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HETEROSIS AND COMBINING ABILITY IN SAFFLOWER (*CARTHAMUS TINCTORIUS* L.) GERMPLASM LINES

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ABSTRACT

Improvement of seed yield and oil content in safflower (*Carthamus tinctorius* L.) as an oilseed crop is the main objective of its breeding programs. However, little genetic information is available for these traits. GCA and SCA mean square were significant with preponderance of GCA effects for all the characters in individual environments and in pooled analysis except for primary branches per plant, biological yield and oil content in pooled analysis. The germplasm lines GMU 7359 and GMU 5394 were good general combiner for many of the important characters, specially seed yield, total capitula per plant, 100 seed weight, biological yield, harvest index and oil content in almost all the four analysis. The germplasm GMU 3806, GMU 5267 and GMU 5394 were good general combiners for earliness, short plant stature and primary branches per plant also. For SCA effects the best crosses identified in pooled analysis were GMU 5815 x GMU 217and GMU 5815 x GMU 217 for seed yield. These crosses also recorded high heterotic effect, high *per se* performance and stability over varied environments. They also depicted high SCA effect and high heterosis for effective capitula per plant, 100 seed weight, biological yield and oil content. For early flowering the cross GMU 5394 x GMU 196 and GMU 3806 x GMU 217 exhibited high SCA effect GMU 5394 x GMU 196, GMU 5712 x GMU 7359 and GMU 5815 x GMU 217 recorded maximum negative SCA effects for days to maturity. Hybrid GMU 5267 x GMU 5815, GMU 3714 x GMU 7359 and GMU 5394 x GMU 217 exhibited maximum SCA effect for oil content.

INTRODUCTION

Safflower (*Carthamus tinctorious* L.) belongs to *Asteraceae* family commonly known as "kusum" and has 2n = 24 chromosomes. Safflower (*Carthamus tinctorius* L.) is one of the important *rabi* oilseed crops of India, cultivated in vertisols under residual moisture in Karnataka, Andhra Pradesh, Chhattisgarh, Madhya Pradesh and Bihar. Safflower is known for its cultivation since time immemorial, either for orange red dye extracted from its florets and for its much valued oil. Latha and Prakash (1984) have reported that the seed contains 27.5 per cent oil, 15 per cent protein, 41 per cent crude fiber and 2.3 per cent ash. Safflower oil, which on average contains 75% linoleic acid, also contains tocopherols, known to have antioxidant effect and high vitamin E content. For this reason, safflower oil is used in the diets of patients with cardiovascular disease, and bears great importance forits anti-cholesterol effect. Safflower oil cake is a valuable animal feed (Weiss, 2000). In India, safflower is grown in 229 thousand hectares with a production of 143 thousand tonnes (2010-11) and ranked first in area and second in production accounting for 60 per cent and 45 per cent of global area and production respectively (Anonymous, 2010). Safflower is a predominantly self-pollinated crop; however, it may have some out crossing depending on genotype and insect activity (Weiss, 2000; Knowles, 1969).

Diallel analysis can provide the necessary genetic information for breeding programs (Hill *et al.*, 2001), and has been frequently used to obtain the genetic information regarding various traits in different crops (Bolanos *et al.*, 2001; Stoddard and Herath, 2001; Guines *et al.*, 2002). Diallel analysis is usually conducted according to the Griffing method (1956) which partitions the total variation of the trait in F_1 progenies into General Combining Ability (GCA) of their parents and Specific Combining Ability (SCA) of the crosses. Genetic analysis based upon F_1 progenies in diallel crosses has been previously used in safflower (Mandal and Banerjee, 1997), but it seems that using germplasm lines in diallel analysis has not been established so far since there is not enough genetic information regarding seed yield, yield components and oil content of the seed in safflower, the objectives of this study were to study magnitude of heterosis and to estimate the general and specific combining ability for seed yield, its components and quality traits.

MATERIALS AND METHODS

Ten diverse germplasm lines of safflower were received from Directorate of Oilseed Research, Rajendranagar, Hyderabad and crossed using diallel mating design according to method-2 and Model-I of Griffing (1956) during *Rabi* 2007-08. The resulted 45 crosses along with ten parents and one standard check planted in randomized block design with three replications under three distinct environments *viz*., Env.1-Rainfed, early sown with fertilizer dose 30N:15P, Env. 2- One irrigation (at capitula development stage), normal sown with recommended dose of fertilizer 60N:30 P, Env.3- two irrigations (one at flowering and second at capitula development), late sown with fertilizer dose 90N:45P at Rajasthan College of Agriculture farm, Udaipur, in 2008-09. Each plot consist of one row of 4 meter length in each replication maintaining the inter and intra row spacing of 45 and 25 cm, respectively. Observations was recorded on 10 randomly selected competitive plants from each treatment in all the environments for characters plant height (cm), number of primary branches per plant, number of secondary branches per plant, total capitula on primary branches, number of effective capitula per plant, number of seeds per capitula on primary branches, number of seeds per capitula on secondary branches, 100-seed weight, seed yield per plant, biological yield, harvest index, hull content, oil content and iodine value. Days to flowering and days to maturity were recorded on population basis. The recommended package of practices was followed to raise a healthy crop.

