Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; 9(2): 949-959
Received: 19-01-2020
Accepted: 21-02-2020

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Extent of heterosis for grain yield and its contributing traits in rabi sorghum [*Sorghum bicolor* (L.) Moench]

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DOI: https://doi.org/10.22271/phyto.2020.v9.i2p.10979

Abstract

Heterosis has been successfully exploited commercially in *kharif* sorghum [*Sorghum bicolor* (L.) Moench]. However, the progress in *rabi* sorghum is restricted and there is a need for critical studies heterosis and combining ability involving diverse sources of germplasm and landraces. A total of 50 sorghum hybrids were derived by line × tester design using two male sterile lines *viz*., M 31-2A and 104A, as testers and were assessed for Extent of heterosis for grain yield and its contributing traits in rabi 2019-20**.** Among 50 crosses 13 exhibited significant standard heterosis for yield over popular variety M 35-1 (check). The crosses M 31-2A × IS 32439 (65.28 g) and M 31-2A × IS 11619 (60.83 g) recorded maximum heterosis for grain yield per plant. The cross M 31-2A × IS 4581 exhibited maximum heterosis for 100 seed weight followed by M 31-2A × IS 30451, 104A × IS 30451 and 104A × IS 4581. for panicle length, the cross 104A × IS 602 exhibited highest significant positive standard heterosis over the checks M 31-2A, BJV 44 and PKV Kranti.

Keywords: Heterosis, sorghum, maldandi, milo, CMS

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the important cereal crop cultivated globally for food, fodder, feed and fuel. It ranks fifth after wheat, rice, maize and barley in area and production. It is mainly grown in semi-arid tropics of Asia, Africa, America and Australia, In Africa and Asia sorghum grain is mainly used as food, while in the United States and Australia it is used to feed cattle. Stover is also an important source of dry season fodder for livestock (Reddy *et al*., 2013) [23].

Globally, sorghum is grown in an area of 42.50 million hectares to produce 59.91 million tonnes, with the productivity of around 1.60 tonnes per hectare. India produces about 4.70 million tonnes of sorghum grain from 1.90 million hectares in *kharif* and 2.60 million hectares in *rabi*. The productivity of *kharif* sorghum is high with 948 kg/ha compared to *rabi* with 790 kg/ha (Anon., 2017).

Rabi sorghum is extensively grown in Deccan Plateau, in the states of Maharashtra, Karnataka and Andhra Pradesh. *Rabi* sorghum has high value because of its good grain quality, large grain size and grain lustrure and excellent fodder. In fact in *rabi* sorghum, the fodder yield is important than that of *kharif* sorghum. High levels of resistance against major pest (shoot fly), disease (charcoal rot) and earliness are essential features of *rabi* sorghum cultivars.

The productivity of *rabi* sorghum is very low (790 kg/ha) due to non-availability of high yielding varieties which could replace the low yielding landraces. Unlike, *kharif* sorghum where heterotic expression is excellent, *rabi* sorghum has narrow low heterotic expression. In addition conditions are harsh and scary in *rabi* sorghum. So far the hybrids released for *rabi* sorghum have not been successful due to poor grain quality, susceptibility to shoot fly, charcoal rot and poor seed set per cent under low temperature conditions.

Use of *milo* based male sterile lines in *rabi* sorghum led to the development of hybrids like CSH 12R, CSH 13R, CSH 15R and CSH 19R. However, these hybrids exhibit poor fertility restoration under low temperature and high incidence of shoot fly and charcoal rot. The heterosis studies have always been very useful in support of crop improvement activities in sorghum.

Hybrid vigour and its commercial exploitation have been successful in *kharif* sorghum leading to the quantum jump in sorghum production (Rana *et al*., 1997) [22]. However, the progress in *rabi* sorghum is restricted and there is a need for critical studies on combining ability and heterosis involving diverse sources of germplasm and landraces. Selection of parents based on phenotypic performance alone is not a sound procedure since phenotypically superior line may yield poor recombination. It is therefore, essential that parents should be chosen based on their genetic value (Krupkar *et al.,* 2013) [9].

Materials and Methods

The present study focusing extent of heterosis involving *maldandi* and *milo* source of male sterility was carried out during *rabi* 2018-19 at Botany garden, Department of Genetics and Plant Breeding, University of Agricultural Sciences, Dharwad. The experimental material consisted of 25 male lines selected from the mini core collection which were identified as restorers by Prasad (2018) [17] and two male sterile lines (M 31-2A and 104A). The 50 hybrids obtained by crossing two male sterile lines (M 31-2A and 104A) with 25 male lines along with three checks (M 35-1, BJV 44 and PKV Kranti) were evaluated for heterosis during *rabi* 2018.

Observations were recorded from five randomly selected competitive plants in each replication. The sterile hybrids were artificially pollinated for 100 per cent seed set. Treatment means were worked out from the data collected on these plants on the characters Days to 50 per cent flowering, Plant height, Number of leaves per plant, Panicle length, Panicle width, primaries per panicle, Panicle weight, 100 seed weight and Grain yield per plant.

The treatment mean value of each trait was used for the estimation of heterosis. The heterotic effects were measured as deviation of F_1 mean from mid-parent (relative heterosis), better parent (heterobeltiosis) and the standard check (standard heterosis) mean, as per the formula given by Turner (1953) [27] and Hayes *et al.* (1956) [6].

$$\text{a. heterosis over mid parent (relative heterosis)} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Where mid parent} = \frac{P_1 + P_2}{2}$$

$$\text{b. heterosis over better parent (heterobeltiosis)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{c. heterosis over check (standard heterosis)} = \frac{\overline{F_1} - \overline{CC}}{\overline{CC}} \times 100$$

$\overline{F_1}$ = Mean of F_1

$\overline{MP}$ = Mean of two parents

$\overline{BP}$ = Mean of the better parent

$\overline{CC}$ = Mean of the check used

Results and Discussion

Mean performance and heterosis

Days to 50 per cent flowering

Flowering is one of the crucial trait in crop improvement. In sorghum early flowering is always desirable since it leads to early maturity and reduces the crop duration. Among the 25 lines evaluated IS 19975 (57.67 days) was early to flowering and late flowering was recorded by IS 4581 (81.33 days). The two testers exhibited narrow range for days to 50 per cent flowering with 82.00 days (104A) and 82.66 days (M 31-2A). The variation among the hybrids for *per se* performance for days to 50 per cent flowering varied from 57.66 (104A × IS 19975) to 82.00 (M 31-2A × IS 28313). It was observed that out of 50 hybrids only one hybrid (M 31-2A × IS 4515) showed significant mid parent heterosis, while 36 hybrids showed significance in negative direction. In case of better parent heterosis except three hybrids *viz*., 104A × IS 11619, M 31-2A × IS 28313 and M 31-2A × IS 29654 all were significant in negative direction.

Six crosses showed positive standard heterosis over checks *viz*., M 35-1 and BJV-44. In contrast 33 crosses exhibited negative standard heterosis over all three checks *viz*., M 35-1, BJV 44 and PKV Kranti. Forty three crosses showed negative significance over check PKV Kranti and none of the crosses were positive significance. The percentage of standard heterosis over PKV Kranti ranged from -29.22 (M 31-2A × IS 19975) to 1.23 per cent (M 31-2A × IS 28313). In case of standard heterosis over BJV 44, a total of 34 crosses showed negative significance and 8 crosses exhibited positive significance. The range of standard heterosis over checks BJV 44 and M 35-1 ranged from -25.54 (M 31-2A × IS 19975) to 6.49 per cent (M 31-2A × IS 28313) and -25.86 (M 31-2A × IS 19975) to 6.03 per cent (M 31-2A × IS 28313) respectively. A total of 39 hybrids showed significance over check M 35-1 of which six crosses showed positive heterosis.

Among 50 crosses, 29 exhibited significant negative heterosis over mid parent, better parent and standard checks over all three checks *viz*., M 35-1, BJV 44 and PKV Kranti. The cross M 31-2A × IS 19975 exhibited highest negative heterosis over mid parent, better parent and standard checks over all three checks. These present findings are supported by earlier works of Patil and Biradar (2005) [14], Aaref *et al.* (2011) [1], Prabhakar *et al*. (2013) [16], Prateeksha (2013) [18], Gite *et al*. (2015) [5], Kalpande *et al.* (2015) [7]. Kumar and chand (2015) [10], Choudhari *et al.* (2016) [4], Mindaye *et al*. (2016) [11] and Prateeksha *et al*. (2018) [19].

