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Indigenously developed SI and CMS lines in hybrid breeding of cabbage

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ABSTRACT

Six SI lines with strong incompatibility reaction and one CMS line with good floral traits and seed setting capacity were tested in Line × Tester design with six broad base testers. Mean sum of squares of all the 42 hybrids were significant for all the seven traits studied. Significant high GCA for earliness was recorded in the SI line, S-696 (-2.20). Significant high GCA for productivity was recorded in 3 SI lines, S-624, S-645 and S-208. Highest SCA effect for head size was recorded in S-208 × 83-6 followed by S-621 × GA-121. Highest heterosis for head weight was recorded in the hybrid, S-621 × GA-121 (37.9%) followed by S-624 × GA-111 (34.1%) and S-208 × GA-111 (31.8%). The line CMS-1 was also useful in developing hybrids with desirable plant type indicating suitability of these SI and CMS lines in developing high yielding F_1 hybrids with desirable plant architecture.

Key words: Cabbage, cytoplasmic male sterility, combining ability, heterosis, self-incompatibility.

INTRODUCTION

In the present era, hybrid varieties are the norm in vegetable cultivation. Among the vegetable *Brassicas* grown in India, F_1 hybrids are highly popular in cabbage because of uniform maturity, better head quality, early maturity, resistance to biotic stresses and higher yield (Fang *et al*., 3). Availability of suitable pollination control mechanism is the most important determinant factor for economic and viable production of hybrid seeds (Kucera *et al*., 6). It ensures the availability of F_1 seeds at reasonable price to the user end. As self-incompatibility (SI) widely exists in cabbage, stable self-incompatible lines are used as the parents to produce hybrids. In the conditions of simultaneity in flowering time the seeds from parents are all high purity hybrid F_1 seeds, so it costs less and easy to use. The instability and complex inheritance of the self-incompatibility mechanism makes its use difficult. Pollination by hand in bud stage to propagate parental lines may cost mass labour force and the parental lines after repeated self-pollination may lose vigor, but use of cytoplasmic male sterile (CMS) lines can remove all these disadvantages (Kucera *et al*., 6). Since, head is the only economic part, fertility of the F_1 hybrid is not important. Therefore, hybrid seed production can be taken up even in the absence of restorer gene.

Male sterility conferred by Ogura cytoplasm of *Raphanus stativus* has been transferred to many crops through repeated backcrossing and selection (Ogura, 7). Limitation to this system is chlorosis of leaves at low temperatures, much-reduced nectaries, and frequent occurrence of malformed flowers. So it is still not widely used in breeding. Now scientists have acquired new improved CMS system devoid of the above problems by protoplast fusion, and have also transferred it to cabbage by backcrossing (Earle *et al*., 2). In cabbage, almost entire cultivated area is under hybrid cultivars (Seed Association of India, 2005). But it is astonishing that until now only one F_1 cultivar of cabbage 'Pusa Cabbage Hybrid-1' (KGMR 1) has been released by the public sector in India. It is mainly attributed to non-availability of stable and reliable pollination control mechanisms like SI and CMS systems. In the present study few SI and CMS lines of cabbage were developed indigenously and tested for their suitability in development of F_1 hybrids.

MATERIALS AND METHODS

Six self-incompatible (SI) lines (S-621, S-624, S-645, S-691, S-696 and S-208) used in the study were developed through single plant selection from different populations. They were selected among 10 SI lines developed based on strong S allele and desirable horticultural traits. These lines were tested for incompatibility and homozygous S allele. These six lines were found very promising as having strong S allele and also possessed desirable horticultural traits. One Ogura based cytoplasmic male sterile (CMS) line, CMS-1 was developed after BC_{10} with variety 'Golden Acre' as recurrent parent and was free from chlorosis of leaves at low temperatures. This line was free from any floral deformities with well developed nectaries and straight style.

