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**RESEARCH PAPER**

# Developing suitable genetically potential combiners and combinations of maize (*Zea mays* L.) for rainfed ecosystem

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**Abstract:** An investigation was undertaken to assess the combining ability, nature of gene action and heterosis with respect to grain yield and its component traits in 48 single cross hybrids of maize developed by crossing 16 lines and three testers in line x tester fashion in *rabi* 2017-18. These hybrids and parents were evaluated against three popular checks during *kharif* 2018 under rainfed ecosystem. Analysis of variance revealed that mean sum of squares of parents and hybrids were significant for 13 characters which imply that presence of variability among the treatments. The contribution of female towards hybrid variance was higher than the males and line x tester interaction for all the characters except shelling percentage. The gene action study revealed highest magnitude of non-additive gene action than additive gene action for all the characters that were studied except days to 50 per cent tasseling, days to 50 per cent silking, days to 75 per cent brown husk maturity and cob girth. The lines *viz.,* NBPGR-1, NBPGR-7, NBGPR-8, NBPGR-9, NBPGR-11 and NBPGR-13 were good general combiners for maximum number of yield contributing characters and the crosses GPBMH-1820 (NBPGR-9 x KDMI-16) and GPBMH-1836 (NBPGR-14 x CI-4) were superior with highest magnitude of *per se* performance along with significant positive SCA effects for most of the yield and yield contributing traits. The crosses *viz.,* GPBMH-1820, GPBMH-1832, GPBMH-1803, GPBMH-1821, GPBMH-1802, GPBMH-1836, GPBMH-1843, GPBMH-1812, GPBMH-1831 and GPBMH-1811 were exhibited highest percentage of standard heterosis over the checks.

**Key Words :** Gene action, General combining ability, Heterosis, Maize

## Introduction

Maize, as a cereal holds tremendous potential and scope not only in increasing the farmer's income but also through providing assured raw material supplies to the upstream agro-industries. It is a 'future cereal' which can perform better in situations of 'global warming' (as it is a $C_4$ plant), highly photosynthetically efficient and at present is the one important cereal which is utilized as food, feed and fodder across the world. Because of its wider use crop improvement programme mainly aimed to increase the grain production.

The two concepts of combining ability *i.e.* general combining ability (GCA) and specific combining ability (SCA) (Sprague and Tatum, 1942) has great influence on evaluation of inbred lines and population improvement in crop breeding. Higher GCA provides the strong evidence of more intense desirable gene flow from parents to offspring and predominant additive gene action. It also indicates that higher heritability, less environmental effect, less gene interaction and higher achievements in selection. High SCA indicates the predominance of non-additive effects. Heterosis is a basic tool for improved production of crops in the form of $F_1$ hybrids. Exploitation of heterosis is the main focus of plant breeders for boosting up yield of many crops. Heterotic study helps to identify the best hybrid combinations in the breeding programmes and their commercial utilization. The line x tester analysis (Kempthorne, 1957) is mostly used mating design for development of hybrids. This technique can evaluate large number of cultivars in terms of GCA and SCA variances and effects and D and H components.

In India, 80 per cent of the area in *Kharif* season is under the cultivation of maize and produces 70 per cent of total Indian maize. Karnataka is the major maize producing state of India and 64 per cent of the farmers grow maize as a rainfed crop in *kharif* season. Throughout the tropics, periodic drought caused by uncertain and uneven rainfall distribution and soil with low water holding capacity cause sizeable reduction in grain yield. Drought is the major abiotic stress, Joshi *et al.* (2005) estimated that loss in production is mainly due to water stress and the most of the productive arable land suffers from water shortage. Inadequate soil moisture during anthesis and grain filling stages reduces the growth and productivity of the crop. Therefore, present investigation was carried out to develop genetically potential combiners and combinations suitable for rainfed ecosystem.

## Material and methods

### Experimental site location

The present investigation was carried out during *rabi* 2017-18 and *kharif* 2018 at Botanical Garden, Department of Genetics and Plant Breeding, College of Agriculture, University of Agricultural Sciences, Dharwad.

### Experimental material

The experimental material consists of 16 elite inbreds of NBPGR selected based on *per se* performance and three testers; CM-501 (broad genetic base), KDMI-16 and CI-4 (narrow genetic base). The 48 experimental single cross hybrids were generated in line x tester mating design during *rabi* 2017-18. Evaluation of experimental single cross hybrids was carried out during *kharif* 2018 along with 19 parents and checks (DKC-9144, GH-0727 and NK-6240) under rainfed ecosystem with three life saving irrigations.

There was no rainfall after the day of sowing therefore, one irrigation was given to facilitate the maximum percentage of germination. In maize tasseling, silking and grain filling stages are very critical for water requirement. Rainfall was nil during these stages. Therefore two irrigations were given to obtain synchronized flowering and to avoid the development of chaffy and shriveled kernels. Hence, totally three life saving irrigations were given to the experimental plot during evaluation programme.

Observations were recorded on following 13 quantitative characters *viz*., days to 50% tasseling, days to 50% silking, days to 75 per cent brown husk maturity, plant height (cm), ear height (cm), cob length (cm), cob girth (cm), number of kernel rows per cob, number of kernels per row, shelling percentage (%), 100-grain weight (g), grain yield per plant (kg) and grain yield (q/ha).

