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Combining ability for antioxidants and economic traits in cabbage

B.K. Singh*, S.R. Sharma and B. Singh**

Indian Agricultural Research Institute, Regional Station, Katrain 175129, Kullu, Himachal Pradesh

ABSTRACT

Fifty-five cross combinations along with their sixteen parents were transplanted in randomized block design to generate information on combining ability of antioxidants and economic traits in cabbage. The significance of mean squares of parents and line x tester interactions revealed the pervasiveness of additive and non-additive variance. Non-additive gene action was found to be predominant for carotenoid content, early maturity, frame spread, gross plant weight, net head weight, core length, harvest index, and head compactness, nevertheless additive genes were responsible for synthesis of ascorbic acid and expression of non-wrapper leaves in desirable direction. Golden Acre was found to be good combiner for seven economically important traits *viz.*, carotenoid, earliness, net head weight, number of non-wrapper leaves, polar and equatorial diameter, and core length. Among 55 cross combinations, Pride of Asia × Red Cabbage, CMS-GA × AC-1019, CMS-GA × EC-490192, and Golden Acre × AC-1021 were most outstanding as indicated by respective high SCA effect. Majority of the cross combinations exhibited desirable SCA effects for various traits and involved at least one of the parents as poor general combiner, which signifies the greater importance of SCA than GCA in predicting hybrid combinations for desirable traits and scope for heterosis breeding for improving the traits of nutrition and economic importance.

Key-words: Combining ability, ascorbic acid, carotenoids, cabbage, GCA, SCA.

INTRODUCTION

Free radicals or reactive oxygen species (ROS) such as singlet oxygen, superoxide radical, hydrogen peroxide, hydroxyl ion, and free hydroxyl radical ($^1O_2$, $^*O_2^-$, H_2O_2, OH^- and *OH, respectively) are invariably produced during normal metabolism and exposure to stresses. If un-neutralised, ROS damage various body cells causing many degenerative diseases associated with ageing, heart disease, cancer, loss of memory, paralysis, etc. in human (Adams and Best, 1; Peterson *et al.*, 11; Dorge, 4). Antioxidants, the phytochemicals, vitamins, pigments and enzymes, have the ability to protect our body against oxidative damage.

Carotenoids are secondary plant compounds that form lipid soluble yellow, orange and red pigments. Lutein (an oxygenated xanthophyll) and β-carotene (a hydrocarbon carotene and precursor of vitamin-A) are two nutritionally important plant derived carotenoids (Zaripheh and Erdman Jr., 16). Diets containing carotenoid rich vegetables are often associated with decreased risk of chronic diseases including cataract (Johnson *et al.*, 5). Ascorbic acid is another highly effective antioxidant and a substrate for ascorbate peroxidase as well as an enzyme cofacter for the biosynthesis of several other important biochemicals.

Cole crops, in general, are good source of carotenoids and ascorbic acid (vitamin-C) (Kurilich *et al.*, 8). Cabbage, a member of Brassicaceae family, is an economically and nutritionally important cole crop grown in more than 90 countries across the world (Chiang *et al.*, 3). Among vegetables, the productivity of cabbage in India is 22.2 t/ ha (next to tapioca) with an area and production of 0.265 mha and 5.888 mt, respectively. Moreover, India ranks 2nd in area and production next to China in world (Kumar, 7). Human health concerns owing to malnutrition on one hand and increasing popularity of cabbage in diet and its cheaper and round the year availability make it imperative for research to initiate efforts to improve the antioxidant level along with yield of this poor man crop. The knowledge of combining ability of antioxidants and quantitative traits in cabbage would offer an economical and viable option to simultaneously increase the quality and the yield per unit area per unit time.

Thus, the objective of this study was to identify the superior genotypes and crosses on the basis of general combining ability (GCA) and specific combining ability (SCA) performance and to suggest suitable breeding approaches.

MATERIALS AND METHODS

Sixteen cabbage genotypes were transplanted during 2005-06 at Naggar Farm of IARI Regional Station, Katrain, Kullu Valley, Himachal Pradesh. The Farm is located at 32.12°N latitude and 77.13°E longitude with an altitude of 1,690 m above the mean sea level. The farm receives 110-130 cm snowfall annually. Plots were replicated three times in a

*Corresponding author's present address of: Directorate of Floricultural Research, Pusa Campus, New Delhi; E-mail: bksinghkushinagar@gmail.com

**Nuclear Research Laboratory, IARI, New Delhi 110012

randomized block design. The 36 plants per plot were transplanted at the spacing of 45 cm.