Plant height

Plant height is one of the important trait in *rabi* sorghum where the fodder yield is as important as grain yield. Plant height influences grain yield and total biomass production in sorghum (Thombre and Patil, 1985) [26].

The two testers *viz.*, 104A and M 31-2A differed significantly for plant height where 104A recorded the mean value of 193.33 cm and M 31-2A found to be tallest with mean plant height of 272.00 cm. Among the lines, IS 25989 (178.33 cm) recorded the lowest plant height. In contrast, IS 30451 with 283.66 cm was found to be tallest among the lines. Plant height among hybrids varied from 220.66 cm (104A × IS 26617) to 299.66 cm (M 31-2A × IS 995). The crosses *viz.*, M 31-2A × IS 995 (299.66 cm) and M 31-2A × IS 32439 (291.33 cm) recorded peak plant height. In contrast to cross 104A × IS 26617 (220.66 cm) which recorded lowest plat height.

The magnitude of heterosis over mid parent and better parent varied from -7.78 (M 31-2A × IS 602) to 39.73 per cent (104A × IS 25989) and -10.05 (M 31-2A × IS 31651) to 34.31 per cent (104A × IS 25989), respectively. The crosses *viz.*, M 31-2A × IS 32439 and 104A × IS 995 showed significant positive heterosis over all the three checks *viz.*, M 35-1, BJV 44 and PKV Kranti. Whereas, the crosses M 31-2A × IS 4581, M 31-2A × IS 11619 and M 31-2A × IS 30451 accounted for significant positive heterosis over the checks *viz.*, M 35-1 and BJV 44. The range of heterosis over checks M 35-1 and BJV 44 varied from -18.27 (104A × IS 26617) to

10.99 per cent (M 31-2A × IS 995) and -20.34 (104A × IS 26617) to 8.18 per cent (M 31-2A × IS 995), respectively. The heterosis over check PKV Kranti varied from -22.21 (104A × IS 26617) to 5.64 per cent (M31-2A × IS 995).

About forty crosses out of 50 showed significant positive heterosis over mid parent while seventeen crosses exhibited significant positive heterosis over better parent. These results are supported by the earlier findings of Rajguru *et al.* (2005) [21], Umakanth *et al.* (2006) [28], Aaref *et al.* (2011) [1], Tariq *et al*. (2014) [25], Gite *et al*. (2015) [5], Kalpande *et al.* (2015) [7], Mindaye *et al*. (2016) [11] and Prateeksha *et al*. (2018) [19].

Number of leaves

Number of leaves per plant is an important trait in *rabi* sorghum as it is directly correlated to fodder yield. The range of variation for number of leaves was low among lines.

Among the lines, IS 26025 (9.0) and IS 25989 (9.0) recorded the lowest number of leaves per plant and the highest number (12) leaves was recorded by lines *viz.,* IS 4581, IS 23590, IS 28313, IS 29654 and IS 30451.The variation among the hybrids for mean performance for this trait was from 8.00 for M 31-2A × IS 995, 104 A × IS 19450 and 104A × IS 995 to 14.00 leaves for M 31-2A × IS 31651, 104A × IS 31651 and 104A × IS 30451. Three hybrids namely, M 31-2A × IS 31651, 104A × IS 31651 and104A × IS 30451 exhibited maximum number of leaves compared to checks *viz.,* M 35-1, BJV 44 and PKV Kranti.

Significant positive heterosis was noticed in twelve crosses over mid parent. The range of heterosis over mid parent was from -34.25 (M 31-2A × IS 995) to 40.00 per cent (104A × IS 31651). Five crosses showed positive heterosis over better parent with the range varying from -38.46 (M 31-2A × IS 995) to 40.00 per cent (104A × IS 31651). The heterosis range of -33.33 to 16.67 per cent and 38.46 to 7.69 per cent over checks M 35-1 and BJV 44 was recorded respectively, The crosses (M 31-2A × IS 31651), (104A × IS 31651) and (104A × IS 30451) exhibited significant positive standard heterosis over checks *viz.,* M 35-1 and BJV 44. However, none of the crosses showed significant standard heterosis over check PKV Kranti for number of leaves per plant. These results are in conformity with earlier reports of Pattanashetti (2000) [15], Pahuja *et al*. (2014) [13], Tariq *et al*. (2014) [25], Kalpande *et al.* (2015) [7] and Aaref *et al*. (2016) [2].

Panicle length

Panicle length is a significant yield attributing trait, it has desirable indirect effect on yield by increasing the number of grains per panicle in sorghum seed yield (Sankarapandian *et al.,* 1994). Greater variation was observed among both lines as well as testers for panicle length. Among twenty five lines, the panicle length ranged from 11.70 cm (IS 29654) to 38.83 cm (IS 602), at the same time, among testers it arrayed from 19.30 cm (M 31-2A) to 25.60 cm (104A). The crosses 104A × IS 602 (32.66 cm), M 31-2A × IS 602 (32.16 cm) and M 31-2A × IS 995 (30.93 cm) were accounted for maximum panicle length over the checks *viz.,* M 35-1, BJV 44 and PKV Kranti. In contrast, M 31-2A × IS 19450 (14.06 cm), M 31-2A × IS 29654 (14.53 cm) and M 31-2A × IS 26617 (15.30 cm) accounted for minimum panicle length. Thirty two hybrids among fifty were found statistically superior over checks BJV 44 (21.26) and PKV Kranti (22.20).

The magnitude of heterosis arrayed from -35.99 (M 31-2A × IS 11619) to 51.54 per cent (104A × IS 19450) over mid parent and -47.45 (M 31-2A × IS 11619) to 16.10 per cent (M31-2A × IS 25989) over better parent. For standard heterosis, fourteen crosses showed positive significance over all the three checks *viz.,* M 35-1, BJV 44 and PKV Kranti. The standard heterosis range over checks *viz.,* M 35-1, BJV 44 and PKV Kranti was from -21.56 (M 31-2A × IS 19450) to 82.16 per cent (104A × IS 602), -33.54 (M31-2A × IS 19450) to 54.33 per cent (104A × IS 602) and -36.64 (M 31-2A × IS 19450) to 47.15 per cent (104A × IS 602) respectively. The crosses *viz.,* 104A ×IS 602, M 31-2A × IS 602 and M 31-2A × IS 4515 exhibited maximum standard heterosis over all the three checks *viz.,* M 35-1, BJV 44 and PKV Kranti. The cross, 104A × IS 602 exhibited highest significant positive standard heterosis over all three checks. These present findings were supported by earlier studies of Premalatha *et al.* (2006) [20], Mahmoud and Kanbur *et al.* (2011) [8], Gite *et al*. (2015) [5], Kalpande *et al.* (2015) [7], Choudhari *et al.* (2016) [4] and Prateeksha *et al*. (2018) [19].

Panicle width

The two testers showed significant difference for plant width ranging from 6.70 cm (104 A) to 7.66 cm (M 31-2A). Among the lines the mean values varied from 5.60 cm (IS 32439) to 9.33 cm (IS 6.02). The line IS 602 (9.33 cm) accounted for maximum mean value for panicle width. Whereas, IS 4515 (5.46 cm) recorded for minimum value. The crosses *viz.,* M 31-2A × IS 30451 (7.53 cm), 104 A × IS 15945 (7.44 cm), M 31-2A × IS 32439 (7.33 cm), 104A × IS 22720 (7.33 cm) and 104A × IS 23891(7.23 cm) accounted for maximum panicle width.

Among 50 crosses, 40 showed significant heterosis over mid parent and out of which five showed positive significance and the remaining 35 crosses showed negative significance. It was observed that the range over better parent varied from -41.61 (104A × IS 602) to 6.33 per cent (104A × IS 15945). Whereas, only two crosses *viz.,* 104A × IS 15945 and 104A × IS 22720 accounted for significant positive heterosis over better parent.