The combining ability analysis for single environment was carried out following Griffing (1956) Method–II, Model–I which assume that variety and block effects are constant (fixed) but environmental effect is variable. For statistical analysis in experiment, the below model was considered.

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + \frac{1}{b} \Sigma \text{ eijk}$$

RESULTS AND DISCUSSION

The analysis of variance for combining ability is significant for all of the traits (Table 1). A perusal of the table revealed that mean square of GCA and SCA variance was significant for all the characters. This indicates variation in GCA of parents and SCA of crosses and significant combination of additive and non-additive gene effect in the expression of the characters.

General combining ability (GCA) effects in F_1 diallel for all of the traits are presented in Table 2. For seed yield per plant GMU 7359 (10.39), GMU 5267 (6.39) and GMU 5815 (3.66) showed significant GCA effect for highest seed yield per plant. Highest significant SCA effect was showed by the cross GMU 217 x GMU 5815 (23.06) followed by GMU 196 x GMU 3806 (21.60) and GMU 5815 x GMU 5267 (21.21) in pooled analysis for increased seed yield per plant.

Parents, GMU 3806 and GMU 196 exhibited significant positive GCA effect for oil content in all the environments including pooled over environments. The genotype GMU 3714 exhibited significant positive GCA effect in E_1, E_2 and pooled environment. Hybrid GMU 217 x GMU 5394 (2.90) exhibited highest SCA effect in pooled over environments for high oil content followed by GMU 196 x GMU 5267 (2.80) and GMU 5815 x GMU 5712 (2.72). Number of seeds per capitula on primary branches the genotype GMU 5815 in E_1, E_3 and Pooled, exhibited significant positive GCA effect. The hybrid GMU 196 x GMU 3806 (14.62) depicted maximum SCA effect followed by GMU 217 X GMU 5815 (13.68) and GMU 5815 X GMU 5267 (11.71) for number of seeds per capitula on primary branches.

In general, there was considerable consistency for the results obtained from analysis of F_1 progenies in terms of GCA and SCA effect and in accordance with the findings of Ramachandram *et al*. (1981), Reddy (1983), Gupta *et al*. (1988), Pahlavani *et al*., 2007(a) and 2007(b).

Range of relative heterosis in F_1 diallel analysis was -79.71 to 121.05 in E_1, -77.98 to 114.29 in E_2, -79.41 to 123.81 in E_3 and -79.01 to 119.55 in POE_{123} and the cross GMU 3806 X GMU 264 (171.19) in E_1, and same cross combination in E_2 (160.32), in E_3 (180.36) and in POE_{123} (170.22) exhibited the highest heterosis for seed yield per plant and same cross combination exhibited the highest heterosis for number of seeds per capitula on primary branches.

The heterosis over better parents varied from 1.07 to 153.97 in E_1, 1.56 to 148.48 in E_2, 3.33 to 161.67 in E_3 and 1.97 to 154.50 in $POE_{123.}$ The cross GMU 3806 x GMU 264 in E_1 (153.97), and same cross combination in E_2 (148.48), in E_3 (161.67) and in POE_{123} (154.50) had the highest heterobeltiosis for seed yield per plant. The cross GMU 3806 x GMU 196 in E_1 (62.69) and same cross combination in E_2 (59.42), in E_3 (47.06) and in POE_{123} (72.76) exhibited highest heterobeltiosis for number of seeds per capitula on primary branches.

For early flowering (heterosis in negative direction) the cross GMU 3806 x GMU 5815 (-4.69) in E_1 and E_2 (-2.72), GMU 3806 x GMU 217 (-3.95) in E_3 and as well as in pooled (-3.32) exhibited the highest heterosis in desired direction. For plant height, the hybrid GMU 3714 x GMU 3806 depicted highest significant negative heterosis in all the environments and over the environments.

Positive significant heterosis for seed yield and other attributes in safflower were also reported by Rao (1982), Reddy *et al*. (1985), Narkhede *et al*. (1987), Alone *et al*. (2003), Kaya (2005a), Sarode *et al*. (2008) and Shivani *et al*. (2010 and 2011).

