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ANALYSIS OF COMBINING ABILITY AND GENE ACTION IN MID-MATURITY SELF-INCOMPATIBLE BASED INDIAN CAULIFLOWER LINES

VEERENDRA KR. VERMA* AND PRITAM KALIA
Division of Vegetable Science,
Indian Agricultural Research Institute, Pusa Campus New Delhi - 110012, INDIA
e-mail:verma.veerendra@gmail.com.

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***Corresponding author**

ABSTRACT
An experiment was conducted to identify the superior hybrids in mid-late maturity group of Indian cauliflower based on gene action and genetic combining ability. 54 F_1 hybrids were developed using self-incompatible lines in line x tester and evaluated along with parental lines for yield and related attributes. The proportions of $\acute{o}^2$gca/$\acute{o}^2$sca were less than unity in all the cases indicating the role of non-additive gene action. Based on general combining ability analysis, line cc-35(64.6days) and tester HR-12-4(59.3days) was found as best general combiner for earliest to curds maturity. However, line cc-22(0.83 and 0.67kg) and tester Pusa Paushja (1.02 and 0.81kg) was identified as best general combiner for economic traits like marketable and net curd weight, respectively. Similarly, from specific combining ability analysis, hybrids cc-35L × HR-6-5-1-2(58days) and cc-35 × Pusa Shukti (62days) were identified as the earliest for days to curd maturity. The high yielding hybrids cc-35L × Pusa Paushja (1.68kg), cc-22 × Palam Uphar (1.56kg), cc-22 × Sarju Maghi (1.53kg) and cc-22 × Sl-1-2 (1.53kg) with maximum SCA effect for marketable curd weight were mid-late in maturity may be utilized for the further testing and commercial exploitation of heterosis.

INTRODUCTION

Cauliflower (*Brassica oleracea* L. var. *botrytis* L. 2n = 2x = 18) is one of the most popular Brassica vegetable after cabbage in production. The crop is also known for good source of vitamins, minerals and anti-carcinogenic phyto-chemicals like sulforaphane, glucosinolates and plant sterols such as indole-3-carbinol which appears to function as an anti-estrogen agent. In cauliflower, F_1 hybrids have been bred for earliness, high early and total yield, better curd quality with respect to compactness and color, uniform maturity, resistance to insect pest, diseases and unfavorable weather conditions (Kucera *et al*., 2006). The *Brassicaceae* family exhibits sporophytic self-incompatibility (Bateman, 1955) which is characterized by the expression of the S-allele of the sporophyte in the exine of the pollen grain. This information facilitates the use of these alleles as a method of pollination control in hybrid seed production. Self-incompatibility in cauliflower provides greater advantage over CMS system as in this case hybrid seed can be harvested from both the parents.

In heterosis breeding, knowledge of combining ability, gene action and presence of relative amount of additive and non-additive gene action in cross combination help to determine the feasibility of its utilization and identification of best combiners. Sprague and Tatum (1942) interpreted GCA as an indicative of additive gene action and SCA of genes having epistasis effect (non-additive gene action). Griffing (1956b) suggested that the GCA includes both additive effect as well as additive × additive interactions. The high yielding lines may not necessarily be able to transmit their superiority to their hybrids (Allard, 1960). Hence, an estimate of GCA and SCA effects may be a more reliable rather than the per se performance of the lines. Kempthorne (1957) gave the concept of line × tester for evaluation of lines in terms of components of variance and combining ability for selection of suitable genotype as parents in hybridization. In cauliflower, significant SCA effect for yield attributing traits were observed by Singh *et al*. (2005); Varalakshmi *et al*. (2009) and Verma *et al*. (2015) in early maturity; Pandey and Naik, (1986); Jamwal *et al*. (1991), Mahajan *et al*. (1999); Dixit *et al*. (2004) in self-incompatible based lines and Verma *et al*. (2011) in CMS based lines of mid-maturity cauliflower.

In India cauliflowers has been categorized into four maturity group and the first three maturity group which produces flowers in North Indian plains is considered as typical Indian cauliflower (Chatterjee and Swarup, 1972). Being a thermo-sensitive crop, the mid-late maturity group requires 12-16^{0}C temperature for curd initiation (Chatterjee and Swarup, 1983) and due to evolution of different maturity groups; cauliflower is grown almost round the year in India. However, there is a gap in the availability of superior cauliflower varieties/hybrids in mid-late maturity groups. Therefore, to identify the superior lines and hybrids for mid-late maturity, the present investigation was undertaken with the objective to study the gene action and combining ability for yield and related traits using self-incompatible lines of mid-maturity cauliflower.