The magnitude of standard heterosis over checks *viz.,* M 35-1, BJV 44 and PKV Kranti varied from -35.94 (104A × IS 32439) to 4.15 per cent (M 31-2A × IS 30451), -53.20 (104A × IS 32439) to -23.91 per cent (M 31-2A × IS 30451) and -53.67 (104A × IS 32439) to -24.67 per cent (M 31-2A × IS 30451), respectively. Forty five crosses out of 50 crosses showed negative significant over all the three checks *viz.,* M 35-1, BJV 44 and PKV Kranti. In contrast, none of the crosses was exhibited significant standard heterosis in positive direction over three checks *viz.,* M 35-1, BJV 44 and PKV Kranti. Similar reports were documented by Prateeksha (2013) [18], Gite *et al*. (2015) [5], Kalpande *et al.* (2015) [7] and Choudhari *et al.* (2016) [4].

Primaries per panicle

The line IS 19540 recorded maximum mean value of 71.33 for number of primaries per panicle, whereas IS 19975 recorded the minimum mean value of 29.00 followed by IS 602 (30.00) and IS 25989 (31.33). On the other hand there was no significant difference among two testers *viz.,* M 31-2A (56.00) and 104A (52.66) for number of primaries per panicle. Among the crosses, M 31-2A × IS 19450 (67.33) had peak value and 104A × IS 31651 (31.66) had lower value. Four hybrids *viz.,* M 31-2A × IS 19450 (67.33), M 31-2A × IS 32439 (63.33), 104A × IS 29269 (63.00) and M 31-2A × IS 4581 (62.66) were found statistically superior over all the three checks *viz.,* M 35-1 (48.33), BJV 44 (61.66) and PKV Kranti (64.33).

The magnitude of heterosis for number of primaries per panicle over mid parent ranged from -34.71 (104A × IS 31651) to 37.40 per cent (M 31-2A × IS 25989). Among all 50 crosses, 22 crosses showed significance in positive direction over mid parent. In case of heterosis over better parent, five crosses showed significant positive heterosis with the magnitude of heterosis ranging from -39.87 (104A × IS 31651) to 13.10 per cent (M 31-2A × IS 32439). Ten crosses exhibited significance in positive direction over check M 35-1.

The range of standard heterosis over checks *viz.*, M 35-1, BJV 44 and PKV Kranti varied from 34.48 (104A × IS 31651) to 39.91 per cent (M 31-2A × IS 19450), -47.57 (104A × IS 31651) to 9.19 per cent (M 31-2A × IS 19450) and -49.74 (104A × IS 31651) to 4.66 per cent (M 31-2A × IS 19450), respectively. The cross M31-2A × IS 19450 exhibited significant heterosis in positive direction over check BJV 44. In contrast, none of the crosses was exhibited significant standard heterosis in positive direction over the check PKV Kranti. The results are in accordance with Patil and Biradar (2005) [14], Kalpande *et al.* (2015) [7], Choudhari *et al.* (2016) [4] and Prateeksha *et al*. (2018) [19].

Panicle weight

Panicle weight is one of the vital component which contribute to grain yield per plant (Nimbalkar *et al.*, 1988). The mean panicle weight among the lines ranged from 30.30 g (IS 25989) to 89.43 g (IS 4581), while among the testers it varied from 65.46 g (104A) to 70.20 g (M 31-2A). The line IS 4581 recorded the maximum value of 89.43 g followed by IS 4581 with 80.40 g. Among the crosses M 31-2A × IS 32439 (106.67 g) and M 31-2A × IS 19450 (95.26 g) accounted for maximum panicle weight. Whereas, the cross 104A × IS 19975 (33.50 g) accounted for least panicle weight. Twenty crosses out of fifty were found statistically significant over check M 35-1 (63.06 g), However, none of the crosses were significant over other two checks BJV 44 (120.53g) and PKV Kranti (121.66 g).

The magnitude of heterosis over mid parent varied from -48.85 (M 31-2A × IS 22720) to 6.73 per cent (M 31-2A ×IS 23891). On the other hand heterobeltiosis ranged from -57.76 (M 31-2A × IS 22720) to 31.03 per cent (M 31-2A ×IS 23891). The magnitude of standard heterosis over checks *viz.*, M 35-1, BJV 44 and PKV Kranti varied from -46.88 (104A × IS 19975) to 69.13 per cent (M 31-2A × IS 32439), -72.71 (104A × IS19975) to -11.50 per cent (M 31-2A × IS 32439) and -72.47 (104A × IS19975) to -12.33 per cent (M 31-2A × IS 32439), respectively.

Among all crosses, 25 and 14 exhibited significant positive heterosis over mid parent and better parent respectively. The cross M 31-2A × IS 32439 exhibited maximum heterosis over mid, better and standard check M 35-1. A total of 20 crosses recorded significant positive heterosis over standard check M 35-1. However, none of the crosses were found significant over the checks BJV 44 and PKV Kranti. These results are in agreement with the reports of Kulkarni and Patil (2004), Umakanth *et al.* (2006) [28], Khapre *et al.* (2007), Prabhakar and Raut (2010), Gite *et al*. (2015) [5] and Prateeksha *et al*. (2018) [19].

Grain yield per plant

The line IS 4581 had peaked the mean value for grain yield per plant with 72.30 g and IS 19975 (26.20 g) had lowest mean for grain yield per plant by all the lines. Among testers 104 A (47.30 g) and M 31-2A (55.20 g) had minimum and maximum grain weight respectively. The variation among crosses ranged from 20.30 g (104A × IS 11619) to 65.28 g (M 31-2A × IS 32439). Nineteen crosses out of fifty were found statistically significant over check M 35-1 (42.83 g). However, none of the crosses were significant over other two checks *viz.*, BJV 44 (81.73 g) and PKV Kranti (81.06 g).

Significant heterosis over mid parent and better parent was observed in both the direction. Out of 50 crosses, 13 and 2 crosses exhibited significant positive heterosis over mid parent and better parent respectively. The range of heterosis over mid parent varied from -53.62 (104A × IS 11619) to 42.67 per cent (M 31-2A × IS 23891). Heterobeltiosis ranged from -58.03 (M 31-2A × IS 20679) to 31.03 18.27 per cent (M 31-2A × IS 32439).

The range of standard heterosis over checks *viz.*, M 35-1, BJV 44 and PKV Kranti varied from -52.61 (104A × IS 11619) to 52.41 (M 31-2A × IS 32439) per cent, -75.16 (104A × IS 11619) to -20.13 per cent (M 31-2A × IS 32439) and -74.96 (104A × IS 11619) to -19.47 per cent (M 31-2A × IS 32439) respectively. Twelve and two crosses exhibited significant positive heterosis over mid and better parent respectively. While, thirteen crosses showed significant positive standard heterosis over the check M 35-1. However, none of the crosses exhibited significant positive standard heterosis over checks BJV and PKV Kranti. Mid parent, better parent and standard heterosis for grain yield per plant have been reported earlier by Sajjanar *et al.* (2011) [24], Aaref *et al.* (2011) [1], Kanbur *et al.* (2011) [8], Gite *et al*. (2015) [5], Kalpande *et al.* (2015) [7], Aaref *et al*. (2016) [2], Choudhari *et al.* (2016) [4], Mindaye *et al*. (2016) [11] and Prateeksha *et al*. (2018) [19].

100 seed weight

Hundred seed weight is one of the vital components which contribute to grain yield per plant. Variation for 100 seed weight was high among lines than testers. Test weight among the lines varied significantly from 0.86 g (IS 20679) to 2.86 g (IS 4515). Whereas, the testers recorded the mean value of 2.66 g (104 A) and 3.10 g (M 31-2A). Among the crosses the test weight varied from 1.96 g (104A × IS 995) to 4.70 g (M 31-2A × IS 4581). The crosses *viz.*, M 31-2A × IS 4581 (4.70 g), M 31-2A × IS 29269 (3.86 g) and 104A × IS 4515 (3.73 g) recorded maximum weight for 100 seeds. Thirty nine hybrids among fifty were found statistically significant over checks *viz.*, M 35-1 (2.53 g), BJV 44 (2.63 g) and PKV Kranti (2.83 g).

