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Original Research Article

Studies on Combining Ability, Heterosis and Gene Action in Restorer Lines of Sunflower (*Helianthus annuus* L.)

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A B S T R A C T

Eight diverse inbred lines (R lines) were crossed in half diallel fashion and the parents, their 28 F_1's with two checks,(SS-2038 and LSFH-35)of sunflower were evaluated to estimate GCA, SCA effects and heterosis to identify and develop elite 'R' lines for important yield and yield contributing character during *rabi*,2017-18. The results exhibited that both GCA and SCA variances were significant for all traits studied except 100 seed weight, which indicated the importance of both additive and non-additive gene action. However, the magnitude of ration of GCA variances and SCA variances was lower than unity for all characters except days to maturity indicating predominance of non-additive gene action. Among the parents, RHA-138-2, CSFI-99and P-93-Rwere found to be best general combiners for seed yield and yield contributing characters. The combination, CSFI 99 x P 93-R recorded high *per se* performance for significant SCA effects and high GCA effects of both or at least one parents(HxH, HxH & LxH) with significant heterosis for seed yield, 100 seed weight and head diameter, respectively. The crosses, CSFI- 99 x R-271-1 for seed yield per plant, and RHA 138-2 x GP 6-263 for head diameter also exhibited high *perse*, significant SCA effects and high GCA effects of both or at least one parents. This indicating additive x additive effect are fixable component and single plant selection would be desirable in segregating generation at least for these characters and utilized in transgressive breeding.

Keywords

Combining ability, heterosis, half diallel, sunflower, restorer lines

Introduction

Sunflower (*Helianthus annuus* L.) is an important annual oilseed crop grown all over the world for its good quality edible oil source extracting from its seed. The sunflower seed contains 40-45 per cent of good quality oil by weight and high amount of quality protein (20%) in cake. The heterosis of sunflower has been practically applied after discovery of the cytoplasmic male sterility - restoration of fertility genetic system. The first stable source of cytoplasmic male sterility (CMS) was discovered by Leclercq (1969). The ideal method to develop new restorer line (R line) is by crossing R x R lines from restorer gene pools, which are already identified for fertility restoration in sunflower (Dudhe *et al.,* 2011). Combining ability analysis provides information on the nature and magnitude of gene effects on yield and yield attributing characters. This analysis helps in identification of the potential parents and superior cross combinations. Hence, the present investigation was planned to identify best R x R crosses from already identified best restores along with elite restorers from the maintained restorer gene pool by using half diallel method in sunflower.

Materials and Methods

Eight diverse restorer lines (R lines) *viz* EC-494430, EC-210309, TSG-104, CSFI-99, RHA-138-2, R-271-1, P-93-R, GP-6-263 were crossed in half diallel manner to obtained 28 hybrids during the *summer*, 2016-17 and these 28 F_1 crosses were evaluated along with their parents and two checks *viz* LSFH-35 and SS-2038 during the *rabi*, 2017-18 using Randomized Block Design with two replications at Oilseeds Research Station, Latur. The F_1s, parents and checks were raised in pair row plot of 3 m length by adopting 60 x 30 cm spacing. Recommended agronomical practices are adopted. The data were collected on yield and yield attributing characters *viz.*, for days to 50 per cent flowering, plant height(cm), days to maturity, hull content(%), oil content(%), 100 seed weight(gm), head diameter(cm), volume weight(g/100ml), seed filling(%) and seed yield per plant(gm). The analysis of variance was carried out by the method as proposed by Panse and Sukhatme (1985). The data were analyzed by using Griffings (1956) method-I of model-II statistical method.