Six SI and one CMS lines were used as female parents (lines) and 6 cabbage genotypes, *viz*., GA-111, GA-121, 83-6-204, 83-6, Sel-6 and GA-122

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were used as pollen parents (testers). Each of the lines was crossed with all the 6 testers individually in Line × Tester fashion during 2009 to develop 42 hybrid combinations as suggested by Kempthorne (5). Female 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 muslin cloth bags. Each male plant was covered individually before opening of flowers. Further, the 42 hybrids along with their parents were raised in a randomized block design with two replications during 2010 at Naggar Experimental Farm of IARI, Regional Station, Katrain situated at an altitude of 1,560 m above mean sea level. Five randomly selected plants were tag-labeled for recording the observations for nine traits. The data were subjected to combining ability analysis following the method suggested by Kempthorne (5). Mid parent heterosis was calculated to work out the superiority of SI and CMS based F_1 hybrids over their parents.

RESULTS AND DISCUSSION

In cabbage, SI and CMS systems are in use for development of F_1 hybrid seeds at a reasonable cost. We have developed and tested the presently used six SI lines for their stability and it was found that they had very strong 'S' allele in homozygous state. Parkash *et al*. (8) previously reported that these SI lines can be used for development of hybrid seeds after testing their combining ability. We have also developed few CMS lines through backcrossing with cabbage lines possessed with Ogura cytoplasm and free from chlorosis at low temperatures. However, most of the developed lines have many floral deformities and reduced nectaries. Among these, one line CMS-1 was selected after 10 generations of backcrossing with no floral deformities and well developed nectaries. All these 6 SI lines and one CMS lines were tested in Line × Tester fashion to determine their combining ability and suitability for use in heterosis breeding.

Line × Tester analysis determined suitability of the SI and CMS lines in heterosis breeding. The Line × Tester design (Kempthorne, 5) 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*., 4). The selected parental lines with better performance can be crossed in suitable combination to exploit heterosis and crosses with high SCA could be best utilized in heterosis breeding.

Significantly high GCA in desirable direction for earliness was found in the SI line, S-696 (-2.20) (Table 1). Thus, this line could be used as one parent in development of F_1 hybrids with early maturity, which is highly desirable for a good hybrid cultivar. Plant architecture is also very important in cabbage. In cabbage, plants with low spread, lesser number of leaves and shorter core length are preferred. Lesser number of leaves and smaller plant spread helps in accommodating higher number of plants per unit area and thus provide more yields (Fang *et al*., 3). Cabbage heads with short core length are more compact in nature. In the present study, the lines, S-691, CMS-1, and S-696 showed significantly high GCA effect in negative direction. Thus, these lines could be utilized in development of F_1 hybrids with smaller plant spread. In the lines, S-645 and CMS-1 significantly high GCA in desirable direction was found for number of leaves. For, core length the CMS-1 was the only line with significantly high GCA effect. Thus, CMS-1 has good potential for its use in cabbage hybrid breeding for development of cultivars with desirable plant type. Significantly high GCA for plant and head weight was recorded in the lines, S-624, S-645 and S-208. Thus, these lines have potential for use in hybrid breeding and development of cultivars with higher productivity.

Among the 42 hybrids, 5 hybrids showed significant SCA effect for both head weight and plant weight. For plant spread, 3 hybrids showed significant SCA in desirable direction, while, 2 hybrids showed significant SCA for head size. For number of leaves and core length one hybrid in each case showed significant desirable SCA effect (Table 2). For head weight, highest SCA was found in the combination of S-645 × GA-122 followed by Sel-621 × GA-121 and Sel-626 × GA-111. For plant weight highest SCA was recorded in the combination of S-645 × GA-122 followed by S-208 × 83-6 and S-691 × 83-6-204. Highest negative SCA effect was recorded in the hybrid S-621 × 83-6 followed by S-691 × 83-6 and S-208 × 83-6-204. Highest SCA effect for head size was recorded in S-208 × 83-6 followed by S-621 × GA-121. For core length highest negative SCA was found in the hybrid S-208 × 83-6-204, while for number of leaves highest negative SCA was found in combination of S-208 × 83-6.

All the yield related traits showed varying degree of heterosis (Table 3). For head weight out of 42

Table 1. Estimates of GCA effects of seven lines and six testers of cabbage for nine traits using Line × Tester analysis.

