Vegetable Science (2026) 53(1): 176-182

doi: 10.61180/vegsci.2026.v53.i1.23

ISSN- 0970-6585 (Print), ISSN- 2455-7552 (Online)

www.isvsvegsci.in

RESEARCH ARTICLE

Heterosis and combining ability studies in low chill requiring SI and CMS lines of cabbage (*Brassica oleracea var. capitata* L.)

Shivani*, Sanjay Chadha, Sheetal and Pratibha Sharma

Abstract

The present investigation entitled "Heterosis and combining ability studies in low chill requiring SI and CMS lines in cabbage (*Brassica oleracea* var. *capitata* L.)" was carried out at Vegetable Research Farm of the Department of Vegetable Science and Floriculture, CSKHPKV Palampur. Six lines viz., SI-2008-09, I-4-6, I-4-4, M-G-7, S-G-7 and 105-III-CMS were crossed with three testers viz., KGAT-II, GAP and Glory-I to produce 18 F_1s during *Rabi* season 2023-2024. These 18 hybrids were evaluated along with parents and one private sector commercial hybrid as standard check (WS-483) in randomized block design with three replications during *Rabi* season 2024-2025. RBD analysis revealed significant differences among genotypes (hybrids and parents) and the line × tester analysis also revealed significant differences for lines, testers and line × tester interaction for head yield and related traits studied. On the basis of *per se* performance and standard heterosis the most promising cross combinations for marketable head yield and other related traits were I-4-6 × GAP (10.87%) and I-4-6 × Glory-I (8.14%). On the basis of combining ability effects, parental lines I-4-6, M-G-7 and tester GAP were found to be the best general combiners for majority of the traits and the cross combinations S-G-7 × Glory-I and 105-III-CMS × GAP were found to be the best specific combinations. The dominant variance (σ^2D) was of greater magnitude than additive variance (σ^2A) for marketable head yield and most of the component traits indicating the role of non-additive gene action in exploitation of these traits, hence justifying the development of hybrids in cabbage. These newly developed hybrids were found quite promising under mid hill conditions of Himachal Pradesh. As the parents involved in the development of these hybrids are low chill requiring, hence, the seed production can be easily done in mid hill conditions.

Keywords: Combining ability, cytoplasmic male sterility, self- incompatibility, standard heterosis

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Citation: Shivani, Chadha, S., Sheetal, & Sharma, P. (2026). Heterosis and combining ability studies in low chill requiring SI and CMS lines of cabbage (*Brassica oleracea var*. *capitata* L.). Vegetable Science, 53(1), 176-182.

Source of support: Nil

Conflict of interest: None.

Received: 27/08/2025; **Revised:** 25/05/2026; **Accepted:** 28/05/2026

Introduction

Cabbage (*Brassica oleracea* var. *capitata* L.) is a member of Brassicaceae family, having a diploid chromosome number 2n=2x=18 and the East Mediterranean and Asia Minor region is probably considered as its primary centre of origin. It has originated primarily from the ancestor *Brassica oleracea* var. *oleracea* L. (syn. *sylvestris* L.) commonly known as wild cabbage through mutation, human selection and adaptation. It exhibits significant diversity in terms of agro-morphological characteristics as well as qualitative and quantitative traits. However, traditional cultivars tend to perform poorly in head formation and yield per unit area. Further improvements can be achieved through the development of F_1 hybrids which are early-maturing, exhibit uniform maturity, and yield high-quality heads. They also offer resistance to various insect pests, diseases, and adverse environmental conditions. Nowadays, more than 90% of cabbage growing area is under hybrids in developed countries, whereas it is 85% in India (Selvakumar, 2014). Traditionally, cabbage requires prolonged low temperatures for flowering and seed setting. However, development of low-chill requiring self-incompatible (SI) and cytoplasmic male sterile (CMS) lines can flower and produce seeds under comparatively warmer conditions allowing efficient hybrid seed production under subtropical and tropical environments. Therefore, with the development of low chill requiring genotypes, the production of hybrid seeds in low and mid hill areas of Himachal Pradesh has become practically possible. Hence, this study was undertaken to estimate the extent of *per se* performance and heterosis in cabbage under mid hill conditions.

