DOI : 10.5958/0974-0112.2019.00106.3

Indian J. Hort. 76(4), December 2019: 663-671

CMS and SI based heterosis for yield and related traits in low chill cabbage under mid hills condition of Himachal Pradesh

Nitish Kumar*, **Sanjay Chadha and Sangeeta Kanwar**

Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur 176 062, Himachal Pradesh

ABSTRACT

In present investigation, 24 cross combinations evolved in a line × tester mating design (8 lines, 3 testers and 24 F_1 hybrids) were evaluated alongwith two standard check hybrids Varun and KGMR-1 during *Rabi* 2015-2016. A wide range of heterosis was observed among the cross combinations for all the traits studied. For marketable head yield per plant, eight cross combinations each over BP and SC-1 and five over SC-2 revealed significant positive heterosis. The cross combinations viz., SI I-4-6×Glory-7 (77.60% and 51.36%), SI III-I-I×KGAT-1 (74.28% and 48.53%), IIS CMS×Glory-7 (66.65% and 42.03%), IIS CMS×KGAT-1 (53.00% and 42.03%) and SI III-I-I×E-1-1&-2 (39.17% and 8.61%) were the most promising as they exhibited significant positive heterosis over check hybrid Varun and KGMR-1, respectively indicating that these crosses may be exploited for commercial release.

Key words: *Brassica oleracea* var. *capitata*, hybrids, cytoplasmic male sterility, self incompatibility.

INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata* L.) is one of the most important cole vegetable crops belonging to the family *Brassicaceae* with chromosome number 2n=2x=18. It is primarily originated from the ancestor *Brassica oleracea* var. *oleracea* L. (syn. *sylvestris* L.), commonly known as wild cabbage through mutation, human selection and adaptation. Among cole crops, it ranks first in acreage and production in the world. However, it is next to cauliflower in India with acreage and production statistics of 407 thousand hectares and 8971 thousand tonnes, respectively (Anonymous, 1). It constitutes an integral part of fast foods in Indian cuisine, because of its wide adaptability, reasonable market price and year-round availability (Prakash et *al.*, 11).

Cabbage contains proteins comprising all essential amino acids, especially sulphur containing amino acids, minerals such as calcium, iron, magnesium, sodium, potassium, phosphorus and chemical compounds like glucosinolates, glutathione, iso-thiocynates and brassinnins, which are reported to have anti-carcinogenic properties. In Himachal Pradesh, it is being cultivated extensively as an offseason vegetable in zone-II (Sub-temperate sub-humid), III (Sub-temperate high hills) and IV (Dry - temperature high hills) with an area of 4.99 thousand hectares and production of 163.37 thousand tonnes (Anonymous, 1). It brings lucrative returns to the farmers and seed production of temperate varieties of cabbage is being done on large scale in high hills on account of its specific thermo-requirements. Due to cool climate of the hilly region, insect-pest and disease problems are less than plain areas.

F_1 hybrids are highly popular in cabbage because of uniform and early maturity, better head quality, resistance to biotic stresses and higher yield. Availability of suitable pollination control mechanism is the most important determinant factor for economic and viable production of hybrid seeds. 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, CMS (cytoplasmic male sterility) and SI (self- incompatibility) are prevalent and have been used commercially. In developed countries, more than 90 per cent cabbage growing area is under hybrid varieties; whereas, it is 31 per cent in India (Kumar *et al.*, 6). This necessitates the development of improved and widely adapted hybrids from public sector institutions. Hence, this study was undertaken to use the SI and CMS lines in combination with elite pollen parents to develop superior F_1 hybrids.

MATERIALS AND METHODS

Eight lines viz., IIS CMS, IIIM CMS, GA (P) M CMS (cytoplasmic male sterile) and SI III-I-I, SI I-4-6, SI I-4-4, SI I-4-3 AND SI SC-5-5-4 (self incompatible) were crossed to each of the three testers Glory-7, KGAT-1, and E-1-&-2 (T) using line × tester mating design to develop 24 hybrids.

*Corresponding author's E-mail: 89.nitish@gmail.com

Pollination was started when majority of the parents had about 20-25% flowering. Pooled pollen of each tester was applied to the opened flowers of SI and CMS lines. The parental lines were also maintained through manual sibmating carried out at bud stage (Cabin, 3) and open flower stage. However, SI parents were sprayed with common salt (3%) in open flowers after about 15-20 minutes of pollinations (Singh and Vidyasagar, 15). The hybrids were evaluated along with parents and two standard checks, Varun (SC-1) and KGMR-1 (SC-2) in RBD with 3 replications at the Vegetable Research Farm, CSKHPKV Palampur during 2015-16. The plot size and spacing were 3.00m × 0.90m and 45cm × 45cm, respectively (12 plants/treatment). Observations were recorded on 5 randomly selected plants in each replication for days to harvest, plant spread (cm), non-wrapper leaves, stalk length, gross weight, net weight of head, polar and equatorial diameters of head, compactness of head, marketable heads per plot marketable head yield/plot and ascorbic acid content. The data were statistically analysed as per Panse and Sukhatme (8). Line × tester analysis was done using the model suggested by Kempthorne (4). The heterosis was estimated as suggested by Allard (2).

RESULTS AND DISCUSSION

The mean performance of parents and hybrids and the estimate of relative heterosis and heterobeltiosis are presented in Tables 1-4.

