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Heterosis and combining ability analysis in snowball cauliflower using indigenously developed CMS lines

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ABSTRACT

Five CMS lines, Ogu12A, Ogu13A, Ogu14A, Ogu15A and Ogu16A were selected among fifteen lines after BC_7 based on superior commercial, floral and seed setting traits. Line × Tester analysis was done by taking these five CMS lines as female parent with ten diverse lines of snowball cauliflower as testers. Data were recorded for 14 important vegetative and commercial traits. For days to 50% curd initiation and days to 50% curd maturity the CMS line Ogu15A exhibited significantly high GCA effect in negative direction (-14.52 and -14.38). For marketable curd weight and marketable curd yield significantly high GCA effects were recorded in the CMS line Ogu15A (0.11; 0.10) and Ogu13A (5.28; 4.75). Among the ten testers only two genotypes, Kt-2 and EC-162587 had significantly high GCA effect for marketable curd yield. Very high and significant SCA effect has been recorded in the combination Ogu16A × Kt-25 (20.25) and Ogu15A × Kt-2 (19.72) for marketable curd yield. The CMS line, Ogu15A was involved in the most of the heterotic combinations for earliness. Average heterosis was in desirable positive direction for 7 among 14 traits. The range of average heterosis for days to 50% curd maturity was -8.55 to 25.0% and it was -32.04 to 127.91% marketable curd yield. Ogu15A was involved in maximum number of combinations for earliness and higher productivity. Highest heterosis for marketable curd yield was recorded in the combination, Ogu15A × Kt-2 (127.91%), followed by Ogu14A × Sel-26 (90.90%) and Ogu15A × Sel-26 (86.18%). The CMS lines with better combiling ability are involved with most of the heterotic combinations for different traits thus can be used for development of F_1 hybrids.

Key words: Combining ability, heterosis, hybrid snowball cauliflower.

INTRODUCTION

Snowball or European summer cauliflower is the main vegetable crop in Indian sub-continent cultivated during winter season. In India, more than 90% of the cauliflower cultivated is F_1 hybrids. In cauliflower, F_1 hybrids are very popular mainly because of uniform maturity, high early and total yield, better curd quality with respect to compactness and colour, resistance to insect-pests, diseases and unfavorable weather conditions (Kucera *et al.*, 7). Two pollination control mechanisms, *viz*. self-incompatibility (SI) and male sterility (particularly cytoplasmic male sterility; CMS) are widely used for production of F_1 hybrid seeds. So far, majority of cruciferous hybrid cultivars have been developed by using SI system (Watanabe and Hinata, 13). However, SI system has several disadvantages like, possibility of sibs in the hybrids and multiplication of SI parents through tedious bud pollination or treatment by enhanced concentration of CO_2 and NaCl spray (Jirik, 4; Kucera, 6; Sharma *et al.*, 9). In case of snowball cauliflower, self-incompatibility system is very weak or not present at all (Watts, 14; Niewhoff, 8). In such situation, CMS system offers a good alternative (Kucera *et al.*, 7; Sharma *et al.*, 9) for production of F_1 hybrid seeds. All the hybrids cultivated in India are imported from different countries. Every year India loses a huge amount of revenue for import of hybrid seeds. Un-availability of suitable pollination control mechanism is the main constraint in developing indigenous F_1 hybrids. There is an urgent need to develop indigenous CMS/ SI lines and standardize technologies for F_1 hybrid seed production.

Good CMS system would be useful when they are transferred to the nuclear background of any cultivars/ lines with good general combining ability (GCA) and specific combining ability (SCA) besides possessing desirable agronomic characteristics. In this study, five superior Ogura based CMS lines were developed at our station and they had good floral and agronomic traits (data not presented). Their suitability in the heterosis breeding was tested through Line × Tester design.

MATERIALS AND METHODS

Five CMS lines, *viz*. Ogu12A, Ogu13A, Ogu14A, Ogu15A and Ogu16A were used as female parent (lines) and ten cauliflower genotypes, *viz*. Kt-22, Kt-25, Kt-2, HLSR-05, Sel-27, PSBK-1, EC-162587, Kt-15, Mukutmani, and Sel-26 were used as pollen parent (testers). Each of the lines was crossed with all the 10 testers individually in Line × Tester fashion