MATERIALS AND METHODS

This experiment was conducted at the main experimental farm, Division of Vegetable Science, IARI Pusa Campus New Delhi during 2009. The experimental material consisted of six homozygous self-incompatible lines (cc-5, ccm-8, cc-22, cc-32, cc-35 and cc-35L) and nine testers (754, 6-5-1-2, HR-12-4, SL-1-2, Sarju Maghi, Pusa Sharad, Palam Uphar, Pusa Paushja and Pusa Shukti) based hybrids of mid-maturity group cauliflower. The parental lines were maintained through bud pollination/ sib mating isogenic fertile lines. The crosses were made among the selected inbred lines in a line x tester mating system as given by Kempthorne, 1957.

The performance of the parents and hybrids was assessed in a Randomized Block Design (RBD) with three replications. The seedlings were raised in plug trays using soil less media comprised of cocopit, perlite and vermiculite (3:1:1) under protected condition. The one month old seedlings were planted at the spacing of 60 x 60cm. The crops were grown with the recommended package of practices. The nine growth and yield attributing characters were studied as days taken to 50% curd maturity, leaf length (cm) leaf breadth (cm) plant height (cm), marketable curd weight (kg), net curd weight (kg), gross plant weight (kg), curd compactness as suggested by Pearson (1931) and harvest index. Six plants were selected from each replication for observations and the mean values for each trait were used for further statistical analyses (Sharma *et al*., 1988). The covariance of half sibs and full sibs were used for obtaining the estimates of general and specific combining ability effects and variances as per the procedure outlined by Kempthorne, 1957. The data were analyzed using software Statistical Package for Agricultural Research (SPAR-1.0) developed by Indian Agricultural Statistics Research Institute, New Delhi. Significance of the combining ability effects was determined at 5% and 1% probability.

RESULTS AND DISCUSSION

The analysis of variance showed highly significant differences among the treatments for all the parameters studied (Table1). Further, the parents were also differed significantly for most of the characters. The mean sum of square due to lines and testers were significant for all the traits. Pandey and Naik (1986) also observed for the traits like plant height, curd weight and curd size and Singh *et al.* (2005) for leaf area

Gene action

The results on estimates of variance components revealed the higher value for dominance variance (σ^2D) over the additive variance (σ^2a). The economic traits like net curd weight, marketable curd weight, curd compactness and harvest index showed predominance of dominant variance (σ^2D) and specific combing ability variance ($\sigma^2 sca$). However, trait days to 50% curd maturity showed predominance of additive variance (σ^2a) rather than dominance variance (σ^2D) (Table 2). Gangopadhyay *et al*. (1997) also reported additive gene action in controlling curd maturity. The traits, showed predominance of dominant gene action and presence of significant level of $\sigma^2 sca$ can be exploited through heterosis breeding. However, trait days to 50% curd maturity showing additive gene action can be exploited through selection. The higher contribution of lines for marketable and net curd weight over tester revealed the superiority of lines. These findings are in conformity with Jamwal *et al*. (1991); Kumar *et al*. (2002); Thakur *et al*. (2004); Jindal *et al*. (2005) and Garg *et al*. (2006) in cauliflower and Kumar *et al*. (2013 and 2014) in Indian mustard.

General combining ability (GCA effects) of the parental lines

It is evident from the results that mean square due to general combining ability (GCA) was highly significant for all the traits under studied (Table 3). To get early crop, GCA effect in negative direction is considered desirable for days to 50% curd maturity. The hybrids of mid-late maturity are also considered as desirable to fulfill the gap of availability between mid and late maturity. The maximum negative GCA (gi) effect for days to 50% curd maturity was recorded in the line cc-35 (-3.33) followed by cc-5 (-1.07), whereas maximum positive GCA (gi) effect was found in cc-32(1.38). However, among the testers maximum negative GCA (gj) effect was observed in HR-12-4 (-6.42) followed by HR-6-5-1-2 (-2.14) while maximum positive GCA (gi) effect was recorded in Pusa Shukti (6.74). Dey *et al*. (2011) also reported the highest negative GCA effect (-2.73)

