Heterosis and Combing Ability Studies for Yield and Yield Component Traits in Sunflower (*Helianthus annuus*)

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A B S T R A C T

Major improvement in sunflower breeding requires heterotic hybrids which can be achieved by tapping combining ability of F_1 hybrids developed from crossing of two genetically diverse female lines with male testers. In the present study, 56 hybrids were evaluated derived from four lines and fourteen testers' crosses in a line × tester mating design. The analysis of variance revealed existence of highly significant differences (p=0.05) among genotypes, parents and parents vs crosses indicating the presence of heterosis for quantitative traits in sunflower. The parental lines CMS-A6 and CMS-A2 and testers DOR-R3 and R-1F proved to be good combiners having the highest positive General Combining Ability (GCA) effect for yield (5.491**) and yield components traits and negative effect for days to 50% flowering (-1.482**) and plant height (-15.71**). The crosses CMS-A5 x R-103, CMS-A6 x R-103, CMS-A6 x R-7 and CMS-A1 x RGM-49 are promising hybrid combinations for seed yield as indicated by significant Specific Combining Ability (SCA) effects. These identified four hybrids can be taken to multi-location trials for further evaluation.

Introduction

Sunflower is highly cross pollinated crop and the main objective of sunflower breeding is to develop high yielding hybrid cultivars with stable and high yield through exploitation of heterosis. Sunflower hybrids are highly self-fertile with better yielding capacity and more uniform in days to maturity (Seetharam, 1977; Kaya and Atakisi, 2004). Sunflower hybrids are genetically homogenous and uniform in plant height and growing period, resulting in decreased harvest losses. Another important advantage of hybrids over variety is easier insertion of genes for resistance to the most important sunflower diseases *viz.*, *Alternaria* leaf spot, and powdery mildew.

Hybrid breeding programme in sunflower started with an aim to exploit the advantages of inter-allelic and intra-allelic interactions. However, crossing any two lines does not necessarily cause heterosis, since lines can be genetically related. Hence, it is prerequisite to estimate combining ability of all inbred lines before involving them in hybrid breeding programme.

In sunflower, heterosis breeding evolved successfully as the detection of cytoplasmic male sterility source (Leclercq, 1969) and fertility restoration (Kinman, 1970) that gave the required vigour to commercial hybrid seed

production. In heterosis breeding programme, the selection of inbreds with good combining ability is very important for superior hybrid production. The estimation of general and specific combining ability helps to identify the potential parents in superior hybrid production for seed yield and oil contents. The line x tester analysis has been widely used for combining ability tests (Singh and Chaudhary, 1984, Patil *et al.,* 2012) and an efficient method to assess the large number of inbreds as it provides the information on the relative importance of general combining ability effects and specific combining ability effects for yield and yield component traits.

To initiate hybrids breeding programme it is prerequisite to develop inbred lines with good combining ability. Information on GCA of lines to be used as parents as well as on their specific combining ability would be of immense value in formulating an efficient breeding strategy (Vikas *et al.,* 2015). Combining ability studies elucidates the nature and magnitude of gene action involved in the inheritance of character by providing the information on the two components of variance *viz.,* additive genetic variance and dominance variance, which are important to decide upon the parents and crosses to be selected for eventual success. Thus, this investigation was undertaken to determine magnitude of heterosis for yield and other quantitative traits and general and specific combining ability effects using L x T mating design.

Materials and Methods

The experiment was conducted at the experimental fields of Sunflower Scheme at Main Agricultural Research Station, UAS, Raichur during 2014-15. The experimental material used in the present study consisted of four lines (CMS-A1, CMS-A2, CMS-A5 and CMS-A6) and fourteen testers (RGM-39,