Early maturing strains are of immense value in catching early markets. Hence, for this trait, the interest of breeder lies in search of combinations having negative heterosis. Over respective BP, SC-1 and SC-2 the range for this character under inorganic conditions (Table1) varied from -10.37 (SI I-4-4 × Glory-7) to -1.37 per cent (SI I-4-6 × E-1-1&-2), -9.73 (IIS CMS × E-1-1&-2) to -1.08 per cent (SI I-4-4 × E-1-1&-2) and -6.70 (IIS CMS × E-1-1&-2) to 2.23 per cent (SI I-4-4 × E-1-1&-2). As many as 19 and 11 cross combinations showed significant negative heterosis over BP and SC-2, respectively. All the cross combinations except SI I-4-4 × E-1-1&-2 and SI I-4-3 × E-1-1&-2 exhibited significant negative heterosis over SC-1. The top five desirable cross combinations on the basis of standard heterosis (over SC-1 and SC-2) were IIS CMS×E-1-1&-2 (-9.73% and -6.70%), IIIM CMS×KGAT-1 (-9.19% and -6.15%), SI III-I-I×Glory-7 (9.19% and -6.15%), SI I-4-6×Glory-7 (-8.92% and -5.87) and SI I-4-4×Glory-7 (-8.92% and -5.87%). Pathak *et al.,* (12), Parkash *et al.,* (10) and Thakur and Vidyasagar (16) also reported negative heterosis for days to harvest over BP.

Varieties with smaller plant spread are desired so that more number of plants can be accommodated per unit area. Heterosis in negative direction is desired for this trait. The magnitude of heterosis for plant spread (Table 1) varied from -21.66 (IIIM CMS × E-1-1&-2) to 4.76 per cent (SI SC-5-5-4 × KGAT-1), -15.90 (IIIM CMS × E-1-1&-2) to 5.60 per cent (SI III-I-I × KGAT-1) and -13.96 (IIIM CMS × E-1-1&-2) to 8.04 per cent (SI III-I-I × KGAT-1). Out of 24 cross combinations 11, 14 and 6 cross combinations gave significant negative heterosis over BP, SC-1 and SC-2, respectively. The cross combinations viz., IIIM CMS×E-1-1&-2 (-15.90% and -13.96%), IIIM CMS×KGAT-1 (-14.66% and -12.70%), IIS CMS×Glory-7 (-14.04% and -12.06%), SI I-4-3×E-1-1&-2 (-13.28% and -11.29%) and SI I-4-4×Glory-7 (-11.70% and -9.67%) were the top five most desirable cross combinations for shorter plant spread over SC-1 and SC-2. The results are in line with the findings of Pathak *et al.,* (12) and Thakur and Vidyasagar (16).

The range of heterobeltiosis and standard heterosis over SC-1 and SC-2 varied from -26.60 (IIS CMS × E-1-1&-2) to -0.07 per cent (SI SC-5-5-4 × E-1-1&-2), -23.70 (IIS CMS × E-1-1&-2) to 11.26 per cent (SI I-4-3 × Glory-7) and -22.93 (IIS CMS × E-1-1&-2) to 12.38 per cent (SI I-4-3 × GLORY-7). Plants with relatively less number of non-wrapper leaves are desired in order to have higher net weight of head in relation to gross head weight and moreover varieties/ hybrids with lesser number of non-wrapper leaves are shorter in frame hence, heterosis in negative direction is desirable. Significant negative heterosis over BP was recorded in 17 cross combinations. Four cross combinations *viz.,* IIS CMS × E-1-1&-2 (-23.70%), IIIM CMS × E-1-1&-2 (-15.23%), GA (P) M CMS × E-1-1&-2 (-12.39%) and SI I-4-4 × Glory-7 (-11.95%) exhibited significant negative heterosis over SC-1. However, IIS CMS × E-1-1&-2 (-22.93%) and IIIM CMS × E-1-1&-2 (-14.38%) also recorded significant negative heterosis over SC-2. Parkash and Verma (9) and Pathak *et al.,* (12) also reported heterosis over BP and standard check in some of the cross combinations.

Plants with shorter stalk length are preferred, so heterosis in negative direction is desirable. The respective magnitude of heterosis (Table 2) varied from -33.97 (IIS CMS × E-1-1&-2) to 25.91 per cent (GA (P) M CMS × E-1-1&-2), -33.60 (SI SC-5-5-4 × E-1-1&-2) to 16.06 per cent (SI III-I-I × GLORY-7) and -32.22 (SI SC-5-5-4 × E-1-1&-2) to 18.47 per cent (SI III-I-I × Glory-7). As many as 11 over BP and 10 each over SC-1 and SC-2 showed significant negative heterosis. The top promising cross combinations for stalk length were SI SC-5-5-4×E-1-1&-2 (-33.60% and -32.22%), SI SC-5-5-4×Glory-7 (-29.89% and -28.44%), SI SC-5-5-4×KGAT-1 (-28.23% and

Table 1. Mean performance of genotypes and F_1 hybrids and extent of heterosis (%) in cabbage for days to harvest, plant spread and number of non-wrapper leaves.

