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**Original Research Article**

# Heterosis and Combining Ability for Grain Yield Trait in Rabi Sorghum [*Sorghum bicolor* (L.) Moench] Using Line x Tester Mating Design

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**A B S T R A C T**

Heterosis has been considered as well proven method for increasing yield and for improvement of trait in crops, thereof the exploitation of heterosis for the hybrid development programme considered as one of the greatest breakthrough in plant breeding. The present investigation was conducted to assess the magnitude of heterosis and combining ability of thirty $F_1$ hybrids of *rabi* sorghum (*Sorghum bicolor* (L.) Moench) developed by crossing three lines and ten testers in line x tester fashion with respect to phenotypic trait, grain yield and its components. The hybrids and their parents were evaluated to estimate the heterosis and combining ability governing quantitative traits. Among thirty hybrids, three potential hybrids AKRMS 30A X AKRB 431, AKRMS 30A X AKRB 335-3, AKRMS 30A X AKRB 428 were found to be good specific combiners with highest standard heterosis and *per se* performance for grain yield plant$^{-1}$ over both checks CSH 15R and CSH 19R. AKRMS 30A was the good general combiner with other males. The estimates of general combing ability and specific combining ability revealed the presence of both additive and non-additive genetic components for most of the traits under study.

## Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) belongs to the tribe Andropogonae of the grass family *Poaceae*. Sorghum is fifth most important cereal crop in the world after rice, wheat, maize and barley (FAO, 2007), cultivated globally for food, fodder, feed and fuel (Praveen *et al.,* 2015). ‘Heterosis’ or ‘hybrid vigour’ is the increased or decreased vigour growth, fitness or yield of a hybrid over the parental values, resulting from the crossing of genetically unlike parents. The term “Heterosis” was proposed by Shull (1914) as the development stimulus resulting from the union of different gametes and hybrid vigour to manifest effects of heterosis. It has been stated by (Praveen *et al.,* 2015) that compared to traditional landraces sorghum $F_1$ hybrids are superior by 50-60% with respect to grain yield. Among the several identified cytoplasm $A_1$ (*milo*) predominantly used for commercial production of hybrids (Reddy *et al.,* 2007).

Thus, till now most of the released sorghum hybrid across the world is based on the $A_1$ cytoplasm (Reddy and Stenhouse, 1994).

The world sorghum area under cultivation was 42.5 million hectare with production of 59.91 million metric tons and productivity was 1.41 metric tons per hectare, whereas, of India 5.58 million hectare area under cultivation with production and productivity were 4.41 million metric tons and 0.79 metric tons per hectare respectively. At present Maharashtra seems to be largest producer accounting for 50 per cent total area i.e. 3.218 million ha with production of 1.20 million tons with productivity 916 kg $ha^{-1}$ (Anonymous, 2017). In Maharashtra area under *kharif* sorghum was 0.621 million ha and *rabi* sorghum was 2.597 million ha with production of 0.368 and 0.837 million tons, respectively (Anonymous, 2015-16). Despite of proving it's importance, *rabi* sorghum, has not attained it's prime importance till date. The many constraints are bottlenecked to make *rabi* sorghum more remunerative such as photoperiod (Mukri *et al.,* 2010), improper restorers and low heterosis (Prabhakar *et al.*, 2010) for low yielding hybrids in *rabi* season. The traits like yield and its components are governed by polygenes with complex gene action and hence before initiating any crop improvement program, it is necessary to understand the genetic nature of the parents.

Combining ability analysis helps in identifying the parents, and these parents can be used for hybridization program in order to produce superior hybrids. As a general rule, general combining ability (GCA) is the result of additive gene effects, while the specific combining ability (SCA) is the result of non-allelic interactions (Jinks, 1954). The estimate of combining ability is useful to predict the relative performance of different lines in hybrid combinations. The information on the nature and magnitude of gene action is important in understanding the genetic potential of a population and deciding the breeding procedure to be adopted in a given population (Prabhakar *et al.,* 2010).

In this background, the present study was undertaken to determine the nature of gene action, evaluation of enviable parents for hybridization and performance of hybrids over their parent in *rabi* sorghum, with a view of exploitation of good hybrids with high heterotic value.

