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# HETEROTIC PERFORMANCE OF CMS BASED EXPERIMENTAL HYBRIDS OVER THE ENVIRONMENTS FOR YIELD, ITS ATTRIBUTING TRAITS AND OIL CONTENT IN SAFFLOWER (*Carthamus tinctorius* L.)

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**ABSTRACT**

Thirty hybrids, their parents along with two checks *viz*., PKV Pink and AKS 207 were evaluated in RBD with three replications and three environments to estimate heterosis for seed yield, its contributing traits and oil content. Highest heterosis over the best check was noted for number of branches per plant in cross AKS CMS 2A x BHIMA and useful heterosis for seed yield per plant in AKS CMS 2A x BHIMA. Significant and positive heterosis observed for majority of yield attributing traits *viz*., primary branches, capitula per plant, and 100 seeds weight over best check and it was recorded by hybrids AKS CMS 2A x BHIMA, AKS CMS 2A x GMU 3876, AKS CMS 2A x BHIMA, respectively. Further, hybrid AKS CMS 2A x BHIMA was found better than both checks for earliness. Among the 30 crosses, AKS CMS 2A x GMU 3876, AKS 2A x GMU 3863 and AKS 2A x BHIMA found to be promising on the basis of mean performance and heterotic response. These promising hybrids may be used for commercial cultivation after thorough multi-location testing and may also be effectively used for isolating transgressive segregants (by crossing B line of concerned CMS with same male parent).

## INTRODUCTION

Safflower is an important and unique rabi oilseed crop owing to its drought tolerance, nutritional and pharmaceutical properties of seed oil and petals. Safflower seeds contain 27.5 per cent oil, 15 *per cent* protein, 41 *per cent* crude fibre and 2.3 *per cent* ash (Latha and Prakash 1984). Safflower oil, on an average contains 75 *per cent* linoleic acid, which plays an important role in reducing blood cholesterol level. It is mainly consumed as vegetable oil in India (Patil *et al*., 1999). Oil has good dying property; hence it is used also in manufacturing of paints and varnishes (Richharia, 1962). Area and production of safflower around the world is fluctuating since last two decades. Among 60 countries, India is producing half of world safflower. The average productivity is very low (465 kg/ha) as compared to world average productivity (905 kg/ha) and other major safflower growing countries. Hence, there is an urgent need to increase the productivity by breaking the present yield barriers, which can be achieved by developing and releasing hybrids (with high magnitude of heterosis) having high yield potential. Safflower is an often-cross pollinated crop and amount of cross pollination depends on genotype and insect activity (Knowels, 1969). Hence, exploitation of heterosis is quite possible if the suitable male sterile source is available. Dr. Panjabrao Deshmukh Krishi Vidyapeeth (Dr. P.D.K.V.), Akola has developed cytoplasmic male sterile lines *viz*., AKS CMS 2A and AKS CMS 3A (Deshmukh *et al*., 2014). Hence, exploitation of heterosis on commercial scale has become feasible and economical. The ease in hybrid seed production is of great importance to plant breeders for exploitation of heterosis by developing high yielding hybrids. The study on the magnitude of heterosis would help in identifying promising cross combinations for exploitation of heterosis and genetic improvement of important economic traits. It is necessary to have detailed information about the desirable parental combination in any breeding program which can reflect a high degree of heterotic response. Heterosis for seed yield and its attributed traits was reported in safflower by earlier workers (Fokmare 2001, Shivani *et al*., 2011, Jhajhariya *et al*., 2013 and Rathod *et al*., 2020a). Hence, the present study was conducted to identify superior hybrids (involving CMS lines) for commercial cultivation, which will exhibit high magnitude of heterosis for seed yield and its components traits.