Genotypes	Days to harvest				Plant spread (cm)				Number of non-wrapper leaves			
	Mean	BPH	SH1	SH2	Mean	BPH	SH1	SH2	Mean	BPH	SH1	SH2
Parents												
IIS CMS	118.67	-	-	-	37.09	-	-	-	12.55	-	-	-
IIIM CMS	120.33	-	-	-	43.37	-	-	-	12.75	-	-	-
GA (P) M CMS	119.67	-	-	-	34.51	-	-	-	13.30	-	-	-
SI III-1-1	124.33	-	-	-	42.87	-	-	-	15.41	-	-	-
SI I-4-6	121.67	-	-	-	45.16	-	-	-	16.95	-	-	-
SI 1-4-4	125.33	-	-	-	32.24	-	-	-	11.50	-	-	-
SI I-4-3	124.67	-	-	-	40.36	-	-	-	14.65	-	-	-
SI SC-5-5-4	120.00	-	-	-	30.44	-	-	-	12.41	-	-	-
Glory-7	121.67	-	-	-	43.78	-	-	-	15.44	-	-	-
KGAT-1	120.67	-	-	-	35.38	-	-	-	13.53	-	-	-
E-1-1&-2	121.00	-	-	-	37.23	-	-	-	13.51	-	-	-
F_1 Hybrids												
IIS CMS × Glory-7	118.00	-3.01*	-4.32*	-1.12	34.72	-20.68*	-14.04*	-12.06*	12.36	-19.95*	-4.90	-3.94
IIS CMS × KGAT-1	118.67	-1.66	-3.78*	-0.56	36.58	-1.37	-9.44*	-7.35	13.08	-3.28	0.67	1.68
IIS CMS ×	111.33	-7.99*	-9.73*	-6.70*	36.27	-2.58	-10.22*	-8.15	9.92	-26.60*	-23.70*	-22.93*
IIIM CMS × Glory-7	119.33	-1.92	-3.24*	0.00	39.56	-9.64*	-2.08	0.18	11.82	-23.45*	-9.05	-8.13
IIIM CMS × KGAT-1	112.00	-7.18*	-9.19*	-6.15*	34.47	-20.51*	-14.66*	-12.70*	12.54	-7.32	-3.54	-2.56
IIIM CMS × E-1-1&-2	115.67	-4.41*	-6.22*	-3.07*	33.97	-21.66*	-15.90*	-13.96*	11.02	-18.46*	-15.23*	-14.38*
GA (P) M CMS × Glory-7	117.67	-3.29*	-4.59*	-1.40	38.33	-12.43*	-5.11	-2.92	12.77	-17.31*	-1.77	-0.78
GA (P) M CMS × KGAT-1	118.33	-1.93	-4.05*	-0.84	36.23	2.41	-10.31*	-8.25	12.19	-9.86	-6.18	-5.23
GA (P) M CMS × E-1-1&-2	116.00	-4.13*	-5.95*	-2.79*	38.07	2.25	-5.77	-3.60	11.39	-15.72*	-12.39*	-11.50
SI III-1-1 × Glory-7	112.00	-9.92*	-9.19*	-6.15*	40.71	-7.00	0.78	3.11	12.92	-16.32*	-0.59	0.41
SI III-1-1 × KGAT-1	114.33	-8.04*	-7.30*	-4.19*	42.66	-0.50	5.60	8.04	13.00	-15.66*	0.03	1.04
SI III-1-1 × E-1-1&-2	112.67	-9.38*	-8.65*	-5.59*	36.26	-15.43*	-10.25*	-8.18	11.54	-25.11*	-11.18	-10.28
SI I-4-6 × Glory-7	112.33	-7.67*	-8.92*	-5.87*	40.94	-9.34*	1.34	3.68	12.83	-24.27*	-1.26	-0.26
SI I-4-6 × KGAT-1	116.67	-4.11*	-5.41*	-2.23	36.82	-18.45*	-8.85*	-6.74	13.30	-21.52*	2.33	3.37
SI I-4-6 × E-1-1&-2	120.00	-1.37	-2.70*	0.56	35.89	-20.53*	-11.16*	-9.12*	12.50	-26.26*	-3.85	-2.88
SI 1-4-4 × Glory-7	112.33	-10.37*	-8.92*	-5.87*	35.67	-18.52*	-11.70*	-9.67*	11.44	-25.89*	-11.95*	-11.06
SI 1-4-4 × KGAT-1	118.67	-5.32*	-3.78*	-0.56	36.85	4.17	-8.77*	-6.67	12.37	-8.53	-4.80	-3.83
SI 1-4-4 × E-1-1&-2	122.00	-2.66*	-1.08	2.23	36.63	-1.60	-9.32*	-7.23	12.17	-9.94	-6.39	-5.44
SI I-4-3 × Glory-7	113.00	-9.36*	-8.38*	-5.31*	41.62	-4.93	3.02	5.39	14.46	-6.35	11.26	12.38*
SI I-4-3 × KGAT-1	116.33	-6.68*	-5.68*	-2.51	37.88	-6.14	-6.22	-4.06	12.80	-12.65*	-1.51	-0.52
SI I-4-3 × E-1-1&-2	120.33	-3.48*	-2.43	0.84	35.03	-13.21*	-13.28*	-11.29*	12.11	-17.36*	-6.82	-5.88
SI SC-5-5-4 × Glory-7	113.33	-6.85*	-8.11*	-5.03*	42.53	-2.85	5.28	7.71	12.86	-16.71*	-1.05	-0.05
SI SC-5-5-4 × KGAT-1	117.00	-3.04*	-5.14*	-1.96	37.06	4.76	-8.26*	-6.15	11.48	-15.11*	-11.64	-10.75
SI SC-5-5-4 × E-1-1&-2	119.00	-1.65	-3.51*	-0.28	37.60	0.98	-6.93	-4.79	13.50	-0.07	3.87	4.92
Checks												
Varun	123.33	-	-	-	40.40	-	-	-	13.00	-	-	-
KGMR-1	119.33	-	-	-	39.49	-	-	-	12.87	-	-	-

Table 2. Mean performance of genotypes and F_1 hybrids and extent of heterosis (%) in cabbage for stalk length (cm), gross weight (g) and net weight of head (g).