## Materials and Methods

### Experimental material

The present investigation was conducted during *rabi* 2015-2016 at Sorghum Research Unit (SRU), Dr. PDKV, Akola. The soil of experimental site was black, alluvial in origin, deep, well drained and had fairly good moisture holding capacity. The experimental material of the present study comprised of three lines, ten testers and their resulting thirty hybrids, along with two checks CSH-15R (National Released *rabi* sorghum hybrid in 1995) and CSH-19R (National Released *rabi* sorghum hybrid in 2000). The seed of following parental lines was provided by Sorghum Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The genotypes and their sources are given in Table 5.

### Development of material

### Trial 1

During *rab*i 2015-16, the parental materials comprised of three lines and ten testers were planted at Sorghum Research Unit, Dr. P.D.K.V. Akola and these lines and testers were crossed in line x tester design to produce 30 possible hybrids. Staggered sowing was carried out with a view to have synchronized flowering of male and female parents. Thus, enough quantity of seed of these resulting 30 hybrids was produced during *rabi* 2015-16 these become $F_0$ seeds.

### Trial 2

The seeds harvested from $F_0$ plants during *rabi* 2015-2016 were raised for $F_1$ generation during *rabi* 2016-17 by using thirteen parents, their 30 possible hybrids along with two standard checks CSH 15R and CSH-19R (total genotypes studied were 45). Recommended package of practice was followed, and the crop stand and crop growth were good in all the three replications. The experimental design was randomized block design with three replicates.

### Phenotypic characterization of parental lines and hybrids

In each replication and in each genotype five $F_1$ plants were randomly selected for observation, except days to 50 per cent flowering and days to maturity where observation was recorded on plot basis. Ten quantitative characters viz., plant height, days to 50% flowering, number of leaves$^{-1}$, length of panicle, panicle weight, panicle breadth, number of primaries $^{-1}$, grain yield and it's components such as number of grains per panicle,100 grain weight and grain yield plant$^{-1}$ were recorded.

### Statistical analysis

The data on parental lines, the $F_1$-hybrids and check hybrids (CSH 15R and CSH 19R) were subjected to different statistical analysis using the computer program Gen Stat (www.vsni.co.uk./software/genstat). The data was subjected to ANOVA separately to detect the significance of genotypic differences (Panse and Sukhatme, 1954) before a combined ANOVA. Combining ability analysis was carried out according to Singh and Chaudhary (1979) based on line× tester general liner model.

### Estimation of heterosis

Heterosis estimates were worked out following Singh and Narayanan (1993) as follows:

Standard Heterosis: Estimated over standard commercial hybrid (SH) as follows:

$[(F_1\text{-SH})/\text{SH}] \times 100$

Where, SH is the mean value of the standard commercial hybrids 'CSH-15R and CSH-19R'.

### Estimation of combining ability

Combining ability from line x tester analysis of variance (Kempthorne, 1957) was carried out for morphological and grain yield traits. The hybrids (crosses) mean squares were partitioned into variances due to testers ($\delta^2$t) and lines ($\delta^2$ι) and due to interaction between lines and testers ($\delta^2$ιt). The estimates of genotypic variances of testers and lines are equivalent to variance due to their GCA, and that of their interaction is equivalent to variance due to SCA. The statistical analysis was performed by Gen Stat software.

### Results and Discussion

From the resultant 30 crosses, three potential hybrids AKRMS 30A X AKRB-431, AKRMS 30A X AKRB-335-3, and AKRMS 30A X AKRB-428 exhibited significant standard heterosis performance over both checks (CSH-15R and CSH-19R) in desirable direction for grain yield and other yield components (Table 1). Among three females and ten males, AKRMS 30A and testers, AKRB 431, AKRB 335-3 and AKRB 431, found significant for yield and yield related attributes.

Among 30 hybrids, the hybrid AKRMS-30A X AKRB- 431 exhibited highest standard heterosis (166.77% and 106.92%) over both the checks (CSH-15R and CSH-19R) for grain yield. In addition, it showed significant heterosis for other phenotypic traits like panicle length, panicle weight, panicle breadth, number of primary panicles$^{-1}$, 100 grain weight, number of grains panicle$^{-1}$ and found potential hybrid over both standard check hybrids.