Crosses 104A × IS 28313 and M 31-2A × IS 4581 exhibited higher magnitude of heterosis over mid parent and better parent with 84.35 and 43.88 per cent respectively. The range of standard heterosis over checks *viz.*, M 35-1, BJV 44 and PKV Kranti varied from -23.38 (104A × IS 995) to 83.12 per cent (M 31-2A × IS 4581), -26.25 (104A × IS 995) to 76.25 per cent (M 31-2A × IS 4581) and -30.59 (104A × IS 995) to 65.88 per cent (M 31-2A × IS 4581), respectively. Among 50 crosses nine showed significant positive heterosis over all three checks *viz.*, M 35-1, BJV 44 and PKV Kranti. The cross M 31-2A × IS 4581 exhibited maximum heterosis for 100 seed weight over all the checks *viz.*, M 35-1 (83.12%), BJV 44 (76.25%) and PKV Kranti (65.88%). Mid parent, better parent and standard heterosis for grain yield per plant have been reported earlier by Premalatha *et al.* (2006) [20], Gite *et al.* (2015) [5], Aaref *et al.* (2016) [2], Choudhari *et al.* (2016) [4], Mindaye *et al*. (2016) [11] and Prateeksha *et al*. (2018) [19].

Table 1: Estimates of mid parent, better parent and standard heterosis for days to 50 per cent flowering in *rabi* sorghum

Sl. No.	Crosses	Days to 50% flowering							
		Per se performance			Heterosis over (%)				
		Female	Male	F_1	Mid parent	Better parent	Standard check		
							M 35-1	BJV-44	PKV Kranti
1	104A × IS 602	82.00	66.00	72.33	-2.25	-11.79**	-6.47**	-6.06**	-10.70**
2	104A × IS 995	82.00	73.67	69.33	-10.92**	-15.45**	-10.34**	-9.96**	-14.40**
3	104A × IS 4515	82.00	72.00	74.00	-3.90**	-9.76**	-4.31**	-3.90**	-8.64**
4	104A × IS 4581	82.00	81.33	77.33	-5.31**	-5.69**	0.00	0.43	-4.53**
5	104A × IS 4698	82.00	77.67	70.66	-11.48**	-13.82**	-8.62**	-8.23**	-12.76**
6	104A × IS 11619	82.00	77.67	77.00	0.21	-2.44	3.45*	3.90**	-1.23
7	104A × IS 15945	82.00	78.00	76.66	-4.17**	-6.50**	-0.86	-0.43	-5.35**
8	104A × IS 19450	82.00	79.00	75.33	-6.42**	-8.13**	-2.59	-2.16	-7.00**
9	104A × IS 19975	82.00	57.67	57.66	-17.42**	-29.67**	-25.43**	-25.11**	-28.81**
10	104A × IS 20743	82.00	62.33	68.66	-4.85**	-16.26**	-11.21**	-10.82**	-15.23**
11	104A × IS 20679	82.00	70.33	70.00	-8.10**	-14.63**	-9.48**	-9.09**	-13.58**
12	104A × IS 22720	82.00	65.00	72.00	-2.04	-12.20**	-6.90**	-6.49**	-11.11**
13	104A × IS 23590	82.00	78.00	75.66	-5.42**	-7.72**	-2.16	-1.73	-6.58**
14	104A × IS 23891	82.00	72.33	65.66	-14.90**	-19.92**	-15.09**	-14.72**	-18.93**
15	104A × IS 24462	82.00	74.33	77.67	-0.64	-5.28**	0.43	0.87	-4.12**
16	104A × IS 25989	82.00	69.00	69.66	-7.73**	-15.04**	-9.91**	-9.52**	-13.99**
17	104A × IS 26025	82.00	66.66	64.00	-13.90**	-21.95**	-17.24**	-16.88**	-20.99**
18	104A × IS 26617	82.00	80.00	75.33	-7.00**	-8.13**	-2.59	-2.16	-7.00**
19	104A × IS 27887	82.00	68.33	63.66	-15.30**	-22.36**	-17.67**	-17.32**	-21.40**
20	104A × IS 28313	82.00	80.66	69.00	-15.16**	-15.85**	-10.78**	-10.39**	-14.81**
21	104A × IS 29269	82.00	74.33	69.00	-11.73**	-15.85**	-10.78**	-10.39**	-14.81**
22	104A × IS 29654	82.00	78.33	79.33	-1.04	-3.25*	2.59	3.03*	-2.06
23	104A × IS 30451	82.00	70.66	67.00	-12.23**	-18.29**	-13.36**	-12.99**	-17.28**
24	104A × IS 31651	82.00	72.66	68.00	-12.07**	-17.07**	-12.07**	-11.69**	-16.05**
25	104A × IS 32439	82.66	78.00	77.33	-3.33	-5.69**	0.00	0.43	-4.53**
26	M 31-2A × IS 602	82.66	66.00	64.66	-13.00**	-21.77**	-16.38**	-16.02**	-20.16**
27	M 31-2A × IS 995	82.66	73.67	64.33	-17.70**	-22.18**	-16.81**	-16.45**	-20.58**
28	M 31-2A × IS 4515	82.66	72.00	80.00	3.45**	-3.23*	3.45*	3.90**	-1.23
29	M 31-2A × IS 4581	82.66	81.33	80.33	-2.03	-2.82*	3.88**	4.33**	-0.82
30	M 31-2A × IS 4698	82.66	77.67	70.33	-12.27**	-14.92**	-9.05*	-8.66**	-13.17**
31	M 31-2A × IS 11619	82.66	77.67	78.00	-2.29	-5.24**	1.29	1.73	-3.29*
32	M 31-2A × IS 15945	82.66	78.00	80.33	0.00	-2.82*	3.88**	4.33**	-0.82
33	M 31-2A × IS 19450	82.66	79.00	74.00	-8.45**	-10.48**	-4.31**	-3.90**	-8.64**
34	M 31-2A × IS 19975	82.66	57.67	57.33	-18.29**	-30.65**	-25.86**	-25.54**	-29.22**
35	M 31-2A × IS 20743	82.66	62.33	72.00	-0.69	-12.90**	-6.90**	-6.49**	-11.11**
36	M 31-2A × IS 20679	82.66	70.33	70.33	-8.06**	-14.92**	-9.05**	-8.66**	-13.17**
37	M 31-2A × IS 22720	82.66	65.00	67.66	-8.35**	-18.15**	-12.50**	-12.12**	-16.46**
38	M 31-2A × IS 23590	82.66	78.00	75.33	-6.22**	-8.87**	-2.59	-2.16	-7.00**
39	M 31-2A × IS 23891	82.66	72.33	76.33	-1.51	-7.66**	-1.29	-0.87	-5.76**
40	M 31-2A × IS 24462	82.66	74.33	67.33	-14.23**	-18.55**	-12.93**	-12.55**	-16.87**
41	M 31-2A × IS 25989	82.66	69.00	70.33	-7.25**	-14.92**	-9.05**	-8.66**	-13.17**
42	M 31-2A × IS 26025	82.66	66.66	65.33	-12.50**	-20.97**	-15.52**	-15.15**	-19.34**
43	M 31-2A × IS 26617	82.66	80.00	70.00	-13.93**	-15.32**	-9.48**	-9.09**	-13.58**
44	M 31-2A × IS 27887	82.66	68.33	68.33	-9.49**	-17.34**	-11.64**	-11.26**	-15.64**
45	M 31-2A × IS 28313	82.66	80.66	82.00	0.41	-0.81	6.03**	6.49**	1.23
46	M 31-2A × IS 29269	82.66	74.33	66.33	-15.50**	-19.76**	-14.22**	-13.85**	-18.11**
47	M 31-2A × IS 29654	82.66	78.33	81.00	0.62	-2.02	4.74**	5.19**	0.00
48	M 31-2A × IS 30451	82.66	70.66	73.66	-3.91**	-10.89**	-4.74**	-4.33**	-9.05**
49	M 31-2A × IS 31651	82.66	72.66	67.33	-12.88**	-18.15**	-12.50**	-12.12**	-16.46**
50	M 31-2A × IS 32439	82.66	78.00	68.00	-15.35**	-17.74**	-12.07**	-11.69**	-16.05**
	Check (M 35-1)	77.34			-				
	Check (BJV-44)	77			-				
	Check (PKV Kranti)	81			-				
S.Em ±					0.98	1.13			
C.D.@ 1%					2.58	2.98			
C.D. @ 5%					1.95	2.25			