Materials and Methods

The present research was conducted at Vegetable Research Farm, Department of Vegetable Science and Floriculture, CSK HPKV, Palampur during *Rabi* seasons of 2023-24 and 2024-25. Six lines [three self-incompatible viz., SI-2008-09, I-4-6, I-4-4, and three cytoplasmic male sterile lines viz., M-G-7, S-G-7 and 105-III-CMS] were crossed with three testers viz., KGAT-II, GAP and Glory-I using line × tester mating design to produce 18 F_1s during *Rabi* season 2023-2024. These 18 hybrids were evaluated along with parents and one standard check (WS-483) in randomized block design with three replications during *Rabi* season 2024-2025. Plot size of 3.0 × 2.70 m and spacing of 45 × 45 cm were kept accommodating 36 plants per plot. The observations were recorded on 5 plants taken at random in each treatment over all the three replications for stalk length (cm), no. of non-wrapper leaves, gross head weight (g), net head weight (g), polar (cm) and equatorial (cm) diameters of head, heading percentage and marketable head yield/plot (kg). Average values/plant for each genotype in each replication for the traits studied were used for statistical analysis. RBD analysis was caried out as per the model given by Panse & Sukhatme (1984). Line × tester analysis was carried out using the method given by Kempthorne (1957) and modified by Arunachalam (1974) using MS-Excel and the OPSTAT package (Sheoran, 2006). The heterosis was estimated as suggested by Turner (1953) and Hayes (1946). Combining ability analysis was caried out using the method given by Arunachalam (1974). The additive and dominance components of variances were estimated using the following formulae (Singh & Chaudhary, 2012).

Results and Discussion

Mean performance and heterosis studies

The mean performance of nine parents and 18 F_1 hybrids along with standard check hybrid (WS-483) and estimates of heterobeltiosis and standard heterosis are presented in the Tables 1-3. The significant positive heterobeltiosis was observed in the crosses I-4-4 × GAP (7.70%), SI-2008-09 × KGAT-II (12.16%) and I-4-6 × KGAT-II (21.37%) for head polar diameter, SI-2008-09 × GAP (7.86%) and I-4-6 × KGAT-II (7.95%) for head equatorial diameter, S-G-7 × Glory-I (15.94%) for heading percentage, I-4-6 × GAP (18.09%), I-4-6 × Glory-I (17.39%) and S-G-7 × Glory-I (16.90%) for marketable head yield (Table 2), while significant negative heterosis over better parent was observed in M-G-7 × GAP (-22.18%) and SI-2008-09 × Glory-I (-8.31%) for stalk length, I-4-4 × KGAT-II (-30.38%), S-G-7 × KGAT-II (-26.67%), 105-III- CMS × KGAT-II (-20.78%) and I-4-6 × KGAT-II (-12.59%) for number of non-wrapper leaves (Table 2).

Based on mean performance (Table 1) and significant positive standard heterosis (Table 3), the most promising cross combinations were I-4-6 × Glory-I (1131.80 g, 11.31%), SI-2008-09 × KGAT-II (1141.60 g, 12.27%), I-4-6 × GAP (1145.13g, 12.62%) and I-4-6 × KGAT-II (1151.07 g, 13.20%) for gross head weight, I-4-6 × Glory-I (818.67g, 15.38%), I-4-6 × GAP (822.00 g, 15.85%) and I-4-6 × KGAT-II (828.20 g, 16.72%) for net head weight, M-G-7 × KGAT-II (13.24 cm, 6.66%), SI-2008-09 × KGAT-II (13.77 cm, 10.90%) and I-4-6 × KGAT-II (14.27 cm, 14.98%) for head polar diameter, SI-2008-09 × GAP (14.45 cm, 5.09%), M-G-7 × KGAT-II (14.59 cm, 6.16%), SI-2008-09 × KGAT-II (14.71 cm, 6.98%) and I-4-6 × KGAT-II (15.39 cm, 11.93%) for head equatorial diameter, S-G-7 × Glory-I (87.96%) for heading percentage, I-4-6 × GAP (8.30 kg/plot, 10.87%) for marketable head yield, while on the basis of mean performance and significant negative standard heterosis, the most promising cross combinations were M-G-7 × GAP (3.13 cm, -20.20%), 105-III- CMS × KGAT-II (3.38 cm, -13.92%) and 105-III-CMS × GAP (3.49 cm, -11.04%) for stalk length and S-G-7 × KGAT-II (11.00, -14.51%) for number of non-wrapper leaves. These findings are in close conformity with Singh et al. (2009), Parkash et al. (2015), Thakur & Vidyasagar (2016), Kumar et al. (2019), Jabeen et al. (2023), Impa et al. (2023) and Aruna et al. (2024).