It was found that GCA had contributions in genetic variation of the traits. Therefore, the additive effects of the genes were important in genetic variation of these traits and selection programs can improve them. For almost all of the traits, GCA variation among the parents had an acceptable consistency in diallel analyses. Combining ability analysis indicated that mean square due to both GCA and SCA effects were significant, but the GCA effect played a greater role in the genetic control of all the characters in individual environments, whereas in pooled analysis both GCA and SCA variances for all the traits except primary branches per plant, biological yield and oil content as for all these traits only GCA variance was significant. Cultivars GMU 3806 and GMU 7359 were good general

Table 1: Best hetrotric crosses for seed yield and Estimates of their genetic parameters based on combining ablity analysis

Cross	Mean Yield (g plant^{-1})	Heterobeltiosis	Economic heterosis	SCA effect	GCA effect P1	P2	Significant heterobeltiosis / economic heterosis in other traits in desired direction
GMU 3714 x GMU 3806	21.44	2.12**	-	-2.43**	-11.15*	2.94**	Days to flower, plant height, 100 seeds weight, harvest index, oil content and iodine value.
GMU 3714 x GMU 264	19.33	-	-	-0.46**	-11.15*	-1.14*	Days to flower, plant height, oil content and iodine value.
GMU 3806 x GMU 196	48.67	108.57**	-	21.60**	2.94**	-7.96*	Days to flower, plant height,PBs per plant, SBs per plant, total capitulaon PBs, effective capitula per plant, number of seeds per capitula on PBs, number of seeds per capitula on SBs, 100 seeds weight, biological yield per plant, harvest index, oil content.
GMU 3806 x GMU 217	49.22	94.30**	-	16.77**	2.94**	-2.57*	Days to flower, plant height, PBs per plant, SBs per plant, total capitulaon PBs, effective capitula per plant, number of seeds per capitula on PBs, 100 seeds weight, ,biological yield per plant, harvest index, oil content and iodine value.
GMU 3806 x GMU 264	53.44	154.50**	-	19.56**	2.94**	-1.14*	Days to flower, plant height, PBs per plant, SBs per plant, total capitula on PBs, effective capitula per plant, number of seeds per capitula on PBs, number of seeds per capitula on SBs, biological yield per plant.
GMU 5267 x GMU 5394	55.56	9.89**	-	18.15**	6.39**	-1.06*	Days to flower, plant height, biological yield per plant and iodine value.
GMU 5267x GMU 5815	63.33	1.97**	-	21.21**	6.39**	3.66**	Days to flower, days to maturity, plant height, number of seeds per capitula on PBs, number of seeds per capitula on SBs, biological yield per plant, oil content.
GMU 196 x GMU 217	25.33	-	-	3.79**	-7.96*	-2.57*	Plant height, PBs per plant, SBs per plant, total capitulaon PBs, effective capitula per plant, oil content.
GMU 217 x GMU 264	26.11	3.07**	-	-2.26**	-2.57*	-1.14*	Days to flower, days to maturity, plant height, PBs per plant, SBs per plant, total capitulaon PBs, number of seeds per capitula on SBs.

*,** Significant at 5 and 1 percent respectively

combiner for many of the important characters specially seed yield per plant, 100-seed weight, effective capitula per plant, biological yield, harvest index and oil content in heterosis and combining ability analysis. The GCA observed to be good in GMU 3806, GMU 3714 and GMU 196 for earliness, seeds per capitula, harvest index and oil content.

Crosses GMU 5814 X GMU 217, GMU 3806 x GMU 264, GMU 3806 x GMU 217 and GMU 3806 x GMU 196 exhibited the highest SCA effects in pooled analysis. This considerable genetic variation among crosses indicates that it is possible to find suitable combinations of the parental lines for hybrid cultivar production. Significant SCA mean squares for different traits in safflower were also reported by Pahlavani *et al.* (2007 and 2007a and Shivani *et al.*, 2010.

The mean squares of SCA for the traits such as days to flowering and plant height were significant. Maximum negative SCA effect was exhibited by the cross GMU 5394 x GMU 196 and GMU 3806 x GMU 217 for days to flower, by the cross GMU 5394 x GMU 196, GMU 5712 x GMU 7359 and GMU 5815 x GMU 217 for days to maturity and by the cross GMU 3714 x GMU 3806 and GMU 5712 x GMU 196 for plant height, while maximum positive SCA effect was showed by the GMU 264 x GMU 7359 and GMU 3714 x GMU 7359 for number of primary branches per plant, GMU 264 x GMU 7359 and GMU 3714 x GMU 7359 for number of secondary branches per plant, hybrids GMU 264 x GMU 7359 and GMU 3714 x GMU 7359 for total capitula on primary branches, GMU 3714 x GMU 7359 and GMU 264 x GMU 7359 for number of effective capitula per plant, hybrids GMU 3714 x GMU 5394 and GMU 3806 x GMU 217 for 100 seed weight, the hybrid GMU 5815 x GMU 217 and GMU 3806 x GMU 196 for number of seeds per capitula on primary branches, hybrids GMU 5267 x GMU 5815 and GMU 5815 x GMU 217 for number of seeds per capitula on secondary branches, hybrids GMU 5815 x GMU 217 and GMU 3806 x GMU 196 for seed yield, and hybrid GMU 5267 x GMU 5815 for biological yield hybrids GMU 5267 x GMU 5394, GMU 3714 x GMU 217 and GMU 5712 x GMU 264 for hull content, GMU 3714 x GMU 196 and GMU 3714 x GMU 217 for harvest index and GMU 5267 x GMU 5815, GMU 3714 x GMU 7359 and GMU 5394 x GMU 217 for oil content and GMU 217 x GMU 264 for iodine value Table 3.

