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Combining ability and heterosis study for yield and its component traits in safflower (*Carthamus tinctorius* L.)

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Abstract
Twelve crosses derived in line (4) × tester (3) mating design F_1s along with their parents were evaluated to study the combing ability and heterosis for fourteen yield and yield contributing traits in safflower. Analysis of genetic component of variance and variance due to specific combining ability (σ^2 *sca*) revealed preponderance of dominant variance and non-additive gene action for all of the traits. In hybrids, contribution of lines was higher over the testers for all the traits. Among the lines MSV-10-5-1 was the best combiner for number of branches per plant, number of capitulum per plant, number of seeds per capitulum, seed yield per plant. Line MMS-white was good combiner for oil content. Among the testers, GMU 1769 was found best combiner for number of seeds per capitulum and seed yield per plant were identified as promising general combiner. However, hybrid MSV-10-5-1 x GMU 1769 was found superior for number of branches per plant, number of capitulum per plant and seed yield per plant. Among the hybrids, identified superior crosses with significantly highest level of heterosis over standard check were GMU 224 x GMU 1303, GMU 224 x RVS-2012-13, GMU 224 x GMU 1769, TMS-3-6-7-9 x GMU 1303 and MSV-10-5-1 x GMU 1769 for seed yield per plant.

Keywords: Safflower, Combining ability, GCA, SCA and Heterosis

Introduction

Safflower, (*Carthamus tinctorius* L.) is an important *Rabi* oilseed crop of India. The common practice of safflower growing by the farmer's in India is as an inter crop under rainfed and as sole crop under irrigated conditions. In India for enhancing the safflower yield, the research efforts mostly being concentrated towards selection of parents followed by hybridization of parents having higher *per se* performance. Yield potential of safflower can be considerably increased through exploitation of hybrid vigour on commercial scale and systematic varietal improvement program. Development of new hybrids and testing magnitude of heterosis is a continuous process of breeding program. In order to assess the extent of heterosis in F_1 hybrids and to know the possibility of exploiting heterosis at commercial scale, it is essential to evaluate newly developed crosses as well as parents in cross combinations for seed yield and its components (Shivani *et al.,* 2011) [8]. Therefore, present investigation was undertaken to study the combining ability for identification of good combiners and promising crosses for future better accomplishment in safflower.

Materials and methods

The crosses were developed in seven parents *viz*., GMU 224, MMS-white (GMS line), MSV-10-5-1 (GMS line), TMS-3-6-7-9 (TGMS line), GMU 1303, GMU 1769 and RVS-2012-13 by adopting the mating system of line x tester in *Rabi,* 2012-13. F_1 and F_2 generations were raised during *Rabi* 2013-14 and *Rabi* 2014-15 respectively in randomized complete block design with three replications at Research cum Instructional Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur. The parents and F_1's were grown in single rows; the row length was 4m. The row to row distance 45 cm and plant to plant distance 20 cm were maintained. F_2's were grown in bulk in 3 replications.

Observations were recorded for 14 traits, viz., rosette period, days to 50% flowering, days to maturity, plant height, number of branches per plant, number of capitulum per plant, number of seeds per capitulum, final plant stand, biological yield per plant, seed yield per plant (g), harvest index, 100 seed weight, hull content and oil content. The observations were recorded on five random competitive plants. Combining ability analysis is employed to identify the desirable parents for inclusion in hybridization program. The statistical analysis for general combining ability (GCA) of the parents and specific combining ability (SCA) of the hybrids was done as per the method suggested by Kempthorne (1957) [2]. Heterosis were calculated over the standard parent-Manjeera, whereas, inbreeding depression (ID) in F_2 generation were estimated over F_1's by using the formulae proposed by Kempthorne (1957) [2].

$$H = \frac{\overline{F_1}-\overline{CV}}{\overline{CV}} \times 100$$

$$ID = \frac{\overline{F_1}-\overline{F_2}}{\overline{F_2}} \times 100$$

Where, CV= Check variety)

Results and Discussion

Analysis of variance revealed that the variance due to lines were significant for all the characters except final plant stand. The variance due to testers were found significant for all the characters except rosette period. Whereas, the variance due to lines x testers were significant for all the characters except 100 seed weight (Table 1). The variance due to sca was greater than the variance due to gca, which indicated the predominant role of non additive gene action in the expressions of all traits (Table 2). Preponderance of non-additive gene action for majority of traits, are in agreement with the findings of Ghorpade and Wandhare (2001) [1].