Combining ability studies

The estimates of GCA effects of lines and testers are presented in Table 4. General combining ability effects revealed that Lines M-G-7 (-0.188) and 105-III-CMS (-0.393) and tester GAP (-0.109) for stalk length and line S-G-7 (-1.669) and tester GAP (-0.441) for number of non-wrapper leaves exhibited significant negative GCA effects indicated as good general combiners. Whereas, significant positive GCA effects were exhibited by lines SI-2008-09 (47.433) and I-4-6 (108.945) for gross head weight, I-4-6 (84.167) and M-G-7 (41.522) for net head weight, SI-2008-09 (0.421) and I-4-6 (0.721) and tester KGAT-II (0.521) for polar diameter of head, SI-2008-09 (0.721) and I-4-6 (0.601) and tester KGAT-II (0.465) for equatorial diameter of head, I-4-6 (0.989) and M-G-7 (0.500) for marketable head yield. All these genotypes were indicated as good general combiners due to their significant positive GCA effects for respected traits. These findings align with the previous studies of Thakur & Vidyasagar (2016), Kumar et al. (2019), Jabeen et al. (2023), Impa et al. (2023) and Aruna et al. (2024). SCA effects, which help to identify the best cross combinations for various traits, are presented in Table 5.

Table 1: Mean performance of parents and hybrids for yield related traits in cabbage

Genotypes	*Stalk length (cm)*	*No. of non-wrapper leaves*	*Gross head weight (g)*	*Net head weight (g)*	*Polar diameter (cm)*	*Equatorial diameter (cm)*	*Heading percentage*	*Marketable head yield (kg/plot)*
Lines								
SI-2008-09	4.18	15.07	1042.33	730.87	12.27	13.19	72.87	6.38
I-4-6	3.99	17.47	1021.87	740.07	11.23	12.57	71.68	6.36
I-4-4	3.93	17.33	884.27	589.40	11.21	12.03	82.78	5.83
M-G-7	4.22	13.60	1089.00	777.13	12.64	13.45	83.06	7.72
S-G-7	4.21	15.00	1055.80	772.00	12.24	13.07	71.41	6.64
105-III-CMS	3.65	17.97	1158.33	852.00	14.80	12.51	85.34	8.69
Testers								
KGAT-II	4.07	21.53	1045.27	746.93	11.76	14.25	85.24	7.64
GAP	4.03	12.00	1039.80	732.33	11.95	13.39	79.66	6.99
Glory-I	4.01	13.33	1091.07	760.80	12.87	14.13	75.87	6.92
Hybrids								
SI-2008-09 × KGAT-II	4.23	15.33	1141.60	774.87	13.77	14.71	81.78	7.60
SI-2008-09 × GAP	4.34	14.20	1050.80	756.53	12.63	14.45	80.39	7.31
SI-2008-09 × Glory-I	3.67	16.73	1051.07	750.73	11.95	13.62	80.22	7.20
I-4-6 × KGAT-II	4.12	15.27	1151.07	828.20	14.27	15.39	83.53	8.26
I-4-6 × GAP	3.94	15.07	1145.13	822.00	12.01	13.17	83.97	8.30
I-4-6 × Glory-I	4.11	14.87	1131.80	818.67	12.96	13.86	82.50	8.09
I-4-4 × KGAT-II	4.41	12.07	1056.67	775.07	12.04	12.90	75.11	7.02
I-4-4 × GAP	4.27	12.47	895.87	674.40	12.87	13.30	74.14	6.00
I-4-4 × Glory-I	4.22	15.33	1037.67	755.07	12.12	13.43	80.64	7.33
M-G-7 × KGAT-II	4.15	14.60	1040.40	760.87	13.24	14.59	83.92	7.72
M-G-7 × GAP	3.13	13.23	1047.33	791.93	11.62	12.98	81.19	7.71
M-G-7 × Glory-I	4.01	13.33	1055.93	788.13	11.87	13.02	81.72	7.74
S-G-7 × KGAT-II	4.11	11.00	966.27	676.67	12.31	13.88	74.75	6.07
S-G-7 × GAP	3.88	12.30	1005.67	727.13	11.80	13.71	82.78	7.24
S-G-7 × Glory-I	3.87	13.10	1055.40	768.27	11.82	12.91	87.96	8.07
105-III- CMS × KGAT-II	3.38	14.23	936.73	622.73	11.67	12.54	84.29	6.31
105-III-CMS × GAP	3.49	12.90	974.73	650.27	11.67	12.63	87.87	6.84
105-III-CMS × Glory-I	3.81	12.40	862.87	556.67	11.89	12.59	74.67	4.99
WS-483 (Standard Check)	3.93	12.87	1016.80	709.53	12.41	13.75	80.48	7.48
S.E. (m)±	0.15	0.79	56.82	49.01	0.30	0.27	3.89	0.54
CD (5%)	0.27	1.42	101.71	87.74	0.55	0.49	6.98	0.96
CV (%)	4.74	6.73	6.70	8.11	3.06	2.50	5.94	9.25

