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EFFECT OF SI AND CMS SYSTEMS ON THE HORTICULTURAL PERFORMANCE OF F_1 HYBRIDS IN CABBAGE (*BRASSICA OLERACEA* VAR. *CAPITATA* L.)

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ABSTRACT
Effectiveness of CMS and SI system on the horticultural performance of F_1 hybrids was studied by evaluating them in randomized block design with two standard checks (Varun and KGMR-1) at the Vegetable Research Farm, CSKHPKV Palampur during 2013-14. The hybrids which involved CMS lines as one of the parents have excelled in their performance for majority of the characters *viz.,* plant spread, non-wrapper leaves, polar diameter, days to harvest, head shape index and head compactness, whereas for the characters *viz.,* gross head weight, net head weight, equatorial diameter and marketable head yield per plot the hybrids developed by SI system excelled in horticultural performance. Based on the horticultural performance, the best two hybrids CMS GAP x E-1-3 and II-12-4-10 x SC 2008-09 were either at par or significantly superior to both the checks *viz.,* Varun and KGMR-1 for marketable head yield and most of the yield contributing traits. These two hybrids showed a yield of 24.40 t/ha (II-12-4-10 x SC 2008-09) and 23.13 t/ha (CMS GAP x E-1-3) which is higher than the checks Varun and KGMR-1 which showed a yield of 19.47 t/ha and 21.69 t/ha, respectively. The CMS system was considered best for development of hybrids in cabbage by using the germplasm used in this study

INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata* L.) a member of family *Brassicaceae* is one of the most important Cole-group vegetable crops. It is widely grown all over India and abroad for its high nutritive value, high productivity and wider adaptability. It can withstand rough handlings as well as long distance transport and thus fetch better return. However, the national productivity of cabbage is far below the global average productivity (Singh *et al.,* 2015). Low productivity of cabbage may be attributed to poor management practices and less number of high yielding hybrids. Hybrids are preferred over open pollinated varieties on account of their higher productivity and better quality produce. Commercialization of hybrids has become possible due to the use of genetic mechanisms in reducing the cost of hybrid seed. In cole crops, the genetic mechanisms of sporophytic self-incompatibility (SSI) and cytoplasmic male sterility (CMS) are prevalent and have been used commercially (Parkash, 2008). In developed countries more than 90% cabbage growing area is under hybrid varieties where as it is 31% in India (Kumar *et al.,* 2013). This is due to the cultivation of traditional open-pollinated varieties, higher cost and non-consistent performance of hybrids released by private companies and non-availability of potential hybrids from the public sector institutions. This necessitates development and release of improved and widely adapted hybrids from public sector institutions for the benefit of vegetable growers. Till now, only limited research work has been carried out to improve cabbage in our country since breeding work has remained confined to few research centers in the hills. Hence this study was conducted to use the self-incompatible (SI) and cytoplasmic male sterile (CMS) lines in combination with elite pollen parental lines to develop hybrids and to compare their effectiveness on the horticultural performance of F_1 hybrids, which will be applicable to find out the best system (CMS or SI) to develop F_1 hybrids in cabbage.

MATERIALS AND METHODS

Four CMS (CMS I, CMS II, CMS III and CMS GAP) and three SI lines (SI-1-4-6, SI 2008-09-03-01 and II-12-4-10) were crossed as females to each of the four testers (males) *viz.,* Glory-1, E-1-3, E-1-10 and SC 2008-09 by line × tester mating design to develop 28 F_1 hybrids. After heading and selection the parental lines were covered with insect proof nylon net enclosures at the time of bolting and initiation of flowering during 2012-13. Pollination work was started when 50% of the plants in parents had about 20-25% flowering. Pooled pollen of each tester was collected and applied to the opened flowers of self-incompatible plants (after removing anthers and petals just before pollination) and male sterile lines. The parental lines were also maintained through manual sibmating carried out in bud stage (Cabin *et al.*, 1996) and open flower stage. However, the self-incompatible parents were sprayed with common salt (3%) after about 15-20 minutes of pollinations (Singh and Vidyasagar, 2012). The matured siliquas of respective hybrids and parental lines were harvested separately