Table 1: Analysis of variance (ANOVA) for yield and related traits

Source of variation	D.F.	Mean square Days to 50% curd maturity	Leaf length (cm)	Leaf breadth (cm)	Plant height (cm)	Marketable curd weight (kg)	Net curd weight ` (kg)	Curd Compactness	Gross plant weight (kg)	Harvest Index
Replication	2	2.12	5.91	1.07	3.26	0.042	0.029	17.83	0.048	21.3
Treatment	68	80.82**	100.18**	21.08**	119.25**	0.096**	0.067**	195.90**	1.024**	162.56**
Parents	14	101.45**	115.08**	26.04**	102.93**	0.02**	0.018**	198.87**	1.03**	273.99**
Lines	5	98.58**	109.52**	27.78**	182.80**	0.013*	0.012*	354.43**	1.08**	231.89**
Testers	8	115.06**	118.12**	28.20**	63.62**	0.012**	0.02**	121.34**	1.10**	333.14**
Lines vs. Testers	1	6.84*	118.67**	0.09	18.14**	0.038**	0.04**	41.36	0.12**	11.32
Parents vs. hybrids	1	110.22**	1629.07**	55.29**	1360.77**	1.45**	0.78**	264.85**	11.82**	363.92**
Hybrids	53	74.82**	76.38**	19.05**	100.14**	0.092**	0.066**	193.82**	0.82**	129.32**
Error	136	1.01	1.67	0.58	2.07	0.0054	0.076	10.62	0.01	5.59

*, ** = Significant at 5% and 1% probability, respectively through F test

Table 2: Estimates of components of variance for yield and related traits

Mean Square	Days to 50% curd maturity	Leaf length (cm)	Leaf breadth (cm)	Plant height (cm)	Marketable curd weight (kg)	Net curd weight (kg)	Curd compactness	Gross plant weight (kg)	Harvest Index
σ^2a (F = 1)	16.91	6.21	1.74	11.46	0.007	0.004	20.21	0.94	15.11
σ^2D (F = 1)	9.56	24.62	5.86	29.19	0.030	0.023	54.47	0.24	34.17
[σ^2 D/σ^2A]1/2	0.75	1.99	1.84	1.59	2.07	2.39	1.64	0.58	1.5
σ^2 *gca*	8.45**	3.10	0.87*	5.73**	0.004	0.002	10.10**	0.05**	7.55**
σ^2 *sca*	9.56**	24.62**	5.86**	29.19**	0.035**	0.023**	54.47**	0.24**	34.17**
σ^2*gca*/σ^2*sca*	0.88	0.13	0.15	0.20	0.11	0.08	0.19	0.20	0.22
Contribution of lines (%)	11.90	4.92	6.68	11.80	15.130	10.77	8.07	10.13	6.82
Contribution of tester (%)	58.11	20.42	21.26	20.63	6.290	5.64	24.15	23.37	30.07
Contribution of L x T (%)	29.97	74.65	72.048	67.56	79.560	83.58	67.76	66.48	63.10

*, ** = Significant at 5% and 1% probability, respectively through F test

Table 3: Estimates of GCA effects of lines and testers for yield and related traits