On second position, hybrid AKRMS 30A X AKRB-335-3 recorded significant highest useful heterosis (123.31% and 73.21%) over the checks (CSH-15R and CSH-19R) for grain yield; it also showed significant standard heterosis for traits like days to 50% flowering, number of leaves plant$^{-1}$, panicle length, panicle weight, panicle breadth, number of primary panicles$^{-1}$, 100 grain weight and number of grains panicle$^{-1}$ over both the checks.

As far as heterotic performance for grain yield is concerned, hybrid AKRMS-30A X AKRB- 428 ranked third and significant in desirable direction for other morphological traits like number of leaves plant$^{-1}$, panicle length, 100 grain weight and number of grains panicle$^{-1}$ over both *rabi* checks.

The heterosis plays an important role for increasing the productivity of crop without much increase in the cost of production. Grain yield is complex character rely on many traits. Yield potential accompanied with desirable combination of traits has always been the major objective of sorghum breeding program (Kumar, 2013). Thus, the phenomenon of heterosis has revolutions the production in many crops including sorghum in commercial basis. The elaborative study of crosses under study revealed that, most of the crosses exhibited positive and significant heterosis for yield also showed heterosis for most of the phenotypic traits except plant height mentioned in Table 1. The findings of the present investigation are consistent with the earlier reports of Nandanwankar (1990) and Jain and Patel (2013). Umakanth *et al.,* (2006) reported positive and significant standard heterosis over the check CSH-19R in his study in *rabi* sorghum.

It has been reported by (Gite *et al.,* 2015) that three sorghum hybrids exhibited significant heterosis over the check CSH-15R and suggested that these hybrids can be incorporated in hybrid development programme. Jadhav and Deshmukh *et al.,* (2017) found significant standard heterosis for grain yield and other yield components in crosses AKRMS-30A X Rb-324 and AKRMS-30A X AKR 354, but in our present findings hybrid AKRMS-30A X Rb-324 found sterile on all the three females and hybrid AKRMS-30A X AKR 354 showed negative heterosis for grain yield.

Gunjal (2014) found that hybrids on line AKRMS 66-2A exhibited high significant heterosis over the check CSH-19R.

But in our present investigation none of the cross combinations found better in case of AKRMS 45A and AKRMS-66-2A over the checks and showed negative heterosis for grain yield trait and therefore only female line AKRMS 30A was taken into consideration and for further evaluation of good heterotic crosses.

The mean sum of squares due to different sources of variation was estimated and presented as in pooled analysis of variance for combining ability (Table 2).

**Table.1** Potential hybrids based on significant standard heterosis in desirable direction for grain yield and other yield components

| SN | Crosses | Mean performance for grain yield (g / plant) | Standard heterosis for grain yield (%) | | Significant Standard heterosis for other phenotypic trait (%) | |
|---|---|---|---|---|---|---|
| | | | CSH-15R | CSH-19R | CSH-15R | CSH-19R |
| | | | (*Rabi* check) | (*Rabi* check) | (*Rabi* check) | (*Rabi* check) |
| 1 | AKRMS- 30A X AKRB 431 | 92.24 | 166.77 ** | 106.92 ** | 4(27.42), 5(71.88), 6(63.50), 7(25.86), 8(35.42), 9(105.96) | 4(22.23), 5(78.41), 6(35.76), 7(23.73), 9(110.68) |
| 2 | AKRMS- 30A X AKRB 335-3 | 77.21 | 123.31 ** | 73.21 ** | 1(2.86), 3(13.04), 4(22.10), 5(44.41), 6(62.04), 7(22.07) 8(26.98), 9(75.64) | 1(3.85), 4(28.38), 5(50.46), 6(34.55), 7(20.17), 9(79.67) |
| 3 | AKRMS- 30A X AKRB 428 | 72.05 | 108.39 ** | 61.64 ** | 3(21.74), 4(20.04), 8(34.66), 9(54.70) | 3(12.00), 4(28.10), 9(58.24) |