Genotypes	Stalk length (cm)				Gross weight (g)				Net weight of head (g)			
	Mean	BPH	SH1	SH2	Mean	BPH	SH1	SH2	Mean	BPH	SH1	SH2
Parents												
IIS CMS	5.97	-	-	-	863.33	-	-	-	458.33	-	-	-
IIIM CMS	5.18	-	-	-	1008.33	-	-	-	541.67	-	-	-
GA (P) M CMS	4.57	-	-	-	900.00	-	-	-	495.00	-	-	-
SI III-1-1	5.66	-	-	-	1046.67	-	-	-	575.00	-	-	-
SI I-4-6	6.47	-	-	-	973.33	-	-	-	525.17	-	-	-
SI 1-4-4	5.06	-	-	-	916.67	-	-	-	479.17	-	-	-
SI I-4-3	5.84	-	-	-	840.00	-	-	-	448.58	-	-	-
SI SC-5-5-4	4.27	-	-	-	708.42	-	-	-	446.98	-	-	-
Glory-7	4.91	-	-	-	916.67	-	-	-	491.67	-	-	-
KGAT-1	5.45	-	-	-	1030.55	-	-	-	601.67	-	-	-
E-1-1&-2	4.35	-	-	-	833.33	-	-	-	469.44	-	-	-
F_1 Hybrids												
IIS CMS × Glory-7	4.11	-31.17*	-23.90*	-22.32*	1106.67	20.73	7.62	11.59	781.67	58.98*	42.12*	28.85*
IIS CMS × KGAT-1	4.05	-32.12*	-24.95*	-23.39*	1043.33	1.24	1.46	5.20	741.67	23.27*	34.85*	22.25*
IIS CMS ×	3.94	-33.97*	-26.99*	-25.47*	970.00	12.36	-5.67	-2.19	491.67	4.73	-10.61	-18.96*
IIIM CMS × Glory-7	4.83	-6.88	-10.56	-8.70	923.33	-8.43	-10.10	-6.90	446.67	-17.54*	-18.79*	-26.37*
IIIM CMS × KGAT-1	5.14	-5.68	-4.69	-2.71	910.00	-11.70	-11.10	-8.24	503.33	-16.34*	-8.48	-17.03*
IIIM CMS × E-1-1&-2	4.83	-6.88	-10.56	-8.70	978.33	-2.98	-4.86	-1.35	621.67	14.77*	13.03*	2.47
GA (P) M CMS × Glory-7	5.31	8.22	-1.61	0.44	936.67	2.18	-8.91	-5.55	496.67	0.34	-9.70	-18.13*
GA (P) M CMS × KGAT-1	5.44	-0.24	0.80	2.90	1003.33	-2.64	-2.43	1.17	568.33	-5.54	3.33	-6.32
GA (P) M CMS × E-1-1&-2	5.75	25.91*	6.55	8.76	1138.33	26.48*	10.70	14.78	605.00	22.22*	10.00	-0.27
SI III-1-1 × Glory-7	6.26	10.72	16.06*	18.47*	1023.33	-2.23	-0.49	3.18	625.00	8.70	13.64*	3.02
SI III-1-1 × KGAT-1	4.27	-24.57*	-20.94*	-19.29*	1096.67	4.78	6.65	10.58	796.67	32.41*	44.85*	31.32*
SI III-1-1 × E-1-1&-2	6.01	6.19	11.30	13.62	1003.33	-4.14	-2.43	1.17	671.67	16.81*	22.12*	10.71
SI I-4-6 × Glory-7	5.95	-8.08	10.25	12.55	1201.67	23.46*	16.86	21.17*	808.33	53.92*	46.97*	33.24*
SI I-4-6 × KGAT-1	5.52	-14.73*	2.29	4.41	906.67	-12.02	-11.30	-8.58	526.67	-12.47*	-4.24	-13.19*
SI I-4-6 × E-1-1&-2	5.34	-17.51*	-1.05	1.01	801.67	-17.64	-22.04*	-19.17	483.33	-7.97	-12.12	-20.33*
SI 1-4-4 × Glory-7	4.13	-18.43*	-23.47*	-21.88*	946.67	3.27	-7.94	-4.55	518.33	5.42	-5.76	-14.56*
SI 1-4-4 × KGAT-1	4.26	-21.88*	-21.06*	-19.42*	871.67	-15.42	-15.40	-12.11	491.67	-18.28*	-10.61	-18.96*
SI 1-4-4 × E-1-1&-2	4.39	-13.23	-18.59*	-16.90*	841.67	-8.18	-18.50	-15.13	416.67	-13.04	-24.24*	-31.32*
SI I-4-3 × Glory-7	5.00	-14.38	-7.29	-5.36	1093.33	19.27	6.32	10.24	603.33	22.71*	9.70	-0.55
SI I-4-3 × KGAT-1	5.24	-10.38	-2.96	-0.95	955.00	-7.33	-7.13	-3.71	533.33	-11.36	-3.03	-12.09*
SI I-4-3 × E-1-1&-2	4.86	-16.89*	-10.01	-8.13	768.33	-8.53	-25.58*	-22.53*	431.67	-8.05	-21.52*	-28.85*
SI SC-5-5-4 × Glory-7	3.78	-22.89*	-29.89*	-28.44*	1081.67	18.00	5.19	9.07	651.67	32.54*	18.48*	7.42
SI SC-5-5-4 × KGAT-1	3.87	-28.97*	-28.23*	-26.73*	768.33	-25.44*	-25.28*	-22.53*	523.33	-13.02*	-4.85	-13.74*
SI SC-5-5-4 × E-1-1&-2	3.58	-17.69	-33.60*	-32.22*	1053.33	26.40*	2.43	6.21	545.00	16.09*	-0.91	-10.16
Checks												
Varun	5.40	-	-	-	1028.33	-	-	-	550.00	-	-	-
KGMR-1	5.29	-	-	-	991.75	-	-	-	606.67	-	-	-

-26.73%), IIS CMS×E-1-1&-2 (-26.99% and -25.47%) and IIS CMS×KGAT-1 (-24.95% and -23.39%). The results are in consonance with the findings of Pathak *et al.,* (12).

The magnitude of heterosis (Table 4.2) for gross weight varied from -25.44 (SI SC-5-5-4 × KGAT-1) to 26.48 per cent (GA (P) M CMS × E-1-1&-2), -25.58 (SI I-4-3 × E-1-1&-2) to 16.86 per cent (SI I-4-6 × Glory-7) and -22.53 (SI I-4-3 × E-1-1&-2 and SI SC-5-5-4 × KGAT-1) to 21.17 per cent (SI I-4-6 × Glory-7) Gross weight of head contributes directly towards yield. Heterosis in positive direction is desired for this trait. Three cross combinations namely GA (P) M CMS × E-1-1&-2 (26.48%), SI SC-5-5-4 × E-1-1&-2 (26.40%) and SI I-4-6 × Glory-7 (23.46%) over BP, only SI I-4-6 × GLORY-7 (21.17%) over SC-2 and none of the cross combinations over SC-1 exhibited significant positive heterosis. The results are in close proximity with the findings of Pandey *et al.,* (7), Parkash and verma (9), Pathak *et al.,* (12) and Thakur and Vidyasagar (16).