Parents	Days to 50% curd maturity	Leaf length (cm)	Leaf breadth (cm)	Plant height (cm)	Marketable curd weight (kg)	Net curd weight (kg)	Curd compactness	Gross plant weight (kg)	Harvest index
A. GCA effect of lines									
cc-5	-1.07**	-1.58**	-0.92**	-1.29**	-0.08**	-0.06**	2.82**	-0.22**	1.17*
ccm-8	0.53**	-0.51*	0.48**	-1.11**	0.01	0.03*	-0.02	0.21**	2.59**
cc-22	1.25**	1.57**	0.19	3.23**	0.10**	0.07**	2.42**	0.05*	2.86**
cc-32	1.38**	0.67**	-0.07	2.04**	0.04**	0.03*	0.44	0.09**	0.47
cc-35	-3.33**	0.56*	-0.66**	-2.33**	-0.08**	-0.07**	-3.39**	-0.22**	0.07
cc-35L	1.23**	-0.88**	0.97**	-0.55	0.018	0.003	-2.27**	0.10**	0.89
SE(gi)	0.24	0.31	0.18	0.34	0.02	0.02	0.77	0.02	0.56
CD (p=0.05)	0.47	0.61	0.36	0.67	0.04	0.03	1.52	0.05	1.11
CD (p=0.01)	0.62	0.8	0.47	0.89	0.05	0.04	2.01	0.06	1.46
B. GCA effect of testers									
754	-2.08**	0.15	0.25	-0.11	-0.06**	-0.04**	0.02	-0.30**	2.56**
Pusa Paushja	-1.08**	0.27	-0.36*	-0.55	0.09**	0.06**	-2.16**	0.09**	0.66
HR-6-5-1-2	-2.14**	-0.57	0.52**	-0.44	0.01	0	-2.99**	0.06**	-0.72
HR-12-4	-6.42**	-2.51*	-0.92**	-3.49**	0.01	0.03*	-3.83**	-0.25**	4.21**
Sl-1-2	0.64**	-0.18	-1.19**	-0.61	-0.01	0	8.50**	-0.15**	2.13**
Sarju Maghi	-1.64**	-3.35**	-1.75**	-3.16**	-0.04*	-0.06**	3.10**	-0.17**	0.98
Pusa Sharad	0.74**	1.54**	-0.03	1.22**	0.03	0	-1.23	-0.06*	1.80**
Palam Uphar	5.24**	-0.4	1.69**	1.22**	0.01	0.03	2.83**	0.27**	-3.26**
Pusa Shukti	6.74**	5.04**	1.80**	5.89**	-0.05**	-0.02	-4.24**	0.51**	-8.35**
SE(gj)	0.19	0.25	0.15	0.28	0.01	0.01	0.63	0.02	0.46
CD (p=0.05)	0.38	0.49	0.29	0.55	0.03	0.03	1.24	0.04	0.9
CD (p=0.01)	0.51	0.65	0.39	0.73	0.04	0.03	1.65	0.05	1.19

*, ** =Significant at 5% and 1% probability, respectively through F test.

from cms line Ogu1A. Thus, line cc-35(64.6days) and tester HR-12-4(59.3days) having negative GCA (gj) effect and earliest in maturity and line cc-32(65.5days) and tester Pusa Shukti (76.6days) having positive GCA (gj) effect with late in maturity can be utilized as a best general combiners. The parents discussed above had high general combining ability and fixable component of gene action i.e. additive and additive x additive type of epistasis, could be successfully exploited by developing homozygous line have used for improved character for which improvement is desired. Further, these parental lines may also be utilized for producing the intermatting population in order to get desirable recombinants.

For yield contributing trait leaf length, maximum positive GCA (gi) effect was recorded in line cc-22(54.67cm) followed by cc-35 (51.33cm). However, maximum negative GCA effect was observed in cc-35L (63.0cm). Among the testers, Pusa Shukti (64.0cm) showed highest positive GCA (gi) effect followed by Pusa Sharad (63.67cm), whereas maximum negative GCA (gj) effect was observed in Sarju Maghi (55.67cm) followed by HR-12-4 (53.0cm). Similarly, for leaf breadth maximum positive GCA (gi) effect was observed in cc-35L (0.97) followed by ccm-8 (0.48) and maximum negative GCA (gi) effect was observed in cc-5 (-0.92). For testers it was maximum in Pusa Shukti (1.80) followed for Palam Uphar (1.69) and highest negative was in Sarju Maghi (-1.75). However, for plant height two lines, namely cc-22 and cc-35 showed positive significant GCA (gi) effect. In case of testers, Pusa Shukti, Pusa Sharad and Palam Uphar showed positive significant GCA (gj) effect for plant height. Similar, findings were also reported by Singh *et al.*, 2005, Kumar *et al*. (2014) in Indian mustard and Verma *et al*. (2015) in early cauliflower.

The perusal of the data on GCA effects of the lines indicated that line cc-22 (0.10) and cc-35 (0.04) was the best general combiner for economic trait marketable curd weight. However, Pusa Paushja was identified as best tester with (0.09) GCA (gi) effect. Similarly, for net curd weight line cc-22 (0.07) was best genotype with highest GCA (gi) effect followed by cc-35 (0.03) and ccm-8(0.03). Among the testers, Pusa Paushja (0.06) showed maximum positive GCA (gj) effect followed by HR-12-4(0.03). This finding is in the line with the results of Verma *et*