## MATERIALS AND METHODS

The experimental material comprised of genetically diverse parents selected on the basis of their distinguishing characters *i.e.* 15 males *viz*., AKS-322, AKS-325, GMU 5728, GMU 7351, GMU 2757, GMU 3876, GMU 3863, GMU 2453, GMU 3773, GMU 3313, GMU 6877, GMU 6881, AKS 8R, AKS 10R and BHIMA and two CMS lines *viz*., AKS CMS 2A and AKS CMS 3A as females. The crosses were made in Line x Tester design (Kempthorne, 1957) and as per the method suggested by Li Dajue and Mundel (1996). The 30 resultant experimental hybrids were raised along with respective parents and two checks in a randomized complete block design (Panse and Sukhatme, 1965) with three replications over the three seasons [*rabi* 2017-2018 (E1), *rabi* 2018-2019 (E2) and late *rabi* 2018-19 (E3)]. This experiment was carried out at the experimental field of Oilseeds Research Unit, and Department of Agril. Botany, Dr. P.D.K.V., Akola. The experimental hybrids, parents and checks were sown in a single row of 3 meter length with inter and intra-row spacing of 30 cm and 10 cm, respectively. All the recommended agronomical package of practices and plant protection measures were followed timely to raise a good crop. The observations on various yield and yield attributing characters *viz*., plant height, number of primary branches per plant, number of capsules per plant, 100 seed weight and seed yield per plant were recorded on five randomly selected plants from each replication from each parent, hybrid and checks. However, the observations on the days to 50 % flowering, days to maturity and oil content were recorded on plot basis. The oil content (%) was determined by using Bench top pulse Nuclear Magnetic Resonance (NMR) Spectrometer (model MQC OXPORD). The data were subjected to analysis of variance for mean performance (Panse and Sukhatme, 1967) and heterosis over mid parent (MP), better parent (BP) and standard check (SC) as per the standard procedure given by Hays *et al*. (1955) and Turner (1953). The mean performance and magnitude of heterosis over mid and better parent and standard check was estimated by taking the average of three different environments to increase the precision. This gives the idea about stable performance of experimental material during different environments.

## RESULTS AND DISCUSSION

The mean performance and magnitude of heterosis over mid and better parent and standard check was estimated by taking the average of three different environments to increase the precision. This gives the idea about stable performance of experimental material during different environments. In the present study, all the treatments and 30 experimental hybrids were found significant in all three environments for all the characters (Table 1). However, the parents differed significantly among themselves in all three environments for all the characters studied except for days to 50% flowering in E2 and plant height E3 (Table 2). It indicated the substantial genetic variability present in the experimental material. The results from pooled analysis of variance (over the three environments) revealed significant differences among the parents and their hybrids for different traits suggesting the presence of considerable genetic variation in respect of various traits studied.

The testers *viz*., AKS CMS 2B and AKS CMS 3B were at par for all traits including seed yield per plant and oil content. None of the lines showed significantly better performance for two important traits *viz*., seed yield per plant and oil content as compared to both the checks. However, nine lines were significantly superior for 100 seed weight as compared to checks. Line GMU 3876 was the best line which performed significantly better for days to maturity, number of branches per plant, number of capitula per plant and 100 seed weight. Among the lines, BHIMA and GMU 6876 were early maturing, while GMU 7351 was found significantly superior for number of branches per plant. Line GMU 2757 had the largest seed size (6.25g per 100 seeds) as compared to checks, other lines and testers (Table 3). Absence of significant variation for economically two important traits like seed yield per plant and oil content among the lines, testers and check showed the importance of exploitation of heterosis to break the plateau for these traits.

Among the crosses, AKS CMS 2A x GMU 3876 exhibited highly significant and highest mean performance for seed yield per plant. Further, it was also found to be superior for number of capitula per plant and oil content as compared to other crosses. The early maturing cross, AKS CMS 2A x BHIMA was found to be superior for number of branches per plant, days to 50% flowering, days to maturity and 100 seed weight and seed yield per plant. The cross AKS CMS 3A x GMU 7351 was found to be superior for plant height at harvest over all the checks. The superior performance of crosses for these traits were also reported in earlier study (Shivani *et al.,* 2011). Above mentioned superior parents and crosses were found to be promising and have good genetic potential to be utilized in further breeding programme.