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

Table 2: Estimates of mid parent, better parent and standard heterosis for plant height (cm) in *rabi* sorghum

Sl. No	Crosses	Plant height (cm)							
		Per se performance			Heterosis over (%)				
		Female	Male	F_1	Mid parent	Better parent	Standard check		
							M 35-1	BJV-44	PKV Kranti
1	104A × IS 602	193.33	276.66	260.00	10.64**	-6.02**	-3.70**	-6.14**	-8.34**
2	104A × IS 995	193.33	278.00	255.33	8.35**	-8.15**	-5.43**	-7.82**	-9.99**
3	104A × IS 4515	193.33	269.33	263.66	13.98**	-2.10	-2.35*	-4.81**	-7.05**
4	104A × IS 4581	193.33	279.66	277.33	17.27**	-0.83	2.72*	0.12	-2.23*
5	104A × IS 4698	193.33	266.67	270.00	17.39**	1.25	0.00	-2.53*	-4.82**
6	104A × IS 11619	193.33	248.00	272.66	23.56**	9.95**	0.99	-1.56	-3.88**
7	104A × IS 15945	193.33	253.00	262.00	17.40**	3.56**	-2.96*	-5.42**	-7.64**
8	104A × IS 19450	193.33	249.00	263.66	19.22**	5.89**	-2.35*	-4.81**	-7.05**
9	104A × IS 19975	193.33	230.00	256.00	20.94**	11.30**	-5.19**	-7.58**	-9.75**
10	104A × IS 20743	193.33	272.66	258.33	10.87**	-5.26**	-4.32**	-6.74**	-8.93**
11	104A × IS 20679	193.33	245.00	246.66	12.55**	0.68	-8.64**	-10.95**	-13.04**
12	104A × IS 22720	193.33	229.33	252.33	19.40**	10.03**	-6.54**	-8.90**	-11.05**
13	104A × IS 23590	193.33	267.66	278.33	20.75**	3.99**	3.09**	0.48	-1.88
14	104A × IS 23891	193.33	213.00	250.66	23.38**	17.68**	-7.16**	-9.51**	-11.63**
15	104A × IS 24462	193.33	272.66	267.33	14.74**	-1.96	-0.99	-3.49**	-5.76**
16	104A × IS 25989	193.33	178.33	259.66	39.73**	34.31**	-3.83**	-6.26**	-8.46**
17	104A × IS 26025	193.33	217.00	238.00	16.00**	9.68**	-11.85**	-14.08**	-16.10**
18	104A × IS 26617	193.33	225.66	220.66	5.33**	-2.22	-18.27**	-20.34**	-22.21**
19	104A × IS 27887	193.33	240.00	257.66	18.92**	7.36**	-4.57**	-6.98**	-9.17**
20	104A × IS 28313	193.33	269.00	259.66	12.33**	-3.47**	-3.83**	-6.26**	-8.46**
21	104A × IS 29269	193.33	255.00	266.67	18.96**	4.58**	-1.23	-3.73**	-5.99**
22	104A × IS 29654	193.33	256.00	262.00	16.62**	2.34	-2.96*	-5.42**	-7.64**
23	104A × IS 30451	193.33	283.66	276.00	15.72**	-2.70*	2.22	-0.36	-2.70**
24	104A × IS 31651	193.33	251.00	254.66	14.63**	1.46	-5.68**	-8.06**	-10.22**
25	104A × IS 32439	193.33	218.33	247.66	20.32**	13.44**	-8.27**	-10.59**	-12.69**
26	M 31-2A × IS 602	272.00	276.66	253.00	-7.78**	-8.55*	-6.30**	-8.66**	-10.81**
27	M 31-2A × IS 995	272.00	278.00	299.66	8.97**	7.79**	10.99**	8.18**	5.64**
28	M 31-2A × IS 4515	272.00	269.33	268.33	-0.86	-1.35	-0.62	-3.13**	-5.41**
29	M 31-2A × IS 4581	272.00	279.66	286.00	3.69**	2.26*	5.93**	3.25**	0.82
30	M 31-2A × IS 4698	272.00	266.67	255.33	-5.20**	-6.13**	-5.43**	-7.82**	-9.99**
31	M 31-2A × IS 11619	272.00	248.00	286.00	10.00**	5.15**	5.93**	3.25**	0.82
32	M 31-2A × IS 15945	272.00	253.00	281.66	7.30**	3.55**	4.32**	1.68	-0.71
33	M 31-2A × IS 19450	272.00	249.00	256.33	-1.60	-5.76**	-5.06**	-7.46**	-9.64**
34	M 31-2A × IS 19975	272.00	230.00	263.00	4.78**	-3.31**	-2.59*	-5.05**	-7.29**
35	M 31-2A × IS 20743	272.00	272.66	268.33	-1.47	-1.59	-0.62	-3.13**	-5.41**
36	M 31-2A × IS 20679	272.00	245.00	266.00	2.90**	-2.21	-1.48	-3.97**	-6.23**
37	M 31-2A × IS 22720	272.00	229.33	267.33	6.65**	-1.72	-0.99	-3.49**	-5.76**
38	M 31-2A × IS 23590	272.00	267.66	276.00	2.29*	1.47	2.22	-0.36	-2.70*
39	M 31-2A × IS 23891	272.00	213.00	264.33	9.00**	-2.82*	-2.10	-4.57**	-6.82**
40	M 31-2A × IS 24462	272.00	272.66	265.33	-2.57*	-2.69*	-1.73	-4.21**	-6.46**
41	M 31-2A × IS 25989	272.00	178.33	273.66	21.54**	0.61	1.36	-1.20	-3.53**
42	M 31-2A × IS 26025	272.00	217.00	265.00	8.38**	-2.57*	-1.85	-4.33**	-6.58**
43	M 31-2A × IS 26617	272.00	225.66	249.33	0.20	-8.33**	-7.65**	-9.99**	-12.10**
44	M 31-2A × IS 27887	272.00	240.00	269.00	5.08**	-1.10	-0.37	-2.89*	-5.17**
45	M 31-2A × IS 28313	272.00	269.00	273.00	0.92	0.37	1.11	-1.44	-3.76**
46	M 31-2A × IS 29269	272.00	255.00	271.33	2.97**	-0.25	0.49	-2.05	-4.35**
47	M 31-2A × IS 29654	272.00	256.00	257.66	-2.40*	-5.27**	-4.57**	-6.98**	-9.17**
48	M 31-2A × IS 30451	272.00	283.66	287.66	3.54**	1.41	6.54**	3.85**	1.41
49	M 31-2A × IS 31651	272.00	251.00	244.66	-6.44**	-10.05**	-9.38**	-11.67**	-13.75**
50	M 31-2A × IS 32439	272.00	218.33	291.33	18.83**	7.11**	7.90**	5.17**	2.70*
	Check (M 35-1)	270			-				
	Check (BJV 44)	277			-				
	Check (PKV Kranti)	283.6			-				
S.Em ±					2.73	3.16			
C.D.@ 1%					7.19	8.30			
C.D. @ 5%					5.43	6.27			

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

Table 3: Estimates of mid parent, better parent and standard heterosis for panicle weight (g) in *rabi* sorghum