in the end of summer season, 2013 and the seeds were extracted after a week and kept for evaluation during 2013-14. The hybrids were then evaluated along with parents and standard checks in randomized block design with 3 replications at the Vegetable Research Farm, CSKHPKV Palampur (mid-hills, sub-temperate with high rainfall) during 2013-14. Observations were recorded on 5 randomly selected plants from each replication for plant spread (cm), number of non-wrapper leaves, gross head weight (g), net head weight (g), polar and equatorial diameters of head (cm), days to harvest, head shape index, compactness of head (g/cm^3), number of marketable heads per plot, heading percentage (%) and marketable head yield/plot (kg). Head Shape index (polar: equatorial diameter) was worked out as per Odland and Noll (1954). Compactness of head was determined as per the procedure suggested by Pearson (1931). The data were statistically analysed as per the procedure given by Panse and Sukhatme (1984).

RESULTS AND DISCUSSION

The analysis of variance indicated significant differences among treatments for all the traits studied. Horticultural performance of 28 hybrids, 11 parents (7 lines and 4 testers) and 2 standard checks *i.e.,* SC1 (Varun) and SC2 (KGMR-1) for all the traits studied are presented in Table 1 and 2. For plant spread the breeders are in search of the combinations having lesser plant spread. Varieties with lesser plant spread are desired by the farmers so that more number of plants may get accommodated per unit area. Plant spread varied from 31.16 cm (E-1-10) to 52.30 cm (SC1). All the hybrids had significantly lesser plant spread as compared to SC1. The hybrid CMS I × E-1-10 (35.83 cm) and CMS GAP × E-1-10 (35.96 cm) had the least plant spread among all the developed hybrids. All the remaining hybrids except II-12-4-10 × E-1-3 (45.80 cm) and SI-1-4-6 × SC-2008-09 (45.70 cm) were at par with SC2 (Table 1). These results were in contrast to Parkash (2008) who had reported that none of the hybrids exhibited significantly smaller plant spread than the check variety, whereas in our study all the hybrids showed significantly lesser plant frame as compared to SC1.

Relatively less number of non-wrapper leaves is desired in cabbage so as to have higher net head yield in relation to the gross head yield. In general, non-wrapper leaves were less in cytoplasmic male sterile system. Yoon *et al.,* (1988) reported slow initial development of hybrids of Chinese cabbage with Ogura cytoplasm, affecting the number of non wrapper leaves. The non-wrapper leaves varied from 11.53 (CMS III) to 18.00 (SI-1-4-6). The hybrid CMS GAP × E-1-3 (12.40) had the minimum number of non-wrapper leaves. As many as 23 hybrids were at par with SC2 whereas only 10 hybrids were at par with SC1 (Table 1). Melo and Giordano (1994) and Parkash (2008) also reported hybrids developed by CMS lines with lesser number of non-wrapper leaves.

The gross head weight varied from 602.00 g (E-1-10) to 1395.33 g (II-12-4-10). Three hybrids *viz.,* II-12-4-10 × SC-2008-09 (1207.00 g), II-12-4-10 × E-1-3 (1062.00 g) and CMS GAP × E-1-3 (1032.00 g) had gross head weight at par with both the standard checks, whereas all the remaining hybrids had gross head weight significantly lower than standard checks (Table 1).

Plants with higher net head weight are required by the farmers in order to get more marketable yield per unit area. The range for net head weight varied from 223.33 g (Glory-1) to 637.00 g (II-12-4-10 × SC 2008-09). The hybrids II-12-4-10 × SC 2008-09 (637.00 g) and CMS GAP × E-1-3 (564.66 g) had significantly higher net head weight as compared to SC1 whereas these were at par with SC2. Eleven hybrids were at par with SC1 (Table 1). Parkash (2008) reported that hybrids developed by SI lines showed higher net head weight than that of CMS based hybrids. In our study, the hybrid with highest net head weight was of SI system but in general the hybrids developed by CMS system showed more net head weight as compared to SI system. This variation in these two studies may be due to differences in the genotypes and prevailing environmental conditions.