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(Kempthorne, 5) during 2012 to develop 50 hybrids. Sterile lines were raised under muslin cloth cage to avoid any natural pollination. Fully opened flowers of male sterile female lines were selected and pollination was performed by collecting fresh pollen from male parents covered with selfing bags of muslin cloth. Each male plant was covered individually before opening of flowers. Further, the 50 hybrids along with their parents were raised in randomized block design with three replications during 2013 at Baragraon Experimental Farm of IARI, Regional Station situated at an altitude of 1,560 m above mean sea level. All the standard agronomic practices for cauliflower as recommended by Singh *et al.* (11) in Kullu valley conditions were followed with a population density of 44,000 plants/ha. Five randomly selected plants were labeled for recording the observations. Fourteen vegetative and commercial traits, *viz*., (i) days to 50% curd initiation, (ii) days to 50% curd maturity, (iii) plant height (cm), (iv) number of leaves, (v) leaf length (cm), (vi) leaf width (cm), (vii) gross plant weight (kg), (viii) marketable curd weight (kg), (ix) net curd weight (kg), (x) curd length (cm), (xi) curd width (cm), (xii) core length (cm), (xiii) marketable curd yield (t/ ha), and (xiv) harvest index (%) were recorded from the selected plants. These traits were recorded to estimate the suitability of the CMS lines in the production of high yielding, early maturity hybrids with other desirable traits. The data were subjected to combining ability analysis following the method suggested by Kempthorne (5). Mid-parental heterosis was calculated to work out the superiority of CMS based F_1 hybrids over their parents.

RESULTS AND DISCUSSION

Line × Tester analysis determined suitability of the CMS lines in heterosis breeding. The Line × Tester design is basically an extension of the top-cross analysis where instead of one tester (as used in top-crossing) more than one tester is employed. This analysis revealed GCA effects of the parental lines besides SCA effect of each cross. The estimate of GCA of a parent is an important indicator of its potential for generating superior breeding populations. A high GCA estimate indicates that the parental mean is superior or inferior to the general mean. This represents a strong evidence of favourable gene flow from parents to offspring at high frequency and gives information about the concentration of predominantly additive genes (Franco *et al.*, 3). The selected parental lines with better performance can be crossed in suitable combination to exploit heterosis. Such crosses with high SCA could be best utilized in heterosis breeding (Singh and Chaudhary, 12).

Mean squares of hybrids and Line × Tester were significant for all the fourteen traits (Table 1). Significantly high GCA in desirable direction for earliness related traits like, days to 50% curd initiation (-14.52) and days to 50% curd maturity (-14.38) was recorded in the CMS line, Ogu15A (Table 2). This indicated the genetic worthiness of the Ogu15A for the development of early maturity hybrids. For marketable curd weight and marketable curd yield, the lines Ogu15A (0.11) and Ogu13A (0.10) had significantly high GCA effect in positive direction. None of the lines had significantly high harvest index (Table 3). The

Table 1. Analysis of variance for combining ability for 14 horticultural traits based on Line × Tester design in snowball cauliflower.

Trait	Replication	Line	Testers	Line × tester	Error
DF	2	4	9	36	136
Days to 50% curd initiation	31.9	2290.7**	524.1*	193.6**	11.8
Days to 50% curd maturity	18.0	2131.6**	452.5*	168.9**	11.9
Plant height (cm)	0.6	32.1	117.6*	46.3**	8.9
Nos. of leaves	1.5	13.8	17.4	11.8**	1.7
Leaf length (cm)	4.5	62.1	115.3*	40.3**	6.2
Leaf width (cm)	4.7	41.3*	30.1*	12.1**	2.3
Gross plant wt. (kg)	0.1	1.94**	0.5	0.3**	0.1
Marketable curd wt. (kg)	0.1	0.40*	0.2	0.1**	0.1
Net curd wt. (kg)	0.01	0.29*	0.12	0.06**	0.01
Curd length (cm)	0.67	9.82*	1.64	2.59**	0.67
Curd width (cm)	0.45	2.85	5.03	3.31**	0.90
Curd depth (cm)	0.68	3.30	3.74**	1.26**	0.57
Marketable curd yield (t/ha)	104.43	961.61*	548.81	301.12**	37.97

*,** significant at 5 and 1% probability levels, respectively by F test

Table 2. Estimates of general combining ability effects of five lines based on Line × Tester design.

