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Study of combining ability analysis and gene action in sunflower (*Helianthus annuus* L.)

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Abstract
The current study was conducted from *Kharif* 2016 to 2018 at the Oilseed Research Station in Latur, Maharashtra. Six lines and six restorers make up the experimental material. These were crossed in a Line x Tester method to create 36 hybrids. In Kharif 2018, at the Oilseeds Research Station in Latur, the entire collection of experimental material consisting of 50 genotypes six CMS lines, six restorers, thirty-six hybrids, and two standard checks was sown in a Randomised Block Design with two replications. The morphological observations on ten quantitative parameters were recorded: hull content (%), seed yield per plant (g), days to 50% flowering, days to maturity, plant height (cm), head diameter (cm), seed feeling (%), 100-seed weight (g), volume weight (g100/ml), and oil content (%).The lines CMS249A and CMS-2A and CMS-234A were found to be good general combiners for seed yield per plant and oil content percentage, respectively. SCG-04 and EC-601951 were two of the testers that performed well overall for seed output per plant. Hetrosis breeding should be encouraged because the majority of crossings had strong positive sca effects for numerous traits, showing a preponderance of non-additive gene activity.

Keywords: Ability analysis, gene action, *Helianthus annuus* L.

Introduction

Sunflower (*Helianthus annuus* L.) is the fourth important oilseed crop in the world. It is a member of the Asteraceae family and genus Helianthus. Many consumers use the 38%–42% edible oil found in sunflower seeds for confections. Compared to other vegetable oils, sunflower oil is regarded as premium edible oil due to its light yellow colour, high smoke point, and high concentration of linoleic acid (between 55% and 60%). Perhaps most importantly, though, is that it has no flavor. Therefore, it does not provide flavor to the meal when cooking. In 1969, sunflower was brought to India from Russia because to its many benefits, including photo insensitivity, greater flexibility over a wide range of environments, short growing season, and superior cooking oil quality. Possessing a high seed multiplication ratio and, more significantly, a high amount of polyunsaturated fatty acids (PUFA). However, the introduction of Russian variety in 1972 marked the beginning of the large-scale cultivation of sunflowers in India. In India, sunflower was grown on 0.66 lakh hectares in 2022–2023, and it is currently grown on 550,000 hectares, yielding 335,000 tonnes of production and 0.64 tonnes of productivity per hectare, respectively (Anonymous, 2018) [3, 4]. With an output of 210,000 tonnes and a yield of 0.57 tonnes per ha in Karnataka, it covers an area of roughly 3,60,000 hectares (Anonymous, 2017) [2]. West Bengal, Maharashtra, and Madhya Pradesh are excellent states to cultivate sunflowers (Dutta, 2011) [11]. In terms of importance as a source of edible oil, sunflower is ranked fifth in India behind soybean, mustard, peanut, and sesame. Maharashtra produces 16.6 thousand tonnes of sunflowers annually on 25.7 thousand hectares with a productivity of 646 kg/ha (2016–17). In the domain of sunflower cultivation, production, and productivity, market prices and both biotic and abiotic stressors directly control and influence the oscillation moments. (Anonymous, 2017–2018) [3, 4].

Materials and Methods

The current study was conducted from *Kharif* 2016 to 2018 at the Oilseed Research Station in Latur, Maharashtra. Six lines and six restorers make up the experimental material. These were crossed in a Line x Tester method to create 36 hybrids. In *Kharif* 2018, at the Oilseeds Research Station in Latur, the entire collection of experimental material consisting of 50 genotypes six CMS lines, six restorers, thirty-six hybrids, and two standard checks was sown in a Randomized Block Design with two replications. A single, 4.5-meter-long row with a 60-centimeter gap between rows and a 30-centimeter gap between plants made up each plot. To prevent the border effect, border rows were planted on all sides of the experimental area. Every suggested agronomic cultural strategy, such as plant protection techniques and application. To grow healthy plants, all advised agronomic cultural practices such as plant protection measures, fertilizer treatment at the required rate, weeding, and irrigation were carried out on schedule and over the entire plot. By randomly choosing three plants from each plot and replication, the morphological observations on ten quantitative characters days to 50% flowering, days to maturity, plant height (cm), head diameter (cm), seed filling (%), 100-seed weight (g), volume weight (g100/ml), hull content (%), seed yield per plant (g), and oil content (%) were recorded. The process described by Sprague and Tatum (1942) [31] for integrating ability analysis and determining the relevance of various genotypes is the foundation for the results.