As mentioned by Kearsy and Pooni (1996), GCA effects provide a measure of the general potential of genetic material. Based on GCA of parental lines (Table 3), it can be concluded that for improvement of seed yield per plant the genotypes GMU 3714, GMU 3806, GMU 5815and GMU 196 have good genetic potential. However, the highest mean of seed yield per plant in F_1 was obtained for crosses GMU 5815 x GMU 217 and GMU 3806 x GMU 196, respectively. This result indicates that for achieving cultivars with high seed yield, both GCA and SCA effects should be considered. GMU 5815 and GMU 7359 were the best combiner parents in terms of the number of capitula per plant and seed per capitula, respectively.

Table 2 : Classification of parents with respect of general combining ability for various quantitative traits.

Parents	Env.	Characters Days to flowering	Days to maturity	Plant height	Number of PBs/ plant	Number of SBs/ plant	Total capitula on PBs	Number of effective capitula/ plant	Number of seeds/ capitula on PBs	Number of seeds/ capitula on SBs	100 seed weight	Seed yield / plant	Hull content	Biological yield/ plant	Harvest index	Oil content	Iodine value
GMU 3714	E1	G	G	P	P	P	P	P	P	P	P	P	P	P	P	G	P
	E2	A	G	P	P	P	P	P	P	P	A	P	P	P	P	G	P
	E3	G	P	P	P	P	P	P	P	P	P	P	P	P	P	G	P
	P	G	P	P	P	P	P	P	P	P	P	P	P	P	P	G	P
GMU 3806	E1	G	G	P	G	G	G	G	G	G	P	G	P	G	G	G	P
	E2	G	G	P	A	G	G	G	G	G	A	G	P	G	G	G	P
	E3	G	P	P	A	G	A	G	G	G	P	G	G	G	G	G	P
	P	G	P	P	G	G	G	G	G	G	P	G	P	G	G	G	P
GMU 5267	E1	P	A	P	G	G	G	G	G	G	P	G	P	G	G	P	G
	E2	P	G	P	G	G	G	G	G	G	A	G	P	G	P	P	G
	E3	P	P	P	G	G	G	G	G	G	P	G	P	G	G	P	G
	P	P	A	P	G	G	G	G	G	G	P	G	P	G	P	G	
GMU 5394	E1	G	G	G	P	G	G	G	G	P	P	P	A	P	G	P	G
	E2	G	G	G	G	G	G	G	G	P	A	P	P	P	G	P	G
	E3	G	G	G	G	G	G	G	P	P	P	P	P	P	G	P	G
	P	G	G	G	A	G	G	G	G	P	P	P	P	P	G	P	G
GMU 5712	E1	P	P	G	A	G	G	P	G	P	P	G	G	G	P	P	G
	E2	P	P	G	G	G	G	P	G	P	A	G	G	G	P	P	P
	E3	P	G	G	G	G	G	G	G	P	P	G	G	G	P	P	G
	P	P	P	G	G	G	G	P	G	P	P	G	G	G	P	P	G
GMU 5815	E1	P	P	P	P	G	G	A	G	P	G	G	G	G	G	P	P
	E2	A	G	P	P	G	G	G	G	P	G	G	G	G	G	G	P
	E3	P	G	P	P	P	G	G	G	G	G	G	G	G	G	G	P
	P	P	G	P	P	G	G	G	G	P	G	G	G	G	G	G	P
GMU 196	E1	P	P	P	P	P	P	P	P	P	A	P	P	P	P	G	P
	E2	P	P	P	P	P	P	P	P	P	G	P	P	P	P	G	P
	E3	P	P	P	P	P	P	P	P	P	G	P	P	P	P	G	P
	P	P	P	P	P	P	P	P	P	P	G	P	P	P	P	G	P
GMU 217	E1	P	P	P	P	P	P	P	P	P	G	P	P	P	P	P	P
	E2	P	P	P	P	P	P	P	P	P	G	P	G	P	P	P	P
	E3	P	P	P	P	P	P	P	G	P	G	P	P	P	P	P	P
	P	P	P	P	P	P	P	P	P	P	G	P	P	P	P	P	P
GMU 264	E1	G	P	G	P	P	P	P	P	G	G	P	G	P	G	P	G
	E2	A	G	G	P	P	P	P	P	G	G	P	G	P	G	P	G
	E3	A	G	G	P	P	P	P	P	G	G	P	P	P	G	P	G
	P	G	G	G	P	P	P	P	P	G	G	P	G	P	G	P	G
GMU 7359	E1	P	P	G	G	G	G	G	G	G	G	G	G	G	G	P	G
	E2	P	P	G	G	G	G	G	G	G	G	G	G	G	G	P	G
	E3	P	P	G	G	G	G	G	G	G	G	G	G	G	G	A	G
	P	P	P	G	G	G	G	G	G	G	G	G	G	G	G	P	G

Table 3: Best parents and general combiners, best crosses and crosses with highest SCA effects, heterobeltiosis and economic heterosis for different characters based on pooled analysis.