Trait	12A	13A	14A	15A	16A
Days to 50% curd initiation	8.51**	1.52	4.43**	-14.52**	0.05
Days to 50% curd maturity	7.43**	1.19	4.28**	-14.38**	1.47
Plant height (cm)	0.67	-0.74	1.31	-0.01	-1.24
No. of leaves	0.50	-0.02	-0.01	-1.09**	0.62
Leaf length (cm)	0.96	-0.28	1.40*	0.21	-2.29**
Leaf width (cm)	0.62	1.32**	0.36	-0.62	-1.68**
Gross plant wt. (kg)	-0.24**	0.23**	0.17**	0.13**	-0.30**
Marketable curd wt. (kg)	-0.12**	0.10**	0.04	0.11**	-0.14**
Net curd wt. (kg)	-0.10**	0.09**	0.01	0.09**	-0.10**
Curd length (cm)	0.02	0.96**	-0.38	-0.45*	-0.14
Curd width (cm)	0.28	0.27	0.01	-0.45*	-0.11
Curd depth (cm)	0.13	0.40*	0.14	-0.35	-0.32
Marketable curd yield (t/ha)	-5.78**	4.75**	2.07	5.28**	-6.32**
Harvest index (%)	0.52	-1.53	-3.13	2.17	1.97

*,** significant at 5 and 1% levels probability, respectively by F test

lines, Ogu13A and Ogu15A could be used in breeding programme for development of hybrids with higher yield. From the GCA analysis it was revealed the usefulness of the CMS line, Ogu15A in development of hybrids with earliness and higher yield. Among the testers significantly negative GCA effect was recorded in the genotype, HLSR-05 (-6.35), EC-162587 (-9.75) and Mukutmani (-5.78). Two tester genotypes, Kt-2 (8.76) and EC-162587 (8.59) had significantly high GCA effect for marketable curd yield. These tester lines could be used as pollen parent in development of cauliflower F_1 hybrid. Earlier, Dey *et al.* (2) also reported the CMS lines with better combining ability improve yield and earliness in cauliflower.

Among the 50 hybrids, 10 hybrids showed significantly negative SCA effect for days to 50% curd initiation, 10 hybrids had significantly negative SCA effect for days to 50% curd maturity (Table 4).

Table 3. Estimates of general combining ability effects of 10 testers based on Line × Tester design.

Trait	Kt-22	Kt-25	Kt-2	HLSR-05	Sel. 27	PSBK-1	EC-162587	Kt-15	Mukutmani	Sel. 26
Days to 50% curd initiation	5.53**	0.24	8.29**	-6.50**	-1.99	2.23	-9.75**	5.45**	-5.78**	2.28
Days to 50% curd maturity	5.02**	-0.52	7.68**	-6.35**	-1.12	2.63*	-9.06**	4.53**	-5.38**	2.55*
Plant height (cm)	0.95	1.49	3.28**	0.11	-4.52**	1.65	1.74	1.43	-5.23**	-0.92
Nos. of leaves	-0.93	0.68	-1.06*	1.35**	-0.79	-0.73	0.70	1.26**	-1.41**	0.94
Leaf length (cm)	-0.26	0.40	4.80**	1.25	-4.09**	-0.94	2.31	1.94	-3.89**	-1.51
Leaf width (cm)	-0.05	-0.03	1.25*	1.68**	-0.97	-0.50	2.30**	0.10	-1.83**	-1.93**
Gross plant wt. (kg)	-0.24**	0.11	0.27**	0.11	-0.12	-0.02	0.24**	-0.03	-0.22**	-0.08
Marketable curd wt. (kg)	-0.14**	0.07	0.19**	-0.09	-0.09	-0.01	0.19**	0.07	-0.21**	-0.01
Net curd wt. (kg)	-0.11**	0.05	0.11**	-0.06	-0.03	-0.04	0.14**	0.05	-0.12**	0.01
Curd length (cm)	-0.35	-0.17	0.11	-0.28	-0.53	0.38	0.02	0.20	0.14	0.47
Curd width (cm)	-0.54	-0.04	0.93**	-0.25	-0.38	0.69*	0.36	0.08	-0.99**	0.14
Curd depth (cm)	-0.31	-0.33	0.75**	-0.18	-0.80**	-0.01	-0.01	0.67*	-0.28	0.51
Marketable curd yield (t/ha)	-6.07**	3.53	8.76**	-4.03	-3.95	-0.89	8.59**	3.53	-9.16**	-0.29
Harvest index (%)	1.19	-0.33	2.50	-8.10**	-1.58	-0.71	3.47	5.30**	-4.36	2.61

*,** significant at 5 and 1% levels probability, respectively by F test

Table 4. Estimates of specific combining ability (SCA) effects of 50 hybrids based on Line × Tester design.