Cabbage genotypes were chosen on the basis of their practical applicability in heterosis breeding (Table 1). The selected parents were crossed in line × tester mating design (Kempthorne, 6). Five parents were used as line (female), *viz*., CMS-GA, Golden Acre, 83-1, 83-2 and Pride of Asia and eleven parents *viz*., AC-204, EC-490174, Pusa Mukta, C-4, Red Cabbage, C-2, AC-1019, EC-490192, MR-1, AC-208 and AC-1021 were used as tester (male). The standard procedure of hand emasculation and pollination was followed to produce the cross seeds. The seedlings of 55 crosses along with 16 parents were transplanted during 2006-07 to study the combining ability.

Observations were recorded with respect to days to 50 % maturity, frame spread (cm), gross plant weight (kg), net head weight (kg), number of non-wrapper leaves, polar diameter (cm), equatorial diameter (cm), core length (cm), harvest index (%), and head compactness on ten randomly selected plants. The head compactness was determined according to Pearson (10).

Samples of heads of each genotype in replicated trials were taken at fresh marketable stage, frozen immediately in liquid nitrogen and stored in -80°C until assay of carotenoid and ascorbic acid. The estimation of carotenoid was based on the extraction of crude pigment mixture in lipid solvent as described by Ranganna (13). The pigment content was determined as total carotenoids by measuring its optical density at 452 nm. The ascorbic acid was also determined by the direct colorimetric method as mentioned by Ranganna (13).

The data were pooled and statistically calculated for analysis of combining ability in line × tester mating design given by Kempthorne (6) and later on modified by Arunachalam (2).

RESULTS AND DISCUSSION

The partitioning of mean squares into line, tester and line x tester interactions (Table 2) revealed that mean squares due to parents were significant for all

Table 1. Details of basic experimental materials used for combining ability study in cabbage.

Parent	Origin	Leaf surface	Remark	Parent	Origin	Leaf surface	Remark
CMS-GA	I	S	Male sterile	C-4	I	B	Savoy type leaf
Golden Acre	E	S	Good yielder and highly adaptive	Red Cabbage	I	S	Diamond back moth tolerant, purple leaf colour
83-1	I	S	Self-incompatible	C-2	I	B	Savoy type leaf
83-2	I	S	Self-incompatible	AC- 1019	E	S	Uniform heading
Pride of Asia	I	S	Highly adaptive	EC-490192	E	S	Vigorous growth
AC-204	E	S	Black rot, downy mildew and diamond back moth tolerant	MR-1	I	S	Black rot, downy mildew and diamond back moth tolerant
EC-490174	E	S	Bigger head size and vigorous growth	AC-208	E	S	Black rot, downy mildew and diamond back moth tolerant
Pusa Mukta	I	B	Good yielder, highly adaptive, savoy type leaf and black rot tolerant	AC-1021	E	S	Uniform heading

Origin: I: indigenous E: exotic; Leaf surface: S: smooth B: bumpy (savoy type) the traits except carotenoid content, net head weight, equatorial diameter and head compactness. Significant mean squares for parents indicate existence of additive variance. However, mean squares due to line x tester interactions were significant for all the traits except ascorbic acid content advocating the pervasiveness of non-additive variance.

The estimates of variance components for various antioxidants and economic traits (Table 3) indicated a lower σ^2_{gca} than the σ^2_{sca} for all the traits except ascorbic acid and number of non-wrapper leaves. Less than unity value of $\sigma^2_{gca}/\sigma^2_{sca}$ ratio indicates predominance of non-additive gene action (dominance and epistatic) for expression of carotenoid, days to 50% maturity (earliness), frame spread, gross plant weight, net head weight, polar diameter, equatorial diameter, core length, harvest index, and head compactness, nevertheless additive genes were responsible for ascorbic acid synthesis and expression of non-wrapper leaves in plants. The observed negative value of σ^2_{gca} for carotenoid and negative value of σ^2_{sca} for ascorbic acid content could be related to the presence of high degree of mean square for line x tester interaction and error, respectively. These findings are further confirmed by lower σ^2_A values than the corresponding value of σ^2_D for all aforementioned traits except ascorbic acid and number of non-wrapper leaves. The above results highlight the significance of non-additive gene action and its scope for heterosis breeding for improving the nutritional and economic traits.