Polar and equatorial diameters have direct influence on net head weight. The Polar diameter varied from 9.24 cm (CMS I × Glory-1) to 13.23 cm (II-12-4-10). Nine and 15 hybrids were at par with SC1 and SC2, respectively. The hybrid CMS GAP × SC 2008-09 (12.32 cm) exhibited highest polar diameter among the entire hybrids (Table 1**).** Adeniji *et al.* (2010) evaluated head yield and horticultural traits in cabbage and find out Gloria F_1 hybrid with maximum head length of 15 cm (pooled data), which is less demanded by the consumers as heads with more length are less compact as compare to round heads (less head length).

The equatorial diameter varied from 8.41 cm (SI-1-4-6) to 13.77 cm (II-12-4-10 × SC 2008-09). The hybrid II-12-4-10 × SC 2008-09 had the highest equatorial diameter of 13.77 cm (Table 1). Our hybrids were of less polar and equatorial diameter than the hybrid (Chunkui) developed by Wang *et al.,* (2007) which had about 22 cm height and 14 cm diameter. This may be due to the difference in the genotypes used in these two studies and also due to preference of consumer for large heads in their country whereas, small heads are preferred in a country like India as the families are small now a days.

Earliness is a highly desirable attribute in vegetables in the sense that the prevailing prices in the market are invariably higher. So, hybrids with lesser number of days to harvest are desirable. Days to harvest varied from 112.80 (SC2) to 135.00 (II-12-4-10). The hybrid CMS I × Glory-1 (113.73 days) was the earliest among all the hybrids. Ren *et al.,* (2008) developed a new cabbage hybrid Xiyuan No. 10, with 105-120 days of maturing period. As many as 16 hybrids were earlier and 12 hybrids were at par with SC1 (Varun) whereas all the hybrids were at par with SC2 (KGMR-1) (Table 2).

Head shape index value (polar: equatorial diameter) determines the shape of cabbage heads. In case of round head, shape index is between 0.8-1.0. The value below 0.8 indicates flat or drumhead type whereas the values > 1.0 indicate pointed heads. Although round heads are preferred in India, but higher head shape index have been considered better while discussing this trait. The head shape index varied from 0.83 (II-12-4-10 × SC 2008-09 and II-12-4-10 × Glory-1) to 1.33 (SI-1-4-6). The hybrid CMS III × SC 2008-09 exhibited highest head shape index of 1.20. Three hybrids had significantly higher head shape index and 21 hybrids were at par with SC1. Eight hybrids had significantly higher head shape index and 20 hybrids

Table 1: Mean values of 28 crosses, 11 parents and 2 checks for plant spread, non-wrapper leaves, gross head weight, net head weight, polar diameter and equatorial diameter