Results and Discussion

By identifying superior parents for upcoming hybridization programmes and particular cross combinations that is, superior crosses for enhancing yield and yield-contributing traits the study of combining ability can be used for a variety of breeding objectives. In the current work, 36 hybrids were synthesized using six cytoplasmic male sterile (CMS) lines and six fertility restorer lines, respectively, as the male and female parents. The combining ability analysis of variance (ANOVA) showed that the hybrids average performance differed from the parents' as evident for the significance of the parents vs. crosses, which indicate that the hybrids mean performance differed from the parents, indicating the presence of heterosis (Table 1). (Parmeswari *et al.*, 2004; Jeena and Sheikh 2004; Rahman *et al.*, 2006; Halaswamy *et al.*, 2004; and Ravi Rana *et al.*, 2004) [24, 14, 28, 13, 29].

Table 1: Analysis of variance for line x tester for 10 characters in Sunflower.

Sources	d.f	Days to 50% Flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Seed yield/plant (g)	Seed filling (%)	100 seed weight (g)	Volume weight (g/100 ml)	Hull content (%)	Oil content (%)
Replicates	1	9.389	1.125	73.003	1.073	22.501**	25.992*	0.720	5.407	16.103	1.590
Crosses	35	33.729**	6.785**	248.293	7.788**	95.816**	46.760**	0.532	18.366**	41.019**	19.850**
Line	5	154.30**	16.71**	371.901	20.760*	290.79**	63.204	0.876	23.693	48.682	35.597
Tester	5	14.133	10.647*	464.909	6.115	92.154	122.89**	0.527	14.447	30.856	9.718
Line x Tester	25	13.533**	4.027	180.249	5.528**	57.552**	28.244**	0.464	18.084*	41.518**	18.726**
Error	35	2.789	2.982	252.512	1.539	2.739	5.161	0.402	8.084	5.708	1.644

*and **Significant at 5% and 1% level respectively.

A crucial component of any hybridization programme is parent selection. The most important step in the hybridization process is the selection of parents with different phenotypes. Parental phenotypes in quantitatively inherited traits make it challenging to forecast how well the parents will combine, increase variability, and pass on the desired gene combination to the progeny. Such predictions are now easily attainable thanks to recent advancements in biometrical genetics. Among the popular biometric techniques for choosing the correct parents are multivariate analysis (Murty and Arunachalam, 1966) [19] and combining ability analysis (Sprague and Tatum, 1942, Jinks and Hayman, 1953) [31, 15].

The magnitude of specific combining ability changes was found to be greater than the general combining ability for all parameters, with the exception of days to 50% flowering, days to maturity, and plant height. The ratio of δ2gca/δ2sca was less than unity, indicating a predominance of non-additive gene activity, except for days to 50% flowering and days to maturity. δ2gca/δ2sca ratios were less than 1 for the following: plant height (-2.3797), head diameter (0.3388), seed yield/plant (0.4046), seed filling (0.4890), volume weight (0.0147), 100 seed weight (0.2444), hull content (-0.0082), and oil content (0.0394). The ratio δ2gca/δ2 sca was larger than 1 for attributes days to 50% blooming (1.1654) and days to maturity (1.7405), indicating the presence of additive gene activity (Table 2.)

Table 2: Estimation of gene action (var.gca and var.sca) for 10 characters in Sunflower

Sr. no.	Character	Variance gca	Variance sca	Ratio var.gca/var.sca	Gene action
1	Days to 50%flowering	5.8903**	5.0543**	1.1656	Additive
2	Days to maturity	0.8044**	0.4622	1.7405	Additive
3	Plant height (cm)	19.8464**	-8.3399	-2.3797	Non-additive
4	Head diameter (cm)	0.6591**	1.9453**	0.3388	Non-additive
5	Seed yield/plant (g)	11.1603**	27.5816**	0.4046	Non-additive
6	Seed filling (%)	5.4005**	11.0442**	0.4890	Non-additive
7	100-seedweight (g)	0.0198*	0.0809	0.2444	Non-additive
8	Vol. weight (g/100ml)	0.0822	5.5767**	0.0147	Non-additive
9	Hull content (%)	-0.1458	17.7630**	-0.0082	Non-additive
10	Oil content (%)	0.3276*	8.3069**	0.0394	Non-additive

*and **Significant at5% and1% level respectively.