*Significant at $p \leq 0.05$

Table 2: Extent of heterosis (%) over better parent for yield related traits in cabbage

Cross combinations	*Stalk length (cm)*	*No. of non-wrapper leaves*	*Gross head weight (g)*	*Net head weight (g)*	*Polar diameter (cm)*	*Equatorial diameter (cm)*	*Heading percentage*	*Marketable head yield (kg/plot)*
SI-2008-09 × KGAT-II	3.76	1.76	9.21	3.74	12.16*	3.18	-4.06	-0.43
SI-2008-09 × GAP	7.78*	18.33*	0.81	3.30	2.87	7.86*	0.96	4.76
SI-2008-09 × Glory-I	-8.31*	25.50*	-3.66	-1.32	-7.09*	-3.63	5.71	4.83
I-4-6 × KGAT-II	3.34	-12.59*	10.12	10.88	21.37*	7.95*	-1.99	7.86
I-4-6 × GAP	-1.17	25.55*	10.13	11.07	0.55	-1.69	5.44	18.09*
I-4-6 × Glory-I	3.01	11.50	3.73	7.60	0.72	-1.93	8.78	17.39*
I-4-4 × KGAT-II	12.39*	-30.38*	1.09	3.76	2.38	-9.49*	-11.88*	-7.86
I-4-4 × GAP	8.82*	3.88	-13.84*	-7.91	7.70*	-0.69	-10.39*	-14.28
I-4-4 × Glory-I	7.47	15.00*	-4.89	-0.75	-5.80	-5.00*	-2.53	6.28
M-G-7 × KGAT-II	1.80	7.35	-4.46	-2.09	4.74	2.38	-1.56	-0.43
M-G-7 × GAP	-22.18*	10.27	-3.82	1.90	-8.07*	-3.47	-2.24	-0.43
M-G-7 × Glory-I	0.17	0	-3.22	1.41	-7.72*	-7.87*	-1.60	0
S-G-7 × KGAT-II	0.81	-26.67*	-8.48	-12.34	0.54	-2.61	-12.28*	-20.52*
S-G-7 × GAP	-3.64	2.50	-4.74	-5.81	-3.59	2.33	3.93	3.33
S-G-7 × Glory-I	-3.32	-1.75	-3.26	-0.48	-8.13*	-8.67*	15.94*	16.90*
105-III- CMS × KGAT-II	-7.31	-20.78*	-19.13*	-26.90*	-21.17*	-12.02*	-1.21	-27.20*
105-III-CMS × GAP	-4.20	7.50	-15.85*	-23.67*	-21.17*	-5.72	2.96	-21.07*
105-III-CMS × Glory-I	4.38	-7.00	-25.51*	-34.66*	-19.64*	-10.94*	-12.46*	-42.91*
SE(m)	0.15	0.79	56.82	49.01	0.30	0.27	3.89	0.54