The estimates of GCA effects of lines and testers (Table 4) revealed that Golden Acre was a good combiner for seven traits, *viz*., carotenoids, earliness, net head weight, number of non-wrapper leaves, polar and equatorial diameter, and core length in desirable direction. All the lines showed poor combining ability for ascorbic acid content and head compactness. The line 83-1 was poor general combiner for all the traits. Pride of Asia and Golden Acre were found to be good combiners for carotenoid content and days to 50% maturity (earliness). Among the eleven testers, Pusa Mukta, C-4 and AC-1021 were good general combiners for six traits, nevertheless AC-208 was poor general combiner for all the traits. Good combining ability for carotenoid content was exhibited by the testers AC-204, EC-490174, C-4, and MR-1. All the parents, i.e., Pusa Mukta, C-4 and C-2 having savoy type leaf (bumpy leaf surface) showed good general combining ability for ascorbic acid and indicating the significance of use of at least one of the above parents in breeding programme to increase the ascorbic acid content in cabbage head. The testers, AC-204, Pusa Mukta, C-4, Red cabbage, C-2 and AC-208 exhibited good combiners for earliness. However, C-4, C-2 and AC-208 were found to be better for smaller frame size which is desired for accommodating more number of plants per unit area and higher productivity. Only one parent, i.e., Red cabbage expressed good combining ability for head compactness which is highly desirable for improving the marketability and consumers' preference of cabbage head. The high GCA effects were observed primarily due to additive and additive × additive gene effects, which can be exploited through hybridization followed by selection programmes. The GCA effects of the lines and testers for various traits of economic and nutritional importance revealed that none of the parents excelled favourably for all the traits. It suggests the value and need for multiple crossing in a suitable mating system to develop the high yielding and good quality genotypes.

Among 55 crosses, desirable and significant SCA effects were observed in 22 crosses for total carotenoids content; 24 crosses for earliness; 14 crosses for smaller core length; 11 crosses for net head weight; and 9 crosses for smaller frame size, harvest index and head compactness. The cross combination Pride of Asia × Red cabbage expressed desirable SCA effects for nine traits followed by CMS-GA × AC-1019, CMS-GA × EC-490192 and Golden Acre × AC-1021 exhibited desirable SCA effects for six characters (Table 5). Only one cross combination (83-1 × EC-490174) exhibited positive and significant SCA effect for ascorbic acid content. The SCA effects represent dominance and epistatic gene action which can be used as an index to determine the usefulness of a particular cross combination for exploitation through heterosis breeding and hybridization programme. The crosses Golden Acre × AC-204; Pride of Asia × AC-1021; 83-2 × EC-490174; and CMS-GA × C-2 and Golden Acre × AC-1021 had high *per se* performance for carotenoid and earliness; smaller frame spread; gross plant weight and net head weight; and harvest index, respectively with significant SCA effects and both the parents of these crosses were good general combiners indicating the role of cumulative effect of additive and additive × additive gene. This finding is in the rationale with the result of Prakash *et al.* (12) for gross plant weight. By restoring the population improvement, modified pedigree breeding programme and heterosis breeding, the aforementioned cross combinations may be utilised to improve the respective traits.

The cross Pride of Asia × Red cabbage had significant desirable SCA effects for carotenoid content, net head weight, polar diameter, equatorial diameter, core length and harvest index although both the parents were poor general combiners. It might be due to presence of high magnitude of non-additive effects especially that of complementary epistatic type which can be essentially utilised for commercial exploitation

Table 2. Analysis of variance (ANOVA) of combining ability for antioxidants and economic traits in cabbage.

Source of variation	d.f.	Mean square											
		Total carotenoids	Ascorbic acid	Days to 50 % maturity	Frame spread	Gross weight	Net head weight	No. of non-wrapper leaves	Polar diameter	Equatorial diameter	Core length	Harvest index	Head compactness
Replication	2	257	3.4	22.6	0.2	0.145	0.050	40.28	6.83	5.63	0.31	435.7	278.6
Line	4	49328	18.5	402.7*	171.2**	0.715**	0.173	123.42**	7.57*	6.86	14.33**	330.7	29.2
Tester	10	87982	841**	402.4**	168.3**	0.542**	0.193	36.40**	9.44**	4.12	8.42**	807.5**	131.1
Line x tester	40	269570**	22.2	125.8**	34.2**	0.140**	0.123**	5.26**	2.37**	3.3**	2.01**	128.9**	99.3**
Error	108	560	36.5	4.3	9.1	0.055	0.024	1.57	0.67	0.87	0.30	30.4	46.5

*,** = significant at 5 and 1% levels, respectively

Table 3. Estimates of variance components for antioxidants and economic traits in cabbage.