Results and Discussion

The analysis of variance for 10 characters (Table 1) revealed significant difference between parents indicating wide diversity in the materials. The mean sum of square due to hybrids was highly significant for all traits indicating the diverse performance of different cross combinations. The parents vs. hybrids mean sum of square were highly significant for all traits except days to maturity and volume weight revealing the presence of heterosis due to the significant difference in the mean performance of hybrids vs. parents. Significant variances due to genotypes, parents, hybrids and parents vs. hybrids were also reported by Machikowa *et al.,* (2011) and Deengra *et al.,* (2012). The analysis of variance for combining ability revealed the mean sum of square of GCA and SCA were highly significant, it indicates importance of both additive and non-additive gene actions in controlling these traits. The ratio between GCA/SCA variances indicated the predominance of non-additive gene action for all characters except days to maturity, were also reported by Asif *et al.,* (2013) and Shinde *et al.,* (2016). In the present investigation among the parents, CSFI 99, P 93-R and EC 210309 recorded significant positive GCA effects for seed yield per plant and 100 seed weight (Table 2). The parents, RHA 138-2and P 93- R also exhibited significant positive GCA effects for head diameter in addition to seed yield and oil content. The parent, TSG 104 and RHA 138-2 exhibited significant positive GCA effects for volume weight, oil content and significant negative GCA effects for hull content. Similar results reported by Ingle *et al.,* (2015) and Shinde *et al.,* (2016). EC 494430 and EC 210309 for days to maturity and TSG 104 for days to 50 % flowering recorded negative significant GCA effects. For plant height negative significant GCA effects were recorded by R 271-1, P 93-Rand CSFI 99.Similar results were also reported by Asif *et al.,* (2013) and Ingle *et al.,* (2015). The parent P 93-R recorded superior per se performance and good GCA effects for seed yield, 100 seed weight, head diameter, oil content and plant height. Thus, close relation between GCA and *per se* performance could be used as criteria to select the parents involve the min breeding programme, was reported by Shinde *et al.,* (2016).

Table.1 Analysis of variances for combining ability analysis for 10 characters in sunflower

Source of variance	D.F.	Days to 50% flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Seed filling (%)	100 seed weight (g)	Volume weight (g/100ml)	Hull content (%)	Oil content (%)	Seed yield / plant (g)
Replications	1	2.42	1.28	625.99*	1.56	2.42	0.18	20.48	0.41	0.02	0.001
Treatments	35	27.54**	8.65**	1045.41**	6.18**	29.10**	1.35**	39.24**	51.45**	5.86**	128.82**
Parents	7	17.26*	7.41**	1555.53**	8.46**	19.93**	1.37**	17.81*	38.56**	2.91**	52.26**
Hybrids	27	28.28**	9.20**	726.12**	5.32**	30.53**	1.37**	45.71**	54.70**	6.50**	150.52**
Parents vs. Hybrids	1	79.29**	2.41	6095.48**	13.39**	54.65**	0.81*	14.33	53.91**	9.28**	79.07**
Error	35	5.54	0.60	143.37	0.56	5.54	0.11	6.18	1.11	0.22	4.02
GCA	7	39.63**	16.34**	829.41**	4.82**	39.81**	1.44	26.653**	20.53**	5.526**	82.43**
SCA	28	7.30**	1.32**	446.03**	2.65**	8.23**	0.48	17.863**	27.02**	2.284**	59.91**
Error	35	2.77	0.30	71.69	0.28	2.77	0.05	3.09	0.55	0.113	2.01
GCA/SCA Ratio		0.81	1.57	0.20	0.19	0.67	0.32	0.15	0.07	0.24	0.13

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

Table.2 Estimates of general combining ability effects for different characters in sunflower

Sr. No	Parents	Days to 50% flowering	Days to maturity	Plant Height (cm)	Head diameter (cm)	Seed filling (%)	100-seed weight (g)	Volume weight (g/100ml)	Hull content (%)	Oil content (%)	Seed yield/ plant (g)
1	EC-494430	-0.97	-2.37**	-3.90	-0.93**	0.75	-0.23**	-2.54**	2.86**	-0.12	-1.88**
2	EC-210309	-0.94	-1.67**	1.19	-0.26	0.18	0.35**	0.65	1.01**	-1.30**	0.95*
3	TSG-104	-4.19**	0.63**	-1.02	-1.01**	-4.87**	-0.72**	1.07*	-0.90**	0.77**	-6.17**
4	CSFI-99	2.01**	1.16**	-7.30**	0.01	1.33*	0.28**	0.80	-1.35**	0.40**	2.90**
5	RHA-138-2	1.107*	0.55**	10.06**	0.46**	0.73	-0.14*	2.24**	-1.30**	0.61**	1.86**
6	R-271-1	1.174*	0.58**	-8.12**	0.29	0.79	0.20**	0.60	0.32	-0.53**	0.08
7	P-93-R	0.805	0.59**	-7.72**	0.90**	0.43	0.37**	-1.94**	0.16	0.84**	1.73**
8	GP-6-263	1.01*	0.49**	16.81**	0.54**	0.63	-0.11	-0.88	-0.80**	0.13	0.51
	SE(m) (gi)	0.49	0.16	2.50	0.51	0.49	0.07	0.52	0.22	0.09	0.41
	SE(m) (gi-gj)	0.74	0.24	3.78	0.23	0.74	0.10	0.78	0.33	0.15	0.63