RGM-41, RGM-49, RGM-69, RGM-27, EC-602060, GMU-520, R-103, DOR-R3, R-1-F, R-7, R-393, R-127 and R-8). The objective of this investigation was to examine, the general and specific combining abilities of newly developed sunflower inbred lines using line x tester analysis (Kempthorne, 1957) and to estimate the amount of heterosis in fifty six hybrids. The crossing block consisting of 4 lines and 14 testers was raised during kharif-2014. Crossing was undertaken in a line x tester fashion using 4 lines and 14 testers at Main Agricultural Research Station, Raichur. A total of 56 hybrids were raised along with 18 parents and three checks viz., RSFH-130, KBSH-44 and GK-202 during *Rabi-2014-15* in a randomized block design with two replications. Observations were recorded in each entries on randomly selected five plants for seven characters viz., plant height (cm), days to 50 per cent flowering, head diameter(cm), test weight (g/100 seeds), volume weight (g/100 ml) and oil content (%).However, the seed yield/ plant (g) was calculated by using plot yield data.

Results and Discussion

Analysis of variance

The production of sunflower can greatly be increased through the cultivation of promising hybrids. The evolution of desirable hybrids can only be possible by crossing potential female lines with male testers. Presence of genetic variability is the basic requirement for developing high yielding and better adapted hybrids in sunflower.

The mean sums of square due to lines were found to be highly significant only for plant height a considerable amount of variation existing for this trait among female lines which can be exploitation for combining ability analysis. The mean sum of squares for testers was not significant for all the seven

characters studied except for plant height. However, line x tester interaction was highly significant for all characters studied suggesting contribution of SCA effects towards variation among the crosses.

General Combining Ability (GCA) and Specific Combining Ability (SCA) effects

Line × tester analysis can evaluate more number of genotypes as compared to diallel and partial diallel mating designs. This technique can be used even when the inbred lines have self-incompatibility and male sterility where diallel crosses entirely fail to use such abnormal conditions. The success of any breeding programme largely depends on selection of suitable parental lines. Information regarding different types of gene action, relative magnitude of genetic variance and combining ability estimates are important genetic parameters for the improvement of sunflower (Sher *et al.,* 2009). The presence of non-additive genetic variances and effects, presumably dominant genes are the primary justification for initiating the hybrid development programme in sunflower. Higher GCA effects are more desirable for self-pollinated crops and varieties released as pure lines while, SCA is more important for the production of hybrids in cross pollinated crops (Hallauer and Miranda, 1986).

General combining ability effects

Minimum number of days to flowering is preferred to reduce crop growth period to accommodate cropping system. The sunflower growers require short duration hybrids coupled with high seed yields, because such hybrids reduce the incidence of insect-pest, disease attack and adverse environmental effects. Main focus in sunflower breeding is therefore diverted to develop early maturing hybrids or open-pollinated cultivars for short growing cycle

(Sher *et al.,* 2009). The general combing ability analysis revealed that line CMS-A2 (-0.429) is the best general combiners for earliness which recorded significantly negative GCA effects for days to 50% flowering, while CMS-A6 (-9.156) exhibited desirable negative GCA effects for plant height. Among fourteen testers evaluated, six (RGM-39, RGM-69, GMU-520, DOR-R3, R-1-F) and seven (RGM-69, GMU-520, DOR-R3, R-1-F, R-7, R-393 and R-127) testers exhibited negative desirable GCA effects for days to 50% flowering and plant height, respectively (Table 2) indicating the importance of additive gene action advocating both these characters. These results indicated that earlier and shorter hybrids could be developed by crossing good general females with male lines having highly negative GCA effects. Significantly negative GCA effects for days to 50% flowering were also reported by Patil *et al.,* 2017, Kang *et al.,* (2013) and Saleem *et al.,* (2014) while Ahmad *et al.,* (2011) observed significantly negative GCA for plant height; hence these identified parents can be considered as good general combiners for developing dwarf/semi-tall and early hybrids in sunflower.