Net weight of head is an important character which accounts for yield. It is considered to be associated directly with yield; therefore, positive heterosis for this trait is desirable. The range of heterobeltiosis and standard heterosis over SC-1 and SC-2 for this character varied from -18.28 (SI I-4-4 × KGAT-1) to 58.98 per cent (IIS CMS × Glory-7), -24.24 (SI I-4-4 × E-1-1&-2) to 46.97 per cent (SI I-4-6 × Glory-7) and -31.32 (SI I-4-4 × E-1-1&-2) to 33.24 per cent (SI I-4-6 × Glory-7). Out of 24, 10 cross combinations showed significant positive heterosis over BP. Eight and four cross combinations gave standard heterosis over SC-1 and SC-2, respectively. On the basis of standard heterosis, cross combinations SI I-4-6×Glory-7 (46.97% and 33.24%), SI III-I-I×KGAT-1 (44.85% and 31.32%), IIS CMS×Glory-7 (42.12% and 28.85%) and IIS CMS×KGAT-1 (34.85% and 22.25%) were most promising. These results are in accordance with Singh *et al.,* (14), Parkash *et al.,* (10), Raygade (13), Kibar *et al.,* (5), and Thakur and Vidyasagar (16), who had reported variable number of hybrids exhibiting significant heterosis over BP and check hybrid for net weight of head.

Polar and equatorial diameters have direct influence on net weight of head. Heterosis in positive direction is desirable. The magnitude of heterosis (Table 3) for this character ranged from -27.53 (SI I-4-3 × E-1-1&-2) to -1.55 per cent (IIS CMS × Glory-7), -16.48 (SI I-4-4 × E-1-1&-2) to 15.66 per cent (SI I-4-6 × Glory-7) and -19.61 (SI I-4-4 × E-1-1&-2) to 11.33 per cent (SI I-4-6 × Glory-7). None of the cross combinations could exhibit significant positive heterosis over BP. One cross combination, namely SI I-4-6 × Glory-7 (15.66% and 11.33%) showed significant positive heterosis over SC-1 and SC-2, respectively.

The magnitude of heterosis for equatorial diameter ranged (Table 3) from -23.26 (IIIM CMS × Glory-7) to 7.82 per cent (SI I-4-6 × Glory-7), -12.94 (SI I-4-6 × KGAT-1 and SI I-4-6 × E-1-1&-2) to 10.63 per cent (SI I-4-6 × Glory-7) and -17.37 (SI I-4-6 × KGAT-1 and SI I-4-6 × E-1-1&-2) to 5.01 per cent (SI I-4-6 × glory-7). None of the cross combinations could exhibit significant positive heterosis over BP and SC-2, however two of the cross combinations, namely SI I-4-6 × Glory-7 (10.63%) and IIS CMS × Glory-7 (10.52%) showed significant positive heterosis over SC-1. Similar results have been reported by Thakur and Vidyasagar (16).

From the perusal of table 3, it was observed that the magnitude of heterosis for compactness of head ranged from -12.55 (IIS CMS × E-1-1&-2) to 41.80 per cent (IIS CMS × KGAT-1), -6.25 (IIS CMS × E-1-1&-2) to 38.77 per cent (IIS CMS × KGAT-1) and -2.32 (IIS CMS × E-1-1&-2) to 44.58 per cent (IIS CMS × KGAT-1). Head compactness is a desirable attribute in the sense that a compact head will have less volume and more weight per unit area, better storage and are less prone to post harvest handling. Heterosis in positive direction is desired for this trait. One-fourth (6) of the cross combinations observed significant positive heterosis each over BP, SC-1 and SC-2. Top five cross combinations exhibiting significant positive heterosis over SC-1 and SC-2 were IIS CMS×KGAT-1 (38.77% and 44.58%), GA (P) M CMS×KGAT-1 (33.77% and 39.37%), IIIM CMS×E-1-1&-2 (33.64% and 39.23%), SI I-4-4×KGAT-1 (29.46% and 34.87%) and SI III-I-I×KGAT-1 (26.00% and 31.28%). These findings are in close agreement with those of Pathak *et al.,* (12) and Thakur and Vidyasagar (16), who had also reported hybrid vigour in a good number of cross combinations attempted and evaluated by them.

Marketable heads per plot contribute directly towards marketable yield. Heterosis in positive direction is desirable for this trait. The heterosis for this character (Table 4) over BP, SC-1 and SC-2 ranged from -18.18 (SI III-I-I × Glory-7) to 30.77 per cent (IIS CMS × Glory-7), -6.90 (SI III-I-I × Glory-7) to 20.69 per cent (SI I-4-4 × KGAT-1, SI I-4-6 × Glory-7, SI III-I-I × KGAT-1 and SI I-4-3 × Glory-7) and -12.90 (SI III-I-I × Glory-7) to 12.90 per cent (SI I-4-4 × KGAT-1, SI I-4-6 × Glory-7, SI III-I-I × KGAT-1 and SI I-4-3 × Glory-7). Significant positive heterosis was observed in five and six cross combinations over BP and SC-1, respectively. None of the cross combinations could exhibit significant positive heterosis over SC-2. The top promising cross combinations exhibiting significant positive heterosis over SC-1 were SI III-I-I×KGAT-1 (20.69%), SI I-4-

Table 3. Mean performance of genotypes and F_1 hybrids and extent of heterosis (%) in cabbage for polar diameter of head (cm), equatorial diameter of head (cm) and Compactness of head (g/cm^3).

