RESEARCH ARTICLE

SABRAO Journal
of Breeding and Genetics
47 (1) 29-39, 2015

EVALUATION OF CYTOPLASMIC MALE STERILE (CMS) PROGENIES AND MAINTAINER LINES FOR YIELD AND HORTICULTURAL TRAITS IN CABBAGE (*Brassica oleracea* var. *capitata* L).

P. THAKUR[1], VIDYASAGAR[2] and S. SINGH[3*]

[1, 2, 3] Department of Vegetable Science and Floriculture,
CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur 176062, India
[*]Corresponding author's email: horticulturesaurabh@gmail.com
Email addresses of co-authors: spaceinlife@gmail.com, vsagar_plp@yahoo.co.in

SUMMARY

Cabbage, *Brassica oleracea* var. *capitata* L. is one of the most important cole group vegetables. Hybrids are known to outperform the open-pollinated varieties in marketable head yield and horticultural traits. Cytoplasmic male sterility (CMS) seems to be a better option over sporophytic self-incompatibility (SSI) to develop hybrids in cole crops because of the standard advantages. Hence, the present investigation was undertaken to compare the CMS progenies with their respective fertile counterparts (maintainer lines) for yield and horticultural attributes. The experimental material was evaluated in RBD with 3 replications at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSKHPKV, Palampur, Distt. Kangra H.P during 2010-11 and 2011-12. Observations were recorded on yield and important horticultural traits. The CMS progenies were also evaluated for their sterility behavior during the flowering regimes *viz*., 25-50%, 50-75% and 75-100%. All the 4 CMS progenies had the head shape index at par with their respective maintainer lines. For days to harvest, except KGAT- I CMS during 2011-12 the CMS progenies were at par with their respective fertile counterparts as well. For the traits heading (%), marketable heads per plot, non wrapper leaves and gross weight, one or two of the CMS progenies were not at par with respective maintainer lines. In respect of compactness of heads, net weight of heads and marketable head yield (kg/plot), the exceptions were even up to 50% of the CMS progenies studied. This may be attributed to the facts that cabbage is a highly cross-pollinated vegetable and the expression of latter traits subject to the influence of prevailing weather conditions. All the CMS progenies revealed break- down of male sterility (very mild to mild pollen grain production) in variable number of plants in all the flowering regimes during both the years (2010-11 and 2011-12). There exists a possibility of developing stable CMS progenies through rigorous selection over the years.

Keywords: Cabbage, cytoplasmic male sterility, stability, yield, flowering regimes, horticulture traits

Short summary statement: Development and standardizing protocol through CMS for HSP in cabbage is required urgently for large and good quality seed production of hybrids. Useful information has been generated especially in low chilling type of cabbage genotypes and the lines will be useful for the breeders for scaling up their HSP in this crop with ease. Hence, the present research work will have an impact and contribution on research in this field.

Manuscript received: July 10, 2014; Decision on manuscript: October 6, 2014; Manuscript accepted: January 3, 2015.

Communicating Editor: Bertrand Collard

INTRODUCTION

Cabbage, *Brassica oleracea* var. *capitata* L. (2n = 2x = 18), a member of family *Brassicaceae*, is one of the most important crops of the cole group of vegetables. Closely related to other cole crops, such as broccoli, cauliflower and brussels sprouts, it has originated from *Brassica oleracea* var. *oleracea* L. (syn. *sylvestris* L.) commonly known as wild cabbage through mutation, human selection and adaptation. Most common cruciferous vegetables eaten by people, known colloquially as cole crops (cabbage, cauliflower, knolkhol, brussels sprout, kale and broccoli) are in a single species (*B. oleracea*); they are not distinguished from one another taxonomically, only by horticultural category of cultivar groups. Cabbage (*B. oleracea* var. *capitata*) is considered to be a typical representative of the C genome of *Brassica*. It is a rich source of vitamins A, B, C and minerals like phosphorus, potassium, sodium and iron. In India it ranks next to cauliflower with acreage and first with respect to production among cole crops occupying an area of 3,72,000 ha with annual production of 8534,000 tons (Anonymous, 2013).