Table 3: per cent contribution of lines, testers and their interaction (L x T) to hybrid sum of squares in Sunflower.

Characters	Lines	Testers	Line x Testers
Days to 50% flowering	65.3537%	5.9862%	28.6602%
Days to maturity	35.1892%	22.4165%	42.3943%
Plant height (cm)	21.3976%	26.7489%	51.8536%
Head diameter (cm)	38.0803%	11.2168%	50.7029%
Seed yield/plant (g)	43.3566%	13.7398%	42.9037%
Seed filling (%)	19.3094%	37.5461%	43.1446%
100-seed weight (g)	23.5109%	14.1570%	62.3321%
Volume weight (g/100ml)	18.4299%	11.2378%	70.3323%
Hull content (%)	16.9546%	10.7463%	72.2991%
Oil content (%)	25.6192%	6.9939%	67.3869%
Pollen viability (%)	19.8718%	5.4554%	74.6728%

**and *indicates significant at 1% and 5%, respectively

Per cent contribution of lines, testers and their interaction (L x T) are presented in table 3. The contribution of tester is higher for the characters viz., Days to maturity, Plant height (cm), Head diameter (cm), Seed yield/plant (g), Seed filling (%),Volume weight (g/100ml) and 100-seed weight (g). the contribution of lines and Line x Testers interaction is higher for all the characters.

The perusal gca effects of 12 parents (6 CMS lines and 6 testers) for 10 traits indicated that the CMS 2A was good general combiner for Head diameter (cm) (1.537**), Seed filling (%) (1.787*), volume weight (2.358**), Oil content (%) (1.506**) exhibiting significant gca effects in positive direction and CMS-249A is also found to be good general combiner for Seed yield/plant (g) (9.170**) in positive direction and significant but in negative direction for Volume weight (g/100ml) (-1.642*), Hull content (%) (-2.095**). CMS 234A was good general combiner for Plant height (cm) (8.568*), Seed filling (%) (2.939**) and oil content (1.886**) (Table 4.).

Among the testers, SCG-04 was good general combiner for seed yield (3.779**), seed filling (5.514) and Volume weight (g/100ml) (1.603*). The restorer line EC-601951 is good general combiner for Head diameter (cm) (1.089**) and seed yield (2.602**). The restorer line LTRR-314 was good general combiner for most of the character but in negative direction. The restorer lines EC-601747 and EC-279309 both are good general combiner for hull content% in positive direction. The restorer line RHA-1-1 was good general combiner for Oil content (%) (1.558**) (Table 5).

Table 4: Estimates of general combining ability (GCA) effect of lines for 10 characters in Sunflower.

Characters	CMS-2A	CMS-249A	CMS-10A	CMS-17A	CMS-207A	CMS-234A
Days to 50% flowering	-1.833**	-0.333	0.583	6.083**	0.333	-4.833**
Days to maturity	-1.097*	-1.014	-0.597	1.736**	1.153*	-0.181
Plant height (cm)	-0.186	3.847	-6.581	-0.892	-4.755	8.568*
Head diameter (cm)	1.537**	0.721	0.616	-1.551**	0.367	-1.688**
Seed yield/plant (g)	-1.344**	9.170**	0.181	-5.348**	-2.576**	-0.083
Seed filling (%)	1.787*	-0.977	0.538	-3.570**	-0.717	2.939**
100 seed weight (g)	0.297	-0.173	0.307	-0.381*	0.029	-0.079
Volume weight (g/100 ml)	2.358**	-1.642*	-0.465	0.501	-1.034	0.282
Hull content (%)	-0.986	-2.095**	-2.104**	2.342**	2.119**	0.724
Oil content (%)	1.506**	0.666	-0.503	-0.779	-2.776**	1.886**

Table 5: Estimates of general combining ability (GCA) effect of testers for 10 characters in Sunflower.