*Significant at $p \leq 0.05$

Table 3: Extent of standard heterosis (%) for yield related traits in cabbage

Cross combinations	*Stalk length (cm)*	*No. of non-wrapper leaves*	*Gross head weight (g)*	*Net head weight (g)*	*Polar diameter (cm)*	*Equatorial diameter (cm)*	*Heading percentage*	*Marketable head yield (kg/plot)*
SI-2008-09 × KGAT-II	7.64*	19.17*	12.27*	9.21	10.90*	6.98*	1.61	1.58
SI-2008-09 × GAP	10.53*	10.36	3.34	6.62	1.72	5.09*	-0.12	-2.27
SI-2008-09 × Glory-I	-6.45	30.05*	3.37	5.81	-3.71	-0.92	-0.32	-3.78
I-4-6 × KGAT-II	4.92	18.65*	13.20*	16.72*	14.98*	11.93*	3.78	10.41
I-4-6 × GAP	0.34	17.10*	12.62*	15.85*	-3.22	-4.22*	4.34	10.87
I-4-6 × Glory-I	4.58	15.54*	11.31*	15.38*	4.40	0.82	2.51	8.14
I-4-4 × KGAT-II	12.39*	-6.22	3.92	9.24	-3.01	-6.16*	-6.67	-6.23
I-4-4 × GAP	8.83*	-3.11	-11.89*	-4.95	3.65	-3.25	-7.88	-19.85*
I-4-4 × Glory-I	7.47	19.17*	2.05	6.42	-2.36	-2.33	0.19	-1.99
M-G-7 × KGAT-II	5.60	13.47*	2.32	7.23	6.66*	6.16*	4.27	3.12
M-G-7 × GAP	-20.20*	2.85	3.00	11.61	-6.39*	-5.58*	0.88	2.98
M-G-7 × Glory-I	2.21	3.63	3.85	11.08	-4.35	-5.29*	1.54	3.46
S-G-7 × KGAT-II	4.58	-14.51*	-4.97	-4.63	-0.86	0.97	-7.12	-18.84*
S-G-7 × GAP	-1.19	-4.40	-1.09	2.48	-4.94*	-0.29	2.85	-3.30
S-G-7 × Glory-I	-1.36	1.81	3.80	8.28	-4.78	-6.11*	9.29	7.80
105-III- CMS × KGAT-II	-13.92*	10.62	-7.87	-12.23	-6.02*	-8.78*	4.73	-15.61*
105-III-CMS × GAP	-11.04*	0.26	-4.14	-8.35	-6.02*	-8.15*	9.18	-8.52
105-III-CMS × Glory-I	-3.06	-3.63	-15.14*	-21.54*	-4.19	-8.44*	-7.22	-33.32*
SE(m)	0.15	0.79	56.82	49.01	0.30	0.27	3.89	0.54

*Significant at $p \leq 0.05$

Table 4: Estimates of general combining ability (GCA) effects of lines (females) and testers (males) for head yield and related traits in cabbage