Sl. No.	Crosses	Panicle weight (g)							
		Per se performance			Heterosis over (%)				
		Female	Male	F_1	Mid parent	Better parent	Standard check		
							M 35-1	BJV-44	PKV Kranti
1	104A × IS 602	65.46	54.70	45.06	-24.99**	-31.16**	-28.54**	-62.61**	-62.96**
2	104A × IS 995	65.46	80.40	62.30	-14.58**	-22.51**	-1.22	-48.31**	-48.79**
3	104A × IS 4515	65.46	53.40	44.70	-24.79**	-38.13**	-29.12**	-62.91**	-63.26**
4	104A × IS 4581	65.46	89.43	55.33	-28.56**	-43.87**	-12.26**	-54.09**	-54.52**
5	104A × IS 4698	65.46	64.83	55.16	-15.32**	-15.73**	-12.53**	-54.23**	-54.66**
6	104A × IS 11619	65.46	53.83	57.90	-2.93*	-11.56**	-8.19**	-51.96**	-52.41**
7	104A × IS 15945	65.46	64.43	61.00	-6.08**	-6.82**	-3.28*	-49.39**	-49.86**
8	104A × IS 19450	65.46	63.26	78.33	21.70**	19.65**	24.21**	-35.01**	-35.62**
9	104A × IS 19975	65.46	35.00	33.50	-33.31**	-48.83**	-46.88**	-72.21**	-72.47**
10	104A × IS 20743	65.46	64.13	54.26	-16.26**	-17.11**	-13.95**	-54.98**	-55.40**
11	104A × IS 20679	65.46	27.96	45.13	-3.39*	-31.06**	-28.44**	-62.56**	-62.90**
12	104A × IS 22720	65.46	69.13	61.90	-8.02**	-10.46**	-1.85	-48.64**	-49.12**
13	104A × IS 23590	65.46	49.83	70.36	22.06**	7.48**	11.58**	-41.62**	-42.16**
14	104A × IS 23891	65.46	36.40	69.56	36.58**	6.26**	10.31**	-42.28**	-42.82**
15	104A × IS 24462	65.46	56.40	74.03	21.50**	13.09**	17.39**	-38.58**	-39.51**
16	104A × IS 25989	65.46	30.30	60.66	26.70**	-7.33**	-3.81**	-49.67**	-50.14**
17	104A × IS 26025	65.46	45.50	50.46	-9.04**	-22.91**	-19.98**	-58.13**	-58.52**
18	104A × IS 26617	65.46	33.86	48.83	-1.68	-25.41**	-22.57**	-59.59**	-59.86**
19	104A × IS 27887	65.46	67.50	53.60	-19.38**	-20.94**	-15.01**	-55.53**	-55.95**
20	104A × IS 28313	65.46	47.83	56.63	-0.03	-13.49**	-10.20**	-53..01**	-53.45**
21	104A × IS 29269	65.46	43.00	58.66	8.17**	-10.39**	-6.98**	-51.33**	-51.78**
22	104A × IS 29654	65.46	50.33	51.20	-11.57**	-21.79**	-18.82**	-57.52**	-57.92**
23	104A × IS 30451	65.46	53.53	61.86	3.98**	-5.50	-1.90	-48.67**	-49.15**
24	104A × IS 31651	65.46	38.93	39.80	-23.69**	-39.15**	-36.84**	-66.84**	-67.15**
25	104A × IS 32439	65.46	64.00	69.86	7.93**	6.72**	10.78**	-42.04**	-42.58**
26	M 31-2A × IS 602	70.20	54.70	40.80	-34.67**	-41.88**	-35.31**	-66.15**	-66.47**
27	M 31-2A × IS 995	70.20	80.40	81.83	8.68**	1.78	29.76**	-32.11**	-32.74**
28	M 31-2A × IS 4515	70.20	53.40	80.30	29.94**	14.39**	27.33**	-33.38**	-34.00**
29	M 31-2A × IS 4581	70.20	89.43	46.53	-41.70**	-47.97**	-26.22**	-61.39**	-61.75**
30	M 31-2A × IS 4698	70.20	64.83	72.76	7.78**	3.66	15.38**	-39.63**	-40.19**
31	M 31-2A × IS 11619	70.20	53.83	80.06	29.11**	14.06**	26.96**	-33.57**	-34.19**
32	M 31-2A × IS 15945	70.20	64.43	76.96	14.34**	9.64**	22.04**	-36.14**	-36.74**
33	M 31-2A × IS 19450	70.20	63.26	95.26	42.76**	35.71**	51.06**	-20.96**	-21.70**
34	M 31-2A × IS 19975	70.20	35.00	76.03	44.55**	8.31**	20.56**	-36.92**	-37.51**
35	M 31-2A × IS 20743	70.20	64.13	64.16	-4.47**	-8.59**	1.74	-46.76**	-47.26**
36	M 31-2A × IS 20679	70.20	27.96	34.03	-30.66**	-51.52**	-46.04**	-71.76**	-72.03**
37	M 31-2A × IS 22720	70.20	69.13	35.63	-48.85**	-49.24**	-43.50**	-70.44**	-70.71**
38	M 31-2A × IS 23590	70.20	49.83	75.70	26.13**	7.83**	20.03**	-37.20**	-37.78**
39	M 31-2A × IS 23891	70.20	36.40	86.20	61.73**	22.79**	36.68**	-28.48**	-29.15**
40	M 31-2A × IS 24462	70.20	56.40	48.73	-23.01**	-30.58**	-22.73**	-59.57**	-59.95**
41	M 31-2A × IS 25989	70.20	30.30	71.23	41.76**	1.47	12.95**	-40.90**	-41.45
42	M 31-2A × IS 26025	70.20	45.50	59.76	3.31**	-14.86**	-5.23**	-50.41**	-50.38**
43	M 31-2A × IS 26617	70.20	33.86	55.50	6.66*	-20.94**	12.00**	-53.95**	-54.38**
44	M 31-2A × IS 27887	70.20	67.50	39.90	-42.05**	-43.49**	-36.73**	-66.90**	-67.21**
45	M 31-2A × IS 28313	70.20	47.83	61.40	4.04**	-12.54**	-2.64*	-49.06**	-49.53**
46	M 31-2A × IS 29269	70.20	43.00	74.23	31.15**	5.75**	17.71**	-38.41**	-38.99**
47	M 31-2A × IS 29654	70.20	50.33	39.96	-33.68**	-43.07**	-36.63**	-66.84**	-67.15**
48	M 31-2A × IS 30451	70.20	53.53	67.73	9.48**	-3.51**	7.40**	-43.81**	-44.33**
49	M 31-2A × IS 31651	70.20	38.93	80.20	46.98**	14.25**	27.17**	-33.36**	-34.08**
50	M 31-2A × IS 32439	70.20	64.00	106.67	46.98**	51.95**	69.13**	-11.50**	-12.33**
	Check (M 35-1)	63.06			-				
	Check (BJV-44)	120.53			-				
	Check (PKV Kranti)	121.66			-				
S.Em ±					0.71	0.82			
C.D.@ 1%					1.86	2.15			
C.D. @ 5%					1.41	1.62			

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

Table 4: Estimates of mid parent, better parent and standard heterosis for 100 seed weight (g) in *rabi* sorghum