Genotypes Crosses	Plant spread (cm)	Non wrapper leaves	Gross head weight (g)	Net head weight (g)	Polar diameter(cm)	Equatorial diameter (cm)
L1 x T1	43.13	17.66	792.66	298.00	9.34	9.64
L1 x T2	42.26	17.46	762.00	292.00	9.44	9.39
L1 x T3	43.66	17.06	834.66	345.33	10.68	9.14
L1 x T4	45.70	15.33	961.33	401.33	11.75	10.42
L2 x T1	41.30	13.86	805.33	383.33	10.39	10.27
L2 x T2	39.13	15.93	678.00	284.00	9.72	9.28
L2 x T3	38.16	14.60	614.00	281.00	9.83	9.06
L2 x T4	39.93	13.60	830.66	422.00	11.25	10.30
L3 x T1	40.16	15.40	778.00	334.00	9.24	10.27
L3 x T2	39.36	14.00	665.33	272.66	9.60	9.08
L3 x T3	35.83	17.00	722.00	345.33	9.86	9.14
L3 x T4	41.80	13.86	924.33	451.00	11.72	10.76
L4 x T1	42.80	15.06	757.33	314.00	9.57	9.67
L4 x T2	43.83	15.93	756.66	264.00	9.49	9.50
L4 x T3	39.43	14.53	895.33	480.00	10.46	10.89
L4 x T4	40.30	14.26	1002.66	499.33	11.25	11.84
L5 x T1	43.43	13.86	947.33	511.33	10.91	11.93
L5 x T2	43.33	15.00	849.33	393.00	10.08	10.99
L5 x T3	41.46	15.06	918.66	435.66	11.07	10.46
L5 x T4	44.10	13.80	928.66	430.00	12.18	10.13
L6 x T1	39.73	12.90	897.33	448.00	11.31	10.95
L6 x T2	42.36	12.40	1032.00	564.66	11.47	11.90
L6 x T3	35.96	14.53	806.00	396.66	10.10	10.14
L6 x T4	37.73	13.10	979.00	531.33	12.32	10.57
L7 x T1	43.93	13.60	985.00	430.00	10.03	11.95
L7 x T2	45.80	15.20	1062.00	446.00	10.66	11.76
L7 x T3	41.66	14.00	971.66	468.00	10.04	11.82
L7 x T4	43.93	12.90	1207.00	637.00	11.31	13.77
Lines						
L1	45.20	18.00	873.33	256.00	11.02	8.41
L2	38.60	16.00	656.00	241.33	9.84	8.45
L3	42.56	13.93	887.33	429.33	10.02	11.54
L4	40.13	15.86	675.00	285.33	9.54	9.94
L5	46.43	11.53	820.66	346.66	12.14	10.13
L6	35.80	12.40	733.00	321.00	11.09	9.17
L7	51.53	15.60	1395.33	434.66	13.23	11.48
Testers						
T1	40.80	17.80	716.66	223.33	9.24	8.67
T2	36.56	17.20	724.00	305.33	9.95	9.24
T3	31.16	16.06	602.00	290.66	9.76	8.45
T4	43.70	14.46	988.00	466.67	13.04	10.06
Checks						
SC1	52.30	11.93	1134.6670	494.00	12.26	12.16
SC2	40.70	13.80	1124.3330	609.66	11.42	12.18
CV (%)	6.74	8.55	8.2245	10.55	6.42	9.79
S.E (m)	1.61	0.73	41.33	23.88	0.39	0.58
C.D (5%)	4.55	2.05	116.3462	67.21	1.11	1.65

L1: SI-1-4-6 L2: SI-2008-09-03-01 L3: CMS I L4: CMS II L5: CMS III L6: CMS GAP L7: II-12-4-10 ; T1: Glory-1 T2: E-1-3 T3: E-1-10 T4: SC 2008-09 SC1: Varun SC2: KGMR-1

were at par with SC2 (Table 2).

Head compactness is a desirable attribute in the sense that a compact head will have less volume and more weight per unit area. Besides, compact heads have better storage and are less prone to post harvest handling. The compactness of head varied from 22.65 g/cm^3 (II-12-4-10) to 37.88 g/cm^3 (E-1-10). The hybrid CMS GAP × E-1-10 showed the highest compactness (37.04) among all the hybrids. Twenty one hybrids were significantly more compact and 7 hybrids were at par with SC1 whereas 25 hybrids were at par with SC2. Tang *et al*. (2010) developed a new cabbage F_1 hybrid Chenggan No 1 which had round and compact heads with a net weight of 0.75 kg (Table 2). Marketable heads per plot is directly proportional to marketable head yield. The range varied from 6.00 (Glory-1) to 14.00 (CMS I). The hybrids, II-12-4-10 × E-1-10 and CMS GAP × E-1-3 were observed to have the highest number of marketable heads per plot (13.66) among all the hybrids (Table 2). Heading percentage also contributes towards total marketable yield. It varied from 57.14 (Glory-1) to 100.00 (SI-1-4-6 × SC 2008-09, CMS GAP × Glory-1, CMS

Table 2: Mean values of 28 crosses, 11 parents and 2 checks for days to harvest, head shape index, compactness of head, marketable heads per plot, heading percentage and marketable head yield

