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Combining ability and gene action studies to select okra (*Abelmoschus esculentus)* inbred for carbohydrate, vitamins and antioxidant traits

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ABSTRACT

Development of quality hybrids having better productivity as well as rich in major antioxidant and phytochemical compounds is a prime objective of any vegetable improvement program throughout the world. Okra (*Abelmoschus esculentus* (L.) Moench.), a member of the family *malvaceae* is a rich source of several minerals, vitamins and crude fiber. Thus, to exploit its nutritional potential in the form of hybrids selection involving right parents is the foremost criteria. With this aim, the present experiment was designed to know about the gene action for quality traits involving 10 lines and 3 testers in line × tester method. ANOVA revealed significance for all the traits. On the basis of both gca effect and *per se* performance, Pusa Bhindi-5 was regarded as the best parent for chlorophyll content (a and b), DOV-92 for total carotenoids, Kashi Pragati for ascorbic acid and sugar content and Pusa Sawani for total phenol. Similarly, on the basis of both sca effect and *per se* performance, the cross Kashi Pragati × Pusa Bhindi-5 was found to be the best hybrid combination for chlorophyll a only, DOV- 1 × Pusa Bhindi- 5 for total carotenoids, Kashi Pragati × Pusa A-4 for ascorbic acid and DOV- 92 × Pusa Bhindi- 5 for antioxidant content of fruit. Analysis of degree of dominance and predictability ratio also indicated the presence of non-additive gene action for all the traits. In was concluded that parents which performed well for particular trait, possessed high potentiality for heterosis breeding program.

Key words: Antioxidant, Combining ability, Degree of dominance, gca, Hybrid, line × tester, Okra, Predictability ratio, sca

Okra (*Abelmoschus esculentus* (L.) Moench.), a member of the family *malvaceae* is one of the most popular vegetable crops in India due to its high nutritious value, larger area cultivation, export potential and wider adaptability. It is also widely cultivated in tropical and sub-tropical regions of world (Hammon and Van Sloten 1989). It is commonly called as *Bhindi* or Lady's finger in our country. Globally, okra produce 9.62 million metric tons (MT) annually from an area of 1.83 million ha with an average yield of 5.26 MT ha^{-1} (FAOSTAT 2014). But in India, the total annual production of okra is 6.095 million tonnes from an area of 0.509 million ha (NHB 2018). It also acts as a source of several minerals, vitamins and crude fiber in human diet (Rashid 1999).

In this twenty-first century, the major goal for any breeding program is to explore the novel genes/alleles which improves the productivity as well as quality and nutritional value of crops (Fernie *et al*. 2006). Thus, development of quality F_1 hybrids having high productivity, high adaptability as well as rich in major antioxidant and phytochemical compounds is a prime objective of any vegetable improvement programme throughout the world. Although, it was reported that the okra fruit is a rich source of protein (1.9%), crude fibre (1.2%), mucilage (4%) and several minerals but very limited information is available about its antioxidant constituents (Kumar *et al*. 2017). Information about heterosis for chlorophyll, ascorbic acid and sugar content was already reported by several workers in okra (Hadiya *et al*. 2018; Senthil kumar *et al*. 2007). Thus, to exploit nutritional potential in the hybrid breeding program, selection of parents is the foremost criteria to achieve higher amount of heterosis for this antioxidant traits. For this reason, combining ability is one of the most powerful tool which is utilized to assess the potentiality of parents that aids in its selection. For measuring the combining ability of the parents, line × tester design was employed in this experiment that is normally the extension of top cross design for inclusion of large number of testers instead of one (in case of top crossing). Analysis of data utilizing line × tester design partitioned the overall-effect into gca and sca. General Combining Ability (gca) measures the potentiality

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of the parent while, Specific Combining Ability (sca) helps to measure the performance of the hybrids. Higher value of gca helps to predict the probability of favourable gene flow from parents to hybrids. High gca value of both the parents as well as high sca effect of that specific cross combination aids in selection of that cross combination for exploitation of heterosis for a particular trait. Ratio of gca and sca also helps to predict the prevalence of additive and dominance nature of gene action for each trait. Keeping the above points in view, the present experiment was designed to gain the knowledge about gene action and also to see the performance followed by selection of the parents through analysis of gca and sca effect for future breeding programme.