Lines/Testers	*Stalk length (cm)*	*No. of non-wrapper leaves*	*Gross head weight (g)*	*Net head weight (g)*	*Polar diameter (cm)*	*Equatorial diameter (cm)*	*Heading percentage*	*Marketable head yield (kg/plot)*
Lines								
SI-2008-09	0.127	1.620*	47.433*	21.922	0.421*	0.721*	-0.407	0.178
I-4-6	0.103	1.265*	108.945*	84.167*	0.721*	0.601*	2.148	0.989*
I-4-4	0.350*	1.620*	-36.989	-3.944	-0.019	-0.327*	-4.552*	-0.422
M-G-7	-0.188*	-0.080	14.167	41.522*	-0.117	-0.005	1.081	0.500*
S-G-7	0.001	-1.669*	-24.611	-14.767	-0.386*	-0.039	0.637	-0.089
105-III-CMS	-0.393*	-0.624	-108.944*	-128.900*	-0.619*	-0.952*	1.093	-1.156*
SE (gi) ±	0.063	0.321	21.552	18.475	0.133	0.074	1.318	0.211
SE (gi-gj) ±	0.069	0.351	23.609	20.239	0.145	0.081	1.443	0.231
Testers								
KGAT-II	0.113*	-0.052	-	-	0.521*	0.465*	-	-
GAP	-0.109*	-0.441*	-	-	-0.263*	-0.165*	-	-
Glory-I	-0.004	0.493*	-	-	-0.258*	-0.300*	-	-
SE (gi) ±	0.040	0.203	-	-	0.084	0.047	-	-
SE (gi-gk) ±	0.097	0.497	-	-	0.206	0.115	-	-

*Significant at $p \leq 0.05$

Table 5: Estimates of specific combining ability (SCA) effects of different cross-combinations for head yield and related traits in cabbage

Cross combinations	*Stalk length (cm)*	*Number of non-wrapper leaves*	*Gross head weight (g)*	*Net head weight (g)*	*Polar diameter (cm)*	*Equatorial diameter (cm)*	*Heading percentage*	*Marketable head yield (kg/plot)*
SI-2008-09 × KGAT-II	0.034	-0.037	45.378	13.211	0.464*	-0.016	1.613	0.261
SI-2008-09 × GAP	0.369*	-0.781	-16.556	-2.433	0.107	0.354*	-0.920	-0.078
SI-2008-09 × Glory-I	-0.403*	0.819	-28.822	-10.778	-0.571*	-0.338*	-0.693	-0.183
I-4-6 × KGAT-II	-0.049	0.252	-6.667	4.300	0.670*	0.784*	0.824	0.083
I-4-6 × GAP	-0.006	0.441	16.267	0.789	-0.806*	-0.806*	0.091	0.044
I-4-6 × Glory-I	0.055	-0.693	-9.600	-5.089	0.136	0.022	-0.915	-0.128
I-4-4 × KGAT-II	-0.002	-1.170*	44.867	39.278	-0.823*	-0.774*	-0.909	0.294
I-4-4 × GAP	0.080	-0.381	-87.067*	-58.700*	0.787*	0.256*	-3.009	-0.811*
I-4-4 × Glory-I	-0.079	1.552*	42.200	19.422	0.036	0.517*	3.919*	0.517
M-G-7 × KGAT-II	0.269*	0.930*	-22.556	-20.389	0.475*	0.597*	2.257	0.039
M-G-7 × GAP	-0.522*	-0.048	13.244	13.367	-0.362	-0.386*	-1.609	-0.033
M-G-7 × Glory-I	0.253*	-0.881	9.311	7.022	-0.113	-0.211	-0.648	-0.006
S-G-7 × KGAT-II	0.040	-1.081*	-57.911	-48.300	-0.190	-0.083	-6.431*	-1.006*
S-G-7 × GAP	0.036	0.607	10.356	4.856	0.087	0.374*	0.402	0.089
S-G-7 × Glory-I	-0.076	0.474	47.556	43.444	0.103	-0.291*	6.030*	0.917*
105-III- CMS × KGAT-II	-0.293*	1.107*	-3.111	11.900	-0.596*	-0.509*	2.646	0.328
105-III-CMS × GAP	0.043	0.163	63.756*	42.122	0.187	0.207	5.046*	0.789*
105-III-CMS × Glory-I	0.250*	-1.270*	-60.644	-54.022*	0.409*	0.302*	-7.693*	-1.117*
SE (Sij) ±	0.089	0.454	30.478	26.128	0.188	0.105	1.864	0.299

*Significant at $p \leq 0.05$

Table 6: Estimates of genetic components of variance and proportional contribution of lines, testers and their interactions for different traits in cabbage