**Results and discussion**

The analysis of variance for all the traits including parents, hybrids and checks for 13 characters are depicted in Table 1. The treatment variance was significant for all the traits indicating the presence of variability among the treatments. Mean sum of squares for 13 characters of parents and hybrids presented in Table 2 implies greater diversity in parental lines for these characters. Even significant variation was found in parent vs. crosses for all the characters *viz.*, days to 50 per cent tasseling, days to 50 per cent silking, 75 per cent brown husk maturity, plant height, ear height, cob length, cob girth, number of kernel rows per cob, number of kernels per row, shelling percentage, 100-grain weight, grain yield per plant and grain yield per hectare depicting considerable amount of average heterosis in hybrids.

The proportional contribution of lines, testers and their interaction to total hybrid variance for 13 characters are presented in Table 3. The contribution of lines for total hybrid variance was higher than the testers for all the characters under study. The percentage contribution of line x tester to total hybrid variance for shelling percentage (71.25%) was higher than lines. This implies that particular cross combinations interact significantly for improvement of *per se* values for important yield influencing traits.

Table 1. Analysis of variance for 13 characters

| Sl. No | Sources of variation | Replication | Treatments | Error |
|---|---|---|---|---|
| | Degrees of freedom (df) | 1 | 69 | 69 |
| 1 | Days to 50 per cent tasseling | 0.064 | 41.94** | 6.84 |
| 2 | Days to 50 per cent silking | 27.45 | 45.57** | 7.00 |
| 3 | Days to 75 per cent brown husk maturity | 3.15 | 47.74** | 11.78 |
| 4 | Plant height (cm) | 146.47 | 1036.26** | 113.02 |
| 5 | Ear height (cm) | 167.20 | 449.65** | 72.09 |
| 6 | Cob length (cm) | 1.36 | 7.38** | 2.33 |
| 7 | Cob girth (cm) | 0.13 | 0.45** | 0.04 |
| 8 | Number of kernel rows per cob | 3.18 | 4.11** | 0.88 |
| 9 | Number of kernels per row | 37.64 | 50.32** | 15.15 |
| 10 | Shelling percentage | 1.77 | 49.40** | 21.85 |
| 11 | 100-grain weight (g) | 11.20 | 83.21** | 10.18 |
| 12 | Grain yield / plot (kg) | 0.71 | 3.55** | 0.28 |
| 13 | Grain yield / ha (q) | 88.73 | 1309.63** | 175.75 |

*-Significant at 5% level **-Significant at 1% level

The estimates of variance components ($\sigma^2_{GCA}$,$\sigma^2_{SCA}$) and their ratios ($\sigma^2_{GCA}$,$\sigma^2_{SCA}$) for 13 quantitative traits are presented in Table 4. The SCA variance was higher than the GCA variance for plant height, ear height, cob length, shelling percentage, 100-grain weight, grain yield per plot and grain yield per hectare indicating that these traits were controlled by non-additive gene action. The ratio of GCA to SCA variance was lesser than unity for plant height, ear height, cob length, number of kernels per row, shelling percentage, 100-grain weight, grain yield per plot

Table 2. Mean sum of squares for parents and hybrids with respect to 13 characters in maize

| Source of variationCharacters | Replication | Parents | Females | Males | Females vs Males | Parents vs Crosses | Crosses | Error |
|---|---|---|---|---|---|---|---|---|
| Degrees of freedom (df) | 1 | 18 | 15 | 2 | 1 | 1 | 47 | 66 |
| Days to 50 per cent tasseling | 2.15 | 75.5** | 89.11** | 8.00 | 6.75 | 67.77** | 25.76** | 6.29 |
| Days to 50 per cent silking | 17.91 | 87.21** | 102.05** | 12.66 | 13.68 | 92.60** | 27.18** | 6.78 |
| Days to 75 per cent brown husk maturity | 6.71 | 75.40** | 89.33** | 4.50 | 8.29 | 30.98 | 37.87** | 11.65 |
| Plant height (cm) | 186.77 | 1055.28** | 1254.15** | 28.16 | 126.52 | 1836.80** | 1048.75** | 116.92 |
| Ear height (cm) | 83.85 | 548.84** | 628.05** | 172.66 | 113.00 | 2237.49** | 397.65** | 63.62 |
| Cob length (cm) | 0.21 | 6.44** | 6.05** | 2.48 | 20.21** | 90.98** | 5.66** | 2.06 |
| Cob girth (cm) | 0.00005 | 0.61** | 0.61** | 0.0064 | 1.93*** | 4.99** | 0.28** | 0.042 |
| Number of kernel rows per cob | 3.32 | 7.12** | 8.29** | 1.94 | 0.0043 | 21.71** | 2.82** | 0.89 |
| Number of kernels per row | 35.94 | 55.96** | 61.63** | 5.84 | 71.05* | 406.05** | 39.42** | 15.44 |
| Shelling percentage | 3.62 | 70.65** | 79.83** | 9.03 | 56.18 | 20.40 | 43.93** | 22.56 |
| 100-grain weight (g) | 10.66 | 112.58** | 105.58** | 38.24* | 366.30** | 661.83** | 56.72** | 10.61 |
| Grain yield / plot (kg) | 0.98 | 2.78** | 2.62** | 0.79 | 11.92** | 28.78** | 2.16** | 0.28 |
| Grain yield / ha (q) | 77.65 | 998.75** | 865.02** | 51.24 | 4889.73** | 19114.56** | 955.52** | 182.51 |