Genotypes Crosses	Days to harvest	Head shape index	Compactness of head (g/cm^3)	Marketable heads per plot	Heading percentage (%)	Marketable headYield (kg/plot)
L1 x T1	115.06	0.96	34.36	12.66	95.23 (79.62)	4.39
L1 x T2	114.86	1.01	34.19	12.66	92.85 (77.39)	3.32
L1 x T3	117.13	1.17	35.14	13.00	95.23 (79.62)	3.81
L1 x T4	117.60	1.13	29.26	13.33	100.00 (89.96)	4.76
L2 x T1	114.60	1.01	33.51	12.00	95.23 (79.62)	4.03
L2 x T2	115.26	1.04	33.03	11.66	90.47 (75.60)	3.12
L2 x T3	117.53	1.09	33.34	12.66	97.61 (84.79)	3.08
L2 x T4	117.86	1.10	32.34	11.66	89.74(78.73)	4.63
L3 x T1	113.73	0.90	34.26	12.00	92.85 (77.39)	3.84
L3 x T2	117.86	1.06	33.11	12.66	92.85 (77.39)	3.09
L3 x T3	117.26	1.08	36.09	11.00	88.09 (73.37)	3.63
L3 x T4	115.13	1.10	30.22	12.00	97.61 (84.79)	5.25
L4 x T1	116.40	1.00	33.96	11.33	88.09 (73.37)	2.72
L4 x T2	115.86	0.99	30.97	10.33	85.71(71.79)	2.67
L4 x T3	114.00	0.93	36.33	12.00	90.10 (74.86)	4.92
L4 x T4	117.26	0.96	32.10	12.66	95.23 (79.62)	5.93
L5 x T1	114.80	0.92	32.15	12.00	92.85 (77.39)	4.86
L5 x T2	114.93	0.91	33.56	12.33	92.85 (77.39)	4.07
L5 x T3	114.73	1.05	34.20	11.66	92.85 (77.39)	4.65
L5 x T4	118.06	1.20	30.00	11.33	85.70 (71.76)	4.48
L6 x T1	116.00	1.01	32.06	13.33	100.00 (89.96)	5.47
L6 x T2	116.40	0.96	34.89	13.66	100.00 (89.96)	6.56
L6 x T3	116.86	1.01	37.04	13.33	100.00 (89.96)	4.43
L6 x T4	116.60	1.17	31.66	13.00	97.61 (84.79)	6.09
L7 x T1	114.70	0.83	32.33	13.00	95.23 (79.62)	5.24
L7 x T2	115.20	0.91	31.31	11.33	100.00 (89.96)	4.76
L7 x T3	114.26	0.84	35.66	13.66	100.00 (89.96)	4.84
L7 x T4	114.20	0.83	31.51	12.33	92.85 (77.39)	6.92
Lines						
L1	116.73	1.33	27.58	9.66	76.18 (61.14)	2.68
L2	117.80	1.17	30.17	8.66	71.42 (57.77)	2.43
L3	118.86	0.86	33.26	14.00	100.00 (89.96)	4.91
L4	120.80	0.95	31.34	8.00	73.80 (59.56)	2.30
L5	127.20	1.19	24.91	8.66	80.94 (64.83)	2.94
L6	121.50	1.21	29.17	9.00	76.18 (61.14)	2.85
L7	135.00	1.15	22.65	8.33	85.71 (71.74)	3.34
Testers						
T1	120.60	1.09	31.72	6.00	57.14 (49.11)	1.53
T2	117.66	1.09	34.00	7.66	68.67 (56.41)	2.13
T3	115.60	1.15	37.88	12.66	92.48 (77.10)	3.73
T4	126.66	1.30	30.01	10.33	73.80 (59.56)	4.85
Checks						
SC1	122.60	1.01	26.78	11.66	92.85 (77.39)	5.52
SC2	112.80	0.94	35.58	12.33	95.23 (79.62)	6.15
CV (%)	3.28	8.70	9.79	12.85	9.25 (12.60)	11.9893
S.E (m)	2.23	0.05	1.82	0.85	4.79 (3.19)	0.28
C.D (5%)	6.27	0.14	5.13	2.40	13.49 (15.56)	0.81

L1: SI-1-4-6 L2: SI-2008-09-03-01 L3: CMS I L4: CMS II L5: CMS III L6: CMS GAP L7: II-12-4-10 T1: Glory-1 T2: E-1-3 T3: E-1-10 T4: SC 2008-09 SC1: Varun SC2: KGMR-1

GAP × E-1-3, CMS GAP × E-1-10, II-12-4-10 × E-1-3, II-12-4-10 × E-1-10 and CMS I). All the hybrids were at par with both SC1 and SC2 (Table 2).