Line GMU 224 was found good general combiner for traits rosette period, days to 50% flowering, days to maturity and final plant stand. Line MMS-white was good combiner for oil content whereas line MSV-10-5-1 was best combiner for traits number of branches per plant, number of capitulum per plant, number of seeds per capitulum, biological yield per plant, seed yield per plant, harvest index and hull content. Line TMS-3-6-7-9 found good combiner for traits plant height and 100 seed weight. Among the testers, GMU 1303 was found best general combiner for rosette period, days to 50% flowering, days to maturity, number of branches per plant, final plant stand, harvest index, hull content and oil content whereas tester GMU 1769 was for plant height, number of seeds per capitulum, biological yield per plant and seed yield per plant. Tester RVS-2012-13 was recorded good combiner for number of capitulum per plant and 100 seed weight.

On the basis of specific combining ability following hybrids have been found superior for different characters. Hybrid, GMU 224 x GMU 1303 were found superior for days to 50% flowering and days to maturity; GMU 224 x GMU 1769 for plant height; GMU 224 x RVS-2012-13 for rosette period; MMS-white x GMU 1303 for harvest index; MSV-10-5-1 x GMU 1303 for oil content; MSV-10-5-1 x GMU 1769 for number of branches per plant, number of capitulum per plant, biological yield per plant, seed yield per plant and hull content; TMS-3-6-7-9 x GMU 1769 for number of seeds per capitulum and TMS-3-6-7-9 x RVS-2012-13 for 100 seed weight.

Heterosis was estimated as per cent increase or decrease of F_1 values over standard variety, Manjeera. The nature and magnitude of heterosis (Table 3) revealed that among 12 hybrids, three exhibited negative heterosis for rosette period over check variety. Such hybrids can be used as early maturity hybrids, since rosette period is positively associated with maturity duration. Number of effective capitula per plant is generally associated with higher productivity. Among 12 hybrids, 11 hybrids showed positive heterosis for number of capitula per plant. This confirms the results of previous worker Patil and Narkhede (1996) [5]. The hybrids with high heterosis for number of capitula per plant are GMU 224 × GMU 1303, GMU 224 × RVS-2012-13, MMS-white × GMU 1769 and MSV-10-5-1 × RVS-2012-13.

Number of seeds per capitulum is one of the most important components for seed yield and will be helpful in breaking the yield ceiling. Thus, the hybrids with positive heterosis were desirable for this important trait. Heterosis for number of seeds per capitulum in general was relatively low but overall it was expressed in positive direction over standard variety. The hybrids exhibiting high heterosis for this trait are MMs-white × GMU 1303, TMS-3-6-7-9 × RVS-2012-13, GMU 224 × GMU 1303 and MSV-10-5-1 × GMU 1769. These results are in agreement with the findings of earlier workers Rao (1982) [7] and Manjare and Jambhale (1995) [4].

100 seed weight is also one of the most important components of yield which influences the yield conspicuously. Heterosis for test weight over standard variety varied from 2.68 per cent (MSV-10-5-1 × GMU 1303) to 80.3 per cent (TMS-3-6-7-9 × RVS-2012-13). Most of the hybrids showed positive heterosis for this trait. Heterosis for seed yield varied from 13.12 per cent (MMs white × GMU 1769) to 949.63 per cent (GMU 224 × GMU 1303). Only nine hybrids *viz*., GMU 224 × GMU 1303, GMU 224 × GMU 1769, GMU 224 × RVS-2012-13, TMS-3-6-7-9 × GMU 1303, MSV-10-5-1 × GMU 1769, TMS-3-6-7-9 × RVS-2012-13, MSV-10-5-1 × RVS-2012-13 and MMS-white × GMU 1303 exhibited significant positive heterosis for seed yield over standard variety Manjeera. In safflower high degree of heterosis for seed yield was also reported by Ramachandram and Goud (1982) [6] and Kulkarni *et al*. (1992) [3]. The standard heterosis estimates for oil content were in negative direction but significant in 2 hybrids studied.