Table.3 Estimates of specific combining ability effects of crosses for 12 different characters in sunflower

Sr. No	Crosses	Days to 50% flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Seed filling (%)	100 seed weight (gm)	Volume weight (gm/ 100ml)	Hull content (%)	Oil content (%)	Seed yield / plant (gm)
1	EC-494430 x EC-210309	-1.74	0.64	4.36	-0.82	-2.67	-1.12**	5.23**	1.80**	-2.85**	-7.25**
2	EC-494430 x TSG-104	-1.07	-0.90	-9.41	-0.37	-0.20	0.06	4.49**	-7.27**	0.38	-1.59
3	EC-494430 x CSFI-99	-0.24	-0.91	12.37	-0.19	0.62	-0.69	-5.72**	2.14**	-1.80**	-2.58
4	EC-494430 x RHA-138-2	3.02	-0.39	-13.49	0.17	3.58**	1.25**	0.65	1.79**	1.30**	1.34
5	EC-494430 x R-271-1	-3.51*	-1.86**	-7.48	-0.47	-2.95	0.19	-6.03**	-5.51**	-0.81**	-1.22
6	EC-494430 x P-93-R	-0.20	-0.73	10.45	0.77	0.36	-0.43	-1.15	2.35**	-0.009	2.79*
7	EC-494430 x GP-6-263	-2.34	-0.29	-3.74	0.33	-1.77	0.26	4.28**	4.14**	0.53	6.68**
8	EC-210309 x TSG-104	-3.49*	-0.95	-11.84	-0.94	-5.02**	-0.17	-2.22	9.45**	-0.34	-4.57**
9	EC-210309 x CSFI-99	-3.24*	-1.27**	-10.06	-0.99	-4.77**	-0.90*	5.99**	4.86**	-1.76**	-9.23**
10	EC-210309 x RHA-138-2	0.57	-0.98	-4.42	-1.16**	1.74	0.69	-1.03	-7.19**	-2.19**	11.71**
11	EC-210309 x R-271-1	-0.88	-0.67	6.25	0.71	0.28	0.02	-3.39	-6.65**	0.43	-4.67**
12	EC-210309 x P-93-R	-0.38	-1.75**	0.18	-1.56**	0.78	0.28	-4.67**	3.50**	-0.76**	-0.93
13	EC-210309 x GP-6-263	1.14	1.59**	18.65**	2.03**	2.31	-0.09	-0.91	3.33**	-2.24**	12.70**
14	TSG-104 x CSFI-99	1.72	0.80	10.98	1.54**	1.98	-0.38	-2.00	0.61	0.01	3.73**
15	TSG-104 x RHA-138-2	-1.38	0.81	11.28	1.58**	-1.41	-0.72	8.21**	-3.27**	-0.79**	-3.26**
16	TSG-104 x R-271-1	3.51*	0.25	31.97**	1.90**	3.48*	0.77	0.18	-2.74**	1.22**	6.18**
17	TSG-104 x P-93-R	-6.70**	0.59	29.90**	0.15	-6.73**	-0.44	-2.76	-0.57	0.70*	-5.91**
18	TSG-104 x GP-6-263	0.13	0.06	34.36**	1.00	0.10	-0.17	-2.66	6.21**	0.56	-0.06
19	CSFI-99 x RHA-138-2	-1.34	-0.64	8.90	0.07	-1.37	0.11	1.80	0.51	1.41**	-1.38
20	CSFI-99 x R-271-1	1.04	0.50	4.58	2.04**	1.01	0.94**	3.46*	3.54**	1.31**	14.04**
21	CSFI-99 x P-93-R	1.54	-0.10	14.51	1.79**	1.51	1.09**	-2.74	4.70**	-0.21	14.65**
22	CSFI-99 x GP-6-263	2.22	1.10*	28.48**	1.64**	2.18	-0.08	1.11	-5.16**	0.49	3.23**
23	RHA-138-2 x R-271-1	-2.91	-0.50	7.22	-0.83	-3.25*	-0.44	-2.15	3.82**	-0.73**	-3.80**
24	RHA-138-2 x P-93-R	0.71	0.64	0.98	0.13	0.37	-0.18	-1.76	-1.18	0.36	0.40
25	RHA-138-2 x GP-6-263	-3.34*	1.42**	7.45	2.16**	-3.67**	0.46	-0.83	7.61**	0.53	9.49**
26	R-271-1 x P-93-R	-0.61	0.28	15.50	-0.49	-0.94	-0.77	4.70**	5.50**	-0.03	-5.55**
27	R-271-1 x GP-6-263	0.01	0.64	-21.52**	-3.95**	-0.31	-1.54**	1.14	-3.00**	-0.57	-14.06**
28	P-93-Rx GP-6-263	2.04	0.48	-38.76**	0.27	1.71	0.39	-7.79**	-10.37**	0.46	-5.16**
	SE(m) (Sij)	1.50	0.50	7.67	0.48	1.50	0.22	1.59	0.67	0.30	1.28
	SE(m) (Sij-Sik)	2.23	0.74	11.35	0.71	2.23	0.32	2.35	0.99	0.45	1.90
	SE(m) (Sij-Skl)	2.10	0.69	10.70	0.67	2.10	0.30	2.22	0.94	0.42	1.79

