |
| EV-70040 × NCEV-1530-11 | 6.8** | 6.06** | 58.86** | 52.58** | 48.37** | 43.84** | 7.28** | 6.27** |
| NCEV-1530-11 × HNG | 14.1** | 12.97** | 70.49** | 67.54** | 51.77** | 46.15** | 12.3** | 10.01** |
| NCEV-1530-11 × NCEV-4 | 9.02** | 8.04** | 61.18** | 59.12** | 35.84** | 33.06** | 18.9** | 18.28** |
| NCEV-1530-11 × NCEV-3 | 8.53** | 5.7** | 56.13** | 50.38** | 40.28** | 37.6** | 11.48** | 9.39** |
| NCEV-1530-11 × EV-70040 | 13.33** | 12.54** | 62.17** | 55.76** | 39.96** | 35.69** | 15.92** | 14.83** |


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***Grain yield per plant***

Positive heterosis and heterobeltiosis was revealed after analysis (Table 4). Maximum value of heterosis was reported for NCEV-1530-11 × HNG (70.49%), followed by HNG × EV-70040 (65.57%) and HNG × NCEV-1530-11 (64.14%), respectively. Hybrid NCEV-1530-11 × HNG revealed highest significant heterosis (70.49%) and heterobeltiosis (67.54%). Minimum heterosis was shown by HNG × NCEV-4 (22.88%) and NCEV-4 × HNG (35.13%) along with positive significant heterobeltiosis. Like Karim *et al.* (2018) and Begum *et al.* (2018) these hybrids response showed more grain yield per plant as compared to their parents.

***Biological yield per plant***

Analysis revealed that all crosses showed positive heterosis as well as heterobeltiosis for biological yield per plant (Table 4). Hybrid NCEV-4 × NCEV-3 revealed highest significant heterosis (58.03%) and heterobeltiosis (57.8%). Minimum heterosis was shown by HNG × NCEV-4 (11.56%) and NCEV-4 × HNG (14.11%) along with positive significant heterobeltiosis. These hybrids response showed more biological yield per plant as compared to their parents. Mahmood *et al*. (2017) and Abuali *et al*. (2012) found similar results.

***Harvest index***

Analysis revealed that some crosses showed positive heterosis as well as heterobeltiosis for harvest index (Table 4). Maximum heterosis regarding harvest index was reported for NCEV-1530-11 × NCEV-4 (18.9%), followed by NCEV-4 × HNG (17.28%) and NCEV-1530-11 × EV-70040 (15.92%), respectively. Hybrid NCEV-1530-11 × NCEV-4 revealed highest significant heterosis (18.9%) along with significant positive heterobeltiosis (18.28%). For harvest index minimum heterosis was shown by EV-70040 × NCEV-1530-11 (7.28%) and NCEV-3 × EV-70040 (7.73%) along with positive significant heterobeltiosis. These hybrids response showed more harvest index as compared to their parents. Similar results of heterosis for harvest index in maize hybrids had also been reported in earlier studies by Bharathi *et al.* (2018) and Ali *et al.* (2013).

## Conclusion

Maximum and highly significant heterosis and heterobeltiosis was found in cross NCEV-1530-11 × HNG (70.49 and 67.54), followed by HNG × EV-70040 (65.57 and 56.39) and HNG × NCEV-1530-11 (64.14 and 61.3), rest of the crosses also showed positive and highly significant heterosis and heterobeltiosis for grain yield per plant. According to General Combining Ability analysis NCEV-3 was identified as best combiner for plant height (3.79), grain yield per plant (4.30), biological yield per plant (9.93). Specific Combining Ability revealed that NCEV-3 × NCEV-4 has best SCA for grain yield per plant (18.10). So these hybrids could be used in future hybridization for yield improvement.

## Conflict of Interest

The authors have not declared any conflict of interest.

## Authors Contributions

All the authors have contributed equally to the research and compiling the data as well as editing the manuscript.

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