Trait	Plant height	Plant spread	Head size	No. of leaves	Core length	Maturity days	Head weight	Plant weight	Harvest index
Lines									
S-621	-0.07	-0.03	6.09	0.83	-0.05	-1.61	0.049	0.05	0.16
S-624	1.12*	2.52*	4.77	2.13*	0.44	0.79	0.114*	0.20*	-1.38
S-645	2.05*	2.07*	15.23*	-1.53*	0.69*	0.13	0.110*	0.11*	1.88
S-691	-0.91	-5.35*	-12.74*	0.65	0.04	-0.70	-0.154*	-0.29*	2.76*
S-696	-1.00	-1.78*	-11.58	-0.66	-0.42	-2.20*	-0.122*	-0.17*	-0.79
S-208	0.34	5.04*	4.23	1.23*	0.21	4.46	0.137*	0.34*	-4.43*
CMS-1	-1.52*	-2.46*	-5.99	-1.37*	-0.92*	-0.86	-0.133*	-0.24*	1.81
Testers									
GA-111	-0.19	0.21	1.37	-0.08	-0.64*	-3.39*	-0.03	0.07	0.23
GA-121	-0.73	-2.94*	2.99	-1.81*	-0.35	-2.09	0.02	-0.09	5.01*
83-6-204	-0.11	-0.75	-16.82*	0.66	0.18	2.82	-0.04	-0.03	-1.81
83-6	2.47*	5.10*	12.10*	1.18*	0.60	6.39	0.06*	0.23*	-4.53*
Sel-6	0.04	0.85	12.58*	1.14*	0.15	0.32	0.05*	0.15*	-2.42*
GA-122	-1.47*	-2.47*	-12.21*	-1.08*	0.07	-4.10*	-0.06*	-0.18*	3.53*

*Significant at P = 0.05

Table 2. Estimates of SCA effects of 42 crosses of cabbage for nine traits.

Cross	Plant height	Plant spread	Head size	No. of non-wrapper leaves	Core length	Maturity days	Head weight	Plant weight	Harvest index
S-621 × GA-111	0.22	1.57	17.59	-0.16	0.11	-1.02	0.01	0.08	3.45
S-621 × GA-121	0.76	2.13	33.50*	-0.62	1.53	-2.38	0.25*	0.31*	2.08
S-621 × 83-6-204	0.34	0.43	-8.32	1.01	0.50	1.76	-0.05	-0.04	-0.33
S-621 × 83-6	-1.79	-4.71*	-41.23*	-0.61	-1.22	2.19	-0.23*	-0.35*	-1.23
S-621 × Sel-6	0.99	0.73	8.40	0.73	-0.28	-0.24	-0.01	0.05	-1.43
S-621 × GA-122	0.51	-0.15	-9.94	-0.35	-0.64	-0.31	-0.07	-0.05	-2.45
S-624 × GA-111	2.02	5.62*	15.03	-0.96	-0.78	1.06	0.24*	0.28*	3.55
S-624 × GA-121	-0.53	.-2.72	-26.24	-0.32	-1.06	4.70	-0.12	-0.31*	-1.46
S-624 × 83-6-204	-1.45	-0.12	0.57	-0.99	-0.49	-5.15	0.21*	-0.15	-1.51
S-624 × 83-6	-0.13	0.34	4.30	4.09*	0.74	-0.23	0.06	0.08	1.05
S-624 × Sel-6	1.90	-0.62	4.36	-0.57	0.53	2.35	0.13	0.23	-0.21
S-624 × GA-122	-1.80	-2.50	1.98	-1.25	1.07	-2.73	-0.10	-0.15	-1.42
S-645 × GA-111	0.44	-3.23	-13.35	0.36	0.12	-2.77	-0.20*	-0.23	-3.10
S-645 × GA-121	0.73	-2.17	8.08	-1.05	-0.61	5.37	0.02	-0.04	3.45
S-645 × 83-6-204	1.96	-1.47	1.42	-0.07	2.46*	-4.49	0.06	0.09	0.93
S-645 × 83-6	0.43	3.69	-0.42	0.95	-1.31	0.44	-0.18	-0.27*	-0.70
S-645 × Sel-6	-2.94*	-0.07	-20.69	0.30	0.28	3.01	0.03	0.02	0.66
S-645 × GA-122	-0.63	3.25	24.95	-0.48	-0.93	-2.06	0.28*	0.44*	-1.24
S-691 × GA-111	-0.34	-2.30	-10.15	0.73	-0.73	6.56	-0.10	-0.04	-5.54

Table contd...