Characters	Best performing parent	Best General combiner	Best performing cross combination	Crosses with highest SCA effect	Hybrid with highest Heterosis	
					Heterobeltiosis	Economic heterosis
Days to flowering	GMU 5394	GMU 5394	GMU 5394 x GMU 196	GMU 5394 x GMU 196	GMU 3806 x GMU 217	GMU 3806 x GMU 5815
	GMU 3806	GMU 3806	GMU 5267x GMU 5712	GMU 5267x GMU 5712	GMU 3806 x GMU 5815	GMU 3806 x GMU 217
	GMU 3714	GMU 3714	GMU 3806 x GMU 217	GMU 3806 x GMU 217	GMU 3806 x GMU 7359	GMU 3806 x GMU 5712
Days to maturity	GMU 5394	GMU 5815	GMU 5394 x GMU 196	GMU 5394 x GMU 196	GMU 5815 x GMU 196	GMU 5394 x GMU 5815
	GMU 5815	GMU 264	GMU 264 x GMU 7359	GMU 264 x GMU 7359	GMU 5712 x GMU 7359	GMU 5394 x GMU 196
	GMU 264	GMU 5394	GMU 5815 x GMU 196	GMU 5815 x GMU 196	GMU 196 x GMU 7359	GMU 264 x GMU 7359
Plant height	GMU 217	GMU 217	GMU 3714 x GMU 3806	GMU 3714 x GMU 3806	GMU 3714 x GMU 3806	GMU 3714 x GMU 3806
	GMU 3806	GMU 3806	GMU 5712 x GMU 196	GMU 5712 x GMU 196	GMU 3714 x GMU 5267	GMU 5267x GMU 217
	GMU 196	GMU 196	GMU 5267x GMU 217	GMU 5267x GMU 217	GMU 5712 x GMU 196	GMU 5712 x GMU 196
Number of PBs/ plant	GMU 7359	GMU 7359	GMU 3714 x GMU 7359	GMU 3714 x GMU 7359	GMU 3806 x GMU 264	GMU 264 x GMU 7359
	GMU 5267	GMU 5267	GMU 264 x GMU 7359	GMU 264 x GMU 7359	GMU 196 x GMU 217	
	GMU 5712	GMU 3806	GMU 3806 x GMU 5815	GMU 3806 x GMU 5815	GMU 3806 x GMU 217	
Number of SBs/ plant	GMU 7359	GMU 7359	GMU 264 x GMU 7359	GMU 264 x GMU 7359	GMU 3806 x GMU 264	
	GMU 5267	GMU 5267	GMU 3714 x GMU 7359	GMU 3714 x GMU 7359	GMU 196 x GMU 217	
	GMU 5712	GMU 5712	GMU 3806 x GMU 5815	GMU 3806 x GMU 5815	GMU 3806 x GMU 196	
Total capitula on PBs	GMU 7359	GMU 7359	GMU 3714 x GMU 7359	GMU 3714 x GMU 7359	GMU 3806 x GMU 264	
	GMU 5267	GMU 5267	GMU 264 x GMU 7359	GMU 264 x GMU 7359	GMU 196 x GMU 217	
	GMU 5712	GMU 5712	GMU 3806 x GMU 264	GMU 3806 x GMU 264	GMU 3806 x GMU 196	
No.of effective capitula/ plant	GMU 5267	GMU 5267	GMU 3714 x GMU 7359	GMU 3714 x GMU 7359	GMU 3806 x GMU 264	
	GMU 7359	GMU 7359	GMU 264 x GMU 7359	GMU 264 x GMU 7359	GMU 3806 x GMU 217	
	GMU 5394	GMU 5394	GMU 3806 x GMU 264	GMU 3806 x GMU 264	GMU 3806 x GMU 196	
No. of seeds/ capitula on PBs	GMU 5712	GMU 5712	GMU 3806 x GMU 196	GMU 3806 x GMU 19	GMU 3806 x GMU 196	GMU 5712 x GMU 7359
