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Heterosis for antioxidants and horticultural traits in single cross hybrids of cabbage (*Brassica oleracea* var. *capitata*)

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ABSTRACT

A study was conducted during 2005–07 to estimate the heterosis simultaneously for antioxidants and horticultural traits in cabbage (*Brassica oleracea* var. *capitata* L.). The significant differences of mean squares among parents and hybrids for various traits of economic importance indicated the presence of sufficient variation. The parents 'CMS-GA', 'Golden Acre', '83-2', 'C 2', 'Pusa Mukta', 'C 4' and 'MR-1' had the potential for use in further breeding as they exhibited desirable hybrid effects for ascorbic acid, earliness, frame size, net head weight and head compactness. All savoy type genotypes exclusively expressed the higher magnitude of heterosis for ascorbic acid. *Per se* performance of topmost 12 hybrids showed that 'Golden Acre', 'CMS-GA' and '83-2' as female line involved in the evolution of 9 hybrids. The hybrid effects and heterosis for various traits indicated that there is need to involve more than two parents to develop productive and antioxidant potential cultivars and hybrids.

Key words: Ascorbic acid, Cabbage, Carotenoid, Horticultural trait, Hybrid vigour

Cabbage (*Brassica oleracea* var. *capitata* L.), a member of cole crop, is economically an important vegetable crop being grown and consumed widely around globe. Antioxidants are the phyto-chemicals including vitamins, pigments, enzymes, phenols, minerals etc. have the ability to protect our body against oxidative damage. Free radicals 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-neutralized, free radicals damage various body cells causing many degenerative diseases associated with ageing, heart problem, cancer, loss of memory, paralysis, etc. in human (Dorge 2005).

Carotenoids, being secondary plant compounds, form lipid soluble yellow, orange and red pigments. Lutein (an oxygenated xanthophyll) and ß carotene (a hydrocarbon carotene and precursor of Vitamin-A) are two nutritionally important plant derived carotenoids. Diets containing carotenoid rich vegetables are associated with decreased risk of chronic diseases including cataract. Humans have no enzymatic capability to synthesise ascorbic acid and eventually, its deficiency causes scurvy disease. Cole crops, in general, are good source of well known antioxidants i.e. carotenoid and ascorbic acid (Kopsell *et al.* 2004, Kopsell *et al.* 2006). The increasing popularity of cabbage due to its wider adaptability, cheaper and round the year availability, and as an integral part of fast food has made it necessary to initiate efforts for improving the antioxidant concentration and yield concurrently.

Appreciable amount of heterosis has been reported and realised in cabbage for high yield, early maturity and larger head by various researchers (Prakash and Verma 2004, Xu *et al*. 2004) but information on simultaneous improvement of nutritional quality is meager as per our knowledge and available literatures. The present study, was to examine the magnitude and direction of heterosis for antioxidants and horticultral traits along with, and identify the superior parents and single cross hybrids for higher productivity, better nutrition and good health.

MATERIALS AND METHODS

The parental lines were selected on the basis of the variability for antioxidants and horticultural traits, and their practical applicability in heterosis breeding. Five females, namely, 'CMS-GA', 'Golden Acre', '83-1', '83-2' and 'Pride of Asia' and 11 males, 'AC 204', 'EC 490174', 'Pusa mukta', 'C 4', 'Red Cabbage', 'C 2', 'AC 1019', 'EC 490192', 'MR

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1', 'AC 208' and 'AC 1021' constituted the basic experimental materials.

The parents were crossed in line × tester mating design during 2005–06 to obtain the adequate amount of F_1 hybrid seeds. The standard procedure of hand emasculation and pollination was followed to produce the seeds of 55 F_1 hybrids. Appropriate buds likely to open within the next 48 hr on the female parents were emasculated to avoid any possibility of sibbing, covered with butter paper bags in the evening and were pollinated by using the previously bagged mixed pollen from at least 8–10 plants of male parent before noon on the following day. The siliques were harvested 30–35 days after pollination, air dried for 3–5 days and hand threshed individually. Finally, F_1 hybrid seeds were kept in moisture proof envelope.