**Table 1. Analysis of variance for experimental design for various characters in safflower over three environment**

| S.N. | Sources of Variations | df | Mean Sum square | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Days 50% flowering | | | Days to maturity | | | Plant height at harvest | | | Number of branches per plant | | |
| | | | E1 | E2 | E3 | E1 | E2 | E3 | E1 | E2 | E3 | E1 | E2 | E3 |
| 1 | Replicates | 2 | 17.1 | 1.86 | 12.86 | 14.5 | 10.49 | 9.88 | 0.39 | 0.47 | 29.85 | 0.29 | 4.95 | 0.16 |
| 2 | Treatments | 46 | 32.98** | 31.01** | 35.39** | 76.37** | 50.27** | 4.06** | 27.21** | 36.37** | 48.34** | 12.54** | 7.86** | 7.89** |
| 3 | Parents | 16 | 26.032* | 25.17 | 42.40** | 72.70** | 53.47** | 3.57** | 18.23* | 32.89** | 17.4 | 6.87** | 6.87** | 9.14** |
| 4 | Parents vs Crosses | 1 | 88.467* | 24.06 | 10.91 | 140.21** | 47.11 | 60.79** | 77.88** | 117.72** | 497.93** | 57.86** | 23.5 | 17.88* |
| 5 | Crosses | 29 | 34.89** | 34.47** | 32.37** | 76.19** | 48.61** | 31.42** | 30.40** | 35.49** | 49.91** | 14.09** | 7.880** | 6.86** |
| 6 | Error | 92 | 14.27 | 14.65 | 72.9 | 17.4 | 13.53 | 7.5 | 8.29 | 8.311 | 3.69 | 2.82 | 1.93 | 2.92 |

| S.N. | Sources of variations | df | Mean Sum square | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Number of capitula | | | 100 Seed weight | | | Seed yield per plant | | | Oil content | | |
| | | | E1 | E2 | E3 | E1 | E2 | E3 | E1 | E2 | E3 | E1 | E2 | E3 |
| 1 | Replicates | 2 | 48.51** | 6.67 | 4.22 | 0.19 | 0.88* | 0.32 | 60.81** | 32.82** | 43.19** | 1.37 | 0.038 | 0.72 |
| 2 | Treatments | 46 | 50.42** | 41.95** | 30.45** | 1.11** | 1.43** | 0.92** | 30.28** | 39.6** | 25.27** | 8.49** | 7.92** | 6.82** |
| 3 | Parents | 16 | 77.39** | 38.96** | 28.02** | 1.19** | 2.025** | 1.064** | 30.97** | 36.91** | 32.18** | 7.56** | 6.66** | 6.20** |
| 4 | Parents vs Crosses | 1 | 188.09** | 132.85** | 75.49** | 1.64* | 1.39* | 1.815 | 61.1** | 18.38** | 2.50** | 52.49** | 17.48** | 2.2 |
| 5 | Crosses | 29 | 30.80** | 40.45** | 30.23** | 1.046** | 1.11** | 0.87** | 28.85** | 41.82** | 22.51** | 7.15** | 8.28** | 7.34** |
| 6 | Error | 92 | 5.46 | 4.038 | 2.22 | 0.32 | 0.25 | 0.33 | 1.31 | 0.5 | 0.0009 | 2.64 | 1.95 | 1.93 |

*,** Significant at 5 and 1 per cent level of significance, respectively;E1, E2 and E3 = Three seasons (rabi 2017-2018, rabi 2018-2019 and late rabi 2018-19, respectively)