Hybrid	Days to 50% curd initiation	Days to 50% curd maturity	Plant height (cm)	No. of leaves	Leaf length (cm)	Leaf width (cm)	Gross plant wt. (kg)	Marketable curd wt. (kg)	Net curd wt. (kg)	Curd length (cm)	Curd width (cm)	Curd depth (cm)	Marketable curd yield (t/ha)	Harvest index (%)
Ogu12A × Kt-22	-13.94**	-10.68**	0.88	3.06**	3.19	-0.99	0.06	0.05	0.01	-0.20	-0.17	-0.30	2.91	1.43
Ogu12A × Kt-25	2.95	4.03	-0.90	-1.31	-2.59	-1.56	-0.27	-0.18	-0.06	-0.68	-0.23	-0.52	-7.93	-0.32
Ogu12A × Kt-2	-3.26	-3.58	6.13*	0.50	4.89*	-1.25	0.35*	0.17	-0.04	-0.72	-0.75	-0.32	7.93	-2.69
Ogu12A × HLSR-05	4.67	3.89	1.58	0.16	1.28	-2.73*	-0.32	0.02	-0.02	-0.12	-0.51	-0.32	1.60	13.04**
Ogu12A × Sel-27	0.09	-2.34	-4.50	-0.81	-2.57	1.49	0.02	-0.05	0.08	0.38	-0.44	-1.56*	-2.12	-5.09
Ogu12A × PSBK-1	9.89**	8.83**	-0.66	-2.47*	-0.53	0.41	0.09	0.04	0.03	-0.05	1.33	0.12	-1.08	-4.99
Ogu12A × EC-162587	5.44	6.30*	1.64	1.14	-0.12	2.48*	0.19	0.08	0.10	2.10**	1.92*	1.34*	4.24	-1.62
Ogu12A × Kt-15	0.31	-0.13	4.95*	-0.57	1.86	1.70	0.14	-0.08	-0.08	0.05	-0.89	0.92	-3.30	-9.01
Ogu12A × Mukutmani	-0.99	-1.20	-8.23**	1.60	-5.54**	-0.51	-0.21	-0.08	-0.01	-1.42*	-0.40	-0.62	-3.51	3.68
Ogu12A × Sel-26	-5.16	-5.12	-0.89	-1.32	0.13	0.97	-0.06	0.02	0.01	0.67	0.16	1.28*	1.25	5.58
Ogu13A × Kt-22	7.24**	7.11*	-2.27	-3.44**	0.02	0.55	-0.06	-0.06	0.07	0.80	2.13**	0.65	-2.91	-1.74
Ogu13A × Kt-25	-4.50	-3.34	0.79	1.37	-1.84	1.24	0.08	0.08	0.09	-0.21	0.52	-0.26	3.60	1.92
Ogu13A × Kt-2	3.79	3.35	-4.50	-3.40**	-5.08*	-0.83	-0.58**	-0.34**	-0.07	0.48	-0.16	-0.40	-15.11**	0.62
Ogu13A × HLSR-05	0.99	-0.20	-0.98	-1.76	-1.43	-2.90*	-0.09	0.03	-0.09	-0.70	-0.48	-0.35	1.49	3.85
Ogu13A × Sel-27	13.24**	12.63**	7.10**	1.52	5.12*	0.27	0.38*	0.13	0.03	-0.04	-0.36	0.43	5.81	-3.73
Ogu13A × PSBK-1	-0.09	-1.20	1.01	1.19	1.89	1.09	-0.14	-0.10	-0.10	-0.72	-1.24	0.07	-3.69	0.18
Ogu13A × EC-162587	-7.76**	-9.06**	0.11	2.22*	-0.43	1.06	0.51**	0.17	0.09	-1.26	-0.98	-0.42	7.64	-6.36
Ogu13A × Kt-15	-0.78	-0.56	-2.68	5.42**	-4.77*	-1.95	-0.22	-0.04	-0.14	0.30	-0.01	0.08	-2.25	4.40
Ogu13A × Mukutmani	-14.44**	-12.30**	2.58	-0.95	7.63**	2.64*	0.20	0.38**	0.27**	1.81**	1.27	0.80	16.74**	13.12**
Ogu13A × Sel-26	2.33	3.58	-1.14	-2.15*	-1.10	-1.18	-0.08	-0.25*	-0.16	-0.44	-0.68	-0.59	-11.33**	-12.28*
Ogu14A × Kt-22	13.03**	11.93**	-3.13	0.07	-1.05	1.44	0.01	-0.14	-0.16	-0.25	-2.05**	-0.25	-6.24	-10.10*
Ogu14A × Kt-25	-1.34	-1.02	-0.14	-1.31	-0.85	-0.73	0.03	0.05	0.01	0.58	-0.07	0.07	2.25	2.25
Ogu14A × Kt-2	8.61**	9.20**	-2.25	1.20	0.21	-0.34	0.24	0.20	0.19*	0.94	0.65	0.42	9.09	3.71
Ogu14A × HLSR-05	-5.02	-4.02	1.63	2.04	0.10	3.14*	0.19	-0.12	-0.05	0.36	0.19	0.72	-5.50	-9.91
Ogu14A × Sel-27	-9.30**	-8.19**	-2.90	-0.82	-2.98	-0.84	-0.26	-0.12	-0.11	0.46	1.65*	0.50	-5.58	1.42
Ogu14A × PSBK-1	0.87	0.18	2.89	0.38	0.57	0.26	-0.10	0.01	0.01	-0.02	0.26	0.14	1.18	4.94
Ogu14A × EC-162587	-5.37	-5.75*	-1.74	0.17	-1.40	-2.66*	-0.55**	-0.16	-0.19*	-0.46	-0.38	0.17	-7.28	9.60