*, **- significant at 5% and 1% level respectively

Parenthesis values represent standard heterosis values

1: Days to 50 % flowering (days)
2: Plant height (cm)
3: Number of leaves plant$^{-1}$
4: Panicle length (cm)
5: Panicle weight (g)
6: Panicle breadth (cm)
7: Number of primaries panicle$^{-1}$
8: 100 grain weight (gm)
9: Number of grains panicle$^{-1}$

**Table.2** Pooled analysis of variance for combining ability

| Sources of variation | d.f. | MEAN SUM OF SQUARES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days to 50% flowering | Plant height (cm) | No. of leaves plant$^{-1}$ | Panicle length (cm) | Panicle weight (gm) | Panicle breadth (cm) | No. of primaries Panicle$^{-1}$ | 100 grain weight (gm) | No. of grains panicle$^{-1}$ | Grain yield plant$^{-1}$ |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| **Replications** | 2 | 0.47 | 106.98 | 0.21 | 19.81 | 117.83 | 0.49 | 5.43 | 0.019 | 28430.87 | 11.77 |
| **Crosses** | 29 | 3.30 ** | 327.01 ** | 0.659 * | 15.99 ** | 4674.39 * | 2.93 ** | 54.98 ** | 3.02 ** | 1527539.4 ** | 1635.03 ** |
| **Females** | 2 | 7.87 * | 1511.92 * | 1.37 | 54.00 * | 8444.60 | 2.88 | 76.8 | 0.41 | 5586243.6 * | 6123.13 * |
| **Males** | 9 | 4.98 * | 125.59 | 0.66 | 9.14 | 6121.54 | 4.80 | 83.16 | 7.95 ** | 2372153.2 * | 2460.16 * |
| **Males x Females** | 18 | 1.96 * | 296.14 * | 0.57 | 15.19 ** | 3531.90 ** | 2.00 ** | 38.46 ** | 0.85 ** | 654265.3 ** | 723.78 ** |
| **Error** | 58 | 0.914 | 106.30 | 0.38 | 3.02 | 46.67 | 0.316 | 6.19 | 0.008 | 7766.28 | 7.18 |
| **GCA Vs SCA** | | 0.068 | 0.074 | 0.036 | 0.073 | 0.023 | 0.006 | 0.028 | 0.011 | 0.105 | 0.109 |

**Table.3** GCA effects of promising parents in desirable direction for yield and yield related components

| Genotypes | GENERAL COMBINING ABILITY | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Days to 50% flowering | Plant height (cm) | No. of leaves plant$^{-1}$ | Panicle length (cm) | Panicle weight (gm) | Panicle breadth (cm) | No. of primaries Panicle$^{-1}$ | 100 grain weight (gm) | No. of grains panicle$^{-1}$ | Grain yield plant$^{-1}$ |
| **Females** | | | | | | | | | | |
| AKRMS-30A | - | - | - | 1.548 ** | 17.16 ** | 0.186 * | 1.600 ** | 0.117 ** | 445.61 ** | 14.90 ** |
| **Males** | | | | | | | | | | |
| AKRB 431 | - | - | - | - | 46.988 ** | - | 3.389 ** | 0.692 ** | 359. 456 ** | 15.665 ** |
| AKRB 335-3 | - | - | - | 1.891 ** | 32.910 ** | 0.937 ** | 2.500 ** | 0.219 ** | 671.233 ** | 21.680 ** |
| AKRB 428 | - | - | - | - | 10.290 ** | - | 3.278 ** | 0.541 ** | 472.345 ** | 15.216 ** |

*, **- significant at 5% and 1% level respectively

**Table.4** Mean yield performance, standard heterosis and SCA effects of the promising crosses

| SN | Crosses | Grain yield plant$^{-1}$ (g) | Standard heterosis (%) over | | SCA effects for Grain yield plant$^{-1}$ | GCA effects of parents for grain yield | Significance SCA effects for other characters in desirable direction |
|---|---|---|---|---|---|---|---|
| | | | CSH-15R | CSH-19R | | | |
| 1 | AKRMS- 30A X AKRB 431 | 92.24 | 166.77 ** | 106.92 ** | 29.44** | 14.90** (L) X 15.665** (H) | 4, 5, 6, 7, 9 |
| 2 | AKRMS- 30A X AKRB 335-3 | 77.21 | 123.31 ** | 73.21 ** | 12.40** | 14.90** (L) X 21.680** (H) | 2, 4, 5, 6, 7, 8, 9 |
| 3 | AKRMS- 30A X AKRB 428 | 72.05 | 108.39 ** | 61.64 ** | 10.706** | 14.90** (L) X 15.216** (H) | 8 |