MATERIALS AND METHODS

The present investigation was carried out at Vegetable Research Farm, Division of Vegetable Science, ICAR-Indian Agricultural Research Institute (IARI), New Delhi during summer-2018 (crossing program) and *kharif*-2018 (hybrid evaluation program). The experimental plot was situated on latitude $28^0 40^/$ N, longitude $77^0 12^/$ E and at an altitude of 228.6 m above mean sea level (MSL) and soil of experimented plot was sandy loamy having neutral pH of 6.0-7.5. Ten lines namely, IC-685583, Arka Anamika, DOV-92, Kashi Pragati, DOV-2, DOV-62, DOV-37, DOV-25, DOV-1 and DOV-64 and three testers namely, Pusa Sawani, Pusa Bhindi-5, and Pusa A-4 were sown to develop 30 hybrids following line × tester design in summer-2018. The parents (lines and testers) along with 30 F_1 hybrids were sown in Randomized Complete Block Design (RCBD) each with three replication following a spacing of 60 cm between row-to-row and 30 cm from plant-to-plant and all the prescribed agronomic and cultural practices were followed to raise a good and healthy crop.

Analysis of chlorophyll a, chlorophyll b, total carotenoids, ascorbic acid, total sugar, total phenol and antioxidants

For the analysis of antioxidant traits, fresh and tender fruits of 6^{th} day after anthesis were taken, washed with double distilled water to remove the adhering soil and dust followed by treating with 0.2% teepol solution, 0.1 (N) HCl solution and again with double distilled water repeatedly for 3-4 times. For analysis of chlorophyll a, chlorophyll b and total carotenoids, 0.5 g samples were treated with 100% acetone (3 ml) and 150 mg of MgO and reading of final volume of 5 ml solution was taken at five different wavelengths on UV-VIS spectrophotometer, i.e. 750 nm ($A_{750,}$ for clear extract), 661.6 nm ($A_{661.6,}$chlorophyll a maximum using 100% acetone), 644.8 nm ($A_{644.8,}$chlorophyll b maximum using 100% acetone), 520 nm (A_{520}, for extracts from green plant tissue, A520 should be <10% A661.6) and at 470 nm (A_{470} carotenoids). Finally following formula was used to measure chlorophyll a, C_a (µg/ml) = 11.87 $A_{661.6}$ –2.42$A_{644.8}$; chlorophyll b, C_b (µg /ml)=20.82 $A_{644.8}$ – 4.60 $A_{661.6}$; total Carotenoids, C_c (µg/ml)= 1000 A_{470} – 1.86 C_a – 74.08 C_b as suggested by Lichtenthaler *et al*. (2001). Ascorbic acid content of 1.0 g sample was measured by colorimetric technique at 760 nm wavelength using 3% meta-phosphoric acid with folin-ciocalteu reagent as suggested by Jagota *et al*. (1982). Total phenol was analyzed according to the procedure as suggested by Singleton *et al*. (1999) with the help of 20% Na_2CO_3 solution with folin-ciocalteu reagent where gallic acid was used as the standard. Finally reading of all the samples were taken at 650 nm in colorimeter. Total sugar was calibrated using anthrone solution with glucose as standard where final reading of all the samples were taken at 630 nm in UV-VIS spectrophotometer (Hansen *et al*. 1975). Total antioxidant was analyzed by the procedure of Cupric Ion Reducing Antioxidant Capacity (CUPRAC) as suggested by Apak *et al*. (2004) using $CuCl_2$ and neocuproine solution, ammonium acetate buffer and gallic acid as standard. Final reading was measured at 450 nm in UV-VIS spectrophotometer.