**Table 2: Pooled analysis of variance for experimental design for various characters in safflower**

| Sr. No. | Sources of variation | d.f. | Mean Sum of Square<br>Days to 50% flow ering | Days to maturity | Plant height at harvest | Number of branches per plant | Number of capitula | 100 seed weight | Seed yield per plant | Oil content |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Environments | 2 | 17.074 | 99.2 ** | 22.18 | 7.74 | 41.60** | 0.172 | 25.99** | 4.89 |
| 2 | Treatments | 46 | 78.041** | 115.097 ** | 93.94** | 21.092** | 97.15** | 2.43** | 63.74 ** | 19.02** |
| 3 | Parents | 16 | 76.04** | 104.30 ** | 49.048** | 16.127** | 96.58** | 3.00** | 78.27** | 15.98** |
| 4 | Parent vs Crosses | 1 | 103.41** | 234.13** | 587.58** | 22.543** | 383.74** | 2.58** | 62.43** | 61.37** |
| 5 | Crosses | 29 | 78.26** | 116.94 ** | 101.69** | 23.781** | 87.58** | 2.12** | 55.77** | 19.23** |
| 6 | Environment x Treatments | 92 | 10.67 | 21.01 ** | 8.99 | 3.602* | 12.83** | 0.52** | 15.71** | 2.11 |
| 7 | Environment x Parents | 32 | 8.78 | 24.35 ** | 9.74 | 3.376 | 23.90** | 0.64** | 10.90** | 2.22 |
| 8 | Environment x Parents vs Crosses | 2 | 10.01 | 6.99 | 52.87** | 38.342** | 6.35 0.27 | 9.76** | 10.37** | |
| 9 | Environment x Crosses | 58 | 11.73 | 19.645 * | 7.063 | 2.528 | 6.96** | 0.45* | 18.57** | 1.766 |
| 10 | Error | 276 | 14.18 | 12.751 | 10.096 | 2.559 | 3.91 | 0.3 | 0.6 | 2.179 |

*,** Significant at 5 and 1 per cent level of significance, respectively.