Achieving higher commercial yield is the basic objective for most of the breeding programmes in any of the crop plants, where more number of photosynthetically active leaves play major role. Higher number of leaves plant^{-1} would lead to more photosynthetic activity, ultimately higher seed yields, while bigger heads inflicts direct effect on number of seeds head^{-1}, consequently imposes significant positive effect on seed yield (Zia-Ullah *et al.,* 2013). The GCA estimates revealed that female lines CMS-A1(0.735) and CMS-A2 (0.910) and testers RGM-49 (1.206), GMU-520 (0.856) and R-1-F (0.831) manifested significantly higher positive GCA effects for head diameter; whereas two lines (CMS-A6, CMS-A1) and

seven testers (R-127, R-393, RGM-49, R-103, RGM-69, DOR-R3 and RGM-39) for seed yield plant^{-1}; and two lines (CMS-A6 and CMS-A5) and four testers (DOR-R3, R-127 and EC-602060) for test weight. Considerably high positive GCA effects with predominantly additive genes suggested that such females lines can be crossed with good general combiner testers to develop potential hybrids, synthetics and composite varieties to improve head diameter (Machikowa *et al.,* 2011); seeds yield (Hladni *et al.,* 2011); test weight and volume weight (Andarkhor *et al.,* 2012). Mirarab and Ahmadikhah (2010) stated that parents which were good general combiners for economic traits might be extensively used in hybridization programmes so as to identify suitable parents for hybridization and developing potential hybrids for 1,000-achene weight and seed yield.

The female lines and testers with higher positive GCA estimates are desirable parents to be used for developing sunflower hybrids with improved oil content (Kang *et al., 2013*; Saleem *et al., 2014*). Most of the characters studies were controlled by additive gene action as indicated by higher GCA effects in sunflower.

Specific combining ability effects

The hybrids which expressed significantly negative SCA effects for days to maturity and plant height contribute favourable additive genes for earliness and shorter plant height (Patil *et al.,* 2017). Out of eleven F$_1$ hybrids exhibiting higher negative SCA effects for day's maturity and plant height, at least three hybrids CMS-A1 x DOR-R3, CMS-A2 x R-127 and CMS-A1 x GMU-520 were identified consistent in expressing significantly higher desirable negative SCA effects for both the traits. Results indicated that these crosses possess dominant or over dominant type of genes with decreasing effect hence may be

exploited for reduced number of days to flowering and plant height (Table 3). Fifteen out of 56 hybrids, exhibited significantly positive SCA effects for head diameter, 10 for seed plant^{-1}; 12 for test weight; 9 hybrids for volume weight; 18 hybrids for seed yield per plant and 4 for oil content (Table 3). The hybrids which manifested significantly positive SCA effects for yield were not consistently higher for all the traits, yet the hybrids *viz*., CMS-A5 x R-103 (head diameter, test weight, volume, seed yield per plant), CMS-A1 x RGM-39(seed yield, head diameter, volume weight and test weight) CMS-A2 × RGM-39(head diameter, yield and oil content) and CMS-A6 x R-8 (for seed yield and test weight) expressed relatively higher positive SCA effects indicating that these characters are influenced by dominant and over dominant type of genes.

In consonance to our findings, Saleem *et al.,* 2014 and Karasu *et al.,* 2010 reported higher positive SCA for seed yield and yield related traits, Abdullah *et al.,* 2010 for head diameter; Andarkhor *et al.,* 2013 for test weight and volume weight; and Kang *et al.,* 2013 for oil content. The heterotic performance of hybrid combinations depends upon the combining abilities of their parents (Kadkol *et al.,* 1984). Kaya and Atakisi (2004) reported that superior hybrids were obtained by crossing females and males with high GCA and SCA effects.

The lines CMS-A1 and CMS-A2 (head diameter), CMS-A5 and CMS-A6 (test weight) and CMS-A1 and CMS-A6 (seed yield) were found to be good general combiner for improving yield. The data revealed that, the female parents CMS-A6 was best general combiner for four characters (plant height, seed yield, oil content and test weight) followed by CMS-A2 for three characters (days to 50% flowering and head diameter).