Sl. No.	Crosses	100 seed weight (g)							
		Per se performance			Heterosis over (%)				
		Female	Male	F1	Mid parent	Better parent	Standard check		
							M 35-1	BJV-44	PKV Kranti
1	104A × IS 602	2.66	2.06	2.03	-14.08*	-23.75**	-20.78**	-23.75**	-28.24**
2	104A × IS 995	2.66	1.96	1.96	-15.11*	-26.25**	-23.38**	-26.25**	-30.59**
3	104A × IS 4515	2.66	2.86	2.76	0.00	-3.49	7.79	3.75	-2.35
4	104A × IS 4581	2.66	3.26	3.73	25.84**	14.29*	45.45**	40.00**	31.76**
5	104A × IS 4698	2.66	1.66	2.43	12.31	-8.75	-5.19	-8.75	-14.12*
6	104A × IS 11619	2.66	2.23	2.70	10.20	1.25	5.19	1.25	-4.71
7	104A × IS 15945	2.66	1.56	2.20	3.94	-17.50*	-14.29*	-17.50*	-22.35**
8	104A × IS 19450	2.66	1.86	2.76	22.06**	3.75	7.79	3.75	-2.35
9	104A × IS 19975	2.66	1.53	2.83	34.92**	6.25	10.39	6.25	0.00
10	104A × IS 20743	2.66	2.43	2.13	-16.34**	-20.00**	-16.88*	-20.00**	-24.71**
11	104A × IS 20679	2.66	0.86	3.20	81.13**	20.00**	24.68**	20.00**	12.94*
12	104A × IS 22720	2.66	1.43	3.16	54.47**	18.75**	23.38**	18.75**	11.76
13	104A × IS 23590	2.66	2.06	2.76	16.90*	3.75	7.79	3.75	-2.35
14	104A × IS 23891	2.66	1.66	2.26	4.62	-15.00*	-11.69	-15.00*	-20.00*
15	104A × IS 24462	2.66	2.63	2.46	-6.92	-7.50	-3.90	-7.50	-12.94*
16	104A × IS 25989	2.66	1.26	2.93	49.15**	10.00	14.29*	10.00	3.53
17	104A × IS 26025	2.66	2.06	2.86	21.13**	7.50	11.69	7.50	1.18
18	104A × IS 26617	2.66	2.33	2.83	13.33*	6.25	10.39	6.25	0.00
19	104A × IS 27887	2.66	1.43	3.16	54.47**	18.75**	23.38**	18.75**	11.76
20	104A × IS 28313	2.66	1.16	3.53	84.35**	32.50**	37.66**	32.50**	24.71**
21	104A × IS 29269	2.66	2.46	3.13	22.08**	17.50*	22.08**	17.50*	10.59
22	104A × IS 29654	2.66	2.20	3.16	31.04**	18.75**	23.38**	18.75**	11.76
23	104A × IS 30451	2.66	2.46	3.83	49.38**	43.75**	49.35**	43.75**	35.29**
24	104A × IS 31651	2.66	2.23	2.30	-6.12	-13.75*	-10.39	-13.75*	-18.82**
25	104A × IS 32439	2.66	2.60	3.16	20.25**	18.75**	23.38**	18.75**	11.76
26	M 31-2A × IS 602	3.10	2.06	2.63	1.94	-15.05*	2.60	-1.25	-7.06
27	M 31-2A × IS 995	3.10	1.96	2.86	13.16*	-7.53	11.69	7.50	1.18
28	M 31-2A × IS 4515	3.10	2.86	3.40	13.97**	9.68	32.47**	27.50**	20.00**
29	M 31-2A × IS 4581	3.10	3.26	4.70	47.64**	43.88**	83.12**	76.25**	65.88**
30	M 31-2A × IS 4698	3.10	1.66	2.96	24.48**	-4.30	-5.19	-8.75	-14.12*

Sl. No.	Crosses	100 seed weight (g)							
		Per se performance			Heterosis over (%)				
		Female	Male	F1	Mid parent	Better parent	Standard check		
							M 35-1	BJV-44	PKV Kranti
31	M 31-2A × IS 11619	3.10	2.23	3.53	32.50**	13.98*	5.19	1.25	-4.71
32	M 31-2A × IS 15945	3.10	1.56	2.56	10.00	-17.20**	-14.28*	-17.50*	-22.35**
33	M 31-2A × IS 19450	3.10	1.86	3.03	22.15**	-2.15	7.79	3.75	-2.35
34	M 31-2A × IS 19975	3.10	1.53	2.86	23.74**	-7.53	10.39	6.25	0.00
35	M 31-2A × IS 20743	3.10	2.43	2.86	3.61	-7.53	-16.88*	-20.00**	-24.71**
36	M 31-2A × IS 20679	3.10	0.86	2.83	42.86**	-8.60	24.68**	20.00**	12.94*
37	M 31-2A × IS 22720	3.10	1.43	2.86	26.47**	-7.53	23.38**	18.75**	11.76
38	M 31-2A × IS 23590	3.10	2.06	2.66	3.23	-13.98*	7.79	3.75	-2.35
39	M 31-2A × IS 23891	3.10	1.66	2.33	-2.10	-24.73**	-11.69	-15.00*	-20.00**
40	M 31-2A × IS 24462	3.10	2.63	3.26	13.95*	5.38	-3.90	-77.50	-12.94*
41	M 31-2A × IS 25989	3.10	1.26	2.46	12.98	-20.43**	14.29*	10.00	3.53
42	M 31-2A × IS 26025	3.10	2.06	2.43	-5.81	-21.51**	11.69	7.50	1.18
43	M 31-2A × IS 26617	3.10	2.33	3.06	12.88*	-1.08	10.39	6.25	0.00
44	M 31-2A × IS 27887	3.10	1.43	2.76	22.06**	-10.75	23.38**	18.75**	11.76
45	M 31-2A × IS 28313	3.10	1.16	2.86	34.38**	-7.53	37.66**	32.50**	24.71**
46	M 31-2A × IS 29269	3.10	2.46	3.86	38.92**	24.73**	22.08**	17.50*	10.59
47	M 31-2A × IS 29654	3.10	2.20	3.46	30.82**	11.83*	23.38**	18.75**	11.76
48	M 31-2A × IS 30451	3.10	2.46	3.23	16.17**	4.30	49.35**	43.75**	35.29**
49	M 31-2A × IS 31651	3.1	2.23	2.76	3.75	-10.75	-10.39	-13.75*	-18.82**
50	M 31-2A × IS 32439	3.10	2.60	3.46	21.64**	11.83*	23.38**	18.75**	11.76
	Check (M 35-1)	2.53			-				
	Check (BJV 44)	2.63			-				
	Check (PKV Kranti)	2.83			-				
S.Em ±					0.154	0.178			
C.D.@ 1%					0.405	0.468			
C.D. @ 5%					0.306	0.353			

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

Table 5: Estimates of mid parent, better parent and standard heterosis for grain yield per plant (g) in *rabi* sorghum

Sl. No.	Crosses	Grain yield per plant (g)							
		Per se performance			Heterosis over (%)				
		Female	Male	F_1	Mid parent	Better parent	Standard check		
							M 35-1	BJV-44	PKV Kranti
1	104A × IS 602	47.30	42.53	33.16	-26.16**	-29.88**	-22.57**	-59.42**	-59.09**
2	104A × IS 995	47.30	52.10	46.90	-5.63	-9.98**	9.49*	-42.62**	-42.15**
3	104A × IS 4515	47.30	41.10	20.70	-53.17**	-56.24**	-51.67**	-74.67**	-74.47**
4	104A × IS 4581	47.30	72.30	35.90	-39.97**	-50.35**	-16.19**	-56.04**	-55.67**
5	104A × IS 4698	47.30	51.76	32.06	-35.26**	-38.06**	-25.14**	-60.77**	-60.44**
6	104A × IS 11619	47.30	40.23	20.30	-53.62**	-57.08**	-52.61**	-75.16**	-74.96**
7	104A × IS 15945	47.30	49.44	37.66	-22.12**	-23.80**	-12.06**	-53.92**	-53.54**
8	104A × IS 19450	47.30	44.33	48.93	6.80	3.45	14.24**	-40.13**	-39.64**
9	104A × IS 19975	47.30	26.20	24.70	-32.79**	-47.78**	-42.33**	-69.78**	-69.53**
10	104A × IS 20743	47.30	36.53	37.60	-10.30*	-20.51**	-12.22**	-54.00**	-53.62**
11	104A × IS 20679	47.30	15.10	30.06	-3.63	-36.43**	-29.81**	-63.21**	-62.91**
12	104A × IS 22720	47.30	41.53	35.16	-20.83**	-25.65**	-17.90**	-56.97**	-56.62**
13	104A × IS 23590	47.30	28.53	50.33	32.75**	6.41	17.51**	-38.42**	-37.91**
14	104A × IS 23891	47.30	26.20	44.23	20.36**	-6.48	3.27	-45.88**	-45.44**
15	104A × IS 24462	47.30	45.50	46.53	0.29	-1.62	8.64	-43.07**	-42.60**
16	104A × IS 25989	47.30	20.06	38.53	14.40**	-18.53**	-10.04*	-52.85**	-52.47**
17	104A × IS 26025	47.30	29.46	32.00	-16.63**	-32.35**	-25.29**	-60.85**	-60.53**
18	104A × IS 26617	47.30	24.76	34.16	-5.18	-27.77**	-20.23**	-58.20**	-57.85**
19	104A × IS 27887	47.30	35.83	37.50	-9.78*	-20.72**	-1245**	-54.12**	-53.74**
20	104A × IS 28313	47.30	36.86	38.76	-7.88*	-18.04**	-9.49*	-52.57**	-52.18**
21	104A × IS 29269	47.30	30.20	36.93	-4.69	-21.92**	-13.77**	-54.18**	54.44**
22	104A × IS 29654	47.30	36.90	28.93	-31.27**	-38.83**	-32.45**	-64.60**	-64.31**
23	104A × IS 30451	47.30	25.76	48.23	32.03**	1.97	12.61**	-40.99**	-40.50**
24	104A × IS 31651	47.30	29.30	26.53	-30.72**	-43.90**	-38.05**	-67.54**	-67.27**
25	104A × IS 32439	47.30	46.20	33.06	-29.72**	-30.09**	-22.80**	-59.54**	-59.21**
26	M 31-2A × IS 602	55.20	42.53	34.16	-30.08**	-38.10**	-20.23**	-58.20**	-57.85**
27	M 31-2A × IS 995	55.20	52.10	53.13	-0.96	-3.74	24.05**	-34.99**	-34.46**
28	M 31-2A × IS 4515	55.20	41.10	35.93	-25.37**	-34.90**	-16.11**	-56.04**	-55.67**
29	M 31-2A × IS 4581	55.20	72.30	31.16	-51.11**	-56.89**	-27.24**	-61.87**	-61.55**
30	M 31-2A × IS 4698	55.20	51.76	50.33	-5.89	-8.82*	17.51**	-38.42**	-37.91**