**Table 3: Mean performance of parents and hybrids over the three environments for different traits in safflower**

| Sr. No. | Genotype | Days to 50% flowering | Days to maturity | Plant height at harvest (cm) | Number of branc hes per plant | Number of capitula per plant | 100 seed weight (g) | Seed yield per plant (g) | Oil content (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | AKS CMS 2A x GMU 7351 | 79.83 | 137.83 | 81.83 | 10.35 | 33.73** | 5.6 | 24.11* | 29.68 |
| 2 | AKS CMS 2A x GMU 3863 | 80.75 | 133.00* | 80.54 | 13.45* | 33.83** | 5.54 | 26.57* | 29.91 |
| 3 | AKS CMS 2A x GMU 5728 | 80.93 | 141.99 | 81.17 | 10.82 | 26.27 | 5.22 | 23.03 | 28.83 |
| 4 | AKS CMS 2A x GMU 2757 | 82.52 | 132.91* | 83.74* | 9.26 | 29.1 | 4.9 | 21.8 | 24.42 |
| 5 | AKS CMS 2A x GMU 3876 | 76.78 | 138.5 | 78.76 | 13.73* | 36.77** | 5.83 | 27.17* | 30.9 |
| 6 | AKS CMS 2A x GMU 3313 | 81.33 | 137.56 | 81.83 | 11.03 | 28.37 | 5.32 | 23.93* | 28.39 |
| 7 | AKS CMS 2A x GMU 2453 | 75.59 | 132.20* | 84.08* | 12.4 | 30.77 | 6.11 | 21.7 | 26.87 |
| 8 | AKS CMS 2A x GMU3773 | 80.34 | 137.1 | 76.09 | 10.07 | 28.34 | 4.88 | 19.94 | 28.89 |
| 9 | AKS CMS 2A x GMU 6881 | 75.02* | 136.79 | 81.31 | 12.32 | 27.83 | 5.19 | 24* | 29.38 |
| 10 | AKS CMS 2A x GMU 6877 | 82.4 | 141.85 | 81.01 | 13.24 | 31.29 | 5.61 | 24.7* | 26.57 |
| 11 | AKS CMS 2A x BHIMA | 71.12** | 129.69* | 81.07 | 15.35** | 35.73** | 6.3 | 26.46* | 30.58 |
| 12 | AKS CMS 2A x AKS10R | 80.07 | 138.57 | 84.35* | 10.8 | 26.93 | 4.72 | 22.76 | 29.15 |
| 13 | AKS CMS 2A x AKS 8R | 78.65 | 134.10* | 80.83 | 13.43 | 32.44 | 5.68 | 25.31* | 26.94 |
| 14 | AKS CMS 2A x AKS 322 | 79.31 | 139.82 | 79.26 | 12.97 | 27.37 | 5.47 | 24.07* | 27.92 |
| 15 | AKS CMS 2A x AKS 325 | 82.05 | 137.55 | 85.19** | 11.13 | 26.7 | 5.14 | 21.3 | 27.22 |
| 16 | AKS CMS 3A x GMU 7351 | 76.6 | 132.35* | 85.92** | 11.5 | 26.57 | 4.48 | 23.89 | 27.25 |
| 17 | AKS CMS 3A x GMU 3863 | 83.11 | 144.11 | 78.02 | 12.73 | 29.5 | 4.81 | 23.16 | 29.51 |
| 18 | AKS CMS 3A x GMU 5728 | 76.82 | 140.76 | 75.47 | 10.62 | 25.86 | 5.77 | 20.9 | 28.9 |
| 19 | AKS CMS 3A x GMU 2757 | 82.02 | 135.87* | 79.33 | 11.61 | 25.14 | 5.62 | 23.67 | 28.98 |
| 20 | AKS CMS 3A x GMU 3876 | 76.66 | 141.92 | 74.28 | 12.55 | 29.79 | 5.75 | 24.47* | 30.2 |
| 21 | AKS CMS 3A x GMU 3313 | 77.69 | 139.01 | 85.71** | 8.56 | 26.98 | 6.08 | 19.38 | 29.06 |
| 22 | AKS CMS 3A x GMU 2453 | 78.26 | 135.99 | 75.81 | 10.94 | 26.11 | 5.5 | 22.1 | 26.96 |
| 23 | AKS CMS 3A x GMU3773 | 75.41* | 144.18 | 83.69* | 12.07 | 29.6 | 5.99 | 23.45 | 27.09 |
| 24 | AKS CMS 3A x GMU 6881 | 78.51 | 141.24 | 81.63 | 9.09 | 26.36 | 5.26 | 23.71 | 30.52 |
| 25 | AKS CMS 3A x GMU 6877 | 75.27* | 137 | 79.8 | 10.35 | 25.88 | 4.74 | 19.99 | 28.8 |
| 26 | AKS CMS 3A x BHIMA | 74.25* | 141.36 | 78.17 | 9.76 | 27.49 | 4.74 | 19.48 | 28.61 |

Considerable heterotic effects were noticed in the crosses derived from genetically diverse parent. Conventionally, parents with higher mean value considered better parent for yield and its attributes, while parents with low mean value considered better parent for earliness. Thus, expected heterosis will be $F_1 > P_1$ for yield and attributes. Early flowering is highly desirable trait for a crop like safflower to fit in various cropping sequences. Hence, for days to flower initiation, negative values are desired. The heterotic effects for this trait ranged from -6.14 to 8.91 *per cent* for relative heterosis, and from -7.77 to 7.03 *per cent* for heterobeltiosis (Table 4). The highest, significant and negative useful heterosis observed in cross AKS CMS 2A x BHIMA (-10.45 %) over best check (AKS 207) (Table 5). In case of days to maturity, the highest significant and negative heterosis over mid parent, better parent and best check (AKS 207) was observed in cross AKS CMS 2A x BHIMA (-5.79%, -7.16 %, -7.85 % ), respectively. Similar results were observed by Deshmukh (1984) for days to 50 % flowering and days to maturity. Dwarf plants are considered as lodging resistant; therefore, negative heterosis in plant height is important. The highest magnitude of heterosis over mid parent for plant height at harvest was observed in cross AKS CMS 3A x AKS 8R (-6.56 %), whereas, cross AKS CMS 3A x GMU 7351 exhibited highest positive and significant useful heterosis (11.01%) over the best check *i.e.* PKV PINK. This is in confirmation with the results observed by Fokmare (2001).