Table.1 ANOVA for seven characters in 56 hybrids of sunflower

Character	Df	Plant height (cm)	Days to 50% flowering	Head diameter (cm)	Test weight (g)	Volume weight (g/100ml)	Seed Yield (g/plant)	Oil content (%)
Replication	1	0.056	0.036	1.181	0.189	0.039	4.400	42.324***
Crosses	55	624.624***	9.958***	12.805***	1.102***	8.284***	136.617***	7.759***
Lines	3	1045.532***	2.452	29.474	2.745	12.533	86.152	11.853
Testers	13	970.527*	5.690	4.440	1.066	6.993	151.737	8.923
Line V/s Tester	39	476.946***	11.959***	14.312***	0.987***	8.387***	135.458***	7.056***

*, **-indicates significance at 5% and 1% level respectively

Table.2 General combining ability effects of the parents on different characters

Sl. No.	Parents	Plant height (cm)	Days to 50% flowering	Head diameter (cm)	Test weight (g)	Volume weight (g/100ml)	Seed Yield (g/plant)	Oil content (%)
Lines								
L1.	CMS-A1	3.451**	0.250**	0.735**	-0.439**	-0.531*	0.575*	-0.932**
L2.	CMS-A2	2.862**	-0.429**	0.910**	0.000	-0.385	-0.332	0.038
L3.	CMS-A5	2.844**	0.071	-1.290**	0.171**	-0.038	-2.214**	0.470
L4.	CMS-A6	-9.156**	0.107	-0.354	0.268**	0.954**	1.971**	0.424
T1.	RGM-39	16.790**	-0.982**	-1.056**	-0.691**	-0.656	-3.146**	0.124
T2.	RGM-41	3.165**	1.643**	-0.444	-0.691**	-0.144	-5.346**	-2.001**
T3.	RGM-49	14.290**	1.268**	1.206**	-0.241*	-0.794	3.916**	0.974*
T4.	RGM-69	-2.335**	-0.357*	-0.069	-0.079	-0.881	2.316**	0.899*
T5.	RGM-27	15.165**	0.268	0.281	-0.066	0.819*	0.804	0.586
T6.	EC_602060	6.040**	0.268	0.606	0.371**	1.244**	0.191	0.186
T7.	GMU-520	-15.710**	-0.607**	0.856*	0.059	-1.319**	1.316*	0.199
T8.	R-103	1.478	0.268	0.344	0.184	0.594	3.554**	-1.101*
T9.	DOR-R3	-13.960**	-0.482**	-1.219**	0.471**	-1.244**	2.166**	-1.214**
T10.	R-1F	-7.335**	-1.482**	0.831*	-0.129	1.544**	5.091**	-0.151
T11.	R-7	-7.835**	0.268	-0.856*	-0.066	-0.669	5.491**	-0.958*
T12.	R-393	-14.335**	0.268	-0.469	0.146	0.656	-9.071**	1.636**
T13.	R-127	-1.835*	-0.732	0.081	0.396**	0.544	-2.459**	-0.501
T14.	R-8	6.415**	0.393*	-0.094	0.334**	0.306	-4.821**	1.324**

Table.3 Specific combining ability effects of the hybrids on different characters