The seedlings of 55 F_1 hybrids along with 16 parents including check variety, ie 'Golden Acre' (71 genotypes) were transplanted at IARI Regional Station, Katrain, located at 32.12 °N latitude and 77.13 °E longitude with an altitude of 1,690 m above the mean sea level. Plot received 100–110 cm rainfall along with 110–130 cm snowfall annually. Each plot had 36 plants with inter- and intra-row spacing of 45 cm. Plots were replicated 3 times in a randomized block design for heterosis study.

The horticultural parameters were recorded with respect to days to 50% maturity, frame spread (cm), plant height (cm), gross 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 10 randomly selected plants. The head compactness was determined as per Pearson (1932).

Samples of heads of each genotype in replicated trials

Table 1 Hybrid effects for carotenoid, ascorbic acid, days to 50% maturity, frame spread and net head weight

Parent	'AC 204'	'EC 490174'	'Pusa Mukta'	'C 4'	'Red Cabbage'	'C 2'	'AC 1019'	'EC 490192'	'MR 1'	'AC 208'	A'C 1021'	Mean
Carotenoid (µg/100 g fresh head weight)												
'CMS-GA'	189.6	580.5	913.3	419.0	415.9	295.2	596.0	548.3	475.9	363.9	407.5	473.2
'Golden Acre'	1865.3	526.3	389.1	496.4	311.9	93.5	397.3	239.9	838.5	317.0	156.7	512.0
'83-1'	174.4	308.6	168.3	252.8	390.1	867.3	581.5	275.0	640.9	475.1	769.7	445.8
'83-2'	487.6	609.5	630.4	693.1	512.9	271.7	325.1	809.1	402.5	505.7	437.1	516.8
'Pride of Asia'	270.9	404.0	275.2	729.5	487.6	267.3	451.5	328.7	708.0	487.6	321.5	430.2
Mean	597.6	485.8	475.3	518.2	423.7	359.0	470.3	440.2	613.1	429.9	418.5	
Ascorbic acid (mg/100 g fresh head weight)												
'CMS-GA'	38.8	36.7	50.0	49.5	36.3	50.9	42.1	37.5	33.2	34.9	33.9	40.3
'Golden Acre'	39.9	37.9	51.2	53.6	34.4	52.0	39.6	40.9	34.4	32.9	34.8	41.1
'83-1'	32.4	43.2	51.9	54.3	31.3	49.9	39.2	30.4	33.6	32.9	32.0	39.2
'83-2'	40.5	33.1	50.4	52.1	33.1	52.3	41.5	40.0	35.5	36.4	34.8	40.9
'Pride of Asia'	38.1	38.8	52.7	52.7	36.9	52.5	33.2	40.9	29.1	35.6	37.9	40.8
Mean	37.9	37.9	51.2	52.4	34.4	51.5	39.1	37.9	33.1	34.6	34.7	
Days to 50% maturity												
'CMS-GA'	77.7	85.0	71.0	66.3	71.3	69.0	89.0	84.3	85.7	81.3	71.7	77.5
'Golden Acre'	67.0	65.7	88.0	72.0	67.0	65.0	84.7	83.7	71.0	68.0	64.0	72.4
'83-1'	69.7	85.7	69.0	67.7	80.0	82.0	85.0	84.0	72.0	84.0	78.7	78.0
'83-2'	73.3	67.0	78.0	67.7	75.7	73.7	83.7	70.3	69.3	80.7	78.7	74.4
'Pride of Asia'	66.3	80.0	60.0	60.0	64.3	66.3	90.0	65.0	73.0	74.7	66.7	69.7
Mean	70.8	76.7	73.2	66.7	71.7	71.2	86.5	77.5	74.2	77.7	71.9	
Frame spread (cm)												
'CMS-GA'	49.7	53.1	56.0	47.9	54.5	49.8	65.3	52.9	51.4	53.8	53.3	53.4
'Golden Acre'	58.2	56.4	52.2	49.8	53.0	48.2	64.3	57.0	57.1	49.8	55.2	54.6
'83-1'	49.5	53.5	54.8	49.9	56.3	51.1	65.1	54.6	52.8	52.7	46.8	53.4
'83-2'	54.5	54.8	57.1	50.6	54.6	53.4	49.1	54.7	51.1	58.2	47.2	53.2
'Pride of Asia'	46.5	49.4	53.0	43.8	56.1	44.4	57.5	47.3	49.2	46.7	42.0	48.7
Mean	51.7	53.4	54.6	48.4	54.9	49.4	60.3	53.3	52.3	52.2	48.9	
Net head weight (kg)												
'CMS-GA'	0.749	1.300	1.008	1.097	0.718	1.278	1.033	1.427	0.950	0.996	0.941	1.045
'Golden Acre'	1.109	1.522	0.904	0.964	1.040	1.158	1.044	0.983	1.258	0.928	1.444	1.123
'83-1'	1.220	1.029	1.269	1.386	0.844	0.978	0.678	1.000	1.198	1.162	1.008	1.070
'83-2'	1.027	1.465	1.304	1.032	0.712	1.138	0.923	1.144	1.263	1.018	0.993	1.093
'Pride of Asia'	0.933	1.079	1.170	0.999	1.367	0.639	0.608	1.019	0.823	0.682	0.948	0.933
Mean	1.008	1.279	1.131	1.095	0.936	1.038	0.857	1.115	1.098	0.957	1.067	