Table 4: Estimates of SCA effect of the 54 F_1 hybrids

Parents	Days to 50%curd maturity	Leaf length (cm)	Leaf breadth (cm)	Plant height (cm)	Marke table curd weight (kg)	Net curd weight (kg)	Curd compa ctness	Gross plant weight (kg)	Harvest index
cc-5 x 754	0.34	3.92 **	0.75	1.73 *	0.12 **	0.14 **	-1.94	0.18 **	0.63
cc-5 x Pusa Paushja	-0.32	-11.85 **	-5.96 **	-12.49**	-0.21**	-0.19 **	4.12 *	-0.29**	-3.80 **
cc -5 x 6-5-1-2	2.06 **	-1.69 *	2.47 **	1.06	-0.05	-0.05	2.34	0.08	-4.58 **
cc -5 x HR-12-4	-0.98	8.92 **	0.58	5.79**	0.05	-0.02	-0.13	-0.20**	6.49 **
cc -5 x SL-1-2	1.62**	4.58**	4.53 **	0.56	0.18 **	0.19 **	-5.85**	1.04 **	-9.06**
cc -5 x SM	-1.76 **	-2.24 **	-0.58	0.45	-0.16 **	-0.11 **	8.13 **	-0.62 **	5.58 **
cc -5 x PS	2.17**	1.19	-0.30	4.06 **	-0.08 *	-0.09 *	0.04	-0.28 **	1.04
cc -5 x PU	-3.98 **	-1.85 *	-1.69**	0.73	-0.08	-0.11**	-7.13**	-0.64 **	5.85 **
cc -5 x P. Shukti	0.84	-0.96	0.19	-1.93 *	0.23**	0.22 **	0.42	0.74**	-2.17
cc m-8 x 754	-2.58**	-3.48 **	-1.32 **	-0.12	0.02	0.002	-1.74	-0.25**	3.70 **
cc m -8 x P. Paushja	-5.58**	4.40 **	3.29 **	5.32 **	0.18 **	0.12 **	0.48	0.17 **	3.53 *
cc m -8 x 6-5-1-2	0.81	2.90 **	2.40**	0.55	-0.05	0.01	13.20 **	0.018	-2.39
cc m -8 x HR-12-4	1.42 *	-4.48 **	-1.48 **	-6.06**	-0.08	-0.04	0.97	-0.33**	1.27
cc m -8 x SL-1-2	0.69	-3.48 **	-3.87 **	-6.28**	0.001	-0.02	-13.12**	-0.46 **	6.86 **
cc m -8 x SM	-1.02	1.01	-1.6 **	0.27	0.04	0.002	-1.89	0.03	0.18
cc m -8 x PS	-1.74 **	5.12 **	1.62**	5.54**	-0.04	-0.03	-10.26**	0.41 **	-6.94 **
cc m -8 x PU	4.75**	-4.26 **	1.23 **	0.55	0.05	0.07	9.97 **	0.53**	-4.13 **
cc m -8 x P. Shukti	3.25**	2.29**	-0.21	0.22	-0.12 **	-0.13 **	2.38	-0.10	-2.10
cc-22 x 754	1.15	1.35**	0.50	0.76	-0.25**	-0.07	3.50*	-0.08	-3.16*
cc-22 x P. Paushja	1.67**	2.80 **	-0.74	3.66**	-0.17**	-0.05	0.93	-0.05	-4.82**
cc -22x 6-5-1-2	1.73 **	-1.02	0.03	-2.78 **	-0.08	-0.12 **	-8.27 **	-0.67 **	8.94**
cc -22x HR-12-4	2.01 **	-5.41 **	-2.85 **	-4.39 **	-0.24 **	-0.21 **	-7.19 **	-0.18 **	-6.54 **
cc -22 X SL-1-2	-1.04	1.25	-2.58**	3.71 **	0.25 **	0.16**	1.15	-0.29**	15.93 **
cc -22x SM	0.23	4.75 **	2.97**	1.27	0.28 **	0.22**	13.46 **	0.68 **	-1.17
cc -22 x PS	0.51	-5.13 **	1.92**	-5.78 **	-0.22**	-0.20 **	7.53 **	-0.29**	-3.87 **
cc -22 x PU	-6.32 **	2.80 **	0.53	-0.78	0.26 **	0.28**	-11.71 **	0.57**	-0.24
cc -22 x P. Shukti	1.17 *	-2.96 **	-0.91 *	-0.45	-0.01	0.02	-7.47 **	-0.18 **	1.17