Sl. No.	Parents	Plant height (cm)	Days to 50% flowering	Head diameter (cm)	Test weight (g)	Volume weight (g/100ml)	Seed Yield (g/plant)	Oil content (%)
	Lines							
1.	CMSA1xRGM-39	14.674**	1.375**	2.028**	0.427*	3.456**	8.250**	-2.193*
2.	CMSA1xRGM-41	4.799**	-1.750**	-0.685	-0.123	0.794	14.450**	-0.668
3.	CMSA1xRGM-49	6.174**	1.625**	-0.835	0.477*	2.094*	6.238**	0.257
4.	CMSA1xRGM-69	26.799**	1.250**	0.040	-0.536**	-0.469	-3.263**	0.632
5.	CMSA1xRGM-27	-19.201**	.1.375**	0.490	0.052	-3.019**	-5.400**	-0.956
6.	CMSA1xEC_602060	-7.576**	-2.375**	0.265	-0.086	-0.694	-2.337*	-0.006
7.	CMSA1x GMU-520	-14.826**	-2.500**	-1.885*	2.177**	-0.781	0.087	1.432
8.	CMSA1x R-103	22.987**	2.625**	0.328	-1.048**	-2.544**	-12.000**	-1.168
9.	CMSA1x DOR-R3	-32.576	-1.625**	-4.410**	0.564**	1.244	5.238**	0.694
10	CMSA1xR-1F	-3.201*	-0.625*	-2.060**	0.064	0.006	-1.288	-0.118
11	CMSAx R-7	-6.701**	-2.375**	1.828*	0.152	1.969*	-4.188	5.213**
12	CMSA1x R-393	-3.701*	2.625**	0.740	-1.361**	0.094	-6.525**	0.044
13	CMSA1xR-127	19.799**	0.625*	3.290**	-0.661**	-1.244	0.813	-1.918*
14	CMSA1xR-8	-7.451**	2.500**	0.865	-0.098	-0.906	-0.075	-1.243
15	CMSA2x RGM-39	-11.237**	1.554**	4.593**	-0.113	-1.690*	4.157**	3.513**
16	CMSA2x RGM-41	-17.112**	3.929**	-4.160**	-0.162	-0.253	-3.443**	-1.238
17	CMSA2x RGM-49	-0.737	-0.696*	0.090	-0.562**	-0.753	-0.855	1.037
18.	CMSA2x RGM-69	-3.112	-0.071	0.065	-0.325	-1.815*	-2.155*	-0.138
19	CMSA2x RGM-27	-14.112	-1.696**	-0.785	0.363	-0.765	4.957**	1.125
20	CMSA2xEC_602060	16.013**	4.304**	2.390**	0.025	0.460	6.170**	-1.025
21	CMSA2xGMU-520	-6.737**	-1.821**	-0.460	-0.463*	-1.378	-0.855	-0.238
22	CMSA2x R-103	-6.674**	-1.696**	-5.047**	-0.637*	-1.690*	-17.643**	-0.488
23	CMSA2x DOR-R3	25.013**	1.054**	2.065**	0.425*	0.947	2.195*	1.025
24	CMSA2x R-1F	19.888**	1.554**	1.865*	0.325	0.410	-0.430	-0.338
25	CMSA2x R-7	-11.112**	-1.696**	-1.547*	0.263	1.522	-0.430	0.168

26	CMSA2xR-393	0.888	-0.696*	1.665*	0.050	2.297**	-0.318	0.775
27	CMSA2x R-127	-15.112**	-4.696**	-3.985**	0.500**	1.160	-0.830	2.212*
28	CMSA2x R-8	24.138**	0.679*	2.890**	0.312	1.547	9.482**	0.637
29	CMSA5x RGM-39	2.281	-4.696**	-5.497**	-0.384*	-3.637**	-5.861**	4.955**
30	CMSA5x RGM-41	15.406**	0.679*	2.940**	0.166	-0.599	-1.111	1.380
31	CMSA5x RGM-49	1.281	-4.446**	1.090	0.416*	0.301	0.727	-0.445
32	CMSA5x RGM-69	-17.594**	-0.571	-0.635	0.554**	0.938	9.927**	-0.920
33	CMSA5x RGM-27	22.406**	0.304	0.115	0.091	3.288**	-6.111**	-1.408
34	CMSA5xEC_602060	-1.969	-1.071**	-0.710	0.004	1.563	-2.498*	0.292
35	CMSA5x GMU-520	10.781**	4.304**	0.240	-1.034**	0.926	-1.023	-1.870*
36	CMSA5xR-103	-13.406**	0.696*	3.353**	0.891**	1.913*	19.189**	1.480
37	CMSA5x DOR-R3	-3.969*	3.679**	1.015	-0.846**	2.251**	-11.423**	1.092
38	CMSA5x R-1F	-17.094**	-0.196	-1.235	0.204	-1.837*	5.702**	0.530
39	CMSA5x R-7	12.406**	1.054**	2.453**	-0.409*	-2.974**	-2.548*	-2.664**
40	CMSA5x R-393	-2.594	-0.446	-3.035**	1.179**	0.599	5.564**	-0.658
41	CMSA5x R-127	-4.094*	2.304**	-0.685	0.079	-1.487	-11.198**	-0.370
42	CMSA5x R-8	-3.844*	-1.196**	0.590	-0.909**	-0.049	0.664	-1.395
43	CMSA6x RGM-39	-5.719**	0.696*	-1.483*	0.070	1.871*	-6.546**	0.751
44	CMSA6x RGM-41	-3.094	-2.321**	1.904**	0.120	0.058	-9.896**	0.526
45	CMSA6x RGM-49	-6.719**	1.518**	-0.346	-0.330	-1.642*	-6.109**	-0.849
46	CMSA6x RGM-69	-6.094**	-1.607**	0.529	0.307	1.346	-4.509**	0.426
47	CMSA6x RGM-27	10.906**	-1.232**	0.179	-0.505**	0.496	6.554**	1.239
48	CMSA6xEC_602060	-6.469**	-1.232**	-1.946**	0.057	-1.329	-1.334	0.739
49	CMSA6x GMU-520	10.781**	.643*	2.104**	-0.680**	1.233	1.791	0.676
50	CMSA6xR-103	-2.906	-0.732*	1.367	0.795**	2.321**	10.454**	0.176
51	CMSA6x DOR-R3	11.531**	-0.482	1.329	-0.143	-4.442**	3.991**	-2.811**
52	CMSA6xR-1F	0.406	-0.482	1.429*	-0.593**	1.421	-3.984**	-0.074
53	CMSA6xR-7	5.406**	1.768**	-2.733**	-0.005	-0.517	7.166**	-2.717**
54	CMSA6xR-393	5.406**	-0.732*	0.629	0.132	-1.792*	1.279	-0.161
55	CMSA6xR-127	-0.594	4.768**	1.379	0.082	1.571	11.216**	0.076
56	CMSA6xR-8	-12.844	-0.857**	-4.346**	0.695**	-0.592	-10.071**	2.001*

