Electronic Journal of Plant Breeding, 2(3): 377- 383 (Sep 2011)
ISSN 0975-928X

Research Article

Combining ability studies and heterosis for yield and its component traits in safflower [*Carthamus tinctorius* L.)]

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(Received:05 Feb 2011; Accepted:18 May 2011)

Abstract:
Evaluation of parents and F_1s derived from crossing four well adapted lines and six testers in a line x tester fashion revealed that variance due to *sca* had higher magnitude than *gca* variance for all the traits studied indicating that these traits are under the influence of non additive gene action. The line Sagarmuthyalu and tester ASD-07-09 revealed significant *gca* effects for seed yield per plant. The tester ASD-07-10 recorded significantly negative *gca* effect for days to 50% flowering. The cross Manjira x GMU 1946, Manjira x SSF 698 and Sagarmuthyalu x ASD-07-09 recorded significantly high *sca* for seed yield per plant. The cross combinations Manjira x GMU 1946, Sagarmuthyalu x ASD-07-09 and Manjira x SSF 698 exhibited significant and positive heterobeltiosis and standard heterosis for seed yield per plant. These crosses also had significant and positive heterosis for number of capitula per plant, number of seeds per capitulum and test weight and would be more desirable to exploit heterosis in safflower.

Key words: Safflower, heterosis, combining ability, gene action

Introduction:

Safflower (*Carthamus tinctorius* L.) is an important edible oilseed crop in India. The common practice of safflower growing is as an inter crop under rainfed and as sole crop under irrigated conditions. In India for enhancing the safflower yield, the research efforts made mostly being concentrated towards individual plant selection of land races and progeny selection followed by hybridization of parents having higher *per se* performance. Yield potential of safflower had considerably increased through exploitation of hybrid vigour on commercial scale and systematic varietal improvement programme. Development of new hybrids and testing their g magnitude of heterosis is a continuous process of breeding programme. In order to assess the extent of heterosis present 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. Therefore, present investigation was undertaken to study the combining ability for identification of good combiners and promising crosses for future better accomplishment in safflower.

Material and methods

The experimental material comprised 24 hybrids derived from crossing between four lines and six testers in line x tester fashion. The lines (Manjira, Sagarmuthyalu, TSF-1 and TSF-2) and testers (GMU 1946, ASD-07-09, ASD-07-10, SSF 658, SSF 698 and SFS 9920) were selected on the basis of desirable agronomic characters and seed yield. The resulting hybrids along with their parents and one standard check (Manjira) were sown in a randomized block design with three replications. The experiment was conducted during 2007-08 and 2008-09 at Agricultural Research Station, Tandur. Each genotype was sown in 2 rows of 4m length with a spacing of 45 x 20 cm between and within the row, respectively. All the recommended cultural practices were followed to raise a normal crop. Data were recorded on five randomly selected competitive plants from each cross/replication for days to 50% flowering, days to maturity, number of capitula per plant, number of seeds per capitulum, test weight (g) and seed yield (kg/ha). The data were subjected to statistical analysis according to L x T design. Mean squares due to line x tester, the latter in turn tested against mean squares due to error. The statistical analysis for combining ability was done as per the method suggested by Kempthorne (1957). The superiority of hybrids was estimated over mid parent as average heterosis, over better parent as heterobeltiosis and over standard check (Manjira) as standard heterosis according to the method of Fonseca and Patterson (1968).

Results and discussion

The analysis of variance showed significant differences among hybrids for all the traits studied, while parents exhibited significant mean squares for number of capitula per plant and number of seeds per capitulum (Table 1). The variance due to lines was significant for number of capitula per plant, while variance due to testers was significant for number of seeds per capitulum. The interaction effect (line x tester) was significant for all the characters studied. 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 except for number of capitula per plant (Table 2). Preponderance of non-additive gene action for majority of traits observed was found in agreement with the findings of Ghorpade and Wandhare (2001).

Perusal of the *per se* performance indicated that the parents Manjira and SSF 698 were high yielder among all the parents. The line Sagarmuthyalu and tester ASD-07-09 recorded significantly positive *gca* effects for seed yield per plant (Table 3). The line TSF-2 and tester SSF 658 also recorded significant *gca* effects for number of seeds per capitulum and test weight. Though the line Sagarmuthyalu is a poor combiner for number of seeds per capitulum, it exhibited significant positive *gca* effect for test weight. The tester ASD-07-10 recorded significant negative *gca* effect for days to 50% flowering, number of seeds per capitulum and test weight and was a poor general combiner for seed yield per plant. Patil *et al*. (2004) reported that crosses involving parents with high and positive *gca* effects might produce heterotic hybrids with high mean performance for respective traits.