*, **- significant at 5% and 1% level respectively; Parenthesis values represent standard heterosis values

Note: L: Low *gca* and H: High *gca*

1: Days to 50 % flowering (days)
2: Plant height (cm)
3: Number of leaves plant$^{-1}$
4: Panicle length (cm)
5: Panicle weight (g)
6: Panicle breadth (cm)
7: Number of primaries panicle$^{-1}$
8: 100 grain weight (gm)
9: Number of grains panicle$^{-}$

**Table.5** Genotypes used for present investigation

| SN | Genotypes | Source |
|---|---|---|
| | **CMS lines** | |
| 1 | AKRMS-30A | CMS line from Sorghum Research Unit, Dr.PDKV, Akola. |
| 2 | AKRMS-45A | CMS line from Sorghum Research Unit, Dr.PDKV, Akola. |
| 3 | AKRMS-66-2A | CMS line from Sorghum Research Unit, Dr.PDKV, Akola. |
| | **Testers** | |
| 4 | RS-585 | Restorer from Directorate of Sorghum Research, Hyderabad |
| 5 | AKR- 354 | Restorer from Sorghum Research Unit, Dr.PDKV, Akola. |
| 6 | AKRB-335-3 | Restorer from Sorghum Research Unit, Dr.PDKV, Akola. |
| 7 | SLR-24 | Restorer from Indian Institute of Millet Research, Solapur |
| 8 | AKRB-428 | Restorer from Sorghum Research Unit, Dr.PDKV, Akola. |
| 9 | RB-324 | Restorer from Sorghum Research Unit, Dr.PDKV, Akola. |
| 10 | AKRB-413-1 | Restorer from Sorghum Research Unit, Dr.PDKV, Akola. |
| 11 | AKRB-429 | Restorer from Sorghum Research Unit, Dr.PDKV, Akola. |
| 12 | AKRB-430 | Restorer from Sorghum Research Unit, Dr.PDKV, Akola. |
| 13 | AKRB-431 | Restorer from Sorghum Research Unit, Dr.PDKV, Akola. |
| | **Checks** | |
| 14 | CSH-15R | NRCS, Solapur |
| 15 | CSH-19R | Sorghum Research Unit, Dr.PDKV, Akola. |

Significant differences were found among the crosses for the studied phenotypic traits indicated the presence of substantial genetic variability. Mean squares due to males were significant for days to 50% flowering, 100 grain weight, number of grains panicle$^{-1}$ and grain yield plant$^{-1}$. Mean square due to females were significant for the days to 50% flowering, plant height, panicle length, number of grains panicle$^{-1}$ and grain yield plant$^{-1}$. Significant male and female variance indicates sizeable genetic variability for general combining ability among males and females respectively for concern traits. Mean squares due to males x female interaction were significant for all the characters under study except number of leaves plant$^{-1}$ which indicate genetic variability for specific combining ability among the crosses.

In hybrid breeding programme, for getting higher heterosis the prerequisites is the diversity of parents. In present investigation, the parents differed significantly for all characters which indicated sufficient variability among the parents for the studied morphological traits (Table 2). Similarly, variations among hybrids were significant for all the characters. This is desirable step in the exploitation of best hybrid combinations with high heterotic value. Similar variability among the parents was also reported by Umakanth *et al.,* (2012), Prabhakar *et al.,* (2013) and Ghorade *et al.,* (2014).

For all traits (viz., days to 50 per cent flowering, plant height, number of leaves per plant, panicle length, panicle weight, panicle breadth, number of primary panicles$^{-1}$, 100 grain weight, number of grains panicle-1 and grain yield plant$^{-1}$) the predictability ratio (GCA vs. SCA) over the environments found to be less than unity. This indicates importance of non-additive gene action in the inheritance of these traits and greater is predictability based on specific combining ability alone for improvement of respective trait. The same results were also reported by Kenga *et al.*, (2004).