	GMU 7359	GMU 7359	GMU 5815 x GMU 217	GMU 5815 x GMU 217	GMU 3806 x GMU 217	GMU 5815 x GMU 217
	GMU 3806	GMU 3806	GMU 5267x GMU 5815	GMU 5267x GMU 5815	GMU 3806 x GMU 264	GMU 5267x GMU 5815
No. of seeds/ capitula on SBs	GMU 7359	GMU 7359	GMU 5267x GMU 5815	GMU 5267x GMU 5815	GMU 3714 x GMU 3806	
	GMU 3806	GMU 3806,264	GMU 5815 x GMU 217	GMU 5815 x GMU 217	GMU 5267x GMU 5815	
	GMU 264	GMU 5267	GMU 5712 x GMU 7359	GMU 5712 x GMU 7359	GMU 217 x GMU 264	
100 seed weight	GMU 7359	GMU 7359	GMU 3714 x GMU 5394	GMU 3714 x GMU 5394	GMU 3714 x GMU 5394	GMU 3806 x GMU 217
	GMU 264	GMU 264	GMU 3806 x GMU 217	GMU 3806 x GMU 217	GMU 3806 x GMU 196	GMU 5815 x GMU 217
	GMU 217	GMU 217	GMU 3806 x GMU 196	GMU 3806 x GMU 196	GMU 3806 x GMU 217	GMU 5815 x GMU 7359
Seed yield /plant	GMU 7359	GMU 7359	GMU 5815 x GMU 217	GMU 5815 x GMU 217	GMU 3806 x GMU 264	
	GMU 5267	GMU 5267	GMU 3806 x GMU 196	GMU 3806 x GMU 196	GMU 3806 x GMU 196	
	GMU 5815	GMU 5815	GMU 5267x GMU 5815	GMU 5267x GMU 5815	GMU 3806 x GMU 217	
Hull content	GMU 3714	GMU 3714	GMU 5712 x GMU 264	GMU 5712 x GMU 264	GMU 3714 x GMU 5394	GMU 5267 x GMU 7359
	GMU 5267	GMU 5267	GMU 3714 x GMU 217	GMU 3714 x GMU 217	GMU 3806 x GMU 196	
	GMU 196	GMU 196	GMU 3806 x GMU 5267	GMU 3806 x GMU 5267	GMU 5394 x GMU 264	
Biological yield/plant	GMU 7359	GMU 7359	GMU 5267x GMU 5815	GMU 5267x GMU 5815	GMU 3806 x GMU 264	GMU 5267x GMU 5815
	GMU 5267	GMU 5267	GMU 3806 x GMU 264	GMU 3806 x GMU 264	GMU 3806 x GMU 196	
	GMU 5815	GMU 5815	GMU 5815 x GMU 217	GMU 5815 x GMU 217	GMU 3806 x GMU 217	
Harvest index	GMU 264	GMU 264	GMU 5815 x GMU 217	GMU 5815 x GMU 217	GMU 3714 x GMU 3806	
	GMU 5815	GMU 5815	GMU 3714 x GMU 196	GMU 3714 x GMU 196	GMU 3714 x GMU 217	
	GMU 7359	GMU 7359	GMU 3714 x GMU 3806	GMU 3714 x GMU 3806	GMU 3714 x GMU 196	
Oil content	GMU 196	GMU 196	GMU 5394 x GMU 217	GMU 5394 x GMU 217	GMU 5267x GMU 196	GMU 5267x GMU 196
	GMU 3806	GMU 3806	GMU 5267x GMU 196	GMU 5267x GMU 196	GMU 5267x GMU 5815,	GMU 3806 x GMU 7359
	GMU 3714	GMU 3714	GMU 5712 x GMU 5815	GMU 5712 x GMU 5815	GMU 196 x GMU 264	GMU 3714 x GMU 7359
Iodine value	GMU 217	GMU 217	GMU 217 x GMU 264	GMU 217 x GMU 264	GMU 5267 x GMU 264	GMU 5394 x GMU 264
	GMU 5815	GMU 5815	GMU 3806 x GMU 5394	GMU 3806 x GMU 5394	GMU 5267x GMU 217	GMU 5267 x GMU 264
	GMU 196	GMU 196	GMU 264 x GMU 7359	GMU 264 x GMU 7359	GMU 5394 x GMU 264	