Contd...

Table 3 Contd...

Hybrid	Days to 50% curd initiation	Days to 50% curd maturity	Plant height (cm)	No. of leaves	Leaf length (cm)	Leaf width (cm)	Gross plant wt. (kg)	Marketable curd wt. (kg)	Net curd wt. (kg)	Curd length (cm)	Curd width (cm)	Curd depth (cm)	Marketable curd yield (t/ha)	Harvest index (%)
Ogu14A × Kt-15	10.38**	10.61**	-2.09	1.96	0.60	-0.46	0.12	0.16	0.15	-0.73	0.23	-0.54	7.14	3.88
Ogu14A × Mukutmani	-7.98**	-8.36**	-0.16	0.02	0.02	-0.68	0.09	-0.12	-0.02	-0.56	-0.85	-0.70	-5.65	-10.65*
Ogu14A × Sel-26	-3.88	-4.57	7.89**	0.18	4.75*	0.89	0.23	0.24*	0.19*	-0.30	0.37	-0.55	10.60*	4.82
Ogu15A × Kt-22	-9.04**	-9.20**	1.53	0.96	-1.63	-0.76	-0.18	-0.02	-0.03	-0.02	0.38	0.01	-0.99	5.67
Ogu15A × Kt-25	-3.18	-3.08	-2.68	-0.59	-0.68	-0.76	-0.37*	-0.41**	-0.25**	-0.10	-0.73	0.05	-18.18**	-10.79*
Ogu15A × Kt-2	-6.63*	-6.26*	6.07*	2.02	6.96**	5.93**	0.79**	0.45**	0.16*	0.67	0.85	0.30	19.72**	-3.19
Ogu15A × HLSR-05	-0.16	-0.55	0.48	-0.99	-0.07	-0.88	0.51**	0.24*	0.31**	1.24	1.58*	0.36	10.50*	-2.01
Ogu15A × Sel-27	4.06	4.18	2.82	0.67	3.86	-0.60	-0.05	0.16	0.04	-0.10	0.38	0.28	7.28	11.42**
Ogu15A × PSBK-1	-2.00	-1.91	-3.17	1.05	-0.98	-0.88	-0.02	0.03	0.01	-0.49	-0.61	0.18	2.52	4.40
Ogu15A × EC-162587	3.65	2.75	-3.33	-3.24**	-1.57	-1.08	-0.47**	-0.22*	-0.14	-0.16	-0.48	-0.33	-9.98*	2.90
Ogu15A × Kt-15	0.77	1.39	-2.62	-1.54	-2.44	-0.22	-0.16	-0.07	0.04	0.43	0.22	-0.22	-3.36	1.68
Ogu15A × Mukutmani	7.88**	8.75**	2.22	-0.66	-0.59	0.31	-0.01	-0.24*	-0.21**	-1.58*	-1.73*	-0.20	-10.91*	-14.96**
Ogu15A × Sel-26	4.65	3.93	-1.32	2.33*	-2.84	-1.03	-0.02	0.07	0.06	0.12	0.12	-0.42	3.40	4.88
Ogu16A × Kt-22	2.71	0.84	2.99	-0.66	-0.53	-0.23	0.17	0.16	0.12	-0.31	-0.28	-0.10	7.23	4.73
Ogu16A × Kt-25	6.07*	3.42	2.92	1.84	5.98**	1.83	0.53**	0.46**	0.21**	0.41	0.51	0.66	20.25**	6.93
Ogu16A × Kt-2	-2.51	-2.70	-5.45*	-0.33	-7.01**	-3.50**	-0.80**	-0.48**	-0.24**	-1.38*	-0.58	0.01	-21.63**	1.54
Ogu16A × HLSR-05	-0.47	0.89	-2.71	0.54	0.10	3.37**	-0.29	-0.18	-0.14	-0.77	-0.77	-0.40	-8.10	-4.96
Ogu16A × Sel-27	-8.09**	-6.28*	-2.52	-0.55	-3.42	-0.32	-0.10	-0.12	-0.05	-0.69	-1.22	0.33	-5.39	-4.02
Ogu16A × PSBK-1	-8.68**	-5.91	-0.07	-0.16	-0.95	-0.88	0.17	0.01	0.04	1.30	0.25	-0.51	1.07	-4.53
Ogu16A × EC-162587	4.04	5.76	3.33	-0.29	3.53	0.20	0.32	0.12	0.14	-0.20	-0.07	-0.75	5.37	-4.52
Ogu16A × Kt-15	-10.68**	-11.31**	2.44	-1.33	4.74*	0.95	0.12	0.04	0.03	-0.06	0.43	-0.24	1.78	-0.95
Ogu16A × Mukutmani	15.53**	13.12**	3.60	-0.01	-1.52	-1.76	-0.06	0.07	-0.02	1.75**	1.71	0.73	3.33	8.80
Ogu16A × Sel-26	2.07	2.17	-4.53	0.95	-0.93	0.35	-0.05	-0.08	-0.09	-0.04	0.01	0.29	-3.92	-3.02