Table.4 Performance of best cross combinations for per *se*, SCA effects, standard heterosis and GCA effect

Sr. N	Character	Best specific combinations	Per se	SCA effect	Standard heterosis		GCA effect
					SS-2038	LSFH-35	
1	**Days to 50%flowering**	TSG-104 x P-93-R	62.76	-6.70**	-18.20 **	-16.87 **	H x L
		EC-210309 x TSG-104	64.22	-3.49**	-16.29 **	-14.93 **	L x H
		EC-494430 x TSG-104	66.61	-1.07	-13.17 **	-11.76 **	L x H
2	**Days to maturity**	EC-494430 x R-271-1	91.36	-1.86**	-2.64 **	-1.85 *	H x L
		EC-494430 x EC-210309	91.62	0.64	-2.37 **	-1.57	H x H
		EC-210309 x P-93-R	92.19	.1 75**	-1.76 *	-0.96	H x L
3	**Plant Height (cm)**	P-93-R x GP-6-263	157.17	-38.76**	-18.43 **	-11.95	H x L
		EC-494430 x R-271-1	167.33	-7.48	-13.15 *	-6.26	L x H
4	**Head diameter (cm)**	RHA-138-2 x GP-6-263	15.40	2.16**	24.85 **	16.05 **	H x H
		CSFI-99 x P-93-R	14.95	1 79**	21.20 **	12.66 *	L x H
		CSFI-99 x R-271-1	14.59	2.04**	18.24 **	9.91	L x L
		EC-210309 x GP-6-263	14.55	2.03**	17.96 **	9.65	L x H
		CSFI-99 x GP-6-263	14.43	1.64**	17.02 **	8.78	L x H
5	**Seed filling (%)**	EC-494430 x RHA-138-2	79.01	3.58**	2.98	4.66	L x L
		CSFI-99 x GP-6-263	78.10	2.18	1.79	3.44	H x L
		CSFI-99 x P-93-R	77.22	1.51	0.65	2.28	H x L
		CSFI-99 x R-271-1	77.08	1.01	0.47	2.10	H x L
6	**100 Seed weight (g)**	CSFI-99 x P-93-R	6.16	1.09**	8.54	31.59 **	H x H
		CSFI-99 x RHA-138-2	5.33	0.11	-17.87 **	-0.43	H x L
7	**Volume weight (g/100ml)**	TSG-104 x RHA-138-2	39.50	8.21**	9.25 **	51.92 **	H x H
		EC-210309 x CSFI-99	35.33	5 99**	-3.38 *	35.88 **	L x L

Table.4 Performance of best cross combinations for per *se*, SCA effects, standard heterosis and GCA effect

Sr. No	Character	Best specific combination	Per se performance	SCA effect	Standard heterosis		GCA effect
					SS-2038	LSFH-35	
		CSFI-99 x R-271-1	32.83	3.46*	8.54 **	26.29 **	L x L
		CSFI-99 x RHA-138-2	31.33	1.80	12.42 **	26.23 **	L x H
8	**Hull content (%)**	P-93-R x GP-6-263	24.47	-10.37**	-25.98 **	-40.03 **	L x H
		EC-210309 x RHA-138-2	28.00	.7 19**	-15.32 **	-31.39 **	L x H
		CSFI-99 x GP-6-263	28.16	-5.16**	-14.82 **	-30.99 **	H x H
		EC-494430 x TSG-104	30.17	-7.27**	-8.76 **	-26.07 **	L x H
		EC-210309 x R-271-1	30.17	-6.65**	-8.77 **	-26.08 **	L x L
		TSG-104 x R-271-1	32.17	-2.74**	-2.72	-21.18 **	H x L
9	**Oil content (%)**	TSG-104 x P-93-R	36.92	0.70*	8.02 **	14.62 **	H x H
		RHA-138-2 x P-93-R	36.42	0.36	6.55 **	13.07 **	H x H
		EC-494430 x RHA-138-2	36.39	0.38	6.47 **	12.98 **	L x H
		CSFI-99 x RHA-138-2	36.21	1.41*	5.94**	12.42 **	L x H
10	**Seed yield per plant (g)**	CSFI-99 x P-93-R	37.83	14.65*	51.86 **	71.04 **	H x H
		CSFI-99 x R-271-1	35.59	14.04**	42.83 **	60.87 **	H x L
		EC-210309 x RHA-138-2	33.09	11.71**	22.10 **	37.52 **	H x H
		EC-210309 x GP-6-263	32.72	12.70**	31.33 **	47.92 **	H x L
		RHA-138-2 x GP-6-263	30.42	9 49**	32.79 **	49.57 **	H x L