*-Significant at 5% level **-Significant at 1% level

Table 3. Proportional contributions of lines, testers and their interaction to total hybrid variance

| Sl. No. | Characters | Characters contribution (%) | | |
|---|---|---|---|---|
| | | Lines | Testers | Line × Tester |
| 1 | Days to 50 per cent tasseling | 78.28 | 0.41 | 21.30 |
| 2 | Days to 50 per cent silking | 78.14 | 0.45 | 21.40 |
| 3 | Days to 75 per cent brown husk maturity | 73.10 | 2.49 | 24.40 |
| 4 | Plant height (cm) | 77.50 | 0.65 | 21.84 |
| 5 | Ear height (cm) | 78.47 | 0.04 | 21.48 |
| 6 | Cob length (cm) | 56.25 | 0.83 | 42.91 |
| 7 | Cob girth (cm) | 86.41 | 0.49 | 13.09 |
| 8 | Number of kernel rows per cob | 56.97 | 10.54 | 32.48 |
| 9 | Number of kernels per row | 59.16 | 0.88 | 39.94 |
| 10 | Shelling percentage | 25.32 | 3.41 | 71.25 |
| 11 | 100-grain weight (g) | 56.94 | 13.93 | 29.13 |
| 12 | Grain yield / plot (kg) | 69.91 | 0.46 | 29.61 |
| 13 | Grain yield / ha (q) | 61.08 | 3.53 | 35.38 |

maturing maize genotypes. The lines NBPGR-12 and NBPGR-14 had significant negative GCA effects for days to 50 per cent tasseling, days to 50 per cent silking and days to 75 per cent brown husk maturity. Therefore, these two lines were considered as best combiners for short duration, the most required feature of terminal drought escape and moisture stress avoidance in rainfed ecosystem. The lines NBPGR-7, NBPGR-8 and NBPGR-11 were the good general combiners for plant height and ear height. NBPGR-1, NBPGR-9 and NBPGR-13 had significant positive GCA for most of the traits *viz.*, ear height, cob girth, number of kernel rows per cob, 100-grain weight, grain yield per plot and grain yield per hectare. Among the testers KDMI-16 showed good GCA effects for number of kernel rows per cob. CI-4 recorded good GCA effects for 100-grain weight and grain yield per hectare. Highly significant and positive GCA effects for 100-kernel weight and grain yield was observed by Ofori *et al.* (2015), Talukder *et al.* (2016) and Karim *et al.* (2018).

Table 4. Estimates of variance components with respect to 13 quantitative characters

| Sl. No. | Characters | $\sigma^2_{GCA}$ | $\sigma^2_{SCA}$ | $\sigma^2_{GCA}/\sigma^2_{SCA}$ | $\sigma^2_A$ | $\sigma^2_D$ | $\sigma^2_A/\sigma^2_D$ |
|---|---|---|---|---|---|---|---|
| 1 | Days to 50 per cent tasseling | 1.39** | 1.15 | 1.21 | 2.79 | 1.15 | 2.42 |
| 2 | Days to 50 per cent silking | 1.47** | 1.16 | 1.25 | 2.94 | 1.16 | 2.51 |
| 3 | Days to 75 per cent brown husk maturity | 2.25** | 1.41 | 1.59 | 4.50 | 1.41 | 3.19 |
| 4 | Plant height (cm) | 65.13** | 120.99** | 0.53 | 130.26 | 120.99 | 1.07 |
| 5 | Ear height (cm) | 22.49** | 35.11* | 0.64 | 44.98 | 35.11 | 1.28 |
| 6 | Cob length (cm) | 0.18** | 0.87* | 0.20 | 0.36 | 0.87 | 0.42 |
| 7 | Cob girth (cm) | 0.019** | 0.008 | 1.97 | 0.03 | 0.008 | 4.68 |
| 8 | Number of kernel rows per cob | 0.27** | 0.27 | 0.99 | 0.53 | 0.27 | 1.97 |
| 9 | Number of kernels per row | 1.32** | 4.61 | 0.28 | 2.65 | 4.61 | 0.57 |
| 10 | Shelling percentage | 0.65 | 13.24** | 0.05 | 1.31 | 13.23 | 0.09 |
| 11 | 100-grain weight (g) | 6.99** | 7.64** | 0.91 | 13.98 | 7.64 | 1.82 |
| 12 | Grain yield / plot (kg) | 0.11** | 0.36** | 0.30 | 0.23 | 0.36 | 0.64 |
| 13 | Grain yield / ha (q) | 59.41** | 173.73** | 0.34 | 118.82 | 173.73 | 0.68 |

and grain yield per hectare confirmed that there was considerable amount of dominance variance than the additive variance. The dominance is intralocus gene interaction which does not respond to selection. Therefore, it is better to go for hybrid development. Higher SCA variance than the GCA variance exhibiting preponderance of non-additive gene effects has also been earlier reported by Kage *et al.* (2013), Katragadda *et al.* (2014) and Anilkumar *et al.* (2018). The genetic control of different yield contributing characters is finally projected through kernel yield. Therefore, non-additive gene action for kernel yield is expected (Matin *et al.* 2016). Parallel to this grain yield was under the control of non-additive gene action in this present experiment.