1. 12A, 2. 13 A, 3. 14A, 4. 15A, 5. 16A 6. Kt-22, 7. Kt-25, 8. Kt-2, 9. HLSR-05. 10. Sel-27, 11. PSBK-1, 12. EC-162587, 13. Kt-15, 14. Mukutmani, 15. Sel-26; *,** significant at 5 and 1% levels probability, respectively by F test

Table 5. Range and average heterosis among the 50 hybrids along with top 10 heterotic hybrids for 14 traits.

Heterosis and genetic combining ability	Days to 50% curd initiation	Days to 50% curd maturity	Plant height (cm)	No. of leaves	Leaf length (cm)	Leaf width (cm)	Gross plant weight (kg)	Marketable curd weight (kg)	Net curd weight (kg)	Curd length (cm)	Curd width (cm)	Curd depth (cm)	Marketable curd yield (t/ha)	Harvest index (%)
Range of Heterosis	-8.64-30.85	-8.55-25.00	-93.79-24.87	-16.62-44.76	-29.87-28.64	-25.13-40.03	-34.17-113.41	-32.04-127.91	-34.38-94.43	-11.97-31.66	-9.99-45.72	-34.85-303.05	-32.04-127.91	-35.73-38.40
Average Heterosis	7.24	6.49	-20.93	14.42	-0.57	-0.26	14.93	24.99	19.44	4.79	11.88	15.48	24.99	8.84
Top 10 heterotic F_1 hybrids	15A × HLSR05 118.8 (-8.64)	15A × Kt-22 116.8 (-8.55)	15A × Kt-2 51.10 (24.87)	14A × HLSR05 23.42 (44.76)	15A × Kt-2 52.17 (28.64)	14A × HLSR05 25.88 (40.03)	15A × Kt-2 2.94 (113.41)	15A × Kt-2 1.79 (127.91)	15A × HLSR05 1.04 (94.43)	13A × Mukut mani 14 (31.66)	12A × Ec162587 16.98 (45.72)	15A × HLSR05 26.83 (303.05)	15A × Kt-2 78.92 (127.91)	15A × Kt-22 68.41 (38.40)
	13A × Mukut Mani 107.2 (-8.23)	13A × Kt-15 140.53 (-7.52)	15A × Kt-22 44.24 (19.10)	13A × Kt-15 26.69 (42.38)	14A × Kt-15 44.14 (27.18)	15A × Kt-2 27.25 (32.43)	15A × HLSR05 2.51 (80.84)	14A × Sel-26 1.30 (90.90)	15A × Kt-2 1.08 (89.59)	12A × EC162587 12.89 (24.96)	12A × PSBK-1 16.72 (37.33)	12A × Kt-22 12.38 (84.60)	14A × Sel-26 57.53 (90.90)	15A × Sel-27 71.37 (37.35)
	15A × Kt-22 107.86 (-6.22)	15A × EC162587 114.66 (-7.04)	12A × Kt-15 48.82 (17.98)	15A × Sel-26 22.23 (33.92)	14A × Sel-26 44.83 (24.62)	12A × EC162587 26.09 (26.37)	14A × Kt-2 2.44 (74.38)	15A × Sel-26 1.217 (86.18)	15A × Sel-26 0.86 (86.81)	16A × Mukut mani 12.36 (19.32)	14A × PSBK-1 15.37 (23.54)	12A*Kt-15 8.41 (30.29)	15A × Sel-26 53.54 (86.18)	16A × Kt-22 67.28 (34.33)
	15A × Ec162587 105.26 (-5.60)	16A × Sel-27 131 (-6.19)	15A × Kt-15 40.56 (13)	14A × Sel-26 21.15 (30.17)	14A × HLSR05 42.95 (19.85)	13A × EC162587 25.38 (20.22)	14A × HLSR05 2.24 (58.68)	15A × PSBK-1 1.18 (82.90)	15A × Kt-15 0.89 (82.99)	13A × Kt-15 12.55 (19.03)	14A × Kt-22 11.81 (21.62)	14A × PSBK-1 6.95 (24.76)	15A × PSBK-1 52.06 (82.90)	16A × Kt-25 67.95 (34.25)
