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Combining ability studies in okra [*Abelmoschus esculentus* (L.) Moench]

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Abstract
The experiment was undertaken to study the combining ability for yield and its contributing traits in okra. The experimental material consisted of seven parents and 21 F_1s produced from diallel mating design excluding reciprocal crosses in randomized block design for fourteen characters. The mean squares due to *gca, sca* effects were significant for fruit yield and yield contributing traits studied. None of the parents identified as good general combiner for fruit yield per plant but the parents AOL-10-22, VRO-6, HRB-55 and AOL-12-59 were identified as average general combiners for yield per plant and can be exploited well in further breeding programme. The estimates of *sca* effects revealed that the cross combinations AOL-10-22 × GAO-5, AOL-10-22 × VRO-6, JDNOL-11-01 × Arka Anamika and HRB-55 × AOL-12-59 were observed most promising for fruit yield and some of its related traits could be used as heterotic hybrids.

Keywords: Combining ability, *Abelmoschus esculentus* (L.) Moench, experimental material

Introduction
Okra [*Abelmoschus esculentus* (L.) Moench] has a prominent position in vegetables due to its wide adaptability, wide popularity, year round export potential and high nutritive value. It is commonly known as Bhindi, lady's finger or gumbo, being a native of tropical Africa and belongs to family Malvaceae. Okra is an amphidiploids having 2n=130 chromosomes. It is an often cross pollinated crop. Immature fresh and green seed pods are consumed as vegetable. It offers mucilaginous consistency after cooking. Often the extract obtained from the fruit is added to different recipes like soups, stews and sauces to increase the consistency. The immature pods are also used in making pickle. The entire plant is edible and is used to have several foods (Babu and Srinivasan, 1995; Madison, 2008; Lim, 2012; Jain *et al*., 2012; Maramag, 2013) [2, 7, 4, 8]. Okra is widely used in ethno medicine in diverse cultures. In Ayruveda, okra is used as an edible infusion and in different preparation for diuretic effect (Maramag, 2013) [8]. An infusion of the fruit mucilage is also used to treat dysentery and diarrhea in acute inflammation and irritation of the stomach, bowels, and kidneys catarrhal infections, ardour urinae, dysuria and gonorrhea. Seeds are used as antispasmodic, cordial and stimulant (Lim, 2012) [4]. Leaves and root extracts are served as demulcent and emollient poultice (Babu and Srinivasan, 1995) [2]. The magnitude of heterosis for yield and its components provides a basis for determining genetic diversity and also serves as a guide for the choice of desirable parents for developing superior F1 hybrids to exploit hybrid vigour. Knowledge of heterosis of yield and its component characters should be placed greater emphasis for the improvement for this crop. Keeping this in view the objective of the present investigation was to assess the magnitude of heterosis for fruit yield and its components in okra.

Materials and Method
The present study consists of 7 different okra genotypes viz., JDNOL-11-01, AOL-10-12, VRO-6, GAO-5, HRB-55, AOL-12-59 and Arka Anamika. The genotypes are crossed in diallel fashion excluding reciprocals to produce 21 hybrids in late kharif 2016. These 21 F_1 hybrids evaluated along with their 7 parents and check HOK-152 in Randomized block design in three replications during summer 2017 at university farm, Department of Genetics and Plant Breeding, Navsari Agricultural University, Navsari.
Each plot consisted of a single row of 10 plants. Inter and intra row spacing was kept 60 and 30 cm, respectively. Agronomic practices followed as per the standard recommendation and sufficient protection measures were taken to raise a healthy crop stand. The different 14 quantitative characters like Days to 50 per cent flowering, Plant height, Number of primary branches per plant, Number of fruits per plant, Fruit yield per Plant, Fruit weight, Fruit length,

Fruit girth, Internodes per plant, Photosynthetic rate, Leaf area, Chlorophyll content, Stomatal conductance and Transpiration rate has been recorded. The various observations were recorded on five competitive plants in each plot leaving border ones.