were taken at fresh marketable stage, frozen immediately in liquid nitrogen and stored at –80°C for assay of carotenoid and ascorbic acid. The amount of carotenoid and ascorbic acid was expressed as µg and mg/100 g fresh head weight respectively. The estimation of carotenoid is based on the extraction of crude pigment mixture in lipid solvent as described by Ranganna (1979). The pigment content was determined as total carotenoid by measuring its optical density at 452 nm. The ascorbic acid was also determined by the direct colourimetric method as mentioned by Ranganna (1979), based on measurement of the extent to which 2, 6-dichlorophenol indo-phenol solution (dye) is decolourized by ascorbic acid available in sample extracts and standard ascorbic acid solution.

Analyses of variance for parents and hybrids were carried out as per method of Kempthorne (1957) later on modified by Arunachalam (1974). The better parent heterosis (%) and economic heterosis (%) for each hybrid were calculated.

RESULTS AND DISCUSSION

The mean squares due to parents and hybrids were observed to be significant for all traits, while parents vs hybrids also showed significant mean square for all traits except ascorbic acid and head compactness. The significance of mean squares indicates the existence of sufficient amount of variation among parents and hybrids which is prerequisite to improve the traits through breeding.

Hybrid effects of various parental combinations (Table 1) revealed that the parents 'Golden Acre', '83-2' and 'AC 204' were good for carotenoid content, while 'Pusa Mukta', 'C 4' and 'C 2' (all savoy type) for ascorbic acid content. It indicates that inclusion of savoy type genotypes in breeding programme would be beneficial to improve the ascorbic acid content in cabbage head. The performance of

Table 2 Hybrid effects, better parent heterosis and economic heterosis of antioxidants and horticultural traits