Table.4 Crosses exhibiting maximum sca effects, their mean performance and gca status of parents with respect seven characters in sunflower

Characters	Desirable crosses	SCA	Mean	GCA study of	
				Female	Male
Plant height (cm)	CMSA1xRGM-27	-19.201	127.500	Low	Low
	CMSA5x RGM-69	-17.594	111.000	Low	High
	CMSA2x RGM-41	-17.112	117.000	Low	Low
Days to 50% flowering	CMSA2x R-127	-4.696	52.000	Low	High
	CMSA5x RGM-39	-4.696	52.500	Low	High
	CMSA5x RGM-49	-4.446	59.500	Low	High
Head diameter (cm)	CMSA2x RGM-39	4.593	26.200	High	Low
	CMSA5xR-103	3.353	23.800	High	Low
	CMSA1xR-127	3.290	25.500	High	Low
Test weight (g)	CMSA1x GMU-520	2.177	6.800	Low	Low
	CMSA5x R-393	1.179	6.500	High	Low
Volume weight (g/100ml)	CMSA1xRGM-39	3.456	38.450	Low	High
	CMSA5x RGM-27	3.288	40.250	Low	Low
	CMSA6xR-103	2.321	40.050	Low	High
Seed yield/Plant (g)	CMSA5xR-103	19.189	55.050	Low	High
	CMSA1xRGM-41	14.450	44.200	High	Low
	CMSA6xR-103	11.216	45.250	High	Low
Oil content (%)	CMSAx R-7	5.213	36.175	Low	Low
	CMSA5x RGM-39	4.955	38.400	Low	Low
	CMSA2x RGM-39	3.513	29.500	Low	Low

GCA: General Combining Ability SCA: Specific Combining Abilit

Among the testers, DOR-R3 and R-1-F was best general combiner for four characters (plant height, head diameter, test weight, yield and plant height, volume weight and yield, respectively) followed by RGM-69 andR-7 for three characters (plant height, seed yield, oil content and plant height, head diameter and seed yield, respectively). Based on total positive and significant GCA scores, it is observed that CMS-A1 among lines and RGM-49 among testers were the good general combiners. The above results are in agreement with Reddy and Madhavi Latha (2005).