Among the 24 crosses evaluated, seven crosses *viz*,.,Manjira x GMU 1946, Manjira x SSF 698, Sagarmuthyalu x ASD-07-09, Sagarmuthyalu x SSF 658, TSF-1 x ASD-07-09, TSF-1 x ASD-07-10 and TSF-1 x SFS 9920 recorded significantly high *sca* for seed yield per plant (Table 4). The cross Sagarmuthyalu x ASD-07-09 and Manjira x GMU 1946 possessed significant *sca* effect for seed yield per plant where both of the parents involved in the cross combination are high x high and low x high *gca* effects respectively for this trait. However, the parents involved in the cross combination of Manjira x SSF 698 having low x low *gca* effects and additive x additive type of gene action recorded high and positive significant *sca* effects for seed yield per plant. The performance of other yield attributing traits indicated that the cross TSF-2 x SSF 658 recorded significantly high mean number of seeds per capitulum and the parents exhibited significant *gca* effects, which indicates the possibility of rapid improvement of this character as it may be under the control of additive gene action. From the foregoing discussion, it may be concluded that the crosses *viz*., Sagarmuthyalu x ASD-07-09, Manjira x SSF 698 and TSF-1 x ASD-07-10 may be rated as best crosses for population improvement.

The range of heterosis, mean heterosis, number of significant heterotic crosses, heterosis over better parent and standard check for six traits are presented in the Table 4. Earliness in flowering and maturity is a desirable trait for any crop. Hence, the crosses exhibiting heterosis in negative direction are of immense value. The hybrid Manjira x ASD - 07-10 showed least heterosis for days to 50% flowering (-7.66%) and days to maturity (-5.14%) over better parent. The magnitude of heterosis was highest for cross TSF-1 x ASD -07-09 (17.27%) over mid parent and better parent for this trait. The magnitude of heterosis ranged from 87.72% (Sagarmuthyalu x ASD-07-09) to -30.99% (TSF 2 x SSF 658) for number of capitula per plant. Significant high positive heterosis over better parent and standard check was observed in Sagarmuthyalu x SSF 698 followed by Sagarmuthyalu x SSF 658 and Manjira x ASD-07-10 for this trait. Heterosis for number of seeds per capitulum ranged from 78.02% to -38.46% and 51.40% to -37.36% and 72.34% to -33.34% over standard check, better parent and mid parent respectively. The cross TSF 2 x SSF 658 exhibited significant and highest positive heterosis over standard check (78.02%) and mid parent (72.34%) for this trait followed by Manjira x SSF 698. The hybrid Manjira x SSF 698 also registered higher seed yield per plant. The cross Sagarmuthyalu x SSF 658 recorded significantly high positive heterosis and heterobeltiosis for number of capitula per plant. Even though the number of seeds per capitula for this cross registered negative significant heterosis indicating fewer seeds per capitulum, the heterosis for test weight and seed yield over mid parent and standard check was positive and significant indicating bolder seed and ultimately resulting in positive significant standard heterosis and heterobeltiosis for seed yield per plant. High significant positive heterosis for test weight over mid parent (23.03%), better parent (19.05%) and standard check (19.57%) was recorded by TSF 2 x SFS 9920. Significant positive heterosis for seed yield per plant ranged from 26.04% (Manjira x GMU 1946) to 45.30% (Sagarmuthyalu x ASD 07-09) over mid parent. The next top hybrids showing positive average heterosis are Manjira x SSF 698 (44.79%) followed by TSF 1 x ASD-07-09 (35.16%) and TSF 1 x ASD-07-10 (30.09%). The cross Sagarmuthyalu x SSF 658 (20.45%) followed by Manjira x GMU 1946 (21.03%) and Manjira x SSF 698 (32.27%) recorded significant positive heterobeltiosis for this trait. Similar results were also reported by Patil *et al*. (1998).

The magnitude of heterosis over mid parent, better parent and standard check varied from cross to cross for seed yield and its components traits indicating that the characters distinctly differed for mean heterosis and its range in desirable direction. Considerable high heterosis in certain crosses and low in others revealed that nature of gene action varied with the genetic makeup of parents involved in the cross. It will be of considerable interest to know the cause of heterosis for seed yield in safflower. A comparison of heterosis for seed yield per plant in six most top heterotic crosses over better parent and standard check (Manjira x GMU 1946, Manjira x SSF 698, Sagarmuthyalu x ASD -07-09, Sagarmuthyalu x SSF 658, TSF-1 x ASD-07-09 and TSF-1 x ASD-07-10) indicated that they were accompanied by significant and positive heterosis for yield attributes like number of capitula per plant, number of seeds per capitulum and test weight in positive direction and negative heterosis for days to 50% flowering and days to maturity indicating that the heterosis for seed yield was manifested through the yield component characters.