Hybrids are known to outperform the open-pollinated varieties in marketable head yield and horticultural traits. The genetic phenomenon of sporophytic self-incompatibility (SSI) and cytoplasmic male sterility (CMS) is being used to develop cabbage hybrids on commercial scale (Parkash, 2008). With the successful transfer of R-cytoplasm (Ogura) induced CMS system in cole crops (including cabbage), there has been a lot of interest in its use for hybrid development during the last over a decade now (Melo and Giordano, 1994). Compared with self-incompatible lines, cytoplasmic male sterile lines could increase cultivars purity in cabbage hybrid by 5-7% (Ding and Jian, 2008). Self-incompatibility is not always stable, and may be suppressed by high temperature or drought and CMS (Cytoplasmic male sterile) lines are stable over the range of environments (Yamagishi and Bhat, 2014). Cytoplasmic male sterility seems to be a better option to develop hybrids in cole crops. In India, the hybrids of cabbage developed in public sector through the use of CMS are KTCBH-84 and H-64 (Anonymous, 2011). This is therefore considered as an seen as an alternative approach overcoming the problems (self in hybrid seed due to breakdown of self incompatibility and lengthy process of development of homozygous SI lines) experienced while using sporophytic self-incompatibility system.

At CSKHPKV, Palampur, the incorporation of cytoplasmic male sterility into low chill requiring genotypes of cabbage had been started in 2003-04. The CMS progenies are now in BC_6 stage quite comparable with their male fertile counterparts. Therefore, considering the importance of cytoplasmic male sterility in the production of hybrid seed in cabbage, present studies were carried out to evaluate the CMS progenies along with their maintainer lines for yield and horticultural traits and to evaluate CMS progenies for their stability in different flowering regimes.

MATERIALS AND METHODS

The investigation was undertaken at the Experimental Farm of Department of Vegetable Science and Floriculture, CSKHPKV, Palampur situated at situated at 32^0 6' N latitude and 76^0 3' E longitudes at an elevation of 1290.8 m above mean sea level, during 2010-2012. During 2010-11, the seeds of 4 CMS lines and their maintainers (Table 1) were sown in the nursery on 9th September, 2010 (inside polyhouse) and transplanting of seedlings was carried out on 21st October, 2010 at 60 x 45 cm spacing in open field following Randomized Complete Block Design (RCBD) with 3 replications. Each experimental plot was of the size 3.0 x 2.7 m accommodating 30 plants. During 2011-12, the seeds of respective CMS and maintainer lines were sown in the nursery on 7th September, 2011 (inside polyhouse) and transplanting was carried out on 15th October, 2011. The experimental design, replication, plot size and spacing were similar to that of 2010-11 seasons.

All the recommended package of practices was followed to ensure the proper growth of plants. The observations on the plant characters namely days to harvest, gross weight (g), number of non wrapper leaves, net weight of

Table1. List of CMS progenies and their male fertile counterparts used in the study.

Genotypes	Source	Remarks
KGAT-I CMS	CSK HPKV, Palampur	male sterile
KGAT-II CMS	CSK HPKV, Palampur	male sterile
KGAT-III CMS	CSK HPKV, Palampur	male sterile
GA(P) CMS	CSK HPKV, Palampur	male sterile
KGAT- I	CSK HPKV, Palampur	male fertile
KGAT- II	CSK HPKV, Palampur	male fertile
KGAT- III	CSK HPKV, Palampur	male fertile
GA(P)	CSK HPKV, Palampur	male fertile

head (g), polar diameter of head (cm), equatorial diameter of head (cm), head shape index, compactness of head, marketable heads per plot (No.), heading(%) and marketable head yield (kg/plot) were recorded in each treatment in each replication. Except heading (%), marketable heads and marketable head yield per plot, the observations were recorded on 10 plants taken at random in each treatment/plot. The shape index of head was calculated by dividing the polar diameter with equatorial diameter (Odland and Noll, 1954). Compactness of head was determined as per the procedure suggested by Pearson (1931). For the stability of CMS progenies, 10 plants per treatment/plot/replication were retained at random for bolting and flowering and were observed for sterility during 3 flowering regimes i.e 25-50% flowering, 50-75% flowering and > 75% flowering. The experimental plots/plants of replication-I were covered with UV stabilized insect-proof nylon-nets during all the flowering regimes on bamboo frame-work. The flowering branches in replication-II and replication-III were covered with butter paper bags of the size 26.0 x 10.0 x 5.0 cm.