cc -32 x 754	2.23 **	-6.34 **	1.23**	-8.26 **	-0.03	-0.11 **	-1.54	-0.45 **	7.82 **
cc -32x P.Paushja	0.23	1.21	-0.48	-1.48	0.05	0.10 **	-5.69 **	0.10	0.74
cc -32X 6-5-1-2	0.95	-6.95 **	-1.37**	-5.93 **	-0.12 **	-0.13 **	1.23	-0.26 **	-0.30
cc -32xHR-12-4	-0.76	2.32 **	0.06	0.12	0.24**	0.23 **	2.06	0.88 **	-5.03 **
cc -32 xSL-1-2	1.84 **	7.66 **	3.34 **	8.56 **	0.02	0.02	4.65 *	0.35**	-4.75 **
cc -32 x SM	-3.54 **	-6.17 **	-3.43 **	-5.21 **	-0.14 **	-0.11 **	-9.37**	-0.28 **	-0.86
cc -32 x PS	0.06	3.27 **	0.51	8.40 **	0.24 **	0.28 **	6.26**	0.50**	0.61
cc -32 x PU	-1.43*	7.88 **	0.45	6.73 **	-0.15**	-0.14 **	1.73	-0.10	-4.04 **
cc -32 x P. Shukti	0.40	-2.89 **	-0.32	-2.93 **	-0.10 *	-0.14**	0.66	-0.73 **	5.81 **
cc -35 x 754	0.45	-2.66**	0.46	-3.75	-0.16*	-0.11**	1.75	-0.56**	-4.50**
cc -35 x P. Paushja	0.27	-2.00 **	1.10 *	-0.78	-0.26**	-0.19 **	4.10 *	-0.30 **	-2.84 *
cc -35 x 6-5-1-2	1.99 **	4.49 **	-1.11 *	7.43 **	0.20 **	0.190**	-3.99*	0.45 **	0.24
cc -35 x HR-12-4	1.93 **	-2.22**	-0.34	-3.17 **	0.01	-0.01	-1.07	-0.21 **	5.20 **
cc -35 x SL-1-2	-2.11**	-7.22**	2.27 **	-7.06 **	-0.21 **	-0.19 **	8.69**	-0.21 **	-5.65 **
cc -35 x SM	2.16 **	-0.39	0.82	0.82	-0.04	0.004	-1.60	0.370**	-7.17 **
cc -35 x PS	-2.22**	-1.95 *	-2.89**	-6.22 **	0.25 **	0.139**	-6.55 **	0.01	9.61 **
cc -35 x PU	5.93 **	1.32	1.38 **	-1.22	-0.04	-0.06	10.80**	-0.53**	6.02**
cc -35x P. Shukti	-6.56**	2.54 **	-0.06	5.72 **	-0.02	-0.02	3.08	-0.16**	0.38
cc -35Lx 754	1.38 *	-2.45 **	-1.13*	-3.34 **	-0.13 **	-0.11 **	7.13**	-0.48 **	3.03 *
cc -35L x P.Paushja	3.71 **	5.44**	2.80 **	5.77 **	0.39 **	0.21**	-3.94*	0.37 **	7.183 **
cc -35 Lx 6-5-1-2	-7.52 **	2.27 **	-2.41 **	-0.34	0.10 *	0.11 **	-4.50 *	0.37 **	-1.91
cc -35 Lx HR-12-4	-3.67 **	0.88	4.03 **	7.716**	0.01	0.03	5.36 **	0.05	-1.40
cc -35L x SL-1-2	-1.00	-2.78**	-3.69**	0.49	-0.25 **	-0.18 **	4.46 *	-0.42**	-3.34 *
cc -35 Lx SM	3.93**	3.04 **	1.86 **	2.38 **	0.03	-0.01	-8.72 **	-0.16**	3.45 *
cc -35 Lx PS	1.21 *	-2.50**	-0.85	-6.00 **	-0.15 **	-0.09 *	2.97	-0.35**	-0.46
cc -35LxPU	1.04	-5.89**	-1.91**	-6.00 **	-0.03	-0.003	-3.66	0.18 **	-3.46 *
cc -35L x P. Shukti	0.88	1.99 **	1.30**	-0.67	0.03	0.04	0.91	0.44 **	-3.08 *
SE(sij)	0.58	0.74	0.44	0.83	0.04	0.03	1.88	0.05	1.36
SE±gi-gj(L)	0.27	0.35	0.20	0.39	0.02	0.02	0.88	0.02	0.64
SE±gi-gj(T)	0.34	0.43	0.25	0.48	0.02	0.02	1.08	0.03	0.78
SE±Sij-Sil	0.82	1.06	0.62	1.17	0.06	0.05	2.66	0.08	1.93
SE±Sij-Sil	0.72	0.93	0.55	1.04	0.05	0.04	02.34	0.07	1.70