Particular/character		Carotenoid (µg/100 g FW)	Ascorbic acid (mg/100 g FW)	Days to 50% maturity	Frame spread (cm)	Gross weight (kg)	Net head weight (kg)
Parent	Range	209.5–2659.7	25.5–53.7	70.3–107.0	35.3–61.5	0.703–2.333	0.312–1.144
	Mean	638.6	38.9	87.1	46.7	1.329	0.712
Hybrid effect	Range	93.5–1865.3	29.1–54.3	60.0–90.0	42.0–65.3	1.207–2.393	0.608–1.465
	Mean	475.6	40.4	74.4	52.7	1.850	1.053
Better parent heterosis	Range (%)	–88.9 to 316.37	–28.97 to 21.40	–39.88 to 23.61	–24.11 to 49.27	–25.36 to 89.19	–35.11 to 119.08
	Mean (%)	–20.77	–4.61	–18.97	5.70	20.95	26.32
	No. of promising better parent hybrids	1	2	48	17	45	45
	Promising hybrid	P2 × P6	P2 × P16 P3 × P7	P5 × P10 P2 × P10 P2 × P11 P5 × P11 P5 × P13 P2 × P7 P1 × P10	P5 × P15 P2 × P15 P5 × P7 P3 × P16 P3 × P15 P1 × P15 P2 × P6	P2 × P12 P1 × P12 P2 × P14 P2 × P16 P2 × P10 P4 × P13 P4 × P8	P4 × P14 P4 × P11 P4 × P8 P4 × P9 P1 × P11 P1 × P13 P3 × P9
Economic heterosis	Range (%)	–78.0 to 337.9	14.0 to 112.8	–14.7 to 28.0	–2.5 to 51.4	–1.9 to 106.2	–30.1 to 75.0
	Mean (%)	–24.5	48.5	5.8	22.2	50.4	21.0
	No. of promising economic hybrids	7	55	16		54	46
	Promising hybrid	P2 × P6 P1 × P8 P3 × P11 P2 × P14 P4 × P13 P3 × P16 P5 × P9	P3 × P9 P2 × P9 P5 × P11 P5 × P8 P5 × P9 P4 × P11 P4 × P9	P5 × P8 P5 × P9 P2 × P16 P5 × P10 P5 × P13 P2 × P11 P2 × P7		P4 × P7 P2 × P7 P1 × P12 P2 × P12 P3 × P12 P3 × P14 P1 × P7	P2 × P7 P4 × P7 P2 × P16 P1 × P13 P3 × P9 P5 × P10 P4 × P8

FW, Fresh weight

Parents:

P1: 'CMS-GA'; P2: 'Golden; P3: 83-1'; P4: 83-2'; P5: 'Pride of Asia'; P6: 'AC 204'; P7: 'EC 490174'; P8: 'Pusa Mukta'; P9: 'C 4'; P10: 'Red cabbage; P11: C 2'; P12: 'AC 1019'; P13: 'EC 490192'; P14: 'MR 1'; P15: 'AC 208'; P16: 'AC 102'

Table 3 Hybrid effects, better parent heterosis and economic heterosis of horticultural traits

Particular/character		No. of non-wrapper leaves	Polar diameter (cm)	Equatorial diameter (cm)	Core length (cm)	Harvest index (%)	Head compactness
Parent	Range	9.3–12.5	9.2–16.7	7.7–16.2	2.3–7.7	41.2–71.3	23.2–57.6
	Mean	14.9	11.7	12.7	4.8	54.4	40.1
Hybrid effect	Range	11.9–22.8	10.5–15.2	12.7–18.2	4.4–9.3	29.1–74.8	23.5–54.0
	Mean	15.3	12.7	15.2	6.4	57.4	39.1
Better parent heterosis	Range (%)	–28.95 to 41.82	–21.00 to 28.28	–11.09 to 29.26	–23.67 to 114.86	–57.72 to 42.48	–40.59 to 42.24
	Mean (%)	–4.01	–1.67	8.06	21.04	–2.33	–9.77
	No. of promising better parent hybrids	33	24	41	10	15	9
	Promising hybrid	P2 × P11	P4 × P14	P4 × P16	P1 × P7	P3 × P9	P3 × P7
		P2 × P7	P1 × P12	P4 × P8	P4 × P6	P4 × P14	P3 × P11
		P1 × P11	P1 × P8	P2 × P16	P2 × P13	P5 × P10	P1 × P11
		P4 × P16	P4 × P8	P4 × P11	P4 × P16	P1 × P9	P1 × P7
		P2 × P15	P2 × P16	P4 × P9	P2 × P8	P4 × P11	P3 × P9
		P4 × P9	P2 × P12	P4 × P13	P4 × P13	P3 × P8	P1 × P13
		P4 × P8	P4 × P13	P4 × P6	P1 × P6	P4 × P9	P2 × P8
Economic heterosis	Range (%)	–3.4 to 84.9	–14.8 to 22.9	–9.5 to 29.5	–17.8 to 73.7	–59.1to 4.8	–37.8 to 42.8
	Mean (%)	23.9	2.7	8.0	19.4	–19.5	3.3
	No. of promising economic hybrids	3	30	43	11		14
	Promising hybrid	P1 × P9	P2 × P7	P2 × P7	P1 × P6		P5 × P10
		P2 × P6	P1 × P12	P2 × P16	P2 × P13		P2 × P15
		P2 × P7	P1 × P8	P4 × P7	P1 × P16		P5 × P16
			P4 × P13	P3 × P9	P1 × P14		P5 × P9
			P4 × P14	P4 × P8	P2 × P8		P1 × P11
			P1 × P7	P3 × P8	P4 × P6		P3 × P10
			P1 × P13	P4 × P11	P1 × P8		P2 × P8