Characters	SCG-04	EC-601951	LTRR-314	EC-601747	EC-279309	RHA-1-1
Days to 50% flowering	-0.083	1.000	-1.750**	1.250*	-0.500	0.083
Days to maturity	-0.181	0.569	-1.764**	0.653	-0.014	0.736
Plant height (cm)	-6.481	3.954	-8.311*	1.344	1.575	7.919
Head diameter (cm)	-0.843*	1.089**	0.422	0.109	-0.105	-0.672
Seed yield/plant (g)	3.779**	2.602**	-2.994**	-2.268**	-1.701**	0.582
Seed filling (%)	5.514**	-0.085	-2.388**	0.969	-0.256	-3.754**
100-seed weight (g)	-0.357*	0.018	0.045	0.291	0.055	-0.051
Volume weight (g/100 ml)	1.603*	-0.240	0.175	0.400	-0.154	-1.783*
Hull content (%)	0.159	-1.435	-0.461	1.600*	2.067**	-1.930**
Oil content (%)	0.323	-0.739	0.212	-0.599	-0.754	1.558**

**and *indicates significant at 1% and 5%, respectively

Among the hybrids, five hybrids shows positive significant sca effects for days to 50% flowering (CMS 2A x RHA-1-1, CMS 10A x EC-279309, CMS 17A x EC-601951, CMS 17A x EC-601747, CMS207A x LTRR-314). Most of the hybrids show negative sca effects for days to maturity and plant height. For head diameter three hybrids (CMS 2A x EC 601747, CMS249A x EC-279309, CMS234A x SCG-04) shows positive significant sca effects and two hybrids (CMS2A x EC-279309, CMS10A x SCG-04) shows negative significant sca effects. Eight hybrids for seed yield per plant, three hybrid for seed filling%, four hybrids for Volume weight (g/100ml), three hybrids for Hull content (%) and seven hybrids for Oil content (%) are showing positive significant sca effects. (Table 6.) this results conforms with Chandrakala *et al*. (2016) [10], Nichal *et al*. (2017) [21].

Table 6: Estimates of specific combining ability (SCA) effects for ten characters in Sunflower.