Genotypes	Polar diameter of head (cm)				Equatorial diameter of head (cm)				Compactness of head (g/cm^3)			
	Mean	BPH	SH1	SH2	Mean	BPH	SH1	SH2	Mean	BPH	SH1	SH2
Parents												
IIS CMS	12.28	-	-	-	13.23	-	-	-	22.43	-	-	-
IIIM CMS	12.30	-	-	-	14.32	-	-	-	23.03	-	-	-
GA (P) M CMS	12.42	-	-	-	11.85	-	-	-	27.75	-	-	-
SI III-1-1	13.29	-	-	-	12.49	-	-	-	26.99	-	-	-
SI I-4-6	13.54	-	-	-	11.85	-	-	-	25.63	-	-	-
SI 1-4-4	12.71	-	-	-	11.82	-	-	-	26.05	-	-	-
SI I-4-3	14.09	-	-	-	11.91	-	-	-	20.54	-	-	-
SI SC-5-5-4	14.08	-	-	-	12.31	-	-	-	19.46	-	-	-
Glory-7	10.64	-	-	-	12.58	-	-	-	31.61	-	-	-
KGAT-1	11.27	-	-	-	13.34	-	-	-	32.33	-	-	-
E-1-1&-2	9.93	-	-	-	11.98	-	-	-	35.42	-	-	-
F_1 Hybrids												
IIS CMS × Glory-7	12.09	-1.55	5.41	1.45	13.55	2.39	10.52*	4.90	37.07	17.26	12.21	16.90
IIS CMS × KGAT-1	10.63	-13.46*	-7.35*	-10.83*	12.85	-3.67	4.79	-0.54	45.84	41.80*	38.77*	44.58*
IIS CMS ×	11.38	-7.33*	-0.78	-4.50	11.95	-9.70*	-2.53	-7.48	30.97	-12.55	-6.25	-2.32
IIIM CMS × Glory-7	10.54	-14.31*	-8.08*	-11.52*	10.99	-23.26*	-10.39*	-14.94*	36.56	15.66	10.68	15.31
IIIM CMS × KGAT-1	11.01	-10.54*	-4.04	-7.64*	11.45	-20.05*	-6.63	-11.38*	35.88	10.98	8.61	13.15
IIIM CMS × E-1-1&-2	10.92	-11.24*	-4.80	-8.36*	11.51	-19.63*	-6.14	-10.92*	44.15	24.66*	33.64*	39.23*
GA (P) M CMS × Glory-7	10.49	-15.57*	-8.57*	-12.00*	11.20	-10.97*	-8.65	-13.29*	38.77	22.65	17.37	22.28
GA (P) M CMS × KGAT-1	10.95	-11.81*	-4.50	-8.08*	10.90	-18.30*	-11.12*	-15.64*	44.19	36.70*	33.77*	39.37*
GA (P) M CMS × E-1-1&-2	11.38	-8.37*	-0.78	-4.50	12.41	3.59	1.22	-3.92	36.26	2.38	9.76	14.35
SI III-1-1 × Glory-7	11.22	-15.58*	-2.18	-5.85	12.83	1.99	4.65	-0.67	36.12	14.27	9.34	13.92
SI III-1-1 × KGAT-1	12.13	-8.73*	5.75	1.79	12.72	-4.65	3.72	-1.55	41.62	28.76*	26.00*	31.28*
SI III-1-1 × E-1-1&-2	12.23	-7.98*	6.63	2.63	12.77	2.27	4.16	-1.14	34.96	-1.28	5.83	10.26
SI I-4-6 × Glory-7	13.27	-1.99	15.66*	11.33*	13.56	7.82	10.63*	5.01	33.65	6.46	1.88	6.14
SI I-4-6 × KGAT-1	11.06	-18.32*	-3.60	-7.22*	10.67	-19.97*	-12.94*	-17.37*	41.19	27.43*	24.70*	29.92*
SI I-4-6 × E-1-1&-2	11.03	-18.54*	-3.87	-7.47*	10.67	-10.91*	-12.94*	-17.37*	38.05	7.44	15.18	20.00
SI 1-4-4 × Glory-7	10.05	-20.88*	-12.35*	-15.64*	12.00	-4.64	-2.15	-7.12	38.71	22.46	17.18	22.09
SI 1-4-4 × KGAT-1	9.89	-22.14*	-13.75*	-16.98*	11.06	-17.07*	-9.79*	-14.37*	42.76	32.29*	29.46*	34.87*
SI 1-4-4 × E-1-1&-2	9.58	-24.61*	-16.48*	-19.61*	11.40	-4.81	-6.99	-11.72*	36.07	1.84	9.18	13.75
SI I-4-3 × Glory-7	11.42	-18.97*	-0.44	-4.17	11.85	-5.83	-3.37	-8.28	38.62	22.17	16.90	21.79
SI I-4-3 × KGAT-1	11.00	-21.93*	-4.07	-7.66*	11.16	-16.32*	-8.97*	-13.60*	39.31	21.61	19.01	23.99
SI I-4-3 × E-1-1&-2	10.21	-27.53*	-10.96*	-14.29	11.20	-6.51	-8.65	-13.29*	35.15	-0.75	6.40	10.85
SI SC-5-5-4 × Glory-7	11.11	-21.09*	-3.11	-6.74	13.20	4.93	7.67	2.19	36.30	14.82	9.87	14.47
SI SC-5-5-4 × KGAT-1	10.74	-23.76*	-6.39	-9.90*	11.42	-14.40*	-6.88	-11.61*	38.68	19.66	17.10	22.00
SI SC-5-5-4 × E-1-1&-2	10.70	-24.05*	-6.74	-10.24*	11.93	-3.06	-2.69	-7.64	37.85	6.87	14.57	19.37
Checks												
Varun	11.47	-	-	-	12.26	-	-	-	33.03	-	-	-
KGMR-1	11.92	-	-	-	12.92	-	-	-	31.71	-	-	-

Table 4. Mean performance of genotypes and F_1 hybrids and extent of heterosis (%) in cabbage for marketable heads per plot (No.), marketable head yield (kg/plot) and ascorbic acid content (mg/100g).