Variance component	Total carotenoids	Ascorbic acid	Days to 50% maturity	Frame spread	Gross weight	Net head weight	No. of non-wrapper leaves	Polar diameter	Equatorial diameter	Core length	Harvest index	Head compactness
σ^2_{gca}	-8371.4	16.98	11.53	5.65	0.02	0.003	3.11	0.26	0.09	0.39	18.34	-0.797
σ^2_{sca}	89669.8	-4.76	40.51	8.37	0.03	0.032	1.23	0.56	0.81	0.56	32.84	17.594
$\sigma^2_{gca/}$ σ^2_{sca}	-0.09	-3.57	0.28	0.68	0.67	0.09	2.53	0.46	0.11	0.70	0.56	-0.05
σ^2_A	-33485.8	67.96	46.12	22.59	0.08	0.01	12.44	1.02	0.37	1.56	73.36	-3.19
σ^2_D	358680.1	-19.11	162.05	33.49	0.11	0.13	4.72	2.26	3.22	2.27	131.38	70.38

Table 4. Estimates of general combining ability (GCA) effects of parents (lines and testers) for different antioxidants and economic traits in cabbage.

S. No.	Parent	Total carotenoids	Ascorbic acid	Days to 50% maturity	Frame spread	Gross weight	Net head weight	No. of non-wrapper leaves	Polar diameter	Equatorial diameter	Core length	Harvest index	Head compactness
Line													
1.	CMS-GA	-2.36	-0.10	3.12*	0.75	-0.10*	-0.01	-1.49*	0.50*	-0.32*	-1.07*	2.75*	-1.07
2.	Golden Acre	36.43*	0.61	-2.01*	1.97*	0.00	0.07*	-2.16*	0.37*	0.35*	0.13	3.76*	0.01
3.	83-1	-29.78*	-1.26	3.60*	0.70	0.18*	0.02	2.65*	-0.24*	0.19	0.39*	-3.81*	0.53
4.	83-2	41.16*	0.43	-0.01	0.52	0.11*	0.04*	-0.02	0.07	0.41*	-0.09	-1.69*	-0.73
5.	Pride of Asia	-45.45*	0.32	-4.70*	-3.94*	-0.18*	-0.12*	1.02*	-0.69*	-0.63*	0.64*	-1.01	1.26
	SE	3.24	0.83	0.45	0.41	0.03	0.02	0.17	0.11	0.13	0.08	0.76	0.93
Tester													
1.	AC-204	122.00*	-2.50	-3.57*	-0.98	-0.06	-0.04	-0.60*	-0.71*	-0.12	-0.78*	-1.52	1.46
2.	EC-490174	10.27*	-2.52	2.30*	0.76	0.35*	0.23*	-0.22	1.37*	0.76*	1.72*	0.82	-0.04
3.	Pusa Mukta	-0.40	10.78*	-1.17*	1.94*	-0.05	0.08*	-1.32*	0.31	0.54*	0.03	5.42*	-0.50
4.	C-4	42.53*	11.98*	-7.64*	-4.28*	-0.24*	0.04	-1.93*	-0.03	0.06	-0.15	10.54*	1.61
5.	Red cabbage	-51.87*	-6.04*	-2.70*	2.23*	-0.07	-0.12*	0.64*	-0.79*	-1.19*	0.48*	-4.56*	3.46*
6.	C-2	-116.60*	11.08*	-3.17*	-3.32*	-0.13*	-0.02	-0.25	-0.50*	-0.07	0.35*	2.66*	1.30
7.	AC- 1019	-5.27	-1.32	12.10*	7.60*	0.33*	-0.20*	3.56*	0.38*	-0.04	0.46*	-18.10*	-8.04*
8.	EC-490192	-35.40*	-2.50	3.10*	0.62	0.11*	0.06*	0.69*	0.79*	0.01	-0.86*	-0.29	-1.09
9.	MR-1	137.60*	-7.30*	-0.17	-0.37	0.01	0.04	0.27	0.70*	-0.46*	-0.44*	1.87	0.49
10.	AC-208	-45.73*	-5.88*	3.36*	-0.43	-0.11*	-0.10*	1.04*	-1.27*	0.06	-0.09	-2.35	1.61
11.	AC-1021	-57.13*	-5.78*	-2.44*	-3.76*	-0.15*	0.01	-1.89*	-0.25	0.46*	-0.71*	5.50*	-0.25
	SE	5.13	1.31	0.28	0.65	0.05	0.03	0.27	0.18	0.20	0.12	1.19	1.48