The hybrid vigour expression occurring in F_1 will be less in F_2 due to segregation. As a result, there is generally a decline in seed yield and also expression of component traits. To assess the extent of decline in performance, the F_2 generation was raised and the extent of inbreeding depression was estimated for the various characters (Table 4 and 5). Inbreeding depression in F_2 for days to 50% flowering varied from -0.87 (TMS-3-6-7-9 × GMU 1303) to 1.70 (MSV-10-5-1 × GMU 1303). The value of inbreeding depression was varied from -9.60 (MSV-10-5-1 × GMU 1769) to 6.00 (MMS-white × RVS-2012-13) for plant height, for number of capitula per plant varied from - 36.76 (GMU 224 × GMU 1769) to 13.04 (MSV-10-5-1 × GMU 1303), for number of seeds per capitulum varied from -23.00 (TMS-3-6-7-9 × RVS-2012-13) to 100.00 (TMS-3-6-7-9 × GMU 1769), for 100 seed weight varied from -1.61 (MSV-10-5-1 × GMU 1769) to 0.17 (GMU 224 × GMU 1303) and for seed yield varied from -15.33 (MMS-white × GMU 1769) to 5.91 (MSV-10-5-1 × RVS-2012-13). Negative inbreeding depression for seed yield was also reported by Patil and Narkhede (1996) [5]. Present investigation indicated the importance of hybrids in safflower to break the platue of yield and oil. Although the less heterosis were recorded for yield and oil but chances to find out better combiner for improvement of such traits. Selection of genetically diverse parents may give better heterosis in safflower.

Table 1: Anova for combining ability for seed yield and its components in Safflower

Source	DF	Rosette period (days)	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches/ plant	Number of Capitulum/plant	Number of seeds per capitulum	Final plant stand	Biological yield /plant (g)	Seed yield per plant (g)	Harvest index (%)	100 seed weight (g)	Hull content (%)	Oil content (%)
Replications	2	2.17	0.43	1.10	12.19**	71.49**	12.00**	6.12*	11.59**	71.84**	0.06	1.14	0.04	0.49	0.64
Treatments	18	3.56**	97.19**	123.82**	125.39**	23.68**	879.75**	162.64**	5.73**	31549.16**	3137.06**	469.39**	6.52**	433.21**	57.02**
Parents	6	1.96	16.60**	25.65**	100.31**	16.85**	307.52**	130.49**	8.77**	16834.36**	481.09**	1132.45**	5.88**	414.32**	78.02**
P. vs. C.	1	1.58	91.80**	98.00**	30.76 *	8.27	378.94**	37.72*	16.37 *	1920.01**	999.17**	6.70	28.53*	849.20**	238.67**
Crosses	11	4.61**	141.64**	179.72**	147.67**	28.81**	1237.40**	191.54**	3.11**	42268.98**	4780.13**	149.79**	4.86**	405.69**	29.05**
Lines	3	8.02 **	104.99**	150.10**	364.35**	36.62**	2257.13 **	242.47 **	0.29	54753.86**	6576.63**	218.16**	11.06**	892.18**	9.35**
Testers	2	1.75	87.25**	179.69**	43.43**	5.44*	17.33**	374.11**	7.69*	4185.20**	951.56**	23.05**	5.30*	331.07**	24.25**
Line X Testers	6	3.86 **	178.10**	194.54**	74.08**	32.70**	1134.22 **	105.22**	2.99*	48721.14**	5158.08**	157.85**	1.62	187.32**	40.51**
Error	36	0.65	1.86	1.64	0.77	2.065*	4.42**	19.86**	5.20**	17.64**	0.63	0.35	0.08	0.13	0.10

Table 2: GCA effects of female and male parents for seed yield and its component in Safflower

	Rosette period (days)	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches/ plant	Number of Capitulum/ plant	Number of seeds per capitulum	Final plant stand	Biological yield/plant (g)	Seed yield/plant (g)	Harvest index (%)	100 seed weight (g)	Hull content (%)	Oil content (%)
Lines														
GMU 224	-0.63	-4.41**	-6.02**	-6.69**	-2.19**	-11.69**	-3.19	0.22	-72.86**	-17.78**	1.75**	-1.11**	7.31**	0.69**
MMS-white	1.36**	-0.97	1.08*	-3.26**	-1.19	-15.25**	-5.19**	-0.22	-57.47**	-21.69**	-5.46**	-0.79**	8.59**	0.93**
MSV-10-5-1	-0.08	2.80**	2.08**	2.10**	2.02**	16.63**	6.25**	0.00	89.08**	37.43**	5.91**	0.88**	-12.61**	-0.35
TMS-3-6-7-9	-0.63	2.58**	2.86**	7.84**	1.36**	10.30**	2.13	0.00	41.25**	2.03**	-2.19**	1.02**	-3.30**	-1.27**
Testers														
GMU 1303	-0.33	-3.08**	-4.13**	-1.40	0.61	-1.00	2.44	0.86	-7.27	-3.45**	0.88**	-0.16	-5.73**	1.63**
GMU 1769	-0.08	1.91**	0.61	2.16**	-0.72	-0.33	3.94**	-0.13	21.21**	10.11**	0.71**	-0.56	1.15**	-0.67
RVS-2012-13	0.41	1.16**	3.52**	-0.75	0.11	1.33*	-6.38**	-0.72	-13.94	-6.65**	-1.59**	0.73**	4.57**	-0.95**