The general combining ability effects of promising parents based on consistent performance and in desirable direction of yield and other yield components mentioned in Table 3.

Among female parents, AKRMS-30A exhibited significant *gca* effects for panicle length, panicle weight, panicle breadth, number of primaries panicle$^{-1}$, 100 grain weight, number of grains panicle$^{-1}$ and grain yield plant$^{-1}$. Among male parents, AKRB 431, AKRB 335-3 and AKRB 428 exhibited significantly high *gca* effects for yield and yield related traits. AKRB 431 showed significant and desirable *gca* effects for panicle weight, number of primaries panicle$^{-1}$, 100 grain weight, number of grains panicle$^{-1}$ and grain yield plant$^{-1}$.

Similarly, AKRB 335-3 exhibited significant and desirable *gca* effects for panicle length, panicle weight, panicle breadth, number of primaries panicle$^{-1}$, 100 grain weight, number of grains panicle$^{-1}$ and grain yield plant$^{-1}$. Further, the male parent AKRB 428 showed significant *gca* effects in desirable direction for panicle weight, number of primaries panicle$^{-1}$, 100 grain weight, number of grains panicle$^{-1}$ and grain yield plant$^{-1}$.

Thus above promising male and female parents having high *gca* effects for yield and yield related traits (more commonly viz., panicle length, panicle weight, panicle breadth, number of primaries panicle$^{-1}$, number of grains panicle$^{-1}$ and grain yield) can be suitably incorporated in hybrid breeding programmes.

Similar types of results and prediction have been reported by (Borikar *et al.*, 2000; Kenga *et al.*, 2004; Kale, 2011). The specific combining ability effect is indicative of heterosis and also non additive gene action. Ghorade in 1991 reported non additive gene action for panicle length, stem girth, panicle breadth, number of whorls, 100 grain weight and grain yield.

The promising hybrids over the environments with respect to specific combining ability effects for grain yield and other morphological traits are presented in (Table 4) along with their mean grain yield and standard heterosis values. Based on high mean performance, significantly high *sca* effect, and significant heterosis over standard check/s three promising hybrids (viz., AKRMS 30A X AKRB-431, AKRMS 30A X AKRB-335-3, and AKRMS 30A X AKRB-428) were selected for grain yield and other yield related components.

AKRMS-30A X AKRB 431 exhibited significant *sca* effects for panicle length, panicle weight, panicle breadth, number of primaries panicle$^{-1}$ and number of grains panicle$^{-1}$. AKRMS-30A X AKRB 335-3 showed significant *sca* effects for plant height, panicle length, panicle weight, panicle breadth, number of primaries panicle$^{-1}$, 100 grain weight and number of grains panicle$^{-1}$. Hybrid, AKRMS-30A X AKRB 428 recorded high *sca* effects for only 100 grain weight.

All the three hybrids also recorded significantly desirable standard heterosis over checks for grain yield plant$^{-1}$. These three hybrids, AKRMS-30A X AKRB 431, AKRMS-30A X AKRB 335-3 and AKRMS-30A X AKRB 428 were the combination of low x high *gca* combination for grain yield (Table 4). Thus, it could be concluded that, hybrids showing high *sca* effects for grain yield and other important traits were having at least one parent with high *gca* effect. Thus, the performance of hybrids mostly relies on the *gca* effects of parents involved in the combinations. Similar findings were reported by Chaudhary and Narkhede (2004) and Kale (2011).

Thus, amongst thirty hybrids, above mentioned three hybrids are expected to be promising in desirable direction of grain yield and other yield related components under study and which can be exploited for heterosis breeding programme.

The present investigation aimed in selecting good combiners for grain yield and other yield contributing characters. The parents, AKRB 431, AKRB 335-3 and AKRB 428 showed good general combining ability over environments for grain yield along with other important yield contributing characters. These parents further can be exploited for sorghum hybrid development programme to develop hybrids with high heterotic values. Similarly, the hybrids AKRMS-30A X AKRB 431, AKRMS-30A X AKRB 335-3 and AKRMS-30A X AKRB 428 showed desirable standard heterosis percentage along with good *sca* effects for grain yield and other important yield contributing traits. Therefore, these hybrids can be commercially exploited using heterosis breeding after the evaluation in multilocation trials.

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