* = Significant at 5% level

Table 5. Estimates of specific combining ability (SCA) effects of crosses for different antioxidants and economic traits in cabbage.

S. No.	Cross	Total carotenoids	Ascorbic acid	Days to 50% maturity	Frame spread	Gross weight	Net head weight	No. of non-wrapper leaves	Polar diameter	Equatorial diameter	Core length	Harvest index	Head compa-ctness
1.	CMS-GA × AC-204	-405.58*	0.96	3.75*	-2.71*	-0.27*	-0.25*	0.07	-1.43*	-0.76	-0.13	-6.08*	-1.28
2.	CMS-GA × EC-490174	97.16*	-1.15	5.22*	-1.08	0.10	0.03	2.10*	-0.34	-1.15*	-1.14*	-1.65	6.79*
3.	CMS-GA × Pusa Mukta	440.49*	-1.12	-5.32*	0.63	0.01	-0.11	0.80	1.42*	0.11	-0.29	-6.15*	-8.92*
4.	CMS-GA × C-4	-96.78*	-2.86	-3.52*	-1.28	0.02	0.01	0.04	0.26	0.45	0.10	0.82	-2.79
5.	CMS-GA × Red cabbage	-5.38	1.97	-3.45*	-1.16	-0.22*	-0.21*	-0.77	-0.88*	-0.19	-0.27	-5.31*	-4.37
6.	CMS-GA × C-2	-61.64*	-0.48	-5.32*	-0.31	0.20*	0.25*	-0.81	0.33	0.52	0.80*	6.84*	5.91*
7.	CMS-GA × AC- 1019	128.02*	3.12	-0.58	4.24*	0.30*	0.18*	-0.89	1.42*	1.13*	-0.53*	1.34	-1.11
8.	CMS-GA × EC-490192	110.49*	-0.38	3.75*	-1.15	0.23*	0.32*	-1.15*	0.21	0.71	1.33*	8.69*	6.91*
9.	CMS-GA × MR-1	-134.84*	0.16	8.35*	-1.66	-0.26*	-0.14*	-0.59	-1.07*	-0.79	-0.06	1.53	2.89
10.	CMS-GA × AC-208	-63.51*	0.48	0.48	0.80	0.00	0.05	0.20	-0.09	0.43	0.19	2.68	-0.53
11.	CMS-GA × AC-1021	-8.44	-0.70	-3.38*	3.67*	-0.11	-0.12	1.00	0.15	-0.44	0.01	-2.73	-3.50
12.	Golden Acre × AC-204	1231.30*	1.31	-1.79*	4.54*	-0.01	0.03	-0.62	0.47	0.61	0.17	1.71	-3.13
13.	Golden Acre × EC-490174	4.04	-0.66	-8.99*	0.96	0.19	0.17*	-0.86	0.76*	1.95*	-0.04	1.51	-5.90*
14.	Golden Acre × Pusa Mukta	-122.63*	-0.64	16.81*	-4.39*	-0.35*	-0.30*	0.74	-2.08*	-2.09*	-1.72*	-4.16	6.46*
15.	Golden Acre × C-4	-58.23*	0.56	7.27*	-0.53	-0.24*	-0.20*	1.28*	-0.74*	-1.05*	-0.76*	-1.79	-0.68
16.	Golden Acre × Red cabbage	-148.16*	-0.61	-2.66*	-3.88*	0.15	0.03	-1.06	0.99*	0.14	1.64*	-2.99	-3.86
17.	Golden Acre × C-2	-301.76*	-0.13	-4.19*	-3.20*	0.04	0.05	-0.46	0.57	0.15	0.34	1.80	-1.07
18.	Golden Acre × AC- 1019	-109.43*	-0.13	0.21	2.09	0.16	0.12	-1.48*	0.69	0.73	1.57*	1.66	-0.96
19.	Golden Acre × EC-490192	-236.63*	2.38	8.21*	1.70	-0.23*	-0.20*	-0.04	-0.32	-0.96*	-1.22*	-3.25	-2.51
20.	Golden Acre × MR-1	189.04*	0.64	-1.19	2.79*	0.20*	0.09	1.52*	-0.23	0.15	0.23	-2.05	3.88
21.	Golden Acre × AC-208	-149.30*	-2.24	-7.73*	-4.42*	-0.22*	-0.10	-0.59	-1.26*	-1.41*	-0.98*	2.41	10.52*
22.	Golden Acre × AC-1021	-298.23*	-0.48	-5.93*	4.32*	0.32*	0.31*	1.54*	1.15*	1.79*	0.77*	5.16*	-2.75
23.	83-1 × AC-204	-393.48*	-4.29	-4.73*	-2.86*	0.01	0.19*	0.10	0.52	0.36	0.21	9.87*	3.88
24.	83-1 × EC-490174	-147.42*	6.54*	5.40*	-0.64	-0.39*	-0.27*	-3.07*	-0.66	-1.69*	-0.56*	-0.96	2.55
25.	83-1 × Pusa Mukta	-277.08*	1.90	-7.80*	-0.56	-0.01	0.12	-1.57*	0.26	0.56	1.07*	5.54*	0.81
26.	83-1 × C-4	-235.35*	3.10	-2.67*	0.80	0.08	0.27*	-0.30	0.94*	1.17*	0.52*	10.61*	0.03
27.	83-1 × Red cabbage	-3.95	-1.81	4.73*	0.66	0.03	-0.11	3.73*	-0.30	-0.87*	-0.12	-5.35*	2.02
28.	83-1 × C-2	538.12*	-0.40	7.20*	1.04	-0.07	-0.08	-0.38	-0.36	0.24	-0.73*	-2.93	-2.06
29.	83-1 × AC- 1019	141.12*	1.34	-5.07*	4.16*	-0.05	-0.20*	1.31*	-0.80*	-0.79	-0.17	-6.41*	-2.95
30.	83-1 × EC-490192	-135.42*	-6.29*	2.93*	0.56	-0.03	-0.13	0.92	-0.64	-0.44	-0.93*	-5.65*	-0.27