| Sr. No. | Genotype | Days to 50% flow ering | Days to maturity | Plant height at harvest (Cm) | Number of branc hes per plant | Number of capitula per plant | 100 seed weight (g) | Seed yield per plant (g) | Oil content (%) |
|---|---|---|---|---|---|---|---|---|---|
| 26 | AKS CMS 3A x BHIMA | 74.25* | 141.36 | 78.17 | 9.76 | 27.49 | 4.74 | 19.48 | 28.61 |
| 27 | AKS CMS 3A x AKS10R | 80.91 | 139.51 | 81.24 | 10.11 | 25.77 | 6.23** | 22.4 | 26.4 |
| 28 | AKS CMS 3A x AKS 8R | 81.25 | 138.06 | 72.32 | 13.54* | 28.64 | 5.08 | 24.10* | 28.4 |
| 29 | AKS CMS 3A x AKS 322 | 75.75 | 137.5 | 78.92 | 13.67* | 32.86* | 5.50** | 21.1 | 28.13 |
| 30 | AKS CMS 3A x AKS 325 | 78.6 | 140.3 | 79.37 | 12.3 | 29.18 | 5.38* | 20.7 | 29.94 |
| | Female | | | | | | | | |
| 1 | AKS CMS- 2B | 77.102 | 136.62 | 74.67 | 11.24 | 25.533 | 4.75 | 17.12 | 28.79 |
| 2 | AKS CMS - 3B | 80.503 | 139.95 | 78.57 | 10.86 | 25.967 | 4.58 | 18.04 | 29.24 |
| | Male | | | | | | | | |
| 1 | GMU 7351 | 79.82 | 135.9 | 78.75 | 13.83** | 26.29 | 4.96 | 20.54 | 26.8 |
| 2 | GMU 3863 | 72.11** | 136 | 75.65 | 10.04 | 26.88 | 4.55 | 18.79 | 26.58 |
| 3 | GMU 5728 | 80.93 | 136.07 | 78.59 | 11.71 | 29.82 | 5.84** | 16.9 | 26.32 |
| 4 | GMU 2757 | 76.51 | 136.93 | 79.72 | 10.81 | 27.79 | 6.25** | 19.32 | 27.65 |
| 5 | GMU 3876 | 75.64 | 135.62* | 76.48 | 13.56** | 33.37* | 6.07** | 21.1 | 25.16 |
| 6 | GMU 3313 | 83.25 | 139.51 | 75.45 | 11.32 | 26.76 | 5.75** | 18.5 | 29.84 |
| 7 | GMU 2453 | 74.61* | 137.39 | 75.77 | 10.64 | 25.74 | 5.53** | 19.6 | 28.94 |
| 8 | GMU 3773 | 77.45 | 134.17* | 74.49 | 12.8 | 30.11 | 5.16* | 20.17 | 27.89 |
| 9 | GMU 6881 | 77.87 | 130.81* | 78.53 | 12.02 | 31.03 | 4.69 | 19.48 | 25.41 |
| 10 | GMU6877 | 79.89 | 139.48 | 80.31 | 10.25 | 24.66 | 5.34* | 21.02 | 27.36 |
| 11 | BHIMA | 73.37* | 127.41** | 79.64 | 10.26 | 31.89 | 4.9 | 21.3 | 28.65 |
| 12 | AKS 10R | 76.03 | 137.59 | 78.18 | 11.42 | 25.43 | 4.73 | 19.72 | 27.99 |
| 13 | AKS 08R | 75.47 | 134.16* | 76.2 | 9.64 | 20.8 | 4.6 | 19.92 | 27.66 |
| 14 | AKS 322 | 79.33 | 140.19 | 82.59 | 9.48 | 22.84 | 5.90** | 19.6 | 28.91 |
| 15 | AKS 325 | 78.71 | 138 | 80.8 | 9.31 | 25.07 | 5.65** | 16.99 | 27.02 |
| | Check | | | | | | | | |
| 1 | PKV PINK | 81.5 | 141.3 | 77.3 | 12.1 | 27.4 | 4.23 | 19.88 | 30.63 |
| 2 | AKS 207 | 79.78 | 139.6 | 80.34 | 10.08 | 28.2 | 4.3 | 20.25 | 29.18 |
| | Mean | 77.86 | 137.37 | 78.21 | 11.47 | 27.38 | 5.18 | 19.99 | 28.11 |
| | SE | 1.58 | 1.72 | 2.12 | 1.24 | 2.23 | 0.3 | 1.41 | 0.92 |
| | CD(0.05) | 4.42 | 3.84 | 5.95 | 3.36 | 6.28 | 0.86 | 3.97 | 2.59 |
| | CD(0.1) | 6.03 | 5.42 | 7.88 | 4.48 | 8.31 | 1.14 | 5.25 | 3.43 |