For most of the characters studied, the low x low GCA combination of parents were noticed in better performing heterotic cross combinations (Table 4), indicating the predominance of non-additive gene action as reported by Kadkol *et al.,* (1984); Reddy and Madhavi Latha (2005). The significant positive SCA effects were noticed in 16 hybrids for seed yield. Among them CMS-A5 x R-103(19.189) which was followed by CMS-A1 x RGM-41 (14.450), CMS-A6 x R-127 (11.216) and CMS-A6 x R-103 (10.454) recorded highest positive SCA effects.

Contribution of lines, testers and lines × testers interaction to total variance

The female lines had contributed normal effect for plant height and seeds yield, hence exhibited fair amount of maternal influence (Table 1). While the tester parents played very important role towards plant height and seed yield manifested significant paternal effect with additive genes for these traits. Line × tester interactions contributed relatively more as compared to female and male lines, however high values were noted for plant height, followed seeds yield and head diameter, which showed preponderance of dominant genes for these traits.

Heterosis

Heterosis is a universal phenomenon which occurs both in self and cross pollinated crop species like sunflower. Heterosis is the superiority of F_1 over the mean of the parents or over the better parent or over the standard commercial check (Hayes *et al.,* 1956). The maximum utilization of heterosis is possible when the variance due to both additive and non additive gene actions are fully exploited since they play a significant role in determining the magnitude of expression of yield and its component characters. In India, the era of sunflower hybrids began with the production and release of first ever sunflower hybrid BSH-1 by Seetharam, (1981).

Several workers as Habib (2009) and Vikas *et al.,* (2015) reported the importance of plant height in contributing higher seed yield as it is significantly associated with seed yield in sunflower. In present study, 33 hybrid combinations recoded significant positive heterosis ranging from 6.16 to 43.56% and only seven hybrids exhibited negative heterosis. The maximum heterosis percentage for plant height was displayed by the crosses CMS-A2 x R-8, CMS-A5 x RGM-27 and CMS-A2 x EC-602060 with a value of 43.56,

41.00 and 36.00, respectively in positive direction. Whereas, the hybrids CMS-A1 x DOR-R3 (-34.87) and CMS-A1 x GMU-520(-22.61) recorded highly significant heterosis in negative direction. Positive average heterosis combined with negative standard heterosis indicates that experimental hybrids are taller than their parents. The positive and significant heterobeltiosis was manifested by 11 cross combinations for plant height. The hybrids *viz.*, CMS-A1 x RGM-39, CMS-A2 x R-8 and CMS-A1 x R-103 showed the highest positive heterobeltiosis with the values of 18.12, 16.61 and 11.83%, respectively. However, CMS-A1 x DOR-R3, CMS-A1 x GMU-520 and CMS-A5 x R-1-F exhibited negatively significant heterobeltosis. Many workers have reported both positive and negative heterosis values for plant height. The predominance of tallness over dwarfness indicates tallness to be dominant character as reported by Patil *et al.,* (2017), Vikas *et al.,* (2015) and Habib *et al.,* (2009) reported negative heterosis. However, Vulpe (1967) did not observe heterosis for plant height.

The variation for days to 50 per cent flowering ranged from 52 days (CMS-A2 x R-127) to 63 days (CMS-A5 x EC-602060) in hybrids. The hybrids CMS-A5 x RGM-39, CMS-A5 x R-1-F, CMS-A5 x R-8, CMS-A5 x R-127 and CMS-A5 x RGM-69 recorded highly significant heterosis in negative direction. Larger head size is a desired trait to affect more yield in sunflower crop. In the present study out of 56 crosses, all the crosses exhibited positive heterosis. The maximum heterosis percentage (148.34, 146.99 and 145.90 %) for head diameter was displayed by the crosses CMS-A2 x RGM-39, CMS-A5 x RGM-41 and CMS-A6 x RGM-41, respectively. The positive and significant heterobeltiosis was manifest 52 cross combinations for head diameter. Hybrids viz. CMS-A2 x RGM-39, CMS-A2 x EC-602060 and CMS-A2 x R-8 showed the highest positive heterobeltiosis with the values of

112.15, 104.86 and 103.24%, respectively for head diameter. Patil *et al.,* (2017) and Patil *et al.,* (2012) also found high positive heterosis for head diameter.