	15A × Sel-27 113.43 (-5.34)	13A × EC162587 118.43 (-5.86)	15A × Sel-26 39.51 (12.90)	16A × Kt-25 23.2 (29.85)	15A × HLSR05 41.59 (18.72)	14A × KT-15 20.68 (15.85)	14A × Sel-26 2.07 (56.87)	14A × Kt-2 1.47 (80.77)	15A × EC162587 0.79 (80)	13A × Kt-22 12.48 (16.81)	15A × EC162587 13.83 (21.45)	14A × Kt-2 7.99 (23.74)	14A × Kt-2 65.09 (80.77)	15A × EC162587 51.10,50.95 (33.11)
	-	15A × Sel-27 124.03 (-5.81)	12A × Kt-2 51.85 (11.72)	12A × Kt-22 22.67 (27.52)	12A × Kt-15 44.96 (18.03)	12A × Kt-15 23.11 (17.72)	13A × EC162587 2.73 (63.87)	16A × Kt-25 1.42 (65.50)	13A × EC162587 1.04 (70.11)	16A × PSBK-1 11.86 (14.94)	15A × Kt-15 14.25 (21.15)	13A × Kt-15 7.84 (22.79)	16A × Kt-25 62.62 (65.50)	15A × Sel-26 67.92 (32.58)
	-	15A × Kt-25 117.36 (24.03)	15A × HLSR05 42.34 (10.39)	12A × HLSR05 22.06 (27.43)	15A × Kt-15 39.90 (17.72)	15A × HLSR05 20.86 (12.57)	14A × Kt-15 2.01 (40.19)	15A × EC162587 1.11 (64.24)	14A × Sel-26 0.92 (68.90)	15A × Sel-26 11.23 (14.90)	15A × Kt-2 15.74 (20.75)	12A × Sel-26 8.60 (21.11)	15A × EC162587 49.04 (64.24)	15A × PSBK-1 65.22 (32.43)
	-	14A × Sel-27 130.33 (-4.12)	15A × Mukutmani 38.73 (8.66)	14A × Kt-2 20.16 (24.87)	12A × Kt-2 50.84 (13.62)	15A × EC162587 21.28 (12.48)	15A × PSBK-1 1.83 (38.11)	14A × Kt-15 1.316 (61.47)	14A × Kt-15 0.93 (62.86)	15A × HLSR05 11.58 (14.77)	14A × EC162587 14.39 (20.74)	14A × EC162587 6.98 (19.78)	14A × Kt-15 57.90 (61.47)	16A × Mukutmani 64.95 (31.48)
	-	14A × Mukutmani 125.9 (-3.40)	15A × PSBK-1 40.23 (5.24)	14A × Kt-25 19.4 (23.96)	14A × Kt-2 46.61 (12.68)	15A × Kt-15 19.93 (11.33)	15A × Sel-26 1.76 (35.79)	14A × PSBK-1 1.08 (59.21)	15A × PSBK-1 0.76 (60.28)	12A × Sel-26 12.25 (14.48)	16A × Kt-15 14.54 (19.98)	14A × Kt-15 6.94 (19.77)	14A × PSBK-1 47.52 (59.21)	14A × EC162587 69.31 (30.94)
	-	15A × Sel-26 127.46 (-2.62)	15A × Kt-25 40.57 (3.69)	15A × Kt-2 19.9 (20.61)	12A × HLSR05 43.69 (11.39)	14A × EC162587 20.68 (9.61)	14A × PSBK-1 1.78 (32.59)	15A × HLSR05 1.29 (58.95)	14A × Kt-2 1.02 (59.48)	13A × Sel-26 12.07 (12.76)	14A × Kt-15 14.73 (19.80)	14A × HLSR05 7.36 (18.25)	14A × EC162587 48.53 (55.35)	13A × Mukutmani 66.60 (24.31)