*,** significant at 5 and 1 per cent level of significance.

**Table 4: Range of heterosis (%) for various traits in safflower**

| Sr. No. | Traits | Range of heterosis (%) over Mid parent | Batter parent | Standard check* |
|---|---|---|---|---|
| 1 | Days to 50 % flowering | -6.14 to 8.91 | -7.70 to 7.03 | -10.45 to 3.91 |
| 2 | Days to maturity | -5.79 to 5.74 | -7.16 to 3.02 | -7.10 to 3.28 |
| 3 | Plant height at harvest | -6.56 to 11.77 | -25.14 to 36.47 | -6.57 to 11.01 |
| 4 | Number of primary branches /plant | -22.65 to 42.76 | -7.97 to 10.97 | -15.1 to 52.26 |
| 5 | Number of capsules / plant | -7.52 to 40.2 | -15.07 to 28.32 | -8.54 to 33.97 |
| 6 | 100 seed weight | -11.04 to 33.87 | -21.69 to 31.81 | 6.56 to 50.11 |
| 7 | Seed yield / plant | -0.66 to 48.02 | -8.54 to 41.40 | -0.85 to 38.29 |
| 8 | Oil content | -13.47 to 14.55 | -15.19 to 7.30 | -16.32 to 5.87 |

*best check among two i.e PKV PINK and AKS 207 for concerned trait

**Table 5: Crosses with maximum heterosis in desirable direction for seed yield and its components in safflower**

| Sr. No. | Traits | Maximum beneficial heterosis (%) over mid parent Crosses | H1 | Maximum beneficial heterosis (%) over batter parent Crosses | H2 | Maximum beneficial heterosis (%) over standard check* Crosses | H3 |
|---|---|---|---|---|---|---|---|
| 1 | Days to 50 % flowering | AKS CMS 3A X GMU 6877 | -6.14** | AKS CMS 2A X BHIMA | -7.70** | AKS CMS 2A X BHIMA | -10..45** |
| 2 | Days to maturity | AKS CMS 2A X BHIMA | -5.79** | AKS CMS 2A X BHIMA | -7.16** | AKS CMS 2A X BHIMA | -7.10** |
| 3 | Plant height at harvest | AKS CMS 3A X 2453 | 11.77** | AKS CMS 2A X GMU2453 | 10.97** | AKS CMS 3A X GMU 7351 | 11.01** |
| 4 | Number of primary branches / plant | AKS CMS 2A X BHIMA | 42.76** | AKS CMS 2A X BHIMA | 36.47** | AKS CMS 2A X BHIMA | 52.26** |
| 5 | Number of capsules per plant | AKS CMS 2A X GMU 3313 | 40.02** | AKS CMS 2A X GMU 7351 | 28.32** | AKS CMS 2A X GMU 3876 | 33.97** |
| 6 | 100 seed weight | AKS CMS 3A X AKS 10R | 33.87** | AKS CMS 3A X AKS 10R | 31.81 | AKS CMS 2A X BHIMA | 50.11** |
| 7 | Seed yield / plant | AKS CMS 2A X GMU 3863 | 48.02** | AKS CMS 2A X GMU 3863 | 41.4 | AKS CMS 2A X GMU 3876 | 38.29** |
| 8 | Oil content | AKS CMS 2A X GMU 3876 | 14.55** | AKS CMS 2A X GMU 3876 | 7.30** | AKS CMS 2A X GMU 3876 | 5.87** |