Table 2 contd...

Cross	Plant height	Plant spread	Head size	No. of non-wrapper leaves	Core length	Maturity days	Head weight	Plant weight	Harvest index
S-691 × GA-121	-0.20	-0.75	-21.53	0.56	-0.41	1.20	-0.08	-0.05	-3.31
S-691 × 83-6-204	-0.02	4.25*	22.73	-0.86	0.81	-3.15	0.23*	0.34*	0.34
S-691 × 83-6	0.55	-4.69*	0.48	-0.17	-0.21	-2.23	0.01	0.04	-2.39
S-691 × Sel-6	0.53	1.45	9.17	-0.19	0.33	-5.65	0.01	-0.12	5.31
S-691 × GA-122	-0.51	2.03	-0.70	-0.07	0.22	3.27	-0.06	-0.16	5.60
S-696 × GA-111	0.14	-1.56	-10.66	-1.46	0.08	-0.44	-0.15	-0.21	-1.30
S-696 × GA-121	-0.62	0.58	8.51	0.47	0.65	-1.80	0.02	-0.01	2.15
S-696 × 83-6-204	1.26	0.48	5.45	1.70	0.17	2.85	0.08	0.15	-0.81
S-696 × 83-6	0.98	2.74	8.86	-0.52	0.10	-5.23	0.07	0.20	-2.46
S-696 × Sel-6	-1.89	-2.62	-21.57	0.27	-0.26	4.35	-0.14	-0.20	-1.66
S-696 × GA-122	0.12	0.40	9.42	-0.46	-0.13	0.27	0.10	0.06	4.09
S-208 × GA-111	0.41	0.21	10.63	0.74	0.36	-7.11	0.15	0.18	2.21
S-208 × GA-121	-0.15	2.06	-3.08	0.68	-0.53	-3.96	0.02	0.12	-3.59
S-208 × 83-6-204	-2.67*	-3.84*	-27.45	-0.19	-2.16*	3.18	-0.25*	-0.46	-1.73
S-208 × 83-6	0.45	4.52*	36.51*	-2.41	1.97	3.61	0.23*	0.36*	2.12
S-208 × Sel-6	-0.12	-1.64	0.99	-0.17	0.36	1.68	-0.10	-0.19	1.33
S-208 × GA-122	2.09	-1.32	-17.61	1.35	-0.001	2.61	-0.05	-0.01	-3.79
CMS-1 × GA-111	2.89*	-0.29	-9.08	0.74	0.83	3.23	-0.04	-0.06	0.72
CMS-1 × GA-121	0.01	0.86	0.75	0.28	0.45	-3.13	-0.2	-0.02	0.69
CMS-1 × 83-6-204	0.59	0.26	5.59	-0.59	-1.28	5.01	-0.05	-0.08	-0.34
CMS-1 × 83-6	-0.49	-1.88	-8.50	-1.31	-0.05	1.44	-0.04	-0.07	3.60
CMS-1 × Sel-6	1.54	2.76	19.34	-0.37	-0.36	-5.49	0.08	-0.22	-3.99
CMS-1 × GA-122	1.24	-1.72	-8.10	1.25	0.42	-1.06	-0.11	-0.14	-0.68

*Significant at P = 0.05

Table 3. Estimates of heterosis (%) over mid-parent of 42 hybrids of cabbage for nine traits.