Traits	*Variation*					*Contribution (%) due to*		
	σ^2GCA	*σ^2SCA*	*σ^2A*	*σ^2D*	*Average degree of dominance*	*Lines*	*Testers*	*Line × Tester*
Stalk length (cm)	0.011	0.074	0.045	0.298	2.57	49.56	7.21	43.22
No. of non-wrapper leaves	0.386	0.851	1.545	3.406	1.49	60.76	6.96	32.27
Gross weight (g)	1,368.60	1,246.47	5,474.40	4,985.88	0.95	72.71	2.16	25.11
Net weight (g)	1,401.30	313.925	5,605.21	1,255.70	0.47	83.53	0.03	16.44
Polar diameter (cm)	0.131	0.332	0.523	1.327	1.59	36.83	24.10	39.02
Equatorial diameter (cm)	0.157	0.341	0.629	1.365	1.47	50.34	17.68	31.97
Heading (%)	-2.513	14.582	-10.053	58.328	-	28.52	1.40	70.07
Marketable head yield/plot (kg)	0.076	0.338	0.304	1.352	2.11	62.49	0.16	37.33

Three cross combinations viz., M-G-7 × GAP (-0.522), SI-2008-09 × Glory-I (-0.403) and 105-III- CMS × KGAT-II (-0.293) for stalk length and three viz., 105-III-CMS × Glory-I (-1.270), 3 I-4-4 × KGAT-II (-1.170) and S-G-7 × KGAT-II (-1.081) for number of non-wrapper leaves were found good specific cross combinations due to their significant negative SCA effects. Whereas, significant desirable positive SCA effects were exhibited by 105-III-CMS × GAP (63.756) for gross head weight, I-4-4 × GAP (0.787), I-4-6 × KGAT-II (0.670), M-G-7 × KGAT-II (0.475), SI-2008-09 × KGAT-II (0.464), and 105-III-CMS × Glory-I (0.409) for polar diameter of head, I-4-6 × KGAT-II (0.784), M-G-7 × KGAT-II (0.597), I-4-4 × Glory-I (0.517), S-G-7 × GAP (0.374), SI-2008-09 × GAP (0.354), 105-III-CMS × Glory-I (0.302) and I-4-4 × GAP (0.256) for equatorial diameter of head, S-G-7 × Glory-I (6.030), 105-III-CMS × GAP (5.046) and I-4-4 × Glory-I (3.919) for heading percentage and S-G-7 × Glory-I (0.917) and 105-III-CMS × GAP (0.789) for marketable head yield per plot, and were considered to be good specific cross combinations. These results are in line with the findings of Singh et al. (2011), Kumar et al. (2019), Jabeen et al. (2023), Impa et al. (2023) and Aruna et al. (2024).

Gene action

The estimates of additive and dominance variances along with the average degree of dominance revealed the nature of gene action governing the expression of different traits in cabbage. The average degree of dominance varied considerably among the traits, indicating the differential role of gene action (Table 6). The present study showed that traits like stalk length (2.57), number of non-wrapper leaves (1.49), polar diameter (1.59), equatorial diameter (1.47) and marketable head yield (2.11), exhibited an average degree of dominance greater than one, indicating the predominance of over-dominance or non-additive gene action. This suggested that these traits could be effectively improved through hybrid breeding or the exploitation of heterosis. In contrast, gross head weight (0.95) and net head weight (0.47) showed average degrees of dominance less than or near unity, implying the importance of partial dominance and the presence of both additive and non-additive gene actions. These traits may be improved using a combination of selection and hybrid development strategies. These findings are in line with past studies by Kumar et al. (2019), Jabeen et al. (2023), Impa et al. (2023) and Aruna et al. (2024) who also reported non-additive gene action for yield and its component traits.

Proportionate contribution of lines, testers and their interactions to genetic variance

The proportional contribution of lines × tester interaction was higher than the corresponding lines and testers for polar diameter (39.02), heading percentage (70.07), while for rest of the traits, contribution of lines was the maximum (Table 6). Therefore, it can be concluded that lines and line × tester interactions played a significant role in the expression of different respective characters in various cross-combinations. These results are in agreement with the findings of Kumar et al. (2019), Jabeen et al. (2023), Impa et al. (2023) and Aruna et al. (2024).