Sl. No.	Crosses	Grain yield per plant (g)							
		Per se performance			Heterosis over (%)				
		Female	Male	F_1	Mid parent	Better parent	Standard check		
							M 35-1	BJV-44	PKV Kranti
31	M 31-2A × IS 11619	55.20	40.23	60.83	27.49**	10.21**	42.02**	-25.57**	-24.96**
32	M 31-2A × IS 15945	55.20	49.44	41.26	-21.12**	-25.24**	-3.66	-49.51**	-49.10**
33	M 31-2A × IS 19450	55.20	44.33	57.73	16.01**	4.59	34.79**	-29.36**	-28.78**
34	M 31-2A × IS 19975	55.20	26.20	45.80	12.53**	-17.03**	6.93	-43.96**	-43.50**
35	M 31-2A × IS 20743	55.20	36.53	44.83	-2.25	-18.78**	4.67	-45.15**	-44.70**
36	M 31-2A × IS 20679	55.20	15.10	23.16	-34.09**	-58.03**	-45.91**	-71.66**	-71.42**
37	M 31-2A × IS 22720	55.20	41.53	26.80	-44.59**	-51.45**	-37.43**	-67.21**	-66.94**
38	M 31-2A × IS 23590	55.20	28.53	53.06	26.75**	-3.86	23.89**	-35.07**	-34.54**
39	M 31-2A × IS 23891	55.20	26.20	58.06	42.67**	5.19	35.56**	-28.96**	-28.37**
40	M 31-2A × IS 24462	55.20	45.50	35.20	-30.09**	-36.23**	-17.82**	-56.93**	-56.68**
41	M 31-2A × IS 25989	55.20	20.06	44.20	17.45**	-19.93**	3.19	-45.92**	-45.48**
42	M 31-2A × IS 26025	55.20	29.46	41.36	-2.28	-25.06**	-3.42	-49.39**	-48.97**
43	M 31-2A × IS 26617	55.20	24.76	40.83	2.13	-26.03**	-4.67	-50.04**	-49.63**
44	M 31-2A × IS 27887	55.20	35.83	29.40	-35.41**	-46.74**	-31.36**	-64.03**	-63.73**
45	M 31-2A × IS 28313	55.20	36.86	39.86	-13.40**	-27.78**	-6.93	-51.22**	-50.82**
46	M 31-2A × IS 29269	55.20	30.20	44.66	4.61	-19.08**	4.28	-45.35**	-44.90**
47	M 31-2A × IS 29654	55.20	36.90	28.03	-39.12**	-49.21**	-34.55**	-65.70*	-65.42**
48	M 31-2A × IS 30451	55.20	25.76	51.23	26.55**	-7.19*	19.61**	-37.32**	-36.80**
49	M 31-2A × IS 31651	55.20	29.30	52.23	23.63**	-5.37	21.95**	-36.09**	-35.57**
50	M 31-2A × IS 32439	55.20	46.20	65.28	28.79**	18.27**	52.41**	-20.13**	-19.47**
	Check (M 35-1)	42.83			-				
	Check (BJV-44)	81.73			-				
	Check (PKV Kranti)	81.06			-				
S.Em ±					1.646	1.900			
C.D.@ 1%					4.324	4.993			
C.D. @ 5%					3.266	3.771			

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

Table 6: Average heterosis and range of heterosis with number of heterotic crosses of parents and F_{1s} in desirable directions in respect of quantitative traits in *rabi* sorghum

Sl. No.	Characters	Average heterosis (%)	Range of heterosis (%)over				No. of crosses with significant heterosis in desired direction over			
			Better parent	Standard check			Better parent	Standard check		
				M35-1	BJV 44	PKV Kranti		M 35-1	BJV 44	PKV Kranti
1	Days to 50% flowering	-2.87	-30.65 to -0.81	-25.86 to 6.03	-25.51 to 6.49	-29.22 to1.23	47	34	34	43
2	Plant height (cm)	6.36	-10.05 to 34.31	-18.27 to 10.99	-20.34 to 8.18	-22.21 to 5.64	17	08	05	02
3	Number of leaves	2.21	-38.46 to 40.00	-33.33 to 16.67	-33.33 to 16.67	-38.46 to 7.69	05	03	03	00
4	Panicle length (cm)	1.88	-47.45 to 26.41	-21.56 to 82.16	-33.54 to 54.33	-36.64 to 47.15	01	32	23	14
5	Panicle width(cm)	-12.07	-41.61 to 6.33	-35.94 to 4.15	-53.20 to -23.91	-53.67 to -24.67	02	00	00	00
6	Primaries Panicle^{-1}	11.03	-39.87 to 19.62	-34.48 to 39.31	-48.65 to 9.19	-50.78 to 4.66	05	19	01	00
7	Panicle weight (g)	12.56	-51.52 to 51.95	-46.88 to 69.13	-72.21 to -11.50	-72.47 to -12.33	14	20	00	00
8	Grain yield per plant (g)	4.07	-58.03 to18.47	-52.61 to 52.41	-75.16 to -20.13	-74.96 to -19.47	02	13	00	00
9	100 seed weight (g)	40.61	-26.25 to 43.88	-23.38 to 83.12	-26.25 to 76.25	-30.59 to 65.88	14	21	19	09

Conclusion

The *per se* performance of parents in line × tester analysis specified that no single parental line exhibited superior performance for all the quantitative traits studied. However, among male parents (lines) *viz.,* IS 995 (Panicle weight and grain yield per plant), IS 30451 (plant height and number of leaves per plant) and IS 602 (panicle length and panicle width) were best performing parents (lines). The line IS 19975 was earliest to flowering as well as to attain physiological maturity

Among the 50 new hybrid, the *per se* performance of crosses *viz.*, M 31-2A × IS 32439 and M 31-2A × IS 23891 recorded maximum grain yield per plant and panicle weight. However, the cross M 31-2A × IS 4581 recorded maximum weight for 100 seeds. The crosses involving the line IS19975 *viz.*, 104A × IS 19975 and M 31-2A × IS 19975 were earlier to flowering. Similarly the crosses involving the line IS 602 *viz.*, 104A × IS 602 and M 31-2A × IS 602 recorded maximum panicle length.

The maximum average heterosis was recorded for 100 seed weight (40.61%) and panicle weight (12.56%) followed by primaries per panicle (11.03%). The average negative heterosis was recorded for number of seeds per panicle (-21.25%) and panicle width (-12.07) followed by days to 50 per cent flowering (-2.87). About 34 (days to 50 per cent flowering and physiological maturity), 2 (plant height), 14 (panicle length) and 9 (100 seed weight) hybrids were significant over all the three checks *viz.*, M 35-1, BJV 44 and PKV Kranti. The crosses *viz.*, M 31-2A × IS 32439 and M 31-2A × IS 19450 exhibited positive standard heterosis over check M 35-1 for grain yield per plant, number of seeds per panicle, panicle weight, number of primaries per panicle and 100 seed weight.

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