Heterosis studies for 100-seed weight revealed that 13 cross combinations showed positive heterosis over the better parent value. The cross combinations CMS-A6 x RGM-41, CMS-A5 x RGM-41 and CMS-A1 x GMU-520 displayed the highest heterosis percentages (100.00, 97.87 and 78.95 %) for 100-test weight. Whereas, positive and significant heterobeltiosis (58.54, 52.44 and 48.68 %) was observed in the crosses, CMS-A5 x R-393, CMS-A5 x R-103 and CMS-A2 x R-8, respectively. High mid parent heterosis was also recorded by Gangappa *et al.,* (1997). The results are in line with the findings of Kandhola *et al.,* (1995) regarding heterobeltiosis. A total of nine hybrids recorded significant positive heterosis over better parent for volume weight. Among them the hybrids *viz.,* CMS-A5 x RGM-27 followed by CMS-A1 x RGM-39 and CMS-A2 x R-393, recorded positive highly significant heterosis over the better parents. These observations were in line with the reports of, Virupakshappa (1991) and Sugoor (1992), Patil *et al.,* (2012) and Patil *et al.,* (2017).

Among the 56 hybrid, 49 crosses exhibited highly significant positive heterosis for seed yield. The maximum heterosis percentage for seed yield per plant was manifested by the crosses CMS-A5 x R-103, CMS-A6 x R-103, CMS-A6 x R-7 and CMS-A1 x RGM-49, with a value of 163.40%, 141.63%, 126.50% and 120.73%, respectively. The positive and highly significant heterobeltiosis was manifested by 40 cross combinations. The hybrids *viz.,* CMS-A5 x R-103, CMS-A6 x R-103, CMS-A6 x R-7 and CMS-A5 x RGM-69 showed the highest positive heterobeltiosis with the values of 119.32%, 92.38%, 87.24% and 77.49%, respectively for seed yield. The

presence of non-additive gene action in determining seed yield per plant has also been reported by several workers. It augurs well for the development of potential high yielding hybrids. Similar conclusions have been drawn by Goksoy *et al.,* (2000), Patil *et al.,* (2012) and Patil *et al.,* (2017). Reports of negative heterosis for seed yield are also on record *viz.,* Naresh *et al.,* (1996), Kumar *et al.,* (1999) and Yadav *et al.,* 2009..

Highest oil content heterosis was indicated in CMS-A5 x RGM-39, CMS-A1 x R-7, CMS-A6 x R-8, CMS-A1 x R-393 and CMS-A1 x GMU-520 hybrids with a value of 22.10, 17.45, 13.49, 9.09 and 8.93 respectively. Prominent heterobeltiosis was observed in CMS-A5 x RGM-39, CMS-A6 x R-8 and CMS-A1 x R-7 for oil content in descending order. The results get support from the earlier findings of Kandhola *et al.,* (1995), Rather and Sandha (1999) and Nehru (2000).

Positive heterosis for oil yield was displayed in 35 crosses. Ten cross combinations showed significant heterosis for oil yield. Maximum heterosis was recorded in CMS-A5 x RGM-39, CMS-A1 x R-7, CMS-A6 x R-8 with a value of 22.10, 17.45 and 9.09, respectively for oil yield. Positive heterobeltiosis for oil yield was recorded in 24 crosses. Positive and significant increase over better parent was observed in ten hybrids for sunflower oil yield. Maximum heterobeltiosis for oil yield was recorded in CMS-A5 x RGM-39 followed by CMS-A6 x R-8 with the value of 19.81 and 8.77%, respectively. Rather and Sandha (1999) observed a wide range heterosis and heterobeltiosis in their respective studies. It is, therefore, concluded hybrid CMS-A5 x RGM-39 can be exploited for better oil yield on commercial basis.

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