Data obtained from each replication for the various traits under study were calibrated according to the method as suggested by Singh and Chaudhary (1977). Variation for general combining ability (gca) and specific combining ability (sca) was analyzed using the procedure as suggested by Kempthorne (1957). Predictability ratio and degree of dominance was measured using following formulae: $(V_d/V_a)^{1/2}$ and $[V_a/(V_a + V_d)]$ where, Additive variance, $V_a = 2\sigma^2_{gca}$ and Dominance variance, $V_d = \sigma^2_{sca}$. While, contribution of lines, tester and their interaction was calibrated by using following formulae:

$$\text{Contribution of lines} = \frac{SS\ (lines)}{SS\ (crosses)} \times 100$$

$$\text{Contribution of testers} = \frac{SS\ (testers)}{SS\ (crosses)} \times 100$$

$$\text{Contribution of (lines} \times \text{testers) interaction} = \frac{SS\ (l \times t)}{SS\ (crosses)} \times 100$$

RESULTS AND DISCUSSION

The knowledge of combining ability along with *per se* performance of the parents and their cross combinations are vital for the breeders to select suitable parents and heterotic combinations for their use in systematic breeding programme. Combining ability analysis is a powerful and most effective tool for predicting the performances of parental combination to develop potential F_1 hybrid. For testing combining ability, general combining ability is used to judge the combining ability of the parents and specific combining ability is used to measure the performance of parental combination of the specific hybrid. It also helps to estimate the preponderance of additive and non-additive gene action to frame breeding strategy for development of desirable hybrid combination. Thereby, 13 parents involving 10 lines and three testers were used to estimate gca and sca effect for the traits, i.e. chlorophyll content, total carotenoids, sugar, ascorbic acid, total phenol, total antioxidant through CUPRAC.

Analysis of variance (ANOVA) for parents and cross combinations

Analysis of variance for seven quality traits are presented in Table 1, which revealed that treatments, parents and their cross combinations were highly significant for all the traits. However, interaction between parents and their cross combination were highly significant for all the trait, except for sugar percentage. Similar findings were also reported by other workers in okra (Solankey *et al*. 2013; Singh *et al*. 2013)

Testing of general combining ability effect of the parents

Variance due to gca for parents are presented in Table 2. Estimation of gca represents whether parental mean is superior or inferior to general mean of the parents and subsequently, selection of parents with high gca helps to predict the performance of their test cross progenies as well as to develop superior breeding population through hybridization. Among the lines, IC-685583 was found as poor combiner for all the traits while Arka Anamika also exhibited similar trend, except for chlorophyll b (0.04) content. However, DOV-92 and Kashi Pragati were recorded as good general combiner for all the traits, except for total phenol (-8.06) in Kashi Pragati. DOV-2was good combiner only for sugar% (0.25) and CUPRAC content (8.63). The line DOV-62 was good combiner for ascorbic acid (11.93),

Table 1 ANOVA of parents and hybrids for quality traits in okra

Source of variation	df	Chl a (mg/100g)	Chl b (mg/100g)	Total carotenoids (mg/100g)	Ascorbic acid (mg/100g)	Sugar (%)	Total phenol (mg/100 g)	CUPRAC (mg/100 g GAE)
Replication	2	0.13	0.07	0.01	62.88	0.11	101.83	1008.30
Treatment	42	24.81**	2.90**	2.44**	341.86**	0.32**	1590.12**	7335.99**
Parents	12	40.60**	5.01**	4.15**	145.69**	0.33**	1899.49**	10694.13**
Crosses	29	19.02**	2.10**	1.78**	426.61**	0.32**	1172.08**	5631.45**
Parents *vs* Crosses	1	3.02**	0.63**	0.89**	238.23**	0.06	10000.70**	16469.77**
Lines	9	23.88**	2.10**	1.53**	591.51**	0.36**	1922.80**	6859.26**
Testers	2	75.25**	8.19**	5.62**	276.40**	0.68**	277.50**	6551.03**
Line × Testers	18	10.35**	1.43**	1.48**	360.84**	0.26**	896.12**	4915.37**
Error	84	0.18	0.03	0.07	25.17	0.04	36.40	512.82