Many top heterotic hybrids for different attributes involved parental combinations of high x high, high x low and low x low yielders. The present study further suggested that heterosis for seed yield should be through component trait heterosis. Hybrid vigour even in small magnitude for individual yield components may have synergistic effect on the end product. Grafius (1959) reported that the yield is the end product of multivariable interaction between yield components. Thus, on the basis of the *per se* performance and heterotic response, the crosses Manjira x GMU 1946, Manjira x SSF 698, Sagarmuthyalu x SSF 658 and Sagarmuthyalu x SSF 698 were identified as suitable for exploitation of heterosis for yield improvement in safflower.

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Table1: ANOVA table for combining ability in safflower

	Degrees of freedom	Days to 50% flowering	Days to maturity	Number of capitula per plant	Num,ber of seeds per capitulum	Test weight (g)	Seed yield (kg/ha)
Replications	2	0.875	0.889	47.764	34.875	0.070	38903.430
Crosses	23	32.783**	29.840**	85.585**	138.493**	0.390**	458155.40**
Line effects(L)	3	46.0	35.940	276.111*	161.407	0.042	108352.80
Tester effects(T)	5	14.667	15.847	36.789	111.333*	0.325	186784.80
L X T effects	15	36.178**	33.284**	63.7444*	142.693**	0.481**	618572.80**
Error	46	0.875	0.976	29.112	23.9333	0.042	21051.10
Total	71	11.211	10.324	45.931	61.352	0.155	163151.20
gca		3.955	3.251	17.702	15.415	0.020	14909.66
sca		11.836	10.591	13.352	40.734	0.149	194275.50
gca/sca		0.334	0.307	1.326	0.378	0.134	0.077

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

Table 2: Estimates of general combining ability (*gca*) effects for yield and its components in safflower

Genotype	Days to 50% flowering	Days to maturity	Number of capitula per plant	Num,ber of seeds per capitulum	Test weight (g)	Seed yield (kg/ha)
Manjira	-2.167**	-2.097**	0.389	-1.278	-0.046	-8.569
Sagarmuthyalu	0.611**	0.458	3.222**	-2.611**	-0.036	107.708*
TSF 1	1.611**	0.958**	2.000	-0.389	0.031	-22.458
TSF 2	-0.056	0.681*	-5.611**	4.278**	0.051	-76.681
GMU 1946	0.917**	0.819*	0.444	-2.333	-0.096	25.931
ASD-07-09	-0.250	-0.014	1.444	0.917	-0.162**	201.681**
ASD-07-10	-0.833**	-0.597	2.361	-3.833**	-0.167**	36.597
SSF 658	1.583**	1.569**	-0.806	4.750**	0.155**	-91.069
SSF 698	-1.417**	-1.764**	-1.056	1.417	0.057	-163.569**
SFS 9920	0.000	-0.014	-2.389	-0.917	0.212**	-9.569

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

Electronic Journal of Plant Breeding, 2(3): 377- 383 (Sep 2011)
ISSN 0975-928X

Table 3: Estimates of specific combining ability (*sca*) effects of 24 crosses for yield and its components in safflower