According to Sprague and Tatum (1942) the SCA is controlled by non-additive gene action. Among 28 crosses, positive significant SCA effects for seed yield per plant, head diameter and 100 seed weight were observed in the cross, CSFI 99 x P 93-R and CSFI 99 x R 271-l.For seed yield per pant, head diameter, seed filling percent and oil content positive significant SCA effects were recorded in the cross, TSG 104 x RHA 271-1. Significant SCA effect for seed yield was also recorded by RHA 138-2 x GP 6-263, EC 210309 x GP 6-263, EC 210309 x RHA 138-2 and EC 494430 x GP 6-263. Positive and significant SCA effect for oil content was exhibited by CSFI 99 x RHA 138-2 and EC 494430 x RHA 138-2. Similar findings were reported by Binodh *et al.*, (2008).

Among the crosses, EC 494430 x TSG 104 and EC 494430 x R 271-1 recorded negative SCA effect for days to 50 % flowering, days to maturity and hull content, whereas, cross combination R 271-1 x GP 6-263 and P 93-R x GP 6-263 also exhibited significant negative SCA effects for plant height and oil content. The results are in the harmony of Ingle *et al.*, (2015) and Shinde *et al.*, (2016). The hybrid, TSG 104 x R 271-1 had negative SCA effect for hull content and positive SCA effect for oil content. It indicates negative correlation was between these traits.

The results of selected crosses (R x R) showing high *per se* performance, SCA and GCA effect and standard heterosis for various characters are presented in Table 4. The high x high GCA effects with high *per se*, significant SCA effects, significant standard heterosis in desirable direction were observed for seed yield per plant (CSFI 99 x P 93-R and EC 210309 x RHA 138-2), 100 seed weight (CSFI 99 x P 93-R), head diameter (RHA 138-2 x GP 6-263) indicating additive x additive effects are fixable component and single plant selection would be desirable in segregating generation at least for these characters and utilized in transgressive breeding. Similar results were obtained by Shinde *et al.*, (2016) and Dudhe *et al.*, (2011)

Significant GCA effects in any one of the parents and negative or non-negative significant effects on the another parents leading to high *per se*, significant SCA effects, standard heterosis were exhibited for seed yield per plant (CSFI 99 x R 271-1, RHA 138-2 x GP 6-263 and EC 210309 x GP 6-263), head diameter (EC 210309 x GP 6-263, CSFI 99 x GP 6-263 and CSFI 99 x P 93-R) and oil content (EC 494430 x RHA 138-2). The few hybrids showed high *per se*, significant SCA effects and heterosis with low x low or high x low GCA effects for plant height. This indicated the presence of additive and dominance type of gene action for these characters. The performance of these crosses needs to be critically evaluated over different seasons and locations to confirm their superiority and stability. Similar finding was reported by Binodh *et al.*, (2008)

The remaining best cross combinations for plant height, head diameter, oil content, showed high *per se*, significant SCA effect and standard heterosis with low x low GCA effects indicating over dominance and epistatic interactions. These could be because of correlation of undesirable effect. In such combinations, to obtain better segregation, selection may be postponed to latter generation to develop high yielding restorers. Similar results were obtained by Shankar *et al.*, (2007).

Thus, on the basis of GCA effects, the parents, P 93-R, RHA 138-2 and CSFI 99 could be batter choice for improvement for yield and its component traits through hybridization. The crosses, CSFI 99 x P 93-R, CSFI 99 x R 271-1 and EC 210309 x GP 6-263 had highly significant SCA effects for seed yield per plant and most of its components in addition to high GCA effects of both or at least one parents with high per se and standard heterosis over both the checks. These promising R x R crosses can be used for the development of new R lines in sunflower.

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