Table 2 GCA effects of parents for quality traits in okra

Parent	Chl a (mg/100g)	Chl b (mg/100g)	Total carotenoids (mg/100g)	Ascorbic acid (mg/100g)	Sugar (%)	Total phenol (mg/100 g)	CUPRAC (mg/100 g GAE)
Lines							
IC- 685583	-3.75**	-0.81**	-0.70**	-14.07**	-0.09	-6.46**	-32.40**
Arka Anamika	-0.02	0.04	-0.14	-3.40*	-0.16*	-1.25	-35.82**
DOV- 92	1.45**	0.35**	0.47**	10.60**	0.27**	13.34**	41.15**
Kashi Pragati	1.48**	0.55**	0.49**	5.93**	0.25**	-8.06**	16.32*
DOV- 2	-0.83**	-0.45**	-0.45**	-2.73	0.25**	-4.59*	8.63
DOV- 62	-1.30**	-0.35**	-0.29**	11.93**	0.11	36.65**	44.52**
DOV- 37	0.66**	0.44**	0.21*	-6.07**	-0.13	-7.94**	-6.76
DOV- 25	0.47**	0.01	-0.08	0.60	-0.21**	-4.01*	-9.32
DOV- 1	0.27	-0.44**	0.02	-6.07**	-0.18*	-13.11**	-9.32
DOV- 64	1.57**	0.57**	0.47**	3.27	-0.14*	-4.59*	-17.02*
SEm.(g_i)	0.14	0.06	0.09	1.67	0.07	2.01	7.53
SEm.(g_i - g_j)	0.20	0.08	0.13	2.37	0.10	2.84	10.68
Testers							
Pusa Sawani	-1.44**	-0.54**	-0.44*	-0.53	-0.05	2.64*	-5.99
Pusa Bhindi- 5	1.70**	0.51**	0.42**	3.27**	-0.12**	0.69	-10.84*
Pusa A-4	-0.25**	0.03	0.02	-2.73**	0.17**	-3.33**	16.83**
SEm. (g_j)	0.08	0.03	0.05	0.92	0.04	1.10	4.13
SEm.(g_i - g_j)	0.11	0.04	0.07	1.30	0.05	1.56	5.85

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

sugar% (0.11), total phenol (36.65) and CUPRAC (44.52) content, while DOV-37 was poor combiner for these trait. DOV-37 was good combiner for chlorophyll (a and b; 0.66 and 0.44), total carotenoids (0.21), while DOV- 62 was poor combiner for these trait. DOV-25 was found to be good combiner for chlorophyll (a and b; 0.47 and 0.01) and ascorbic acid (0.60), while poor combiner for rest of the traits. DOV-1 was good combiner for chlorophyll a (0.27) and total carotenoids (0.02), while poor combiner for rest of the traits. DOV-64 was good combiner for chlorophyll (a and b; 1.57 and 0.57), total carotenoids (0.47) and ascorbic acid (3.27), while poor combiner for sugar%, total phenol and CUPRAC content. Among the testers, Pusa Bhindi-5 was found to be good combiner for most of the traits, except for sugar% (-0.12) and CUPRAC content (-10.84), while Pusa Sawani was poor combiner for majority of the traits, except for total phenol (2.64). The tester Pusa A-4 was considered as good combiner for chlorophyll b (0.03), total carotenoids (0.02), sugar% (0.17) and CUPRAC content (16.83),while poor combiner in case of chlorophyll b, total phenol and