Statistical analysis

Average values/plant or plot for each genotype in each replication for the traits studied were subjected to statistical analysis. The statistical analysis of experimental data was accomplished by Analysis of Variance in randomized block design (RBD) as per the procedure given by Panse and Sukhatme (1985) using CPCS-1 software (Cheema and Singh, 1990).

RESULTS AND DISCUSSION

Analysis of variance for the experimental data (Table 2) revealed that mean squares due to genetic stocks (treatments) were significant for all the traits studied. The genotype KGAT- I CMS was the earliest to produce marketable heads in 115.1 and 110.7 days during 2010-11 and 2011-12 respectively. The genotype KGAT-III took the maximum days of 128 and 130 during 2010-11 and 2011-12 respectively. Except the progeny KGAT- I CMS during 2011-12, all the remaining 3 CMS progenies were at par with their respective maintainer lines during both the years. This implies that the CMS lines are by and large as good as maintainer lines except for being male sterile. The mean values of gross weight are presented in Table 3. The highest and the lowest gross weight/plant were recorded in KGAT- III CMS (1235 g) and GA(P) (938.3 g) in 2010 -11 and in KGAT- I CMS (999.6 g) and KGAT- III (786 g) during 2011-12. Except the progenies KGAT- III CMS and GA(P) CMS during 2010-11 and KGAT- III CMS during 2011-12, all the remaining CMS progenies were at par with their maintainer lines. The gross weight of CMS progenies KGAT- II CMS, KGAT- III CMS and GA(P) CMS were higher than that of respective male fertile maintainer during 2010-11. It is possible that these CMS progenies might not have turned isogenic even after BC_6 generation for this trait.

Table 2. Analysis of variance with respect to 11 traits studied during 2010-12.

Character	Source	Replications		Genotypes		Error	
	Degrees of freedom	2		7		14	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Days to harvest		78.31*	346.73*	49.05*	109.37*	16.87	11.02
Gross weight(g)		112011.0*	29390.0*	31328.0*	15402.38*	3827.85	1837.24
Number of non wrapper leaves		1.17	8.04*	11.50*	11.49*	1.50	0.51
Net weight of head(g)		58650.0*	6650.25*	10536.8*	14219.19*	891.59	637.72
Polar diameter of head(cm)		2.95*	2.26*	0.75*	1.16*	0.12	0.06
Equatorial diameter of head(cm)		7.80*	4.62*	0.77*	0.81*	0.14	0.20
Head shape index		0.006*	0.02*	0.01*	0.008*	0.001	0.001
Head compactness		897.96*	142.31*	44.52*	54.98*	10.40	8.78
Marketable heads per plot (No.)		0.405*	0.25*	0.359*	0.25*	0.05	0.04
Heading (%)		28.79*	12.87*	23.61*	10.99*	1.93	1.77
Marketable head yield (kg/plot)		13.77*	8.40*	23.21*	10.69*	0.77	0.35

Table 3. Days to harvest (No.) and gross weight (g/plant) in cytoplasmic male sterile (CMS) and maintainer lines of cabbage.

Genotype	Days to harvest		Gross weight/plant	
	2010-11	2011-12	2010-11	2011-12
KGAT- I CMS	115	111	1183	999
KGAT- II CMS	120	119	1208	865
KGAT- III CMS	124	127	1235	875
GA(P) CMS	118	124	1093	946
KGAT- I	122	120	1197	971
KGAT- II	119	121	1207	904
KGAT- III	128	130	1056	786
GA(P)	120	126	938	977
C.D. (5%)	7.2	5.8	108.3	75.1
C.V. (%)	3.4	2.7	5.4	4.5

*Values in table are round off to whole number

Alternatively, this may be attributed to the fact that in CMS progenies we had taken a random sample of seeds harvested from true male sterile plants whereas in case of maintainer lines we had taken a random sample from the seeds harvested on all the plants.