Genotypes	Marketable heads per plot (No.)				Marketable head yield (kg/plot)				Ascorbic acid content (mg/100g)			
	Mean	BPH	SH1	SH2	Mean	BPH	SH1	SH2	Mean	BPH	SH1	SH2
Parents												
IIS CMS	8.00	-	-	-	3.69	-	-	-	15.38	-	-	-
IIIM CMS	9.00	-	-	-	4.89	-	-	-	19.25	-	-	-
GA (P) M CMS	8.67	-	-	-	4.30	-	-	-	18.35	-	-	-
SI III-1-1	11.00	-	-	-	6.30	-	-	-	16.93	-	-	-
SI I-4-6	10.00	-	-	-	5.24	-	-	-	18.57	-	-	-
SI 1-4-4	9.67	-	-	-	4.63	-	-	-	15.88	-	-	-
SI I-4-3	11.00	-	-	-	4.93	-	-	-	17.87	-	-	-
SI SC-5-5-4	8.67	-	-	-	3.89	-	-	-	13.79	-	-	-
Glory-7	8.67	-	-	-	4.24	-	-	-	17.42	-	-	-
KGAT-1	9.33	-	-	-	5.61	-	-	-	17.73	-	-	-
E-1-1&-2	11.00	-	-	-	5.17	-	-	-	18.39	-	-	-
F_1 Hybrids												
IIS CMS × Glory-7	11.33	30.77*	17.24*	9.68	8.87	109.19*	66.65*	42.03*	16.91	-2.95	6.49	9.50
IIS CMS × KGAT-1	11.00	17.86*	13.79	6.45	8.15	45.28*	53.00*	30.40*	17.89	0.90	12.68	15.87
IIS CMS ×	10.00	-9.09	3.45	-3.23	4.90	-5.35	-8.07	-21.65*	17.87	-2.83	12.58	15.76
IIIM CMS × Glory-7	10.33	14.81	6.90	0.00	4.61	-5.79	-13.45	-26.24*	16.74	-13.04	5.42	8.40
IIIM CMS × KGAT-1	10.67	14.29	10.34	3.23	5.35	-4.58	0.50	-14.35	18.48	-4.00	16.38	19.67*
IIIM CMS × E-1-1&-2	11.00	0.00	13.79	6.45	6.83	31.96*	28.16*	9.23	20.06	4.21	26.33*	29.90*
GA (P) M CMS × Glory-7	10.00	15.38	3.45	-3.23	4.92	14.50	-7.57	-21.23*	20.82	13.46	31.11*	34.82*
GA (P) M CMS × KGAT-1	11.00	17.86*	13.79	6.45	6.23	11.05	16.96	-0.32	19.60	6.85	23.47*	26.96*
GA (P) M CMS × E-1-1&-2	10.00	-9.09	3.45	-3.23	6.04	16.69	13.33	-3.41	21.03	14.32	32.44*	36.18*
SI III-1-1 × Glory-7	9.00	-18.18*	-6.90	-12.9	5.63	-10.69	5.63	-9.97	18.85	8.21	18.73*	22.09*
SI III-1-1 × KGAT-1	11.67	6.06	20.69*	12.9	9.28	47.35*	74.28*	48.53*	18.69	5.41	17.72*	21.05*
SI III-1-1 × E-1-1&-2	11.00	0.00	13.79	6.45	7.41	17.67*	39.17*	18.61*	20.62	12.12	29.90*	33.57*
SI I-4-6 × Glory-7	11.67	16.67*	20.69*	12.9	9.46	80.65*	77.60*	51.36*	16.90	-9.03	6.42	9.43
SI I-4-6 × KGAT-1	11.00	10.00	13.79	6.45	5.79	3.21	8.70	-7.36	17.01	-8.42	7.14	10.17
SI I-4-6 × E-1-1&-2	10.00	-9.09	3.45	-3.23	4.84	-7.64	-9.20	-22.61*	18.70	0.68	17.78*	21.11*
SI 1-4-4 × Glory-7	10.33	6.90	6.90	0.00	5.35	15.38	0.44	-14.40	19.38	11.25	22.07*	25.52*
SI 1-4-4 × KGAT-1	11.67	20.69*	20.69*	12.9	5.73	2.08	7.51	-8.37	19.15	8.03	20.64*	24.05*
SI 1-4-4 × E-1-1&-2	11.00	0.00	13.79	6.45	4.57	-11.66	-14.21	-26.88*	18.02	-2.05	13.48	16.69
SI I-4-3 × Glory-7	11.67	6.06	20.69*	12.9	7.05	42.97*	32.42*	12.85	22.75	27.31*	43.29*	47.34*
SI I-4-3 × KGAT-1	11.33	3.03	17.24*	9.68	6.04	7.72	13.45	-3.31	19.22	7.54	21.04*	24.46*
SI I-4-3 × E-1-1&-2	10.33	-6.06	6.90	0.00	4.47	-13.53	-16.02	-28.43*	19.17	4.24	20.76*	24.18*
SI SC-5-5-4 × Glory-7	10.00	15.38	3.45	-3.23	6.50	53.18*	22.03*	4.00	18.09	3.87	13.96	17.18
SI SC-5-5-4 × KGAT-1	9.67	3.57	0.00	-6.45	5.07	-9.63	-4.82	-18.88*	17.87	0.81	12.58	15.76
SI SC-5-5-4 × E-1-1&-2	9.33	-15.15*	-3.45	-9.68	5.09	-1.48	-4.32	-18.45*	17.31	-5.87	9.05	12.13
Checks												
Varun	9.67	-	-	-	5.33	-	-	-	15.88	-	-	-
KGMR-1	10.33	-	-	-	6.25	-	-	-	15.44	-	-	-

6×Glory-7 (20.69%), SI I-4-4×KGAT-1 (20.69%), SI I-4-3×Glory-7 (20.69%) and IIS CMS×Glory-7 (17.24%).Thakur and Vidyasagar (16) also observed significant positive heterosis over BP in 13 out of 28 cross combinations studied.

The magnitude of heterosis (Table 4) for marketable head yield (kg/plot) varied from -13.53 (SI I-4-3 × E-1-1&-2) to 109.19 per cent (IIS CMS × Glory-7), -16.02 (SI I-4-3 × E-1-1&-2) to 77.60 per cent (SI I-4-6 × Glory-7) and -28.43 (SI I-4-3 × E-1-1&-2) to 51.36 per cent (SI I-4-6 × Glory-7). Eight cross combinations each over BP and SC-1 and five over SC-2 revealed significant positive heterosis. The cross combinations viz., SI I-4-6×Glory-7 (77.60% and 51.36%), SI III-I-I×KGAT-1 (74.28% and 48.53%), IIS CMS×Glory-7 (66.65% and 42.03%), IIS CMS×KGAT-1 (53.00% and 42.03%) and SI III-I-I×E-1-1&-2 (39.17% and 8.61%) were the most promising for heterosis over SC-1 and SC-2, respectively. Pathak *et al.,* (12) and Thakur and Vidyasagar (16) have also reported hybrid vigour over BP and standard check in some of the cross combinations studied by them.