Table 3 SCA effects of the hybrids for quality traits in okra

Hybrid	Chl a (mg/100g)	Chl b (mg/100g)	Total carotenoids (mg/100g)	Ascorbic acid (mg/100g)	Sugar (%)	Total phenol (mg/100 g)	CUPRAC (mg/100g GAE)
IC- 685583 × Pusa Sawani	1.17**	0.16	0.17	-8.13**	-0.10	-11.09**	-52.99**
IC- 685583×Pusa Bhindi-5	-1.92**	-0.52**	-0.86**	-1.93	0.04	-9.23**	-9.67
IC- 685583 × Pusa A-4	0.75**	0.38**	0.69**	10.07**	0.06	20.32**	62.66**
Arka Anamika × Pusa Sawani	-0.42	-0.32**	0.12	-0.80	-0.26**	-16.39**	-11.11
Arka Anamika × Pusa Bhindi-5	0.89**	0.76**	-0.33*	3.40	-0.11	18.30**	1.44
Arka Anamika × Pusa A-4	-0.47	-0.44**	0.21	-2.60	0.37**	-1.91	9.66
DOV- 92 × Pusa Sawani	-1.40**	-0.56**	-0.53**	5.20	0.11	11.56**	11.91
DOV- 92 × Pusa Bhindi-5	1.63**	0.57**	0.71**	-0.60	0.22	10.60**	60.54**
DOV- 92 × Pusa A-4	-0.22	-0.01	-0.18	-4.60	-0.33**	-22.18**	-72.45**
Kashi Pragati × Pusa Sawani	-1.21**	-0.20*	-0.64**	-2.13	-0.16	7.45*	29.07*
Kashi Pragati × Pusa Bhindi-5	1.65**	0.16	0.66**	-15.93**	-0.02	-4.79	-27.62*
Kashi Pragati × Pusa A-4	-0.45	0.04	-0.02	18.07**	0.17	-2.66	-1.45
DOV- 2 × Pusa Sawani	-1.30**	-0.43**	-0.45**	-15.47**	0.42**	-4.53	5.99
DOV- 2 × Pusa Bhindi-5	0.81**	0.33**	0.22	-1.27	-0.26*	-5.42	-35.31**
DOV- 2 × Pusa A-4	0.49**	0.09	0.23	16.73**	-0.16	9.95*	29.32*
DOV- 62 × Pusa Sawani	-0.01	-0.14	0.44**	-2.13	0.10	13.34**	39.32**
DOV- 62 × Pusa Bhindi-5	1.65**	0.89**	0.49**	4.07	0.13	17.96**	-1.98
DOV- 62 × Pusa A-4	-1.64**	-0.75**	-0.93**	-1.93	-0.23	-31.30**	-37.34**
DOV- 37 × Pusa Sawani	1.33**	0.49**	0.35*	5.87*	0.09	-13.48**	-1.70
DOV- 37 × Pusa Bhindi-5	-1.84**	-0.62**	-0.42**	-1.93	0.35**	-7.75*	10.84
DOV- 37 × Pusa A-4	0.51*	0.13	0.07	-3.93	-0.44**	21.23**	-9.14
DOV- 25 × Pusa Sawani	2.08**	0.72**	0.88**	7.20*	-0.04	19.34**	-14.52
DOV- 25 × Pusa Bhindi-5	-4.46**	-1.57**	-1.42**	1.40	-0.06	-14.52**	5.72
DOV- 25 × Pusa A-4	2.37**	0.85**	0.53**	-8.60**	0.10	-4.82	8.81
DOV- 1 × Pusa Sawani	-0.37	0.19	-0.26	9.87**	0.03	1.50	31.63*
DOV- 1 × Pusa Bhindi-5	1.33**	-0.35**	0.72**	-1.93	0.04	3.09	5.72
DOV- 1 × Pusa A-4	-0.97**	0.16	-0.46**	-7.93**	-0.07	-4.24	-37.34**
DOV- 64 × Pusa Sawani	0.13	0.09	-0.09	0.53	-0.20	-7.37*	-37.60**
DOV- 64 × Pusa Bhindi-5	0.25	0.35**	0.23	14.73**	-0.34**	-8.26*	-9.67
DOV- 64 × Pusa A-4	-0.38	-0.44**	-0.15	-15.27**	0.54**	15.62**	47.27**
SEm.(sij)	0.25	0.10	0.16	2.90	0.12	3.48	13.07
SEm.(sij - sji)	0.35	0.15	0.22	4.10	0.17	4.93	18.49

*, ** significant at 5% and significant at 1% probability levels, respectively.

ascorbic acid. High gca value was mainly due to additive variance and interaction between two additive genes present in two different loci. However, categorization of parents only on the basis of gca effect is not an ideal method for selection of the parents. Result of this study itself revealed that none of the parents exhibited all the desirable traits at a time. It shows the importance and need for testing the combining ability with different lines and following different mating designs to create variation for increasing the concentration of each trait (Dey *et al*. 2014). Therefore, in this study *per se* performance along with gca effect was used to select desirable parents which is represented in the Table 5. On the basis of both gca effect and *per se* performance, Pusa Bhindi-5 was found to be best for both chlorophyll a and chlorophyll b, DOV-92 for total carotenoids, Kashi Pragati for ascorbic acid and sugar%, DOV-62 for ascorbic acid, DOV-2 for sugar% and Pusa Sawani for total phenol. However, no parent was found to be best for antioxidant CUPRAC content. Variance due to gca for the above traits was also reported by several workers (Senthil kumar *et al*. 2007; Dey *et al*. 2014, Hadiya *et al*. 2018).