Days to harvest indicate the maturity of a given genotype. The mean values for days to harvest after transplanting are presented in Table 3. The mean values of non-wrapper leaves, net weight of head, polar and equatorial diameter of head are presented in Table 4. The genotype KGAT- I recorded the maximum number of non wrapper leaves 17 and 16 in 2010-11 and 2011-12 respectively. On the other hand, GA(P) CMS recorded the minimum number of non-wrapper leaves 11 and 10.6 in 2010-11 and 2011-12 respectively. KGAT- II CMS and KGAT- III CMS were at par with their maintainer lines during both the years. However, GA(P) CMS was at par to its maintainer line in 2011-12 only. The net weight of head is a direct component of marketable head yield. The highest and the lowest net head weight/plant were recorded in KGAT- III CMS (660 g) and KGAT- III (475 g) in 2010-11 and in GA(P) (606 g) and KGAT- III (432 g) during 2011-12 respectively. The progenies KGAT- I CMS and KGAT- II CMS were at par with their respective maintainers in 2010-11 whereas KGAT- III CMS and GA(P) CMS in 2011-12 were at par with their respective maintainer lines. This may be attributed to seasonal/climatic variations. Polar diameter of head is one of the 2 traits which govern the head shape.

During 2010-11, the highest and lowest values for polar diameter were recorded in GA(P) (12 cm) and KGAT- II CMS (10 cm) respectively, whereas in 2011-12, KGAT- I (12) as well as GA(P) (12 cm) recorded the highest whereas KGAT- III CMS (10 cm) had the lowest polar diameter. However, KGAT- III CMS and KGAT- II CMS were at par with each other during 2011-12. Except the progeny KGAT- III CMS in 2010-11 and KGAT- I CMS in 2011-12, all the other CMS progenies were at par with their maintainer lines. The perusal of mean values (Table 4) revealed that in 2010-11 both KGAT- III CMS (12 cm) as well as KGAT- II (12 cm) recorded the maximum equatorial diameter whereas in 2011-12, KGAT- II had the highest value (13 cm) but this was at par with KGAT- III CMS (11 cm). During 2010-11, the lowest equatorial diameter (11 cm) was in the treatment GA(P) CMS but during 2011-12, this was in the treatment KGAT- III CMS (11 cm) which was at par with GA(P) CMS.

Head shape index value (polar: equatorial diameter) reflects the shape of cabbage heads. In case of a normal head (spherical) the head shape index value is between 0.8-1.0. The head shape index values below 0.8 indicate flat or drumhead type heads whereas the values > 1.0 indicate pointed heads. The ratio of polar and equatorial diameter was used to work out the head shape index (Table 5). This ranged between 0.8 in KGAT- II CMS to 1.0 in GA(P) and GA(P) CMS during 2010-11 and 0.8 in KGAT- II CMS and 0.9 in GA(P) CMS during 2011-12. All the 4 CMS progenies were at par with their maintainer lines indicating similarity in head shape. Since the head shape index values are between 0.8 and 1.00, all the CMS progenies as well as maintainer lines fall in the category of normal (spherical) heads which are acceptable to the consumers.

Head compactness is a desirable attribute in the sense that more produce can be accommodated in lesser shape/volume. The perusal of mean values (Table 5) revealed that head compactness varied from 34.8 in GA(P) to 46.1 in KGAT- II CMS during 2010-11 whereas the range was from 24.2 in KGAT-I to 37.5 in GA(P) CMS during 2011-12. In general, the head compactness (z) values were higher during 2010-11 as compared to 2011-12 indicating the effect of season/climate on the expression of this character. Except the CMS progenies KGAT- II CMS and GA(P) CMS during 2010-11 and KGAT- I CMS 2011-12, all the remaining CMS progenies were at par with the maintainer lines.

Marketable heads per plot contribute directly towards marketable yield. The mean values for number of marketable heads per plot have been presented in Table 5.

Table 4. Number of non-wrapper leaves and net weight of head (g)/plant, polar diameter of head (cm) and equatorial diameter of head (cm)/plant in CMS and maintainer lines of cabbage.