Sr. no.	Characters	Days to 50% flowering	Days to maturity	Plant height (cm)	Head diameter (cm)	Seed yield/plant (g)	Seed filling (%)	100-Seed weight (g)	Volume weight (g/100 m)	Hull content (%)	Oil content (%)
	Crosses	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	CMS 2A x SCG-04	-2.333	0.264	1.972	-1.381	-10.237**	0.476	0.054	-0.200	0.494	2.726*
2	CMS 2A x EC601951	0.083	0.014	14.698	0.938	-2.661*	-0.175	-0.531	-0.846	3.307	1.637
3	CMS 2A x LTRR-314	1.333	-1.653	-17.217	1.605	-6.234**	-4.622*	-0.333	-5.971**	1.894	-4.194**
4	CMS 2A x EC 601747	-1.167	1.431	-1.437	2.918**	13.880**	4.231*	0.536	5.874**	-5.498**	1.328
5	CMS2A x EC-279309	-1.417	-0.903	3.081	-3.868**	-0.297	1.246	-0.238	0.367	1.805	-2.018
6	CMS 2A x RHA-1-1	3.500*	0.847	-1.098	-0.212	5.549**	-1.156	0.513	0.776	-2.002	0.521
7	CMS249A x SCG-04	-0.333	0.681	-0.761	0.685	6.408**	-4.859**	-0.196	-2.980	4.492*	-1.004
8	CMS249A x EC-601951	0.083	-2.569*	-6.745	-1.747	4.945**	-5.986**	0.014	2.524	-1.815	-1.893
9	CMS249A x LTRR-314	-0.667	-1.236	6.265	1.416	-0.948	3.742*	0.202	1.979	-5.668**	3.546**
10	CMA249A x EC-601747	-0.667	0.847	-4.730	-1.817	-3.399**	-1.315	-0.049	-0.596	0.890	0.508
11	CMS249A x EC-279309	1.083	2.014	-0.647	1.948*	-3.212**	8.061**	0.252	-1.073	0.689	-0.028
12	CMS249A x RHA-1-1	0.500	0.262	6.619	-0.486	-3.795**	0.358	-0.222	0.146	1.411	-1.129
13	CMS10A x SCG-04	1.750	0.264	5.197	-2.215*	-5.392**	-0.399	-0.116	2.314	-9.179**	3.534**
14	CMS 10A x EC-601951	-4.833**	1.014	-6.737	1.188	2.164	1.174	-0.381	5.107**	-6.720**	-0.614
15	CMS10A x LTRR-314	1.417	-0.653	0.028	-0.479	2.781*	1.127	0.622	-2.518	3.151	-1.236
16	CMS 10A x EC-601747	-0.583	-0.069	9.038	0.838	2.215	-3.630*	0.416	-4.073*	2.235	2.126*
17	CMS 10A x EC-279309	3.167*	0.597	0.306	1.048	-2.562*	1.696	-0.293	-1.210	7.053**	-3.799**
18	CMS 10A x RHA-1-1	-0.917	-1.153	-7.833	-0.381	0.7940	0.033	-0.247	0.380	3.460	-0.011
19	CMS 17A x SCG-04	-1.750	0.431	-7.992	0.117	1.006	0.583	0.277	0.197	2.690	4.151**
20	CMS 17A x EC-601951	3.167*	1.181	3.904	-0.145	-4.917**	3.511	-0.573	-1.920	-0.271	-1.557
21	CMS 17A x LTRR-314	-4.583**	1.014	8.509	-0.807	1.519	0.755	0.160	0.905	-0.495	-2.079
22	CMS 17A x EC-601747	4.917**	0.597	-11.981	-1.500	-2.757*	-0.453	0.309	-1.730	-1.546	-1.248
23	CMS 17A x EC-279309	0.667	-0.736	-1.548	0.549	3.506**	-5.352**	-0.150	4.784*	0.632	-1.103
24	CMS17A x RHA-1-1	-2.417	-2.486	9.108	1.786	1.643	0.956	-0.024	-2.237	-1.010	1.836
25	CMS207A x SCG-04	0.500	0.514	6.036	0.204	3.884**	3.121	0.002	1.432	3.634*	-5.433**
26	CMS207A x EC-601951	1.917	-0.236	-4.399	0.938	1.751	1.579	0.667	-2.875	4.742**	0.159
27	CMS207A x LTRR-314	2.667*	0.597	-9.134	-1.395	0.808	3.052	-0.760	1.160	1.294	-0.783
28	CMS207A x EC-601747	0.167	-1.819	-2.284	0.418	-2.758*	-4.170*	-0.516	1.055	-4.143*	-0.041
29	CMS207A x EC-279309	-3.083*	-0.153	-2.855	-0.033	-2.136	-1.829	0.060	-1.641	-6.575**	4.374**
30	CMS207A x RHA-1-1	-2.167	1.097	12.636	-0.132	-1.549	-1.752	0.546	0.868	1.048	1.722
31	CMS234A x SCG-04	2.167	-2.153	-4.452	2.589**	4.331**	1.079	-0.020	-0.764	-2.131	-3.974**
32	CMS234A x EC-601951	-0.417	0.597	-0.721	-1.172	-1.282	-0.103	0.805*	-1.990	0.757	2.267*
33	CMS234A x LTRR-314	-0.167	1.931	11.594	-0.340	2.074	-4.054*	0.109	4.445*	0.176	4.746**
34	CMS234A x EC-601747	-2.667*	-0.986	11.549	-0.340	2.074	-4.054*	0.109	4.445*	0.176	4.746**
35	CMS234A x EC-279309	-0.417	-0.819	1.662	0.357	4.701**	-3.821*	0.369	-1.227	-3.605*	2.573*
36	CMS234A x RHA-1-1	1.500	1.431	-19.432	-0.577	-2.642*	1.561	-0.566	0.067	-2.907	-2.939**

Conclusion

For the percentage of oil content and seed yield per plant, respectively, it was discovered that the lines CMS249A, CMS-2A, and CMS-234A were effective general combiners. Two of the testers that did well overall for seed yield per plant were SCG-04 and EC-601951. Most crossovers that generate significantly more seeds per plant indicate that non-additive gene activity and heterosis breeding should be promoted.

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