Table 4: Estimation of general combining ability effects for different characters in Safflower

Characters	Env.	GMU 3714	GMU 3806	GMU 5267	GMU 5394	GMU 5712	GMU 5815	GMU 196	GMU 217	GMU 264	GMU 7359
Days to flowering	E1	-0.51**	-0.62**	0.36**	-0.73**	0.55**	0.24*	0.80**	0.19	-0.48**	0.19
	E2	-0.11	-0.80**	0.53**	-0.52**	0.09	-0.16	0.51**	0.39**	-0.16	0.23*
	E3	-0.64**	-0.36**	0.25*	-0.67**	0.08	0.17	0.31**	0.78**	-0.17	0.25*
	P	-0.42*	-0.59*	0.38**	-0.64*	0.24**	0.08	0.54**	0.45**	-0.27*	0.22**
Days to maturity	E1	-0.57**	-1.04**	-0.02	-1.16**	0.59**	0.09	0.79**	0.68**	0.01	0.62**
	E2	-0.26**	-0.28**	-0.81**	-0.64**	1.97**	-0.59**	0.11	0.88**	-0.51**	0.13
	E3	1.62**	1.73**	0.67**	-0.55**	-0.52**	-1.91**	0.03	0.70**	-1.88**	0.12
	P	0.26**	0.13**	-0.05	-0.78*	0.68**	-0.80*	0.31**	0.75**	-0.79*	0.29**
Plant height	E1	-0.24**	-0.92**	-1.42**	2.91**	1.78**	-0.70**	-1.41**	-3.05**	1.33**	1.71**
	E2	-0.43**	-1.03**	-1.34**	2.57**	1.77**	-0.53**	-0.76**	-2.73**	0.98**	1.49**
	E3	-0.07	-0.62**	-1.25**	2.99**	1.09**	-0.72**	-0.33**	-2.44**	0.54**	0.83**
	P	-0.25*	-0.86*	-1.34*	2.83**	1.54**	-0.65*	-0.83*	-2.74*	0.95**	1.34**
Number of PBs/ plant	E1	-1.24**	0.52**	1.04**	-0.26	0.19	-0.32*	-0.79**	-0.15	-0.16	1.15**
	E2	-1.46**	0.12	1.53**	0.31**	0.24**	-0.18*	-1.12**	-0.44**	-0.61**	1.61**
	E3	-1.08**	0.03	1.05**	0.07**	0.18**	-0.02	-0.82**	-0.34**	-0.31**	1.24**
	P	-1.26*	0.23**	1.21**	0.04	0.20**	-0.17*	-0.91*	-0.31*	-0.36*	1.33**
Number of SBs/ plant	E1	-1.48**	0.26**	1.36**	0.07**	0.20**	0.26**	-0.86**	-0.73**	-0.43**	1.34**
	E2	-1.47**	0.15**	1.22**	0.09**	0.34**	0.11**	-1.21**	-0.36**	-0.43**	1.56**
	E3	-1.29**	0.07**	0.96**	0.07**	0.32**	-0.01	-0.80**	-0.36**	-0.25**	1.30**
	P	-1.41*	0.16**	1.18**	0.08**	0.29**	0.12**	-0.96*	-0.48*	-0.37*	1.40**
Total capitula on PBs	E1	-1.54**	0.30**	1.24**	0.05**	0.17**	0.10**	-1.02**	-0.38**	-0.49**	1.57**
	E2	-1.44**	0.11**	1.50**	0.27**	0.19**	0.23**	-1.13**	-0.50**	-0.68**	1.43**
	E3	-1.13**	0.01	0.94**	0.11**	0.14**	0.05**	-0.70**	-0.34**	-0.27**	1.19**
	P	-1.37*	0.14**	1.23**	0.14**	0.17**	0.13**	-0.95*	-0.41*	-0.48*	1.40**
Number of effective capitula/ plant	E1	-2.08**	0.19*	2.45**	0.66**	-0.13	0.19	-1.23**	-1.03**	-1.04**	2.02**
	E2	-2.20**	0.30**	2.63**	0.57**	-0.07**	0.12**	-1.20**	-1.09**	-1.18**	2.12**
	E3	-1.96**	0.33**	2.34**	0.55**	0.07**	0.07**	-1.16**	-1.02**	-1.13**	1.90**
	P	-2.08*	0.28**	2.47**	0.59**	-0.04	0.13**	-1.20*	-1.05*	-1.12*	2.02**
Number of seeds/ capitula on PBs	E1	-5.67**	2.49**	2.24**	0.69**	3.19**	1.27**	-5.17**	-0.31	-1.14**	2.41**
	E2	-4.79**	2.57**	2.32**	0.98**	2.84**	0.23	-5.10**	-0.24	-1.10**	2.29**
	E3	-4.44**	2.72**	0.56**	-0.36*	2.44**	0.47**	-4.17**	0.42**	-1.17**	3.53**
	P	-4.97*	2.59**	1.71**	0.44**	2.83**	0.66**	-4.81*	-0.04	-1.14*	2.74**
Number of seeds/ capitula on SBs	E1	-1.37**	0.66**	1.13**	-1.81**	-0.64**	-0.20*	-0.89**	-0.48**	1.19**	2.41**
	E2	-1.00**	1.17**	0.92**	-1.83**	-0.92**	-0.22*	-0.97**	-0.47**	0.78**	2.56**
	E3	-0.73**	1.22**	0.61**	-1.78**	-0.92**	0.24*	-1.51**	-0.37**	1.05**	2.19**
	P	-1.03*	1.01**	0.89**	-1.81*	-0.83*	-0.06	-1.12*	-0.44*	1.01**	2.39**
100 seed weight	E1	-0.21**	-0.03**	-0.12**	-0.20**	-0.16**	0.13**	0.01	0.12**	0.19**	0.27**
	E2	-0.17**	-0.02*	-0.08**	-0.19**	-0.15**	0.11**	0.02*	0.11**	0.15**	0.23**
	E3	-0.21**	-0.02**	-0.07**	-0.19**	-0.18**	0.10**	0.05**	0.12**	0.14**	0.25**
	P	-0.20*	-0.03*	-0.09*	-0.19*	-0.16*	0.11**	0.03**	0.12**	0.16**	0.25**

Table 4: Cont............