Testing of specific combining ability effect of the crosses

GCA effect is not always a true measure for prediction of heterotic combination, thus sca effect used to denote presence of non-additive gene action of the hybrids. Selected parents with high gca along with high sca of their crosses can be used in heterosis breeding programme. Variance due to sca effect for 30 hybrids was given in Table 3. It was found that DOV- 25 × Pusa A-4 (2.37) exhibited highest sca effect for chlorophyll a followed by DOV- 25 × Pusa Sawani (2.08) and Kashi Pragati × Pusa Bhindi-5 (1.65), while for chlorophyll b, cross DOV- 62 × Pusa Bhindi-5 (1.65) had highest positive sca effect followed by DOV-25 × Pusa A-4 (2.37) and Arka Anamika × Pusa Bhindi- 5 (0.89). For total carotenoids, highest positive sca effect was observed in the DOV- 25 × Pusa Sawani (0.88) followed by DOV-1 × Pusa Bhindi-5 (0.72) and DOV-92 × Pusa Bhindi-5 (0.71). The hybrid Kashi Pragati× Pusa A-4 (18.07), DOV-2 × Pusa A-4 (16.73) and DOV-64 × Pusa Bhindi-5 (14.73) exhibited highest sca effect in desirable direction for ascorbic acid. For sugar%, cross DOV-64 × Pusa A-4 (0.54) was found to be best for sca effect followed by DOV-2 × Pusa Sawani (0.42) and Arka Anamika × Pusa A-4 (0.37). Highest positive sca effect for total phenolic compounds was found in DOV-37 × Pusa A-4 (21.23) followed by IC- 685583 × Pusa A-4 (20.32) and DOV-25 × Pusa Sawani (19.34) while, for total antioxidant capacity analyzed through CUPRAC was highest in IC- 685583 × Pusa A-4 (62.66) followed by DOV-92 × Pusa Bhindi-5 (60.54) and DOV-64 × Pusa A-4 (47.27). Similar to gca effect sca effect alone cannot judge the specific cross combination, thus mean performance of the hybrid along with their sca effect was considered to select the best cross combination. Therefore, on the basis of both sca and mean value (Table 6) Kashi Pragati× Pusa Bhindi- 5 (good × good) was found to be best for chlorophyll a content, cross DOV-92 × Pusa Bhindi- 5 for both total carotenoid (good × good) and CUPRAC (good × poor) and DOV-1 × Pusa Bhindi- 5 (good × good) alone for total carotenoid. Additionally, Kashi Pragati × Pusa A-4 (good × poor) followed by DOV-64 × Pusa Bhindi-5 (good × good) was regarded best for ascorbic acid content, while DOV-64 × Pusa A-4 (poor × good) followed by DOV-2 × Pusa Sawani (good × poor) were regarded as best for sugar percentage. Similar type of resultswas also observed by several other workers (Rani *et al*. 2003, Hadiya *et al*. 2018 Singh *et al*. 2018). However, none of the cross combination was found to be the best on the basis both mean and sca effect for chlorophyll b and total phenolic content. It revealed that there must be involvement of at least one good combiner in

Table 4 Estimation of genetic components and contribution of lines, testers and their interaction to total variance for quality traits in okra