Genotype	No of non wrapper leaves		Net weight of head /plant		Polar diameter of head (cm)		Equatorial diameter of head	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
KGAT- I CMS	13	13	630	551	11	11	12	12
KGAT- II CMS	14	14	611	450	10	11	12	13
KGAT-III CMS	12	12	660	443	11	10	12	11
GA(P) CMS	11	11	610	575	11	12	11	12
KGAT- I	17	16	588	445	10	12	11	13
KGAT- II	15	13	597	515	11	11	12	13
KGAT- III	13	12	475	432	10	11	11	12
GA(P)	12	12	527	606	12	12	12	12
C.D. (5%)	1.3	1.2	52.3	44.3	0.6	0.4	0.7	0.8
C.V. (%)	5.4	5.3	5.0	5.0	3.3	2.4	3.3	3.7

Table 5. Head shape index, head compactness and marketable heads/plot in CMS and maintainer lines of cabbage.

Genotype	Head shape index		Head compactness (Z value)		Marketable heads /plot	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
KGAT- I CMS	0.9	0.9	43.9	34.6	26.7	29.3
KGAT- II CMS	0.8	0.8	46.0	29.7	27.0	28.0
KGAT-III CMS	0.9	0.9	41.8	35.3	26.3	28.0
GA(P) CMS	1.0	0.9	44.2	37.4	21.6	27.3
KGAT- I	0.9	0.9	44.7	24.2	27.0	30.0
KGAT- II	0.8	0.8	38.6	31.8	27.0	28.6
KGAT- III	0.9	0.9	38.7	31.5	20.6	25.0
GA(P)	1.0	0.9	34.8	36.3	22.0	24.6
C.D. (5%)	0.1	0.07	5.6	5.2	2.4	2.3
C.V. (%)	4.0	4.7	7.7	9.1	5.6	4.8

*Values in tables are round off to 1 decimal point only.

During 2010-11, KGAT- II CMS, KGAT- I and KGAT- II recorded the maximum (27) number of heads/plot whereas KGAT- III produced the minimum (20.6) marketable heads per plot.

The data for heading (%) have been presented in Table 6. During 2010-11, KGAT- II CMS (97.3%) and KGAT- III (76 %) and during 2011-12, KGAT- I (100 %) and GA(P) (82.6 %) recorded the highest and the lowest heading (%) respectively. Except KGAT- III CMS during 2010-11 and GA(P) CMS during 2011-12, all the remaining CMS progenies were at par with their maintainer lines.

Marketable head yield is the dependent variable which is of economic concern/importance to the breeders and farmers. The perusal of mean values (Table 6) revealed that the genotype KGAT- III CMS (17.3 kg) and KGAT- III (9.8 kg) in 2010-11 and the genotype KGAT- I CMS (16.1 kg) and KGAT- III (10.8 kg) in 2011-12 recorded the maximum and the minimum head yield (kg/plot) as well as q/ha respectively. In the year 2010-11, KGAT- I CMS and KGAT- II CMS were at par with their respective maintainer lines whereas in 2011-12, GA(P) CMS was the only progeny which was at par with its maintainer line. The CMS progenies and the maintainer lines did not reveal a definite trend in marketable head yield (kg/plot or q/ha) probably due to variation in climatic conditions during the period of the present investigation. As per the mathematical expectations of backcross method, the BC_6 progenies should behave isogenic to the recurrent parent. Jian and Ding (2005) had also developed cytoplasmic male sterile lines in cabbage through backcrossing of inbred lines in cabbage for 5-6 generations and they had been successful in getting perfect hybrids with uniform and good characters. Chen *et al.* (1995) had also developed cytoplasmic male sterile lines of Indian mustard which were almost equal to the maintainer lines and standard varieties in economic traits.

In this study, all the four CMS progenies had the head shape index at par with their respective maintainer lines. For days to harvest, the exception was KGAT- I CMS during 2011-12 only. For the traits heading (%), marketable heads per plot, non-wrapper leaves and gross weight, one or two of the CMS progenies were not at par with respective maintainer lines. In respect of the traits compactness of heads, net weight of head and marketable head yield (kg/plot), the exceptions were even up to 50 % of the CMS progenies studied. This may be attributed to the facts that cabbage is a highly cross-pollinated vegetable crop and the latter traits are prone to the influence of prevailing weather conditions.

Table 6. Heading percentage, marketable head yield (kg/plot and q/plot) in CMS and maintainer lines of cabbage.