Seed yield /plant	E1	-11.08**	2.89**	6.23**	-1.27**	0.53**	3.70**	-7.91**	-2.44**	-1.08**	10.42**
	E2	-11.43**	2.93**	6.74**	-1.04**	0.46**	3.77**	-8.04**	-2.65**	-1.07**	10.32**
	E3	-10.94**	3.01**	6.20**	-0.88**	0.53**	3.51**	-7.94**	-2.63**	-1.27**	10.42**
	P	-11.15*	2.94**	6.39**	-1.06*	0.51**	3.66**	-7.96*	-2.57*	-1.14*	10.39**
Hull content	E1	-1.40**	-0.52**	-0.57**	0	0.42**	0.57**	-0.22**	-0.49**	0.76**	1.45**
	E2	-0.94**	-0.41**	-0.31**	-0.26**	0.23**	0.33**	-0.26**	0.17**	0.38**	1.07**
	E3	-0.50**	0.51**	-1.34**	-0.16**	0.30**	0.39**	-0.32**	-0.28**	-0.02	1.42**
	P	-0.95*	-0.14*	-0.74*	-0.14*	0.32**	0.43**	-0.27*	-0.20*	0.38**	1.31**
Biological yield/plant	E1	-42.03**	10.61**	22.47**	-2.64**	2.30**	11.91**	-26.59**	-3.73**	-7.59**	35.30**
	E2	-40.63**	10.73**	25.18**	-2.38**	2.07**	10.82**	-27.38**	-5.21**	-8.27**	35.07**
	E3	-40.71**	9.63**	23.02**	-3.54**	1.74**	12.07**	-26.68**	-3.84**	-7.93**	36.24**
	P	-41.12*	10.32**	23.55**	-2.85*	2.04**	11.60**	-26.88*	-4.26*	-7.93*	35.54**
Harvest index	E1	-0.24**	0.12**	0.01	0.15**	-0.10**	0.42**	-0.50**	-1.07**	0.88**	0.32**
	E2	-0.03	-0.04	-0.12**	0	-0.34**	0.41**	-0.26**	-1.00**	1.35**	0.03
	E3	-0.21*	0.28**	0.20*	0.29**	-0.13	0.32**	-0.59**	-1.20**	0.89**	0.16
	P	-0.16*	0.12**	0.03	0.15**	-0.19*	0.38**	-0.45*	-1.09*	1.04**	0.17**
Oil content	E1	1.10**	1.26**	-0.38**	-0.26*	-0.65**	-0.23	1.15**	-0.24*	-0.48**	-1.28**
	E2	0.29**	0.87**	-0.34**	-0.59**	-0.35**	0.29**	0.98**	-0.84**	-0.01	-0.29**
	E3	0.13	0.60**	-0.56**	-0.20*	-0.51**	0.53**	0.90**	-0.39**	-0.56**	0.05
	P	0.50**	0.91**	-0.42*	-0.35*	-0.50*	0.20**	1.01**	-0.49*	-0.35*	-0.51*
Iodine value	E1	-0.43**	-0.17**	0.99**	1.15**	0.09**	-0.87**	-0.43**	-1.18**	0.23**	0.62**
	E2	-0.37**	-0.02	1.07**	1.16**	-0.01	-0.80**	-0.60**	-1.17**	0.18**	0.55**
	E3	-0.32**	-0.06**	1.09**	1.07**	0.04*	-0.73**	-0.60**	-1.11**	0.12**	0.52**
	P	-0.37*	-0.08*	1.05**	1.12**	0.04**	-0.80*	-0.54*	-1.15*	0.18**	0.57**

*,** Significant at 5 and 1 percent respectively.

Production cultivars with shorter time to 50% flowering and maturity could be obtained by utilizing GMU 3714, GMU 3806 and GMU 5394 as a parent, since it was the only lines with negative and significant GCA for this trait (Table 4). The highest and negative GCA effect for plant height was for GMU 217 and GMU 5267 which was the shortest genotype among the parents. Therefore, for producing short cultivars of safflower, GMU 5267 can be used in breeding programs.

Genotype GMU 3806 and GMU 196had the highest mean of oil content among parental lines and also the highest positive GCA effects (1.26*) and (1.15*) for this trait. This genotype was a germplasm line and it has a good genetic potential for oil content improvement. However, among the progenies, the highest oil content belonged to the cross GMU 196 x GMU 5267 in E_3 (3.90) showed highest positive SCA effect followed by with a high SCA effect. This indicates that both GCA and SCA effects should be considered in choosing the parental lines in breeding programs of safflower.

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