	Chl a (mg/100g)	Chl b (mg/100g)	Total carotenoids (mg/100g)	Ascorbic acid (mg/100g)	Sugar (%)	Total phenol (mg/100 g)	CUPRAC (mg/100g GAE)
Contribution of Lines (%)	38.96	31.05	26.63	43.03	34.77	50.91	37.80
Contribution of Testers (%)	27.28	26.85	21.77	4.47	14.46	1.63	8.02
Contribution of Line × Tester (%)	33.76	42.10	51.60	52.50	50.77	47.46	54.18
Var (lines)	1.50	0.08	0.01	25.63	0.01	114.08	215.99
Var (testers)	2.16	0.23	0.14	-2.81	0.01	-20.62	54.52
Var (gca)	0.16	0.01	0.01	1.23	0.00	5.16	13.39
Var (sca)	3.39	0.47	0.47	111.89	0.07	286.57	1467.52
Var(gca)/Var (sca)	0.05	0.03	0.01	0.01	0.01	0.02	0.01
Additive Variance (V_a)	0.32	0.03	0.01	2.46	0.00	10.32	26.78
Dominance Variance (V_d)	3.39	0.47	0.47	111.89	0.07	286.57	1467.52
V_a/V_d	0.10	0.05	0.02	0.02	0.03	0.04	0.02
Degree of Dominance	3.23	4.29	6.46	6.75	5.81	5.27	7.40
Predictability Ratio	0.09	0.05	0.02	0.02	0.03	0.03	0.02

Table 5 Promising parents of okra on the basis of gca effect and per se performance for quality traits in okra

Character	Best parent with gca effect	Best parent with *per se* performance	Best parent based on both gca effect and *per se* performance
Chl a (mg/100g)	Pusa Bhindi- 5 (1.70)	DOV- 25 (13.62)	Pusa Bhindi- 5
	DOV- 64 (1.57)	Pusa Bhindi- 5 (11.05)	
	Kashi Pragati (1.48)	DOV-92 (10.16)	
Chl b (mg/100g)	DOV- 64 (0.57)	DOV- 25 (4.95)	Pusa Bhindi- 5
	Kashi Pragati(0.55)	Pusa Bhindi- 5 (3.58)	
	Pusa Bhindi- 5 (0.51)	DOV-92 (3.24)	
Total carotenoid (mg/100g)	Kashi Pragati (0.49)	DOV- 25 (4.69)	DOV- 92
	DOV- 92 (0.47)	Pusa Bhindi- 5 (4.03)	
	DOV- 64 (0.47)	DOV-92 (3.71)	
Ascorbic acid (mg/100g)	DOV- 92 (11.93)	DOV- 62 (50.00)	DOV- 62 Kashi Pragati
	DOV- 62 (10.60)	Pusa Sawani (50.00)	
	Kashi Pragati (5.93)	DOV- 2/ Kashi Pragati (48.00)	
Sugar (%)	DOV- 92 (0.287)	DOV- 25 (2.24)	Kashi Pragati, DOV- 2
	Kashi Pragati (0.25)	Kashi Pragati (1.76)	
	DOV- 2 (0.25)	DOV- 2 (1.63)	
Total phenol (mg/100 g)	DOV- 62 (36.65)	Pusa A-4 (106.67)	Pusa Sawani
	DOV- 92 (13.34)	Pusa Sawani (96.00)	
	Pusa Sawani (2.64)	DOV- 25 (92.00)	
CUPRAC (mg/100g GAE)	DOV- 62 (44.52)	DOV- 64 (307.69)	-
	DOV- 92 (41.17)	DOV- 25 (307.69)	
	Pusa A-4 (16.83)	Pusa Sawani (307.69)	

Table 6 Promising hybrids of okra on the basis of sca effect and *per se* performance for quality traits in okra