Genotype	Days to 50% flowering	Days to maturity	Number of capitula per plant	Number of seeds per capitulum	Test weight (g)	Seed yield (kg/ha)
Manjira x GMU 1946	2.917**	2.514**	4.778	-0.056	0.415**	518.736**
Manjira x ASD-07-09	-1.583**	-1.653*	-3.556	-1.639	0.304	-381.347**
Manjira x ASD-07-10	-2.000**	-1.403	4.194	-3.222	-0.157	-213.264
Manjira x SSF 658	-1.417**	-1.569*	2.028	-4.472	-0.229**	-209.264
Manjira x SSF 698	4.583**	4.764**	-6.056*	9.194**	-0.061	778.236**
Manjira x SFS 9920	-2.500**	-2.653**	-1.389	0.194	-0.273*	-493.097**
Sagarmuthyalu x GMU 1946	-2.861**	-2.042**	-2.722	5.944*	-0.511**	-368.875**
Sagarmuthyalu x ASD-07-09	3.639**	3.792**	-1.722	1.694	-0.479**	325.708**
Sagarmuthyalu x ASD-07-10	-0.111	0.042	-3.972	-3.222	0.710**	-218.542
Sagarmuthyalu x SSF 658	1.472**	1.875*	3.861	-6.806*	0.534**	461.458**
Sagarmuthyalu x SSF 698	-0.528	-1.792*	8.111**	1.194	-0.177	-300.708**
Sagarmuthyalu x SFS 9920	-1.611**	-1.875*	-3.556	0.194	-0.076	100.958
TSF 1 x GMU 1946	-2.528**	-2.875**	-1.167	0.056	-0.125	-288.042*
TSF 1 x ASD-07-09	4.639**	3.958**	7.167*	2.806	-0.024	315.542**
TSF 1 x ASD-07-10	-1.111*	-1.458*	-2.417	2.222*	-0.238*	485.625**
TSF 1 x SSF 658	-0.528	-0.625	-3.250	-6.361*	0.171	-92.708
TSF 1 x SSF 698	-1.528**	-0.625	-2.333	-3.028	0.182	-683.208**
TSF 1 x SFS 9920	1.056*	1.625*	2.000	0.306	-0.014	262.792*
TSF 2 x GMU 1946	2.472**	2.403**	0.889	-5.944*	0.221*	138.181
TSF 2 x ASD-07-09	-6.694**	-6.097**	-1.889	-2.861	0.151	-259.903*
TSF 2 x ASD-07-10	3.222**	2.819**	2.194	-0.778	-0.315**	-53.819
TSF 2 x SSF 658	0.472	0.319	-2.639	17.639**	-0.376**	-159.486
TSF 2 x SSF 698	-2.528**	-2.347**	0.278	-7.361**	0.056	205.681
TSF 2 x SFS 9920	3.056**	2.903**	2.944	-0.694	0.363**	129.347

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

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ISSN 0975-928X

Table 4: Heterosis (in percent) over midparent (MP), better parent (BP) and standard check (SC) for different characters in safflower

Cross combination	Days to flowering			Days to maturity			Number of capitula per plant		
	MP	BP	SC	MP	BP	SC	MP	BP	SC
Manjira x GMU 1946	1.28	0.85	1.72	-0.15	-0.61	0.31	37.78*	30.99	30.99
Manjira x ASD-07-09	-2.00*	-5.58**	-5.58**	-1.90*	-4.33**	-4.33**	8.40	0.00	0.00
Manjira x ASD-07-10	-7.26**	-7.66**	-6.87**	-3.75**	-4.64**	-4.64**	44.78*	36.62*	36.62
Manjira x SSF 658	-4.64**	-6.22**	-3.00**	-3.98**	-5.14**	-2.79**	25.58	14.08	14.08
Manjira x SSF 698	2.40**	0.86	0.86	1.10	0.00	0.00	-14.50	-21.13	-21.13
Manjira x SFS 9920	-2.24**	-6.44**	-6.44**	-2.70**	-5.26**	-5.26**	-2.22	-7.04	-7.04
Sagarmuthyalu x GMU 1946	0.00	-2.98**	-1.25*	-0.47	-2.44*	-1.55	33.90	23.44	11.27
Sagarmuthyalu x ASD-07-09	11.67**	10.41	4.72**	7.42**	6.39**	3.10**	49.12**	41.67*	19.72
Sagarmuthyalu x ASD-07-10	1.32	-1.70	-0.86	1.59	0.95	-0.93	38.46*	28.57	14.08
Sagarmuthyalu x SSF 658	5.19**	0.83	4.29**	3.11	0.30	2.79**	69.64**	63.79**	33.80*
Sagarmuthyalu x SSF 698	2.01*	0.88	-2.15*	-1.11	-1.58	-3.72**	87.72**	78.33**	50.70**
Sagarmuthyalu x SFS 9920	5.53**	3.62**	-1.72*	2.10	0.96	-2.17*	15.25	6.25	-4.23
TSF 1 x GMU 1946	4.27**	-1.28	-0.43	0.16	-2.76**	-1.86	25.98	25.00	12.68
TSF 1 x ASD-07-09	17.27**	15.74**	7.30**	9.12**	9.12**	3.72**	75.61	71.43**	52.11**
TSF 1 x ASD-07-10	3.82**	1.70	-0.86	1.60	0.00	-1.86	30.16	30.16	15.49
TSF 1 x SSF 658	6.43**	-0.14	3.00**	2.91*	-1.51	0.93	15.70	11.11	-1.41
TSF 1 x SSF 698	4.59**	0.88	-2.15*	1.44	0.00	-2.17*	17.07	14.29	1.41
TSF 1 x SFS 9920	13.48**	12.68**	3.00**	7.01**	6.84**	1.55	27.56	26.56	14.08
TSF 2 x GMU 1946	8.04**	2.98**	3.86**	5.23**	1.84	2.79**	-8.66	-9.38	-18.31
TSF 2 x ASD-07-09	-1.63*	-2.31*	-9.44**	-0.65	-0.98	-5.88**	-5.69	-7.94	-18.31
TSF 2 x ASD-07-10	6.70**	1.70	2.58**	5.79**	3.79**	1.86	15.87	15.87	2.82
TSF 2 x SSF 658	4.85**	-1.24	2.15*	3.14**	-0.91	1.55	-19.01	-22.22	-30.99
TSF 2 x SSF 698	0.23	-2.65**	-5.58**	-0.16	-1.90	-4.02**	-7.31	-9.52	-19.72
TSF 2 x SFS 9920	13.15*	13.15**	3.43**	8.35**	8.71**	2.48*	-3.94	-4.69	-14.08