The mean of general combining ability effects for all the traits are presented in Table 5. Lower values of days to 50 per cent tasseling, days to 50 per cent silking and days to 75 per cent brown husk maturity is considered while developing early

The results of SCA effects of crosses for different traits are presented in Table 6. Negative SCA effects for hybrid combination are considered for improvement of maturity traits, because negative values are the indicative of reduction in days to maturity compared to the parents whereas positive SCA are indicative of increase of given trait compared to the parents. GPBMH-1834 (-3.82) had significant negative SCA effect for days to 50 per cent silking and GPBMH-1835 (-7.35) had significant negative SCA for days to 75 per cent brown husk maturity. Therefore, these two cross combinations were considered as good source for earliness in hybridization programme for development of early maturing genotypes. GPBMH-1836 showed significant SCA effects for plant height, ear height, cob length, number of kernels per row, shelling percentage, 100-grain weight, grain yield per plot and grain yield per hectare. GPBMH-1820 had significant positive SCA effects for cob girth, grain yield per plot and grain yield per hectare.

Table 5. General combining ability (*GCA*) effects of parents in respect of 13 characters

| Female (Lines) | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | X12 | X13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NBPGR-1 | 5.43** | 4.62** | 6.85** | 6.83 | 0.25 | 0.60 | 0.39** | 0.04 | 0.46 | 0.32 | 5.87** | 1.51** | 25.89** |
| NBPGR-2 | 2.27* | 2.62* | -1.14 | -5.50 | 3.08 | -0.90 | -0.09 | 0.74 | -1.47 | -1.29 | -6.16** | -0.73** | -14.73* |
| NBPGR-4 | 1.10 | 1.45 | 4.02** | -13.66** | -2.41 | 1.56* | -0.68** | -1.65** | 4.42** | -1.80 | -7.56** | -0.98** | -22.84** |
| NBPGR-6 | 1.43 | 2.29* | 3.35* | 2.16 | 8.58* | -0.43 | 0.03 | -0.98* | 0.89 | -1.18 | 3.60** | 0.18 | 13.48* |
| NBPGR-7 | -0.06 | 0.62 | 0.85 | 9.66* | 9.08** | 0.17 | -0.26** | 0.21 | 1.76 | 1.42 | -2.69* | -0.31 | -2.48 |
| NBPGR-8 | 2.27 | 2.45* | 1.35 | 17.50** | 13.75** | 2.31** | 0.04 | -0.85* | 1.62 | -2.79 | 4.37** | 0.34 | 4.78 |
| NBPGR-9 | -0.06 | 0.79 | 1.35 | 4.16 | 7.08* | -0.06 | 0.60** | 1.48** | -0.23 | -0.57 | 4.90** | 1.43** | 21.69** |
| NBPGR-10 | -0.72 | -1.20 | 0.68 | 15.83** | 4.25 | 0.79 | -0.12 | -0.25 | 3.19 | 6.50** | -0.29 | 0.01 | 5.24 |
| NBPGR-11 | -1.06 | -0.70 | -1.47 | 17.50** | 9.41** | 0.07 | -0.09 | 0.41 | -0.73 | -1.37 | 2.14 | 0.01 | -0.71 |
| NBPGR-12 | -5.39** | -6.37** | -6.31** | -42.83** | -30.91** | -1.67** | -0.60** | 0.08 | -3.87* | 2.21 | -5.36** | -1.40** | -31.18** |
| NBPGR-13 | -0.22 | -0.70 | 0.18 | 14.16** | 5.75 | 0.39 | 0.63** | 1.61** | 1.09 | 0.80 | 0.87 | 1.18** | 23.90** |
| NBPGR-14 | -8.56** | -8.70** | -9.31** | -52.50** | -30.25** | -3.25** | -0.13 | -0.45 | -10.27** | -3.04 | -3.99** | -1.48** | -28.75** |
| NBPGR-15 | 1.10 | 0.45 | -0.81 | -2.50 | -2.58 | -0.35 | 0.16 | 0.21 | 2.69 | -1.35 | 1.97 | 0.18 | -2.17 |
| NBPGR-16 | -1.39 | -0.54 | -1.81 | 14.83 | -0.25 | 0.48 | -0.05 | -1.31** | 2.66 | 2.64 | 0.006 | -0.15 | 1.53 |
| NBPGR-17 | 1.93 | 1.45 | 1.85 | 8.50 | 3.75 | 0.92 | 0.01 | -0.05 | 0.42 | 0.89 | -0.12 | 0.34 | 8.43 |
| NBPGR-18 | 1.93 | 1.45 | 0.35 | 5.83 | 1.41 | -0.65 | 0.18* | 0.73 | -2.67 | -1.37 | 2.44 | -0.15 | -2.06 |
| Males (Testers) | | | | | | | | | | | | | |
| CM-501 | 0.32 | 0.32 | 0.54 | 0.08 | 0.34 | 0.05 | 0.01 | 0.13 | -0.24 | -0.26 | 1.36* | -0.08 | -4.7 |
| KDMI-16 | -0.14 | -0.05 | -0.95 | -2.29 | 0.03 | -0.20 | -0.03 | 0.38* | -0.33 | -0.89 | -2.78** | -0.005 | -0.51 |
| CI-4 | -0.17 | -0.27 | 0.41 | 2.20 | -0.37 | 0.15 | 0.02 | -0.52** | 0.58 | 1.15 | 1.41* | 0.08 | 5.21* |
| C.D. at 5% female | 2.06 | 2.13 | 2.80 | 8.88 | 6.55 | 1.18 | 0.16 | 0.77 | 3.22 | 3.90 | 2.67 | 0.43 | 11.08 |
| C.D. at 1% female | 2.75 | 2.85 | 3.74 | 11.85 | 8.74 | 1.57 | 0.21 | 1.03 | 4.30 | 5.20 | 3.57 | 0.58 | 14.79 |
| S.Em.± | 1.02 | 1.06 | 1.39 | 4.41 | 3.25 | 0.58 | 0.81 | 0.38 | 1.60 | 1.93 | 1.32 | 0.21 | 5.51 |
| C.D. at 5% male | 0.89 | 0.92 | 1.21 | 3.84 | 2.83 | 0.51 | 0.07 | 0.33 | 1.39 | 1.68 | 1.15 | 0.18 | 4.80 |
| C.D. at 1% male | 1.19 | 1.23 | 1.62 | 5.13 | 3.78 | 0.68 | 0.09 | 0.44 | 1.86 | 2.25 | 1.54 | 0.25 | 6.40 |
| S.Em.± | 0.44 | 0.46 | 0.60 | 1.91 | 1.41 | 0.25 | 0.03 | 0.16 | 0.69 | 0.83 | 0.57 | 0.09 | 2.38 |