*, ** = Significant at 5% and 1% probability, respectively through F test.Where; PU = Palam Uphar, PS = Pusa Sharad, SM = Sarju Maghi, P. Paushja = Pusa Paushja, P.Shukti = Pusa Shukti

al. (2011) in cytoplasmic male sterile lines and testers of early and mid-maturity cauliflower. The superior lines cc-22 (0.83 and 0.67 kg), cc-35(.95 and 0.72kg) and tester Pusa Paushja (1.02 and 0.81kg), HR-12-4(1.02 and 0.83kg) may be utilized as a best general combiner for marketable and net curd weight, respectively.

Moreover, for curd compactness line cc-5 showed maximum positive GCA (gi) effect (2.82) followed by cc-22 (2.42). While, Sl-1-2 was noticed best tester with maximum GCA (gj) value (8.50) followed by Sarju Manghi (3.10) and Palam Uphar (2.83). Likewise, for gross plant weight maximum GCA (gi) effect was noticed in ccm-8 (0.21) followed by cc-35 L (0.10), whereas, among the testers maximum GCA (gj) effect were observed in Pusa Shukti (0.51) followed by Palam Uphar (0.27). Maximum GCA (gi) effect for harvest index was in line cc-22 (2.86) followed by cc-8 (2.59). While, among the testers, maximum GCA (gj) effect showed by HR-12-4 (4.21), followed by 754 (2.56). Maximum negative GCA (gj) effect among testers was however, recorded in Pusa Shukti (-8.35). Similar findings were also reported by Verma *et al*. (2011) in cytoplasmic male sterile lines and testers of early and mid-maturity cauliflower.

Among the lines, cc-35(64.67days) was identified as best general combiner for earliest to curd maturity. Although, line cc-22 was late in maturity (76.33 days) but it was found to be suitable for filling the gap of curd availability with superior in yield and contributing traits such as plant height(74.67cm), marketable curd weight(0.83kg), net curd weight(0.67kg) and harvest index(53.73). However, among the testers, HR-12-4 was best general combiner for earliest to curd maturity (59.33days) and Pusa Shukti for leaf length (64.0cm), leaf breadth (23.33cm), plant height (69.33cm) and gross plant weight (3.44kg). While, Pusa Paushja was identified as best combiner for economic traits like, marketable (1.12kg) and net curd weight (0.92kg). 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 favorable gene flow from parents to offspring at high frequency and gives information about the concentration of predominantly additive genes (Franco *et al*., 2001). 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, 1979).

Specific combining ability (SCA effects) of the hybrids

The SCA effects represent dominance and epistatic effects; can be used as an index to determine the usefulness of a particular cross combination in the exploitation of heterosis. In the present investigation, SCA effects of the F_1 hybrid were significant for all the traits (Table 4). To get earliest crop, the estimates of SCA effects in negative direction is considered as a desirable for days to 50% curd maturity. Among the crosses, 13 hybrids showed negative SCA effect and maximum negative SCA effect was recorded in cc-35L × HR 6-5-1-2 (-7.52) followed by cc-35 × Pusa Shukti (-6.56) and cc-22 × Palam Uphar (-6.32). The maximum positive SCA effect was recorded in cc-35 × Palam Uphar (5.93). These findings are in agreement with those of Sharma *et al*. (1988); Vara lakshmi (2009) and Verma *et al*. (2015). Thus, hybrid cc-35L × HR 6-5-1-2(58.33days) may be selected as earliest for curd maturity under the mid-maturity group of cauliflower which may pay higher price to the growers. However, hybrid cc-35 × Palam Uphar of late maturity (72 days) could be utilized as a mid-late maturing hybrid to ensure the availability in mid-late maturity segment of Indian cauliflower. For yield contributing trait leaf length, 19 out of 54 hybrids, showed positive SCA effect with maximum positive value in cc-5 × HR-12-4 (8.92) followed by cc-32 × Palam Uphar (7.88) and cc-35 × Sl-1-2 (7.66). The maximum negative SCA effect was recorded in hybrid cc-5 × Pusa Paushja (-11.85). Similarly for leaf breath, 17out of 54 hybrids, exhibited significant positive SCA effect with maximum effect in hybrid cc-5 × Sl-1-2 (4.53) followed by cc-35L × HR-12-4 (4.03), cc-32 × Sl-1-2 (3.34) and ccm-8 × Pusa Paushja (3.29). However, maximum negative SCA effect was obtained in cc-5 × Pusa Paushja (-5.96) followed by ccm-8 × Sl-1-2 (-3.87). Likewise, for plant height maximum SCA effect in positive direction was recorded in cc-35 × Sl-1-2 (8.56) followed by cc-35 × Pusa Sharad (8.40) and cc-35L × HR-12-4 (7.72). This is in line with the findings of Verma *et al*. (2011) in cauliflower. Hybrids, having higher yield with lower plant height may be selected for close planting while taller hybrids can be selected for the wider spacing and also for the high rainfall area.