Character	Best hybrid with sca effect	Best parent with *per se* performance	Best hybrid based on both sca effect and *per se* performance
Chl a (mg/100g)	DOV- 25 × Pusa A-4 (2.37)	Kashi Pragati × Pusa Bhindi- 5 (11.09)	Kashi Pragati × Pusa Bhindi- 5
	DOV- 25 × Pusa Sawani (2.08)	DOV- 92 × Pusa Bhindi- 5 (11.04)	
	Kashi Pragati × Pusa Bhindi- 5 (1.65)	DOV- 64 × Pusa Bhindi- 5 (9.78)	
Chl b (mg/100g)	DOV- 62 ×Pusa Bhindi- 5 (0.89)	DOV- 64 × Pusa Bhindi- 5 (3.65)	-
	DOV- 25 × Pusa A-4 (0.85)	DOV- 92 × Pusa Bhindi- 5 (3.64)	
	Arka Anamika × Pusa Bhindi- 5 (0.76)	Kashi Pragati 6 × Pusa Bhindi- 5 (3.43)	
Total carotenoid (mg/100g)	DOV- 25 × Pusa Sawani (0.88)	DOV- 92 × Pusa Bhindi- 5 (4.02)	DOV- 1 × Pusa Bhindi- 5 DOV- 92 ×Pusa Bhindi- 5
	DOV- 1× Pusa Bhindi- 5 (0.72)	Kashi Pragati ×Pusa Bhindi- 5 (4.00)	
	DOV- 92 × Pusa Bhindi- 5 (0.71)	DOV- 1 × Pusa Bhindi- 5 (3.58)	
Ascorbic Acid (mg/100g)	Kashi Pragati × Pusa A-4 (18.07)	Kashi Pragati × Pusa A-4 (60.00)	Kashi Pragati × Pusa A-4 DOV- 64 x Pusa Bhindi- 5
	DOV- 2 × Pusa A-4 (16.73)	DOV- 64 × Pusa Bhindi- 5 (60.00)	
	DOV- 64 × Pusa Bhindi- 5 (14.73)	DOV- 62 × Pusa Bhindi- 5 (58.00)	
Sugar (%)	DOV- 64 × Pusa A-4 (0.54)	DOV- 2 × Pusa Sawani (2.02)	DOV- 64 × Pusa A-4 DOV- 2 × Pusa Sawani
	DOV- 2 × Pusa Sawani (0.42)	Kashi Pragati × Pusa A-4 (1.99)	
	Arka Anamika × Pusa A-4 (0.37)	DOV- 64 × Pusa A-4 (1.96)	
Total phenol (mg/100 g)	DOV- 37× Pusa A-4 (21.23)	DOV- 62 ×Pusa Bhindi- 5 (98.67)	-
	IC- 685583 × Pusa A-4 (20.32)	DOV- 62×Pusa Sawani (96.00)	
	DOV- 25 × Pusa Sawani (19.34)	DOV- 92 × Pusa Sawani (70.92)	
CUPRAC (mg/100 g GAE)	IC- 685583 ×Pusa A-4 (62.66)	DOV- 92 × Pusa Bhindi- 5 (313.00)	DOV- 92×Pusa Bhindi- 5
	DOV- 92 × Pusa Bhindi- 5 (60.54)	DOV- 62 × Pusa Sawani (300.00)	
	DOV- 64 × Pusa A-4 (47.27)	DOV- 2×Pusa A-4 (276.92)	

each best cross combination that indicated the presence of both additive and non-additive components. Concurrently, the crosses which are the combination of both good × good combiner parents and exhibited both high mean value as well as high sca effect for a specific traits revealed the role of cumulative effect of additive and additive × additive gene action. Similar findings were also reported by Prakash *et al*. (2003) in cabbage.

Studies of gene components and contribution of lines, testers and their interaction

From Table 4, it was estimated that the contribution of lines towards genetic variances was greater than testers for all the traits. Contribution of interaction between lines and testers was also greater from both the lines and testers for majority of the traits, except for chlorophyll a content. Contribution from female lines greater than male was also in same line as reported by Kishor *et al*. (2013) and Akotkar *et al.* (2014). Magnitude of variance due to gca was lower than variance due to sca for all traits indicated the presence of dominance variance for all the traits studied. However, estimation of value of degree of dominance more than one and value of predictability ratio less than 0.5 also supported the prevalence of non-additive components for all the traits. Presence of non-additive gene action for most of the characters were also reported by Kumar *et al.* (2013).

It was concluded that on overall basis, Pusa Bhindi-5, DOV-92, Kashi Pragati 6, DOV-62, DOV-2 and Pusa Sawani were found to be best combiner parents for different plant pigment and antioxidant traits. Similarly, for better F_1 combinations in most of the crosses, presence of Pusa Bhindi-5, DOV-92 or Kashi Pragati as one parent showed desired value for most of the traits, irrespective of its high sca value showing their importance in the hybrid development.

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