Table 3: SCA effects of hybrids for different seed yield and its component in safflower

S. No.	Hybrids	Rosette period (days)	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches/ plant	Number of Capitulum/ Plant	Number of seeds per capitulum	Final plant stand	Biological yield per plant (g)	Seed yield /plant (g)	Harvest index (%)	100 seed weight (g)	Hull content (%)	Oil content (%)
1.	GMU 224 x GMU 1303	1.55**	-11.58**	-13.63**	-3.03	2.61**	8.11**	0.11	0.36	-3.94	-0.02	-1.58	0.65**	-7.47**	-3.95**
2.	GMU 224 x GMU 1769	-0.69	5.75**	8.61**	5.27**	-1.38	-1.88	-4.72	-0.30	-35.89**	-15.26**	-2.52	-0.16	11.98**	0.75**
3.	GMU 224 x RVS-2012-13	-0.86	5.83**	5.02**	-2.24	-1.22	-6.22**	4.61	-0.05	39.84**	15.29**	4.10**	-0.48**	-4.51**	3.19**
4.	MMS-white x GMU 1303	-0.44	3.30**	3.58**	4.75**	-0.05	3.00*	1.11	-0.86	32.17**	17.51**	7.29**	0.33**	-1.64	-0.51
5.	MMS-white x GMU 1769	0.30	-7.02**	-1.83	-8.04**	0.61	-0.33	-4.05	-0.52	-31.38	-17.38**	-5.30**	0.48**	-4.74**	1.50**
6.	MMS-white x RVS-2012-13	0.13	3.72**	-1.75	3.28**	-0.55	-2.66	2.94	1.38	-0.78	-0.12	-1.98	-0.81**	6.39**	-0.98**
7.	MSV-10-5-1 x GMU 1303	-0.66	4.19**	6.25**	-0.02	-4.94**	-30.22**	2.33	0.91	-173.94**	-59.65**	-9.15**	-0.45**	6.09**	5.21**
8.	MSV-10-5-1 x GMU 1769	1.08*	0.52	-4.50**	0.84	3.72**	20.77**	-0.50	-0.08	169.38**	54.66**	4.04**	0.02	-6.11**	-4.16**
9.	MSV-10-5-1 x RVS-2012-13	-0.41	-4.72**	-1.75	-0.81	1.22	9.44**	-1.83	-0.83	4.55	4.98**	5.10**	0.42**	0.02	-1.04**
10.	TMS-3-6-7-9 x GMU 1303	-0.44	4.08**	3.80**	-1.69	2.38**	19.11**	-3.55	-0.41	145.71**	42.16**	3.44**	-0.53**	3.03**	-0.74
11.	TMS-3-6-7-9 x GMU1769	-0.69	0.75	-2.27	1.91**	-2.94**	-18.55**	9.27**	0.91	-102.10**	-22.01**	3.78**	-0.33	-1.13	1.90**
12.	TMS-3-6-7-9 x RVS-2012-13	1.13*	-4.83**	-1.52	-0.22	0.55	-0.55	-5.72	-0.50	-43.60**	-20.15**	-7.22**	0.87**	-1.90	-1.16**

Table 4: Estimates of heterosis over standard checks for seed yield and its components in safflower hybrids