*,** Significant at 5 and 1 per cent level of significance, respectively;H1, H2 and H3 = heterosis, heterobeltiosis and standard heterosis

In case of number of primary branches per plant, the cross AKS CMS 2A x BHIMA showed highest and significant positive heterosis over mid parent (42.76 %), better parent (36.47 %) and best check i.e., AKS 207 (52.26 %), respectively. The cross AKS CMS 2A x AKS 8R showed highest positive average heterosis (40.02 %) while the cross AKS CMS 2A x GMU 2757 exhibited highest standard heterosis (33.97 %) for number of capitula per plant. Similar results were also reported by Deshmukh (1991) and Kulkarni *et al*. (1992) for both the traits in safflower. These cross combinations can be used in further breeding programme to enhance yield potential through plant height, number of primary branches and number of capsules per plant.

The highest heterosis (33.87 %) and heterobeltiosis (31.81 %) in desirable direction were recorded for 100 seed weight in hybrid AKS CMS 3A x AKS 10R. Among all the crosses, AKS CMS 2A x BHIMA (50.11 %) exhibited highly significant and positive useful heterosis over the best check (PKV PINK) for 100 seed weight. These results are in agreement with Deshmukh (1991) in safflower. Among all hybrids, AKS CMS 2A x GMU 3876 showed highest average heterosis (14.55%), heterobeltiosis (7.30 %) and useful heterosis (5.87 %) for oil content over the check AKS 207. The highest heterosis (48.02 %) and heterobeltiosis (38.29 %) in desirable direction were recorded for seed yield per plant in AKS CMS 2A x GMU 3863 and the cross AKS CMS 2A x GMU 3876 showed highest and significant positive standard heterosis over both the checks *i.e.,* PKV PINK (38.29 %) and AKS 207(33.24 %). These results are in conformity of the results obtained by Rathod *et al*. (2020[a] and 2020[b]) in protected condition of aphid attack and also in unprotected condition in safflower and Ramesh *et al*. (2013) in castor.

For enhancement of seed yield and its attributing traits, best heterotic experimental hybrids performing well over the different environments were selected on the basis of present study are presented in Table 5. The best hybrids *viz*., AKS CMS 2A x BHIMA and AKS CMS 2A x GMU 3876 showed superiority for multiple traits like days to 50 % flowering, plant height, number of primary branches per plant and number of capsules per plant. Among all the traits, the highest range and magnitude of heterosis over mid parent and better parent was recorded for seed yield per plant. Whereas, over the standard check, it was recorded for primary branches per plant. Hence, the above hybrids having high heterosis can be effectively used for isolating transgressive segregants, which will increase the frequency of desirable genes for yield component traits along with economic traits in safflower. Heterosis for seed yield per plant and its associated traits has been reported in similar studies in safflower by Fokmare (2001), Shivani *et al*. (2011) Jhajharia *et al*. (2013) and in sunflower by Yamgar *et al*. (2015). Spoorthi and Nadaf (2016) and Chandra *et al*. (2014) also studied heterosis over the different locations and reported significant standard heterosis for yield and oil content and recommended best identified hybrids for heterosis breeding after screening yield stability in sunflower.

Considerable heterobeltiosis and standard heterosis was observed for seed yield and other associated traits suggested the presence of genetic variation and the uni-directional distribution of allelic constitution in male and female parents which contributing towards desirable heterosis. Low and non-significant magnitude of heterosis and heterobeltiosis observed for oil content indicated the narrow genetic base along with the ambi-directional distribution of allelic constitution among male and female parents contributing towards undesirable heterosis.

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