Marketable head yield is the dependent variable which is economically important to breeders and farmers. The hybrid II-12-4-10 × SC 2008-09 (24.40 t/ha) showed the highest marketable head yield among all the hybrids (Table 2). Elavarasan *et al*. (2013) carried out studies on the performance of different genotypes of cabbage grown in plains and higher altitude of kerala. Their best cabbage genotype Tropical Sun Plus exhibited head yield (22.06 Kg /16m^2) *i.e.* 14.12 t/ha, while our two best hybrids, CMS GAP × E-1-3 (23.13 t/ha) and II-12-4-10 × SC 2008-09 (24.40 t/ha) showed higher yield than Tropical Sun Plus and both the checks. Ten hybrids were at par with SC1. No hybrid could surpass but 5 hybrids were at par with SC2. Chen *et al*., (2011) developed a new cabbage hybrid Xiahua No.2 with a mean yield of 37.5-45.0 t /ha.

The comparison of top five hybrids on the basis of their respective horticultural performance with standard checks has

Table 3: Mean values of top 5 hybrids and standard checks (SC1 and SC2) on the basis of horticultural performance for marketable yield per plot and component traits.

S.No	Traits	L7 x T4	L6 x T2	L6 x T4	L4 x T4	L6 x T1	SC1	SC2	CD (5%)
1	Plant spread (cm)	43.93	42.36	37.73	40.30	39.73	52.30	40.70	4.55
2	Non wrapper leaves	12.90	12.40	13.10	14.26	12.90	11.93	13.80	2.05
3	Gross weight (g)	1207.00	1032.00	979.00	1002.66	897.33	1134.66	1124.33	116.34
4	Net weight (g)	637.00	564.66	531.33	499.33	448.00	494.00	609.66	67.21
5	Polar diameter (cm)	11.31	11.47	12.32	11.25	11.31	12.26	11.42	1.11
6	Equatorial diameter (cm)	13.77	11.90	10.57	11.84	10.95	12.16	12.18	1.65
7	Days to harvest	114.20	116.40	116.60	117.26	116.00	122.60	112.80	6.27
8	Head shape index	0.83	0.96	1.17	0.96	1.02	1.01	0.94	0.14
9	Compactness of head (g/cm^3)	31.51	34.89	31.66	32.10	32.06	26.78	35.58	5.13
10	Marketable heads per plot	12.33	13.66	13.00	12.66	13.33	11.66	12.33	2.40
11	Heading percentage (%)	92.85	100.00	97.61	95.23	100.00	92.85	95.23	13.49
12	Marketable head yield (kg/plot)	6.92	6.56	6.09	5.93	5.47	5.52	6.15	0.81

Lines: L1- SI-1-4-6 L2- SI-2008-09-03-01 L3- CMS I L4- CMS II L5- CMS III L6- CMS GAP L7- II-12-4-10. Testers: T1- Glory 1 T2- E-1-3 T3-E-1-10 T4- SC 2008-09 SC1- Varun SC2- KGMR-1

been presented in Table 3. All the top 5 hybrids were significantly superior or either at par with SC1 (Varun) and SC2 (KGMR-1) for most of the yield contributing traits.

The hybrids CMS GAP × E-1-3 and II-12-4-10 × SC 2008-09 were either at par with the standard check 1 (Varun) and standard check 2 (KGMR-1) or significantly superior to both the checks for marketable head yield and most of the component traits. The hybrids developed by CMS lines showed better horticultural performance for majority of the characters whereas for the characters *viz*., gross head weight, net head weight, equatorial diameter and marketable head yield per plot, the hybrids developed by SI lines excelled in their performance. Although the hybrid (II-12-4-10 × SC 2008-09) developed by SI system revealed better horticultural performance for major yield contributing traits but yield can be increased by using hybrids with lesser plant spread and less number of non wrapper leaves i.e., CMS system in this study. Also the plants with shorter plant spread showed higher compactness and head shape index near one, which is the requirement of consumers today. Therefore CMS system was found better option for development of F_1 hybrids in cabbage using current germplasm.

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