$X_1$ - Days to 50% tasseling; $X_2$ - Days to 50% silking; $X_3$ - Days to 75% brown husk maturity; $X_4$ – Plant height (cm); $X_5$ - Ear height (cm); $X_6$ – Cob length (cm); $X_7$ – Cob girth (cm); $X_8$ – Number of kernel rows per cob; $X_9$ – Number of kernels per row; $X_{10}$ – Shelling percentage; $X_{11}$ – 100- grain weight (g); $X_{12}$ – Grain yield / plot (kg); $X_{13}$ – Grain yield (q/ha)

Table 6. Specific combining ability (*SCA*) effects of single cross hybrids in respect of 13 characters

| Hybrids | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ | $X_{11}$ | $X_{12}$ | $X_{13}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GPBMH-1801 | -0.15 | -0.65 | -1.04 | -0.58 | -3.34 | -1.65 | 0.15 | 0.76 | -4.31 | -1.76 | -2.83 | 0.10 | -7.54 |
| GPBMH-1802 | -0.68 | 0.71 | 0.95 | 12.29 | 7.46 | 0.70 | 0.007 | -0.68 | 4.26 | -0.26 | 1.61 | 0.17 | 5.31 |
| GPBMH-1803 | 0.84 | -0.06 | 0.08 | -11.70 | -4.12 | 0.94 | -0.16 | -0.08 | 0.05 | 2.03 | 1.22 | -0.17 | 2.23 |
| GPBMH-1804 | 6.01** | 5.34** | 1.45 | -0.25 | -0.67 | -0.55 | 0.02 | 0.26 | -0.28 | -0.42 | -4.70* | 0.25 | 7.54 |
| GPBMH-1805 | -3.02 | -2.78 | -0.04 | 2.12 | 3.13 | 1.05 | -0.12 | -0.78 | 0.60 | 1.59 | 5.34* | 0.42 | 10.61 |
| GPBMH-1806 | -2.99 | -2.56 | -1.41 | -1.87 | -2.45 | -0.50 | 0.09 | 0.52 | -0.31 | -1.16 | -0.64 | -0.67 | -18.15 |
| GPBMH-1807 | -2.32 | -1.99 | -3.70 | -11.58 | -10.17 | -0.61 | -0.15 | -0.93 | -2.68 | -0.56 | 1.59 | 0.25 | 9.14 |
| GPBMH-1808 | 0.64 | 0.88 | 4.79 | 4.79 | 1.13 | 1.22 | -0.02 | 0.41 | 2.70 | 2.53 | -2.65 | -0.32 | -5.79 |
| GPBMH-1809 | 1.66 | 1.10 | -1.08 | 6.79 | 9.04 | -0.61 | 0.17 | 0.52 | -0.01 | -1.97 | 1.05 | 0.07 | -3.35 |