Conclusion

The present study concluded that parental lines I-4-6, M-G-7 and tester GAP were superior for head yield and related traits, based on general combining ability. These can be utilized for further heterosis breeding in cabbage. Based on heterosis, SCA and *per se* performance, the most promising cross-combinations for marketable head yield and related traits were I-4-6 × GAP, I-4-6 × Glory-I and S-G-7 × Glory-I. Promising results were obtained from the evaluation of these newly developed hybrids under mid hill conditions of Himachal Pradesh. The involvement of low chill requiring parental lines in the development of these hybrids allows the seed production in mid hill conditions. These hybrids can be further evaluated at multiplications for release.

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सारांश

वर्तमान अनुसंधान “पत्तागोभी (ब्रैसिका ओलेरासिया वार. कैपिटाटा एल.) में कम शीत आवश्यकता वाली एस.आई. एवं सी.एस.एम. लाइनों में हेटेरोसिस तथा संयोजन क्षमता अध्ययन” शीर्षक के अंतर्गत सब्जी विज्ञान एवं पुष्पकृषि विभाग, सी.एस.के.एच.पी.के.वी., पालमपुर के सब्जी अनुसंधान प्रक्षेत्र में सम्पन्न किया गया। छह लाइनें अर्थात् एस.आई.-2008-09, आई-4-6, आई-4-4, एम.जी.-7, एस.जी.-7 तथा 105-3-सी.एम.एस. को तीन परीक्षकों अर्थात् केजीएटी-2, जीएपी तथा ग्लौरी-1 के साथ रबी ऋतु 2023–2024 के दौरान संकरण कर 18 F1 संकर विकसित किए गए। इन 18 संकरों का मूल्यांकन उनके जनकों तथा एक निजी क्षेत्र के व्यावसायिक संकर (डब्ल्यू.एस.-483) के साथ यादृच्छिक खंड डिजाइन (आरबीडी) में तीन पुनरावृत्तियों सहित रबी ऋतु 2024–2025 के दौरान किया गया। आरबीडी विश्लेषण से जनद्रव्यों (संकर एवं जनक) के मध्य महत्वपूर्ण भिन्नताएँ पाई गईं तथा लाइन × परीक्षक विश्लेषण ने भी लाइनों, परीक्षकों तथा लाइन × परीक्षक अंतःक्रिया के लिए शीर्ष उपज एवं संबंधित लक्षणों में महत्वपूर्ण भिन्नताएँ प्रदर्शित कीं। *Per se* प्रदर्शन एवं मानक हेटेरोसिस के आधार पर विपणनीय शीर्ष उपज तथा अन्य संबंधित लक्षणों हेतु सर्वाधिक आशाजनक संकरण आई-4-6 × जीएपी तथा आई-4-6 × ग्लौरी-1 पाए गए। संयोजन क्षमता प्रभावों के आधार पर जनकीय लाइनें आई-4-6 और एम.जी.-7 तथा परीक्षक जीएपी अधिकांश लक्षणों हेतु श्रेष्ठ सामान्य संयोजक पाए गए, जबकि एस.जी.-7 × ग्लौरी-1 तथा 105-3-सी.एम.एस. × जीएपी सर्वोत्तम विशिष्ट संयोजन सिद्ध हुए। विपणनीय शीर्ष उपज तथा अधिकांश अवयवी लक्षणों के लिए प्राबल्य प्रसरन (σ^2D) का मान योगात्मक प्रसरन (σ^2A) से अधिक पाया गया, जो इन लक्षणों में गैर-योगात्मक जीन क्रिया की भूमिका को दर्शाता है तथा पत्तागोभी में संकर विकास की उपयुक्तता को सिद्ध करता है। विकसित किए गए ये नवीन संकर हिमाचल प्रदेश की मध्य पर्वतीय परिस्थितियों में अत्यंत आशाजनक पाए गए। चूँकि इन संकरों के विकास में प्रयुक्त जनक कम शीत आवश्यकता वाले हैं, अतः इनके बीज उत्पादन को मध्य पर्वतीय परिस्थितियों में आसानी से किया जा सकता है।