S. No.	Hybrids	Rosette period	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches per plant	Number of capitulum per plant	Number of seeds per capitulum	Final plant stand	Biological yield (g)	Seed yield per plant (g)	Harvest index (%)	100 seed weight (g)	Hull content (%)	Oil content (%)
1.	GMU 224 x GMU 1303	2.38	31.52**	19.53**	85.12**	88.88*	217.64**	8.57	-65**	440.8**	949.63**	95.7**	8.06	19.19	-22.53
2.	GMU 224 x GMU 1769	0	25**	23.43**	76.78**	66.66	152.94**	-22.85	-75**	200.44**	459.58**	87.35**	40.69	54.17**	-13.27
3.	GMU 224 x RVS-2012-13	-4.76	29.34**	22.65**	84.51**	77.77	194.11**	-14.28	-65**	320.62**	496.38**	42.54	7.48	61.8**	-6.81
4.	MMS-white x GMU 1303	-4.76	31.52**	21.87**	97.01**	0	70.58**	54.28**	-60**	50.22**	123.15**	45.61*	3.64	72.52**	-5.74
5.	MMS-white x GMU 1769	0	23.91**	24.21**	89.28**	55.55	188.23**	-45.71**	-70**	80.26**	13.12	-40.82	51.82	81.99**	-16.66
6.	MMS-white x RVS-2012-13	-4.76	29.34**	20.31**	75**	33.33	135.29**	-25.71*	-60**	200.44**	56.63*	-47.88*	12.28	67.6**	-2.51
7.	MSV-10-5-1 x GMU 1303	0	29.34**	21.09**	73.8**	0	52.94*	-31.42**	-70**	20.17**	18.65	-2.39	2.68	-0.95	-50.45**
8.	MSV-10-5-1 x GMU 1769	0	27.17**	21.87**	88.69**	66.66	111.76**	5.71	-45*	188.42**	190.48**	0.3	28.4	45.28**	-13.63
9.	MSV-10-5-1 x RVS-2012-13	0	29.34**	21.87**	94.05**	44.44	170.58**	-28.57**	-55**	157.42**	169.61**	6.75	50.28	117.13**	-18.55
10.	TMS-3-6-7-9 x GMU 1303	0	22.82**	26.56**	78.57**	33.33	105.88**	-48.57**	-60**	-9.86*	268.87**	308.1**	14.39	57.53**	-14.48
11.	TMS-3-6-7-9 x GMU1769	2.38	31.52**	24.21**	63.69**	-22.22	-11.76	-60**	-55**	60.23**	41.51	-13.75	19	-3.81	-4.95
12.	TMS-3-6-7-9 x RVS-2012-13	0	28.26**	23.43**	69.64**	55.55	76.47**	31.42**	-70**	200.44**	177.21**	-8.1	80.03	94.73**	-31.37*

Table 5: Estimates of Inbreeding depression for seed yield and its components in safflower hybrid

S. No.	Hybrid	Rosette period	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches per plant	Number of capitulum per plant	Number of seeds per capitulum	Final plant stand	Biological yield (g)	Seed yield per plant (g)	Harvest index (%)	100 seed weight (g)	Hull content (%)	Oil content (%)
1.	GMU 224 x GMU 1303	2.38	-0.81	0.65	-0.74	-5.55	-27.02**	-11.62	40	0.44	2.5	2.01	0.17	3.96	-2.34
2.	GMU 224 x GMU 1769	2.43	-0.86	0	-1	-11.76	-36.76**	3.84	0	0.8	1.76	0.92	0	-0.04	-0.41
3.	GMU 224 x RVS-2012-13	-2.43	-0.83	0.64	-0.64	-11.11	-24.24**	-11.76	-30	0.57	1.62	1.04	-0.7	-0.32	-1.03
4.	MMS-white x GMU 1303	-2.43	-0.81	0.64	-1.08	-25	-6.45	-25	-11.11	-10.71**	-5.81	5.46	-0.18	-1.35	-0.89
5.	MMS-white x GMU 1769	-4.54	-1.72	1.27	5.07	-6.66	2.08	46.15	20	-6.25*	-15.33	-9.73	-0.12	-0.56	0.03
6.	MMS-white x RVS-2012-13	0	0.84	-0.64	6	-25	-4.76	8.33	-20	0	-0.23	-0.11	0	-0.76	-2.35
7.	MSV-10-5-1 x GMU 1303	-2.32	1.7	-0.64	-2	-40	13.04	9.09	0	-9.09*	-3.51	6.14	-0.37	-0.42	-0.58
8.	MSV-10-5-1 x GMU 1769	-6.66	-0.84	0.64	-9.6	-11.76	-5.26	-17.77**	-26.66	-4*	-1.18	0.12	-1.61	-0.39	-0.67
9.	MSV-10-5-1 x RVS-2012-13	-2.32	0.84	-0.63	-0.11	-18.75	2.22	-3.84**	12.5	7.1**	5.91	-7.05	-0.76	-0.21	-0.02
10.	TMS-3-6-7-9 x GMU 1303	-2.32	-0.87	0.62	-3.4	-25	6.06	-18.18	-33.33	-62.5	-0.95	5.64	-0.16	-1.38	0.22
11.	TMS-3-6-7-9 x GMU1769	2.38	0.833	0	-3.96	-22.22	-16.66	100	0	-4.76	-6.67	-2.02	-0.16	-2.13	-0.1
12.	TMS-3-6-7-9 x RVS-2012-13	5	-0.84	2.59	0	-22.22	7.14	-23	0	-3.84*	-1.21	2.67	-0.1	-0.13	-1.08

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