*Contd...*

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GPBMH-1810 | 0.84 | 2.17 | 1.45 | 4.08 | -1.67 | -0.12 | 0.07 | -0.60 | 0.54 | 0.83 | 0.33 | 0.08 | -8.00 |
| GPBMH-1811 | -0.18 | 0.05 | 2.45 | 9.95 | 2.63 | 0.04 | -0.02 | 0.54 | 0.63 | 2.31 | 1.08 | 0.005 | 6.35 |
| GPBMH-1812 | -0.65 | -2.22 | -3.19 | -14.04 | -0.95 | 0.08 | -0.05 | 0.05 | -1.18 | -3.15 | -1.41 | -0.08 | 1.65 |
| GPBMH-1813 | -0.15 | 0.34 | -2.04 | 16.08* | 5.32 | 0.66 | 0.09 | -0.40 | 2.38 | 2.10 | 1.43 | 0.58 | 16.68 |
| GPBMH-1814 | -0.68 | -0.28 | 1.45 | -14.04 | -6.36 | 0.53 | 0.15 | 0.34 | -1.73 | 0.32 | 2.88 | 0.005 | 0.11 |
| GPBMH-1815 | 0.84 | -0.06 | 0.58 | -2.04 | 1.04 | -1.19 | -0.24 | 0.05 | -0.65 | -2.42 | -4.31 | -0.58 | -16.80 |
| GPBMH-1816 | 0.01 | 0.01 | -1.54 | -4.25 | -1.34 | -0.67 | -0.02 | 0.26 | 0.11 | -3.83 | -1.93 | -0.08 | -1.61 |
| GPBMH-1817 | 1.97 | 1.88 | 2.45 | 3.62 | -0.03 | 1.79 | 0.13 | 0.41 | 1.60 | -0.25 | 2.31 | 0.33 | 5.47 |
| GPBMH-1818 | -1.99 | -1.88 | -0.91 | 0.62 | 1.37 | -1.11 | -0.10 | -0.68 | -1.71 | 4.08 | -0.37 | -0.25 | -3.86 |
| GPBMH-1819 | 0.34 | 0.17 | -0.54 | -3.91 | -2.67 | -0.68 | -0.21 | -0.06 | -2.31 | -0.89 | -0.26 | -1.16** | -26.84** |
| GPBMH-1820 | -2.18 | -1.94 | -2.54 | 6.95 | 3.13 | 0.22 | 0.38** | 0.68 | 2.66 | 3.00 | -0.51 | 1.00* | 21.49* |
| GPBMH-1821 | 1.84 | 1.77 | 3.08 | -3.04 | -0.45 | 0.46 | -0.17 | -0.61 | -0.35 | -2.10 | 0.78 | 0.16 | 5.35 |
| GPBMH-1822 | 0.51 | 1.17 | -0.37 | -6.58 | -0.84 | 0.15 | -0.00 | 0.06 | 1.34 | 1.11 | 0.43 | -0.25 | 0.01 |
| GPBMH-1823 | -0.52 | -1.94 | 0.62 | -7.70 | -2.03 | 0.81 | 0.02 | -0.18 | 2.13 | -2.23 | 1.08 | 0.67 | 10.38 |
| GPBMH-1824 | 0.01 | 0.77 | -0.25 | 14.29 | 2.87 | -0.97 | -0.01 | 0.12 | -3.48 | 1.12 | -1.51 | -0.42 | -10.40 |
| GPBMH-1825 | 0.34 | -0.32 | -0.20 | -7.75 | -0.51 | -1.15 | 0.03 | -0.40 | -3.21 | 1.50 | 0.49 | -0.25 | -0.72 |
| GPBMH-1826 | 0.81 | 1.05 | -0.20 | 14.12 | 0.80 | -0.52 | -0.07 | 0.34 | -0.73 | 5.52 | 2.24 | 0.32 | -0.62 |
| GPBMH-1827 | -1.15 | -0.72 | 0.41 | -6.37 | -0.29 | 1.67 | 0.03 | 0.05 | 3.95 | -7.02* | -2.74 | 0.57 | 1.34 |
| GPBMH-1828 | -1.82 | -1.65 | 1.12 | 4.08 | 3.32 | 0.84 | -0.02 | 0.53 | 1.61 | 2.18 | -0.002 | -0.33 | -1.06 |
| GPBMH-1829 | 0.14 | -0.28 | -1.37 | -13.54 | -12.86* | -0.82 | -0.31* | -0.32 | -2.69 | 0.64 | -3.05 | -0.66 | -18.81 |
| GPBMH-1830 | 1.67 | 1.93 | 0.25 | 9.45 | 9.54 | -0.02 | 0.33* | -0.21 | 1.08 | -2.82 | 3.05 | 0.99* | 19.88* |