The number of hybrids with significant SCA effect in desirable direction was 5, 5, 7 and 5 for plant height, number of leaves, leaf length and leaf width, respectively. Highest SCA effect in negative direction for days to 50% curd maturity was observed in the hybrid, Ogu13A × Mukut mani (-12.30) followed by Ogu16A × KT-15 (-11.31) and Ogu12A × KT-22 (-10.68). For gross plant weight, marketable curd weight, net curd weight, curd length and curd width numbers of the hybrids with desirable SCA effect was recorded in 6, 4, 6, 2 and 4 hybrids, respectively. For marketable curd yield 5 hybrids had significantly high positive SCA effect. Highest positive SCA effect was recorded in the hybrid; Ogu16A × Kt-25 (20.25) followed by Ogu15A × Kt-2 (19.72) and Ogu13A × Mukutmani (16.74). For harvest index only three hybrids had significantly high positive SCA effect.

All the 14 traits under study showed varying degree of heterosis (Table 5). The range of heterosis for days to 50% curd initiation and days to 50% curd maturity was -8.34 to 30.85 and -8.55 to 25%, respectively. Highest negative heterosis for days to 50% curd maturity was recorded in the hybrid, Ogu15A × Kt-22 (-8.55%) followed by Ogu13A × Kt-15 (-7.52%) and Ogu15A × EC-162587 (-7.04%). Five among the top 10 heterotic hybrid for curd maturity had Ogu15A as female parent. The range of heterosis for plant height, number of leaves, leaf length, leaf width and gross plant weight was -93.79-24.87%, -16.62-44.76%, -29.87-28.64%, -25.13-40.03% and -34.17-127.91%, respectively. Whereas, the range of heterosis was -32.04-127.91%, -34.38-94.43%, -11.97-31.66%, -9.99-45.72%, -34.85-303.05%, -32.04-127.91% and -35.73-38.4% for marketable curd weight, net curd weight, curd length, curd width, core length, marketable curd yield and harvest index, respectively. Average heterosis was in desirable positive direction in 7 yield and yield related traits and harvest index. The average heterosis for marketable curd weight and net curd weight was 24.99 and 19.44%, respectively. Highest heterosis for marketable curd weight was recorded in the hybrid, Ogu15A × Kt-2 (127.91%) followed by Ogu14A × Sel-26 (90.90%), Ogu15A × Sel-26 (86.18%), Ogu15A × PSBK-1 (82.90%) and Ogu14A × Kt-2 (80.77%). Among the top 10 heterotic hybrids for curd yield, five had Ogu14A and 4 had Ogu15A as female parents. Moderate to low heterosis for various traits was mainly attributed to the narrow genetic base of Indian snowball cauliflower. Low genetic diversity is because of high degree of self-compatibility and consequent selfing to a considerable percentage (Watts, 14; Nieuwhof, 8). Moreover, most of the snowball cauliflower lines in India have derived from European materials. Genetic base of Indian snowball cauliflower is low as the base population had low genetic diversity. Astarini *et al.* (1) also reported narrow genetic base in cauliflower.

The lines with better estimates of GCA and SCA effects were involved in the hybrids with better performance for various traits. Therefore, it was concluded that careful selection of parental lines for good combining ability would help in developing more productive and early maturity F_1 hybrids. Singh *et al.* (10) also reported similar result in early Indian cauliflowers. Thus, the CMS lines, Ogu13A, Ogu14A and Ogu15A would be immensely useful in the development of heterotic hybrids for yield and early maturity after selection of suitable pollen parent line.

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