Parents:
P1: 'CMS-GA'; P2: 'Golden Acre'; P3: '83-1'; P4: '83-2'; P5: 'Pride of Asia'; P6: 'AC 204'; P7: 'EC 490174'; P8: 'Pusa Mukta'; P9: 'C 4'; P10: 'Red Cabbage'; P11: 'C 2'; P12: 'AC 1019'; P13: 'EC 490192'; P14: 'MR 1'; P15: 'AC 208'; P16: 'AC 1021'

hybrids having 'C 4' and 'Pride of Asia' as one of the parent was found to be useful for earliness. Moreover, smaller frame size was realized with parents 'Pride of Asia', 'C 4', 'C 2' and 'AC 1021' which would be useful to accommodate more number of plants and ultimately maximise productivity/unit area of land.

Hybrid effects, better parent heterosis and economic heterosis were computed to find out suitable parents and hybrids for various traits of economic importance (Tables 2, 3). The parental mean value and range were found to be higher than the mean value and range of hybrid for carotenoid and days to 50% maturity showing the negative heterosis for aforementioned traits. Further, this is justified with negative heterobeltiosis. Negative heterosis is desirable for days to 50% maturity to get an early crop, nevertheless undesirable for carotenoid content. In contrary to this, Sreekala and Raghava (2003) reported positive heterosis for total carotenoid content in petals of *Tagetes erecta*. The higher value of mean and range of hybrid than parental mean value and range indicate the positive heterosis for frame spread, gross plant weight, net head weight and core length which further gets the justification by positive sign of heterobeltiosis. It is desirable for net head weight, while undesirable for frame spread and core length. High core length will reduce the shelf life as well as consumers' preference.

Among 55 single cross hybrids, only 11 hybrids 'CMS-GA' × 'Pusa Mukta', 'Golden Acre' × 'AC 204', 'Golden Acre' × 'MR 1', '83-1' × 'C 2', '83-1' × 'AC 1021', '83-2' × 'EC 490192' and 'Pride of Asia' × 'C 4' exhibited significant and high economic heterosis for carotenoid content in cabbage head. However, all 55 hybrids were found to be positive and significant over standard check for ascorbic acid content indicating that most popular variety has low amount of ascorbic acid and signifying the immediate steps to be taken to develop new cultivars/hybrids rich in ascorbic acid

Table 4 *Per se* performance of top 12 hybrids and desirable economic heterosis for various traits

Hybrid	Net head weight (kg)	Economic heterosis (%) for net head weight	Desirable economic heterosis
'Golden Acre' × 'EC 490174'	1.522	75.0	Ascorbic acid, days to 50% maturity, gross weight, number of non-wrapper leaves, and polar and equatorial diameter (6)
'83-2' × 'EC 490174'	1.465	68.4	Ascorbic acid, days to 50% maturity, gross weight, and polar and equatorial diameter (5)
'Golden Acre' × 'AC 1021'	1.444	66.0	Ascorbic acid, days to 50% maturity, gross weight, and polar and equatorial diameter (5)
'CMS-GA' × 'EC 490192'	1.427	64.0	Ascorbic acid, gross weight, polar and equatorial diameter and head compactness (5)
'83-1' × 'C 4'	1.386	59.3	Ascorbic acid, days to 50% maturity, gross weight, and polar and equatorial diameter (5)
'Pride of Asia' × 'Red Cabbage'	1.367	57.1	Ascorbic acid, days to 50% maturity, gross weight, equatorial diameter and head compactness (5)
'83-2' × 'Pusa Mukta'	1.304	49.9	Ascorbic acid, gross weight, and polar and equatorial diameter (4)
'CMS-GA' × 'EC 490174'	1.300	49.4	Ascorbic acid, gross weight, polar and equatorial diameter and head compactness (5)
'CMS-GA' × C 2'	1.278	46.9	Ascorbic acid, gross weight, polar and equatorial diameter and head compactness (5)
'83-1' × 'Pusa Mukta'	1.269	45.9	Ascorbic acid, gross weight, and polar and equatorial diameter (4)
'83-2' × 'MR 1'	1.263	45.1	Ascorbic acid, gross weight, and polar and equatorial diameter (4)
'Golden Acre' × 'MR 1'	1.258	44.6	Ascorbic acid, carotenoid, gross weight, polar and equatorial diameter and head compactness (6)