| GPBMH-1831 | -2.49 | -2.3 | 0.62 | -5.14 | -4.84 | -0.44 | -0.02 | -0.40 | -0.25 | 0.02 | -0.23 | 0.33 | 0.29 |
| GPBMH-1832 | 2.47 | 2.05 | 0.62 | 14.95 | 11.96* | 0.58 | 0.06 | 0.74 | 0.63 | -0.33 | 0.61 | 0.75 | 13.55 |
| GPBMH-1833 | 0.01 | 0.27 | -1.25 | -9.54 | -7.12 | -0.13 | -0.03 | -0.34 | -0.38 | 0.30 | -0.37 | -1.08** | -13.84 |
| GPBMH-1834 | -2.15 | -3.82* | 4.62 | 12.25 | 5.15 | 1.79 | -0.00 | 0.86 | 1.11 | 4.90 | 4.63 | -0.75 | -15.80 |
| GPBMH-1835 | 2.31 | 2.05 | -7.37** | -39.87** | -20.03** | -3.89** | -0.08 | -1.58* | -8.09** | -17.3** | -10.00** | -1.07** | -30.33** |
| GPBMH-1836 | -0.15 | 1.77 | 2.75 | 27.62** | 14.87* | 2.09* | 0.08 | 0.72 | 6.98* | 12.39** | 5.48* | 1.82** | 46.14** |
| GPBMH-1837 | 1.67 | 2.01 | 1.62 | 8.75 | 6.99 | 2.34* | 0.11 | 0.01 | 3.34 | -2.85 | 2.36 | 0.58 | 6.64 |
| GPBMH-1838 | -1.35 | -2.11 | -1.37 | -0.87 | 3.80 | -1.54 | -0.19 | 0.74 | 3.13 | 1.79 | -6.28** | -0.49 | -4.58 |
| GPBMH-1839 | -0.32 | 0.10 | -0.25 | -7.87 | -10.79 | -0.80 | 0.07 | -0.74 | -6.48* | 1.06 | 3.92 | -0.08 | -2.06 |
| GPBMH-1840 | -0.82 | -0.99 | -2.37 | -5.08 | -4.34 | -0.61 | -0.19 | -0.86 | 0.18 | 0.50 | -1.46 | -0.08 | -0.96 |
| GPBMH-1841 | 1.64 | 1.38 | 2.62 | 7.79 | 6.46 | 0.20 | 0.04 | 0.28 | -0.13 | 1.49 | 2.38 | -0.16 | -2.88 |
| GPBMH-1842 | -0.82 | -0.39 | -0.25 | -2.70 | -2.12 | 0.41 | 0.15 | 0.58 | -0.05 | -2.00 | -0.91 | 0.24 | 3.84 |
| GPBMH-1843 | -1.15 | -0.99 | -0.54 | 1.75 | 3.65 | 0.80 | -0.02 | -0.93 | 4.61 | 2.05 | 0.36 | 0.41 | 18.57 |
| GPBMH-1844 | -0.18 | -0.15 | -1.04 | -3.37 | 6.46 | -0.11 | 0.05 | 0.81 | -4.09 | -1.25 | 0.51 | -0.16 | -6.36 |
| GPBMH-1845 | 1.34 | 1.10 | 1.58 | 1.62 | -10.12 | -0.69 | -0.02 | 0.12 | -0.51 | -0.79 | -0.87 | -0.25 | -12.20 |
| GPBMH-1846 | 1.34 | 1.51 | 1.45 | -1.58 | 5.99 | -0.10 | 0.14 | 1.83** | -2.18 | -4.89 | -0.20 | 0.41 | 3.67 |
| GPBMH-1847 | -1.18 | -0.61 | -2.04 | 2.79 | -5.69 | -0.29 | -0.04 | -1.77* | -0.89 | 2.41 | 2.54 | -0.16 | -3.90 |
| GPBMH-1848 | -0.15 | -0.89 | 0.58 | -1.20 | -0.29 | 0.39 | -0.10 | -0.06 | 3.08 | 2.48 | -2.34 | -0.25 | 0.22 |
| C.D. at 5% | 3.56 | 3.70 | 4.85 | 15.38 | 11.34 | 2.04 | 0.28 | 1.34 | 5.59 | 6.75 | 4.63 | 0.75 | 19.20 |
| C.D. at 1% | 4.76 | 4.94 | 6.48 | 20.52 | 15.14 | 2.72 | 0.37 | 1.79 | 7.46 | 9.01 | 6.18 | 1.00 | 25.62 |
| S.Em.± | 1.77 | 1.50 | 2.41 | 7.64 | 5.64 | 1.01 | 0.14 | 0.66 | 2.77 | 3.35 | 2.30 | 0.37 | 9.54 |