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ISSN 0975-928X

Table 4: Contd..

Cross combination	Number of seeds per capitulum			Test weight (g)			Seed yield (kg/ha)		
	MP	BP	SC	MP	BP	SC	MP	BP	SC
Manjira x GMU 1946	-14.46	-21.98	-21.98	5.26	-0.64	11.91**	26.04**	24.03**	28.12**
Manjira x ASD-07-09	-16.48	-16.48	-16.48	6.43*	4.83	8.09*	-5.80	-14.79	-14.79
Manjira x ASD-07-10	-33.33**	-37.36**	-37.36**	-7.21**	-11.88**	-2.02	-9.45	-14.61	-14.61
Manjira x SSF 658	-20.20*	-26.17*	-13.19	3.66	3.39	3.39	-16.83	-21.94*	-21.94*
Manjira x SSF 698	25.00*	20.88	20.88	-4.03	-11.56**	4.91	44.79**	32.27**	32.27**
Manjira x SFS 9920	-15.08	-16.48	-16.48	3.46	3.24	3.68	-31.76**	-33.93**	-33.93**
Sagarmuthyalu x GMU 1946	20.57	13.33	-6.59	-22.30**	-25.96**	-7.94*	-20.29*	-20.37*	-17.58
Sagarmuthyalu x ASD-07-09	4.46	-9.89	-9.89	-19.68**	-26.54**	-8.66*	45.30**	29.44**	33.98**
Sagarmuthyalu x ASD-07-10	-23.29	-30.00*	-38.46**	-0.66	-5.91*	16.98**	-4.27	-11.16	-8.04
Sagarmuthyalu x SSF 658	-21.39	-36.45**	-20.19*	7.35**	-3.37	20.14**	30.40	20.45*	24.68**
Sagarmuthyalu x SSF 698	8.61	-3.53	-9.89	-15.24**	-17.48**	2.60	-19.19*	-27.32**	-24.76**
Sagarmuthyalu x SFS 9920	-6.49	-18.18	-20.88	-3.76	-13.01**	8.16*	9.72	4.48	8.16
TSF 1 x GMU 1946	-9.20	-15.91	-18.68	-10.78**	-12.36**	1.88	-23.68**	-24.32**	-20.50
TSF 1 x ASD-07-09	2.79	1.10	1.10	-5.46*	-10.81**	3.68	35.16**	19.62*	25.67**
TSF 1 x ASD-07-10	4.76	0.00	-3.30	-13.90**	-15.78**	-2.09	30.09**	19.91*	25.97**
TSF 1 x SSF 658	-22.05	-28.97**	-16.48	5.42*	-2.17	13.72**	-12.70	-19.91*	-15.86
TSF 1 x SSF 698	-12.14	-13.64	-16.48	-4.76	-5.72*	11.64**	-52.21**	-57.29**	-55.13**
TSF 1 x SFS 9920	-10.23	-10.23	-13.19	2.43	-4.53	10.97**	10.75	4.74	10.03
TSF 2 x GMU 1946	-10.26	-13.58	-23.08	6.33*	-2.50	9.82**	9.72	-1.70	1.54
TSF 2 x ASD-07-09	3.49	-2.20	-2.20	8.46**	3.64	6.83*	8.63	8.04	-11.63
TSF 2 x ASD-07-10	0.62	0.00	-10.99	-5.74*	-13.05**	-3.32	6.57	2.47	-9.20
TSF 2 x SSF 658	72.34**	51.40**	78.02**	3.55	0.65	0.14	-9.18	12.25	-23.03*
TSF 2 x SSF 698	-7.23	-9.41	-15.38	3.06	-7.67**	9.53*	14.67	14.04	-5.69
TSF 2 x SFS 9920	6.51	2.27	-1.10	23.03**	19.05**	19.57**	12.76	5.63	-1.09

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