Ascorbic acid content in vegetables is considered as an important quality attribute in addition to other horticultural traits. Ascorbic acid is required for the growth and repair of tissues in all parts of the human body.

From the perusal of table 4, it was revealed that the magnitude of heterosis ranged from -13.04 (IIIM CMS × GLORY-7) to 27.31 per cent (SI I-4-3 × Glory-7), 5.42 (IIIM CMS × Glory-7) to 43.29 per cent (SI I-4-3 × Glory-7) and 8.40 (IIIM CMS × Glory-7) to 47.34 per cent (SI I-4-3 × Glory-7). Only one cross combination, viz., SI I-4-3 × Glory-7 (27.31%) exhibited significant positive heterosis over BP. As many as 13 and 14 cross combinations showed significant positive heterosis over SC-1 and SC-2, respectively. On the basis of standard heterosis over SC-1 and SC-2; cross combinations viz., SI I-4-3×Glory-7 (43.29% and 47.34%), GA (P) M CMS×E-1-1&-2 (32.44% and 36.18%), GA (P) M CMS×Glory-7 (31.11% and 34.82%), SI III-I-I×E-1-1&-2 (29.90% and 33.57%) and IIIM CMS×E-1-1&-2 (26.33% and 29.90%) were promising. The results are in line with the findings of Pathak *et al.,* (12) and Parkash *et al.,* (11), who also reported heterosis for ascorbic acid content.

From the present investigation it can be concluded that cross combinations SI I-4-6 × GLORY-7, SI III-I-I × KGAT-1, IIS CMS × GLORY-7, IIS CMS × KGAT-1 and SI I-4-3 × GLORY-7 significantly surpassed the standard check hybrids Varun (SC-1) and KGMR-1 (SC-2) for marketable head yield (kg/plot).

REFERENCES

1. Anonymous, 2017. Horticultural Statistics at a Glance 2017. Horticulture Statistics Division, Department of Agriculture, Cooperation & Farmers Welfare Ministry of Agriculture & Farmers Welfare, Government of India, pp. 514.
2. Allard, R.W. 1960. Principles of Plant Breeding. John Wiley and Sons, New York. pp. 485.
3. Cabin, R. J., Evans, A.S., Jennings, D.L., Marshall, D.L., Mitchell, R.J. and Sher, A.A. 1996. Using bud pollinations to avoid self incompatibility implications from studies of three mustards. *Canadian J. Bot*. **74**: 285-89.
4. Kempthorne, O. 1957. An Introduction to Genetic Statistics. John Wiley and Sons. Inc. P 458-71.
5. Kibar, B., Karaagac, O. and Kar, H. 2015. Heterosis for yield contributing head traits in cabbage (*Brassica oleracea* var. *capitata*). *Ciencia E Investi. Agraria,* **42**: 205-16.
6. Kumar, C., Raturi, H. C. and Uniyal, S. P. 2013. Performance of cabbage hybrids under rainfed mid hills conditions of Uttrakhand. *Asian J. Hort*. **8**: 110-13.
7. Pandey, V., Ahmed, Z. and Kumar, N. 2003. Hybrid vigour in cabbage (*Brassica oleracea* var. *capitata*) under mid hill conditions of central himalaya. *J. Applied Hort.* **5**: 29-31.
8. Panse, V.G. and Sukhatme, P.V. 1984. Statistical Methods for Agricultural Workers. ICAR, New Delhi, pp. 381.
9. Parkash, C. and Verma, T.S. 2004. Heterosis in cytoplasmic male sterile lines of cabbage (*Brassica oleracea* L. var. *capitata*). *Cruciferae Newsletter*, **25**: 49-50.
10. Parkash, C., Dey, S.S., Bhatia, R. and Dhiman, M.R. 2015. Indigenously developed SI and CMS lines in hybrid breeding of cabbage. *Indian J. Hort.* **72**: 212-17.
11. Parkash, C., Kumar, S., Thakur, N., Kumar, S., Dey, S.S., Bhatia, R., Dhiman, M.R., Sharma, V.K. and Kumar, R. 2017. Genetic analysis of important antioxidant compounds in cabbage (*Brassiaca oleracea* var. *capitata* L.). *J. Crop Impr.* **31**: 418-37.

12. Pathak, S., Kumar, J., Vidyasagar and Verma, S. 2007. Heterosis and combining ability for marketable yield and component traits in cabbage (*Brassica oleracea* var. *capitata* L.). *Indian J. Agric. Sci.* **77**: 97-100.

13. Raygade, Y.K. 2015. Studies on the genetic analysis, correlation coefficient and standard heterosis in hybrid cabbage. MSc. Thesis, Department of Horticulture, College of Agriculture, Jawaharlal Nehru Krishi Vishya Vidyalaya Jabalpur, MP pp. 78.

14. Singh, B.K., Sharma, S.R. and Singh, B. 2010. Heterosis for superoxide dismutase, peroxidase and catalase enzymes in the head of single cross hybrids of cabbage (*Brassica oleracea* var. *capitata*). *J. Genet.* **89**: 217-21.

15. Singh, S. and Vidyasagar. 2012. Effect of common salt (Nacl) sprays to overcome the self-incompatibility in the s-allele lines of *Brassica oleracea* var. *capitata* L. *SABRAO J. Breed. Genet.* **44**: 339-48.

16. Thakur, H. and Vidyasagar. 2016b. Combining ability, gene action and heterosis studies involving SI and CMS lines and testers in cabbage. *Green Farming*, **7**: 580-85.

Received : August 2018; Revised : November, 2019; Accepted : November, 2019