Cross	Plant height	Plant spread	Head size	No. of non-wrapper leaves	Core length	Maturity days	Head weight	Plant weight	Harvest Index
S-621 × GA-111	-30.8*	7.5	13.6	15.0	31.2	10.1	28.0*	14.3	14.5*
S-621 × GA-121	-14.1	6.2	26.7*	6.0	43.4*	-39.2*	37.9*	26.0*	13.6*
S-621 × 83-6-204	-32.9*	0.2	-15.9	21.7*	18.1	-17.4*	13.8	-0.3	14.1*
S-621 × 83-6	-39.0*	-8.4	-27.1*	11.3	0.8	-19.5*	-12.9	-23.5*	8.5
S-621 × Sel-6	-20.7*	2.3	15.7*	18.2*	30.8	-24.3*	23.1	16.0*	8.2
S-621 × GA-122	-40.0*	-4.7	-11.9	5.6	14.9	-23.1*	-14.8	-25.2*	9.0
S-624 × GA-111	-6.7	20.1*	9.5	-0.3	-3.0	4.9	34.1*	24.4*	11.5*
S-624 × GA-121	-7.0	4.3	-4.1	-2.8	-6.4	-22.8*	6.6	-3.2	5.7
S-624 × 83-6-204	-29.2*	6.4	-13.5	0.9	-12.6	-24.3*	6.9	-3.1	8.9
S-624 × 83-6	-15.2*	7.9	-1.5	23.3	9.0	-19.5*	13.2	4.8	8.4
S-624 × Sel-6	-2.9	6.9	11.1	1.8	20.4	-16.7*	29.2*	24.3*	6.3

Table contd...

Table 3 contd...

Cross	Plant height	Plant spread	Head size	No. of non-wrapper leaves	Core length	Maturity days	Head weight	Plant weight	Harvest Index
S-624 × GA-122	-32.2*	-1.7	-7.9	-11.5	16.7	-23.1*	-17.6	-26.8*	7.2
S-645 × GA-111	-23.6*	5.0	-13.3	18.3	3.2	-13.5	4.3	-0.8	4.1
S-645 × GA-121	-10.0	4.5	6.1	-0.5	-6.5	-22.8*	24.9*	12.0	14.0*
S-645 × 83-6-204	-18.0*	3.1	-20.6*	16.3	15.5	-24.3*	21.9	9.0	14.4*
S-645 × 83-6	-20.4*	12.3*	-11.0	20.1*	-26.1	-19.5*	-5.6	-15.4	8.0
S-645 × Sel-6	-40.4*	7.1	-9.5	16.1	11.0	-16.7*	24.6*	16.2	9.9
S-645 × GA-122	-33.3*	8.5	-2.8	2.3	-16.5	-23.1*	15.5	7.2	9.5
S-691 × GA-111	-16.0	6.3	-9.4	0.7	0.0	12.8	-16.1	-7.8	-7.0
S-691 × GA-121	-0.3	6.9	-7.2	-8.6	6.6	-30.9*	-7.4	-6.9	-1.2
S-691 × 83-6-204	-17.2	13.6*	-5.5	-9.4	7.0	-23.5*	14.8	8.3	6.7
S-691 × 83-6	-8.5	-3.4	-8.8	-5.5	-0.7	-24.7*	-13.6	-14.3	-2.1
S-691 × Sel-6	-5.5	9.8	9.7	-5.9	21.1	-32.2*	3.1	-6.5	9.5
S-691 × GA-122	-20.1*	5.9	-16.4	-15.9	9.4	-15.8*	-48.7*	-68.9*	11.8*
S-696 × GA-111	-16.2	9.6	-14.8	-11.3	13.2	2.4	-27.0*	-19.9	-5.2
S-696 × GA-121	-6.1	11.4*	6.2	-3.3	21.3	-39.2*	1.3	-1.1	2.1
S-696 × 83-6-204	-12.6	8.1	-22.3	13.0	-1.9	-16.7*	-1.3	-1.2	0.0
S-696 × 83-6	-9.1	12.4*	-8.2	-2.8	3.2	-32.0*	-9.2	-2.6	-8.1
S-696 × Sel-6	-24.3*	3.4	-13.0	2.4	5.7	-18.1*	-17.3	-10.1	-6.1
S-696 × GA-122	-19.2	4.4	-14.1	-13.4	4.7	-23.1*	-26.5*	-34.2*	5.9
S-208 × GA-111	-14.4	20.0*	9.3	18.8*	10.4	-9.8	31.8*	30.5*	1.2
S-208 × GA-121	-3.9	21.3*	10.9	13.7	-1.6	-30.9*	27.0*	30.2*	-6.4
S-208 × 83-6-204	-38.5*	8.6	-33.8	14.6	-55.4*	-7.4	-3.0	-8.0	5.0
S-208 × 83-6	-11.8	20.9*	14.1*	-1.1	18.2	-9.8	24.9*	23.6*	0.9
S-208 × Sel-6	-12.4	13.6*	11.4	12.6	15.9	-12.5*	18.1	18.8*	-0.3
S-208 × GA-122	-7.3	10.0*	-19.3	15.1	1.1	-9.3	-7.8	-1.5	-5.5
CMS-1 × GA-111	-64.7*	3.4	-11.4	8.0	26.2	19.6*	14.0	-0.8	14.3*
CMS-1 × GA-121	-23.6*	3.0	3.6	-3.3	21.7	-39.2*	19.9	4.5	15.0*
CMS-1 × 83-6-204	-36.8*	-1.1	-19.5*	-0.2	-31.3	-11.8	17.3	-0.3	17.6*
CMS-1 × 83-6	-35.6*	-3.6	-16.8*	-7.7	2.3	-19.5*	7.2	-14.0	18.9*
CMS-1 × Sel-6	-21.8*	5.5	11.3	-0.6	15.8	-32.2*	26.2*	20.0*	8.0
CMS-1 × GA-122	-32.7*	-9.8	-24.6*	2.5	14.5	-23.1*	-33.6	-53.2*	14.8*