Contd...

Table contd…

S No.	.Cross	Total carotenoids	Ascorbic acid	Days to 50% maturity	Frame spread	Gross weight	Net head weight	No. of non-wrapper leaves	Polar diameter	Equatorial diameter	Core length	Harvest index	Head compa-ctness
31.	83-1 × MR-1	57.58*	1.71	-5.80*	-0.18	0.27*	0.08	-1.00	0.71*	1.03*	0.48*	-3.75	-4.15
32.	83-1 × AC-208	74.92*	-0.37	2.67*	-0.22	0.17	0.19*	1.56*	0.65	0.88*	0.45	3.97	-0.10
33.	83-1 × AC-1021	380.98*	-1.41	3.13*	-2.78*	-0.01	-0.07	-1.30*	-0.31	-0.45	-0.22	-4.94*	0.23
34.	83-2 × AC-204	-151.09*	2.16	2.54*	2.25	0.14	-0.02	-0.29	0.07	0.08	-0.59*	-4.21	-1.26
35.	83-2 × EC-490174	82.64*	-5.28*	-9.66*	0.81	0.22*	0.15*	0.44	-0.01	0.46	1.27*	1.23	2.27
36.	83-2 × Pusa Mukta	113.98*	-1.26	4.81*	1.96	0.18	0.13	-0.26	0.05	0.44	-0.37	0.83	2.10
37.	83-2 × C-4	133.71*	-0.72	0.94	1.65	-0.08	-0.11	0.11	-0.21	0.19	0.30	-3.70	-3.74
38.	83-2 × Red cabbage	48.11*	-1.76	4.01*	-0.80	-0.22*	-0.26*	-1.36*	-0.61	-0.92*	-0.48*	-8.37*	-4.05
39.	83-2 × C-2	-128.49*	0.32	2.47*	3.48*	0.17	0.06	-0.04	0.37	0.86*	-0.37	-1.31	-2.13
40.	83-2 × AC- 1019	-186.49*	1.92	-2.79*	-11.66*	-0.38*	0.03	0.72	-1.71*	-1.24*	-0.15	10.48*	13.75*
41.	83-2 × EC-490192	327.64*	1.62	-7.13*	0.91	0.07	-0.01	0.92	0.81*	0.71	0.27	-2.30	-5.87*
42.	83-2 × MR-1	-252.02*	1.89	-4.86*	-1.76	-0.05	0.13	0.61	1.20*	-0.55	0.11	8.01*	1.25
43.	83-2 × AC-208	34.64*	1.41	2.94*	5.43*	0.12	0.02	0.20	0.31	-0.17	0.33	-1.27	0.76
44.	83-2 × AC-1021	-22.62*	-0.30	6.74*	-2.27	-0.18	-0.11	-1.03	-0.29	0.16	-0.32	0.61	-3.08
45.	Pride of Asia × AC-204	-281.15*	-0.13	0.24	-1.22	0.14	0.04	0.73	0.36	-0.28	0.34	-1.29	1.79
46.	Pride of Asia × EC-490174	-36.42*	0.56	8.04*	-0.06	-0.12	-0.08	1.39*	0.25	0.43	0.46	-0.12	-5.71
47.	Pride of Asia × Pusa Mukta	-154.75*	1.12	-8.50*	2.36	0.17	0.16*	0.29	0.34	0.99*	1.30*	3.94	-0.45
48.	Pride of Asia × C-4	256.65*	-0.08	-2.03*	-0.65	0.22*	0.02	-1.13*	-0.25	-0.77	-0.17	-5.95*	7.18*
49.	Pride of Asia × Red cabbage	109.38*	2.21	-2.63*	5.17*	0.25*	0.55*	-0.54	0.81*	1.85*	-0.77*	22.02*	10.26*
50.	Pride of Asia × C-2	-46.22*	0.69	-0.16	-1.02	-0.33*	-0.28*	1.69*	-0.91*	-1.77*	-0.03	-4.40	-0.65
51.	Pride of Asia × AC- 1019	26.78*	-6.24*	8.24*	1.17	-0.03	-0.13	0.34	0.41	0.17	-0.72*	-7.07*	-8.74*