Genotype	Heading %		Marketable head yield		Marketable head yield	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
KGAT- I CMS	92.3 (9.6)	97.3 (9.8)	16.9	16.1	209.3	198.9
KGAT- II CMS	97.3 (9.8)	94.0 (9.7)	16.5	12.6	203.6	155.1
KGAT-III CMS	94.6 (9.7)	94.0 (9.7)	17.3	12.3	213.9	152.8
GA(P) CMS	87.3 (9.3)	92.6 (9.6)	13.4	15.7	164.8	194.3
KGAT- I	90.6 (9.5)	100 (10)	15.9	13.3	196.4	164.7
KGAT- II	92.0 (9.6)	95.0 (9.7)	16.1	14.7	198.4	182.1
KGAT- III	76.0 (8.7)	87.6 (9.3)	9.8	10.8	120.9	133.5
GA(P)	89.6 (9.4)	82.6 (9.1)	11.6	15.4	143.0	189.1
C.D. (5%)	0.4	0.4	1.5	1.0	18.8	12.7
C.V. (%)	2.4	2.3	5.9	4.2	5.9	4.2

Values in the parentheses are square root transformations.
Values are round off to 1 decimal point only.

Stability of male sterility in cytoplasmic male sterile progenies

Ten plants per CMS progeny per replication were observed for stability of male sterility in the CMS progenies during the flowering regimes 25-50%, 50-75% and >75% flowering and the data are presented in Table 7. During 2010-11, the number of plants showing the production of very mild to mild pollen grains ranged from 0 (KGAT- III CMS) to 9 in GA(P) CMS in the flowering regime 25-50%. It ranged from 3 in KGAT- II CMS and KGAT- III CMS to 9 in GA(P) CMS and KGAT- I CMS in the flowering regime 50-75%. The range was from 3 in KGAT- II CMS to 9 in GA(P) CMS and KGAT- I CMS during the flowering regime 75-100%. During 2011-12, the number of plants showing the production of very mild to mild pollen was relatively lesser. The range was 0 in KGAT- I CMS and KGAT- III CMS to 1 in KGAT- II CMS and GA(P) CMS in the flowering regime 25-50%, 2 in KGAT- III CMS to 4 in KGAT- II CMS in the flowering regime 50-75% and 4 in KGAT- IIICMS and GA(P)CMS to 6 in KGAT- I CMS in the flowering regime 75-100%.

In order to ensure whether the pollen grains produced on otherwise male sterile plants were fertile or not, these were subjected to acetocarmine staining test (Chandrashekra *et al.*, 2013) along with maintainer lines producing abundant pollen grains during the year 2010-11. The average numbers of stained pollen grains are given in Table 8.

All the CMS progenies showed stained pollen grains which were found in numbers ranging from 54.7 in KGAT- III CMS to 104.3 in KGAT- ICMS but these were slightly lower in number as compared to their respective maintainer lines.

The number of plants showing the production of very mild to mild pollen grains during 2011-12 was lower in the CMS progenies KGAT- I CMS and GA(P) CMS constant in KGAT- III CMS and more in KGAT- II CMS. This indicates that there is a possibility of reducing the breakdown of male sterility in the CMS progenies through rigorous selection over the years.

Table 7. Number of plants showing stability and breakdown of male sterility in different flowering regimes in the CMS progenies of cabbage during 2010-11 and 2011-12.

S.N0.	CMS progenies	Flowering regimes						Stable plants(%) in CMS progenies	Breakdown of sterility (%)	Pollen category	Plant mortality due to stalk rot (No.)
		25-50%		50-75%		75-100%					
		Stable	breakdown	stable	breakdown	stable	breakdown				
2010-11											
1	KGAT- I CMS	27	3	21	9	21	9	70.0	30.00	Very mild-mild	0
2	KGAT- II CMS	28	2	27	3	27	3	90.0	10.00	Very mild-mild	0
3	KGAT- III CMS	30	0	27	3	26	4	86.7	13.33	Very mild-mild	0
4	GA(P) CMS	18	9	18	9	18	9	66.7	33.33	Very mild	3
2011-12											
1	KGAT- I CMS	29	0	26	3	23	6	79.3	20.68	Very mild-mild	1
2	KGAT- II CMS	28	1	25	4	24	5	82.7	17.24	Very mild-mild	1
3	KGAT- III CMS	30	0	28	2	26	4	86.6	13.33	Very mild-mild	0
4	GA(P) CMS	29	1	27	3	26	4	86.6	13.33	Very mild-good	0

* All the plants in the maintainer lines KGAT-I, KGAT-II, KGAT- III and GA(P) were male fertile.