*Significant at P = 0.05

hybrids, 10 showed significant heterosis in desirable direction. Highest heterosis for head weight was recorded in the hybrid, S-621 × GA-121 followed by S-624 × GA-111, S-208 × GA-111 and S-621 × GA-111. Large number of heterotic hybrids indicated the potentiality of the developed SI and CMS lines in development of F_1 hybrids with more productivity. Parkash (9) showed that SI and CMS lines could be used effectively in developing F_1 hybrids with higher productivity. In cauliflower Dey *et al.* (1) showed suitability CMS lines with good combining ability in developing hybrids with desirable traits. For plant weight nine hybrids showed significant heterosis in positive direction. Highest heterosis for this was recorded in the hybrid S-208 × GA-111 followed by S-208 × GA-121 and S-621 × GA-121. For harvest index, 12 hybrids showed heterosis in positive direction and none of the hybrids showed significant heterosis in negative direction. Harvest index is the indicator for efficient conversion of total energy towards development of economic plant part. Thus, it may be concluded that cabbage hybrids are more efficient user of inputs for giving higher productivity. Earliness is a very important criterion in developing F_1 hybrids. Significant heterosis in desirable negative direction was recorded in 31 hybrids and only one hybrid showed heterosis in positive direction. Thus SI and CMS lines could be used effectively in developing hybrids with early maturity. In late cauliflower Dey *et al.* (1) also reported the usefulness of CMS lines in development of hybrids with higher yield and earliness. Highest heterosis of -39.2% was recorded in 3 hybrids, *viz.*, S-621 × GA-121, S-696 × GA-121 and CMS-1 × GA-121 and a heterosis of 32.2% was recorded in 2 hybrids, *viz.*, S-691 × Sel-6 and CMS-1 × Sel-6. Three hybrids showed positive heterosis for head index and highest heterosis was found in the hybrid S-621 × GA-121 followed by S-621 × 83-6 and S-208 × 83-6. For plant spread, 10 hybrids showed significant heterosis in positive direction and none of the hybrids showed significant heterosis in desirable negative direction. Core length is an important criterion for compactness of head and lesser core length is desirable (Fang *et al.*, 3). However, among the 42 hybrids only one hybrid in each had heterosis in positive and negative direction. Hybrid vigour in F_1 hybrids may be the main reason for it and there is a need to develop lines which produce F_1 hybrids with smaller plant spread and core length. Thus, the SI and CMS lines developed indigenously can be used in developing cabbage hybrids with better productivity and other desirable traits.

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