52.	Pride of Asia × EC-490192	-66.08*	2.67	-7.76*	-2.02	-0.04	0.02	-0.65	-0.07	-0.01	0.56*	2.52	1.74
53.	Pride of Asia × MR-1	140.25*	-4.40	3.50*	0.80	-0.16	-0.16*	-0.53	-0.61	0.16	-0.76*	-3.74	-3.87
54.	Pride of Asia × AC-208	103.25*	0.72	1.64	-1.60	-0.06	-0.16*	-1.37*	0.39	0.27	0.01	-7.79*	-10.66*
55.	Pride of Asia × AC-1021	-51.68*	2.88	-0.56	-2.94*	-0.02	0.00	-0.21	-0.70	-1.06*	-0.24	1.90	9.10*
	SE	10.25	2.62	0.90	1.31	0.10	0.07	0.54	0.36	0.41	0.24	2.39	2.96

* Significant at 5% level

of heterosis. This finding is in the line with the result of Prakash *et al.* (12).

Desirable SCA effects for carotenoid, earliness and net head weight, shown by most crosses, resulted from one good and one poor general combining parent. Heterosis breeding and random mating along with selection among segregants (i.e. recurrent selection) may be used to exploit both additive and non-additive gene effects. This finding is in agreement with Verma *et al.* (15) for net head weight. Majority of the cross combinations exhibiting desirable SCA effects for various traits of economic importance had at least one of the parents as poor general combiner. Similar finding was reported by Liu *et al.* (9) for early maturity. Some of the resultant crosses exhibited low SCA effects despite both their parents possessing high GCA effect like Golden Acre × EC-490174, Golden Acre × C-4, 83-2 × AC-204 and 83-2 × MR-1 for carotenoid; Golden Acre × Pusa Mukta, Golden Acre × EC-490192 and 83-2 × Pusa Mukta for net head weight; and CMS-GA × AC-204, CMS-GA × EC-490192 and CMS-GA × MR-1 for smaller core length. This is possible only in the absence of any interaction among favourable alleles contributed by the parents. Thus, it is evident that two parents with high GCA effects for a trait may not always result in a combination showing high SCA effects. Similar finding for carrot root yield has been reported by Verma *et al.* (14). These results show that SCA is more important than GCA in predicting hybrid combinations for desirable traits for developing productive and nutritious cultivars, synthetics and hybrids in cabbage.

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