Table 8. Stained pollen grain count of male sterile plants contributing very mild to mild pollen grains and the fertile maintainer lines during 2010-11.

Genotype	Average number of stained pollen grains/count
KGAT- I CMS	104.3
KGAT- II CMS	64.4
KGAT- III CMS	54.7
GA(P) CMS	79.8
KGAT- I	134.5
KGAT- II	100.9
KGAT- III	88.5
GA(P)	89.6

All the 4 CMS progenies had the head shape index at par with their respective maintainer lines. For days to harvest, except KGAT- I CMS during 2011-12, the CMS progenies were at par with their respective fertile counterparts as well. For the traits heading (%), marketable heads per plot, non-wrapper leaves and gross weight per plant, 1 or 2 of the CMS progenies were not at par with respective maintainer lines. In respect of the traits compactness of heads, net weight of head and marketable head yield (kg/plot), the exceptions were even up to 50% of the CMS progenies studied. This may be attributed to the facts that cabbage is a highly cross-pollinated vegetable crop and the latter traits are subject to the influence of prevailing weather conditions.

All the CMS progenies revealed breakdown of male sterility (very mild to mild pollen grain production) in variable number of plants in all the flowering regimes during both the years (2010-11 and 2011-12). The number of plants showing the production of very mild to mild pollen grains during 2011-12 were lower in the CMS progenies KGAT-I CMS and GA(P) CMS, constant in KGAT- III CMS and more in KGAT- II CMS. This suggests the possibility of developing stable CMS progenies through rigorous selection over the years. Alternatively, it will be a desirable proposition to study the impact of very mild – mild pollen grain production in the plants of CMS progenies on the true to type characteristics of the hybrids developed by using such CMS lines.

REFERENCES

Anonymous (2011). Annual Report IARI-2011. Indian Agricultural Research Institute, New Delhi, India.

Anonymous (2013). Indian Horticulture Database-2013. National Horticulture Board, Gurgaon, Ministry of Agriculture, Govt. of India

Parkash C (2008). Effectiveness of self-incompatibility and cytoplasmic male sterility systems in developing F_1 hybrids of cabbage. *Int. J. Plant Sci.* 3(2): 468-470

Chandrashekar US, Prasad M, Chakrabarty SK, Dadlini M, Vishwanath K (2013). Pollen viability assays in protogyny and self-incompatibility system in Indian mustard [*Brassica juncea* (L.) Czern. and Cross]. *Bioinfolet* 10: 782-784.

Chen ZJ, Zhang MF, Wang BL, Dong WM, Huang SQ (1995). Study of fertility and agronomic traits in cytoplasmically male sterile lines of Indian Mustard. *Acta Hort. Sin.* 22(1): 40-46

Cheema SS, Singh B (1990). CPCS-1: A computer programs package for the analysis of commonly used experimental design. Punjab Agricultural University, Ludhiana, India.

Ding Y, Jian Y (2008). Cabbage cytoplasmic male sterile line breeding and its application in hybrid seed production. *Acta Hort.* 771: 89-95

Jian YC, Ding YH (2005). Breeding and utilization of *Brassica oleracea* cytoplasmic male sterile lines. *China Vegetables* 6: 4-6

Melo PE, Giordano LB (1994). Effect of Ogura male-sterile cytoplasm on the performance of cabbage hybrid variety. *Euphytica.* 76 (1-2): 117-123

Odland ML, Noll CJ (1954). Vegetable variety trials 1953. Progressive Report Pennsylvania Agricultural Experiment Station. p 114

Panse VG, Sukhatme PK (1985).*Statistical Methods for Agricultural Workers*. ICAR, New Delhi. p 347

Pearson OH (1931). Methods of determining the solidarity of cabbage heads. *Hilgardia* 5: 383-393

Yamagishi H, Bhat SR (2014). Cytoplasmic male ster ility in brassicaceae crops. *Breed Sci.* 64 (1): 38-47.