However, for economic trait marketable curd weight 13 out of 54 hybrids had positive and significant SCA effect. The maximum positive SCA effect was noticed in cc-35L × Pusa Paushja (0.39) followed by cc-22 × Sarju Maghi (0.28) and cc-22 × Palam Uphar (0.26). The maximum negative SCA effect was recorded in hybrid cc-35L × Sl-1-2 (-0.25). Similarly for net curd weight maximum positive SCA effect was observed in cc-22 × Palam Uphar (0.28) followed by cc-35 × Pusa Sharad (0.28), cc-35 × HR-12-4 (0.23), cc-22 × Sarju Maghi (0.22) and cc-5 × Pusa Shukti (0.22).The maximum negative SCA effect was recorded in cc-22 × HR-12-4 (-0.21). Thus, hybrid cc-35L × Pusa Paushja (1.68 and 1.18kg), cc-22 × Palam Uphar (1.56 and 1.25kg), cc-22 × Sarju Maghi (1.53 and1.15kg), cc-35 × Pusa Sharad (1.38 and 0.98kg) and cc-35 × HR-12-4 (1.12 and 0.87kg) may be used for the development of hybrids having highest marketable and net curd weight, respectively. Similar findings were also reported by Verma *et al*. (2015) in early maturity cauliflower.

Among the crosses for curd compactness**,** 14 hybrids showed significant and positive SCA effect and it was highest in cc-22 × Sarju Maghi (13.46) followed by ccm-8 × HR-6-5-1-2 (13.20) and cc-35 × Palam Uphar (10.80). The maximum SCA effect in negative direction was observed in ccm-8 × Sl-1-2 (-13.12). Hybrid, cc-22 × Sarju Maghi having maximum curd compactness (45.27) and higher yield may be selected for testing and production of hybrids for long distance transport.

For gross plant weight, out of 54 hybrids 51 showed positive SCA effect and maximum SCA effect was observed in hybrid cc-5 × Sl-1-2 (1.04) followed by cc-35 × HR-12-4 (0.88) and cc-22 × Sarju Maghi (0.68). However, for harvest index, out of 54 crosses 16 showed positive and significant SCA effect and maximum SCA effect was noticed in hybrid cc-22 × Sl-1-2 (15.93) followed by cc-35 × Pusa Sharad (9.16) and cc-22 × HR-6-5-1-2 (8.94). This is in line with the findings of Pandey *et al*. (1986) and Verma *et al*. (2011) in cauliflower.

The above findings of the present investigation have shown the preponderance of the dominant gene action with significantly higher variance due to specific combing ability for yield attributing traits. The promising crosses based on significant SCA effects and per se performance revealed the predominance of SCA effect for leaf length, leaf breadth and gross plant weight, marketable curd weight, net curd weight, curd compactness and harvest index. Majority of the crosses exhibited desirable SCA effects had at least one of the parents as good or average general combiner. Similar, reports have also been put forward by Thakur *et al*. (1999). Li *et al*. (2013) also reported that lines with more traits of good characters can be combined in the same cultivar. The identified superior hybrids cc-35L × Pusa Paushja, cc-22 × Sarju Maghi, cc-22 × Palam Uphar and cc-35 × Pusa Sharad having good combining ability for yield and attributing traits with mid-late in maturity can be utilized for exploitation of heterosis to fulfilling the gap of curd availability in mid-late maturity group of Indian cauliflower.

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