$X_1$ - Days to 50% tasseling; $X_2$ - Days to 50% silking; $X_3$ - Days to 75% brown husk maturity; $X_4$ – Plant height (cm); $X_5$ - Ear height (cm); $X_6$ – Cob length (cm); $X_7$ – Cob girth (cm); $X_8$ – Number of kernel rows per cob; $X_9$ – Number of kernels per row; $X_{10}$ – Shelling percentage; $X_{11}$ – 100- grain weight (g); $X_{12}$ – Grain yield / plot (kg); $X_{13}$ – Grain yield (q/ha)

Table 7. Magnitude of heterosis over checks for grain yield (q/ha)

| Hybrids | Grain yield (q/ha) | | | Hybrids | Grain yield (q/ha) | | |
|---|---|---|---|---|---|---|---|
| | Standard heterosis | | | | Standard heterosis | | |
| | GH-0727 | DKC9144 | NK 6240 | | GH-0727 | DKC9144 | NK 6240 |
| GPBMH-1801 | -11.75 | -25.34* | 6.06 | GPBMH-1825 | -29.74* | -40.55** | -15.56 |
| GPBMH-1802 | 3.73 | -12.24 | 24.66 | GPBMH-1826 | -25.85* | -37.26** | -10.88 |
| GPBMH-1803 | 6.14 | -10.20 | 27.56 | GPBMH-1827 | -18.84 | -31.33** | -2.46 |
| GPBMH-1804 | -34.96** | -44.97** | -21.84 | GPBMH-1828 | -57.73** | -64.24** | -49.21** |
| GPBMH-1805 | -28.38* | -39.40** | -13.92 | GPBMH-1829 | -70.06** | -74.67** | -64.02** |
| GPBMH-1806 | -49.31** | -57.11** | -39.08* | GPBMH-1830 | -29.69* | -40.51** | -15.50 |
| GPBMH-1807 | -40.88** | -49.98** | -28.95 | GPBMH-1831 | -6.45 | -20.85 | 12.43 |
| GPBMH-1808 | -50.65** | -58.24** | -40.69** | GPBMH-1832 | 9.41 | -7.43 | 31.49* |
| GPBMH-1809 | -43.22** | -51.96** | -31.76* | GPBMH-1833 | -10.28 | -24.09* | 7.82 |
| GPBMH-1810 | -23.45 | -35.23** | -8.00 | GPBMH-1834 | -68.92** | -73.70** | -62.64** |
| GPBMH-1811 | -6.61 | -20.98* | 12.24 | GPBMH-1835 | -78.32 | -81.65** | -73.94** |
| GPBMH-1812 | -5.66 | -20.18 | 13.38 | GPBMH-1836 | -3.61 | -18.45 | 15.84 |
| GPBMH-1813 | -15.52 | -28.52** | 1.53 | GPBMH-1837 | -24.37 | -36.01** | -9.10 |
| GPBMH-1814 | -26.78* | -38.05** | -12.00 | GPBMH-1838 | -30.77* | -41.43** | -16.80 |
| GPBMH-1815 | -36.94** | -46.64** | -24.21 | GPBMH-1839 | -23.27 | -35.08** | -7.79 |
| GPBMH-1816 | -25.56** | -37.01** | -10.53 | GPBMH-1840 | -27.91* | -39.00** | -13.36 |
| GPBMH-1817 | -15.31 | -28.34** | 1.79 | GPBMH-1841 | -25.86* | -37.27** | -10.90 |
| GPBMH-1818 | -18.58 | -31.11** | -2.15 | GPBMH-1842 | -14.53 | -27.68* | 2.72 |
| GPBMH-1819 | -33.10** | -43.40** | -19.60 | GPBMH-1843 | -3.89 | -18.69 | 15.50 |
| GPBMH-1820 | 14.62 | -3.03 | 37.75* | GPBMH-1844 | -22.75 | -34.64** | -7.16 |
| GPBMH-1821 | 5.16 | -11.02 | 26.38 | GPBMH-1845 | -22.85 | -34.72** | -7.28 |
| GPBMH-1822 | -23.66 | -35.41** | -8.25 | GPBMH-1846 | -26.96* | -38.20** | -12.22 |
| GPBMH-1823 | -10.43 | -24.21* | 7.65 | GPBMH-1847 | -30.04* | -40.81** | -15.93 |
| GPBMH-1824 | -24.11 | -35.79** | -8.79 | GPBMH-1848 | -21.08 | -33.23** | -5.16 |

These cross combinations had highest grain yield than the expected mean performance of its parents and showed genetic diversity hence heterosis. By further improving these hybrids for other yield related characters one can go for commercial release of these hybrids suitable for rainfed ecosystem. The results corroborate with the findings of Begum *et al.* (2018), Singh *et al.* (2019) and Yong *et al.* (2019) who reported negative SCA effects for days to pollen shedding, silking and brown husk maturity and positive SCA effects of kernel weight and grain yield.

The percentage of standard heterosis for grain yield (q/ha) given in the Table 7. The values ranged from -68.92 (GPBMH-1834) to 14.62 (GPBMH-1820) over GH-0727, -81.65 (GPBMH-1835) to -3.03 (GPBMH-1820) over DKC-9144 and -73.94 (GPBMH-1835) to 37.75 (GPBMH-1820) over NK-6240. Five hybrids exhibited positive heterosis over the check GH-0727 and 16 hybrids registered positive standard heterosis over the check NK-6240. None of the hybrids showed positive standard heterosis over the best check DKC-9144. Top ten promising hybrids were identified based on the principle component grain yield and standard heterosis such as GPBMH-1820, GPBMH-1832, GPBMH-1803, GPBMH-1821, GPBMH-1802, GPBMH-1836, GPBMH-1843, GPBMH-1812, GPBMH-1831 and GPBMH-1811. The hybrids GPBMH-1820 and GPBMH-1832 registered favorable standard heterosis for all the traits under study. These hybrids adjudged as the superior hybrids for exploitation of heterosis under rainfed ecosystem and may be recommended for multilocation trials. The same trend was found out by Sharma *et al.* (2017) and Sandesh *et al.* (2018) who reported hybrids with positive heterosis for grain yield could be selected and used in breeding programs.

## Conclusion

The lines NBPGR-12 and NBPGR-14 were proved to be the best general combiners for days to 50 per cent tasseling, days to 50 per cent silking and days to 75 per cent brown husk maturity and were good sources for earliness in hybridization program for development of early maturing genotypes. The lines, NBPGR-1, NBPGR-9 and NBPGR-13 showed significant GCA effects for most of the traits under study in desirable direction. Hence, they were considered as potential combiners. Among the testers KDMI-16 was the best general combiner for number of kernel rows per cob and CI-4 for 100-grain weight and grain yield per hectare. Among the 48 single cross hybrids, GPBMH-1836, GPBMH-1820, GBPMH-1830 were the top three hybrids which exhibited higher SCA effects. The hybrids *viz.,* GPBMH-1820, GPBMH-1832, GPBMH-1803, GPBMH-1821, GPBMH-1802, GPBMH-1836, GPBMH-1843, GPBMH-1812, GPBMH-1831 and GPBMH-1811 were found promising for grain yield under rainfed ecosystem as they had positive standard heterosis against the checks GH-0727 and NK-6240. These crosses gave higher yield because of high x low, low x low and high x high parental combinations.

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