Figures in parentheses are number of traits expressing desirable and significant heterosis

content. Ten hybrids '83-1' × 'C 4', 'Golden Acre' × 'C 4', 'Pride of Asia' × 'C 4', 'Pride of Asia' × 'Pusa Mukta', 'Pride of Asia' × 'C 2', '83-2' × 'C 2', '83-2' × 'C 4', 'Golden Acre' × 'C 2', '83-1' × 'Pusa Mukta' and 'Golden Acre' × 'Pusa Mukta' showed >100% economic heterosis for ascorbic acid and demonstrating that all the hybrids possess one of the parent as savoy type.

The significance of 48 and 16 hybrids over better parent and standard check, respectively for earliness (negative heterosis for days to 50% maturity) indicating the dominance of earliness and provides the prospect to breed the short duration hybrids for fetching better market price. This corroborates with finding of Prakash *et al*. (2003). Nevertheless, none of the hybrids were found to be significant for smaller frame size over standard check, while 17 hybrids reflected significant heterosis for smaller frame size which is in corroboration with Prakash and Verma (2004). Nowadays, smaller frame size is becoming one of the most important traits as it accommodate more number of plants per unit area with smaller head size which is the choice of nuclear and metro family. Forty-five hybrids were found to be vigorous for gross plant weight over better parent, while 54 hybrids exhibited economic heterosis revealing the presence of heterosis for vigour. The similar trend of results were also observed by Pandey *et al.* (2003), and Prakash and Verma (2004). Among 55 hybrids, 46 and 45 hybrids expressed heterosis for net head weight over standard check and better parent, respectively enlightening that there is enough scope to increase the productivity/plant. The result is in conformity with the findings of Li *et al*. (2004) and Ren *et al*. (2004). None of the hybrids articulated better than standard check for harvest index signifying the reason of being superior cultivar.

Per se performance of topmost 12 hybrids ('Golden Acre' × 'EC 490174', '83-2' × 'EC 490174', 'Golden Acre' × 'AC 1021', 'CMS-GA' × 'EC 490192', '83-1' × 'C 4', 'Pride of Asia' × 'Red Cabbage', '83-2' × 'Pusa Mukta', 'CMS-GA' × 'EC 490174', 'CMS-GA' × 'C 2', '83-1' × 'Pusa Mukta', '83-2' × 'MR 1' and 'Golden Acre' × 'MR 1') along with desirable economic heterosis for antioxidant and horticultural traits (Table 4) revealed that 'Golden Acre', 'CMS-GA' and '83-2' as female line involved in the evolution of nine hybrids. Among them 'CMS-GA' and '83-2' have advantage of being male sterile and self-incompatible parent, respectively which will facilitate the cost-effective hybrid seed production commercially. 'MR 1' has the advantage of being multiple resistant to insect pest and diseases, while savoy type genotypes ('C 2', 'C 4' and 'Pusa Mukta') are rich source of ascorbic acid. Thus it is concluded that the parents 'CMS-GA', 'Golden Acre', '83 2', 'C 2', 'Pusa Mukta', 'C 4' and 'MR 1' have the potential for use in further breeding programme as they exhibited higher hybrid effects for yield and quality traits simultaneously. The hybrid effects and heterosis for various traits of economic importance revealed

that there is need to involve more than two parents to develop productive and nutritionally rich cultivars and hybrids.

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