Results and discussion

The knowledge of combining ability is necessary for selection of appropriate parents in hybridization. Since it gives an idea whether a particular parent combines well in a cross and also denote the specific performance of a cross combination against the expectations from the *gca* of the parents. The analysis of variance for the combining ability was carried out for all the observed fourteen characters (Table 1).The mean squares due to *gca* effect significant for majority of characters and *sca* effects were significant for all the characters, indicating substantial genetic variations for *gca*, *sca* and reciprocal effect for all the characters studied.

An overall appraisal of *gca* effects revealed that parents *viz*., AOL-10-22, VRO-6, HRB-55 and AOL-12-59 were found to be average general combiners for fruit yield per plant. None of the parent found to be good general combiner for fruit yield per plant (Table 2.). Among parents, JDNOL-11-01 observed to be good general combiners for days to 50 per cent flowering and fruit length. AOL-10-22 also exhibited good *gca* effects for plant height and primary branches per plant. Among parents, VRO-6 was reported to be good combiners for primary branches per plant, fruit girth, stomatal conductance and transpiration. Similarly, GAO-5 reported as good combiner for fruit girth. Parent HRB-55 also exhibited good gca for chlorophyll content. AOL-12-59 recorded good gca for traits like days to 50 per cent flowering, chlorophyll content, stomatal conductance and transpiration rate. Arka Anamika exhibited poor gca for all traits The general combining ability (gca) effects of the parents revealed that none of the parent was found to be good general combiner for all the traits. Present findings are in close association with the results of Rajani *et al.* (2001) [17], Sharma *et al*. (2008) [19], Raghuvanshi *et al.* (2011) [15], Obiadalla-Ali *et al.* (2013) [10], Kayande *et al*. (2018) [5] and Reddy *et al.* (2018) [18].

Specific combining ability effects are indicative of heterosis. Similarly they represent both dominant and epistatic gene actions. The promising F_1 hybrids based on specific combining ability effect for yield and its components are presented in (Table 3). Out of twenty one hybrids, AOL-10-22 × GAO-5 (88.27), AOL-10-22 × GAO-5 (78.17), JDNOL-10-22 × Arka Anamika (38.75) and HRB-55 × AOL-12-59 (34.01) depicted highest significant and desirable sca effect. This cross also showed significant *sca* effect for seven other component characters in F1.

The estimates of specific combining ability effect for days 50 per cent flowering indicated that out of twenty one hybrids, GAO-5 × HRB-55 (-3.36), AOL-12-59 × Arka Anamika (-3.21) and VRO-6 × GAO-5 (-3.18) depicted significant negative sca effects. For plant height out of twenty one hybrids, AOL-10-22 × GAO-5 (32.60) depicted highly significant and desirable sca effect followed by AOl-10-22 × VRO-6 (29.02), JDNOL-11-01 × AOL-12-59 (9.52) and HRB-55 × Arka Anamika (9.19).

AOL-10-22 × GAO-5 (1.00), AOL-10-22 × VRO-6 (0.53), JDNOL-11-01 (0.25) and HRB-55 × Arka Anamika (0.23) were top ranking cross combination which exhibited significant sca effect for primary branches per plant. For fruits per plant, highest significant and positive sca effect was recorded by cross AOL-1.-22 × GAO-5 (4.76) followed by AOL-1.-22 × VRO-6 (3.93), HRB-55 × AOL-12-59 (2.29) and VRO-6 × GAO-5 (1.83) and thus these combinations proved to be good for higher number of fruits per plant.

AOL-10-22 × VRO-6 (2.41), AOL-10-22 × GAO-5 (2.40) and JDNOL-11-01 × Arka Anamika (1.36) recorded as top three cross combination which depicted significant and positive sca effect for fruit weight. Similarly, JDNOL-11-01 × Arka Anamika (1.67), GAO-5 × HRB-55 (1.53) and GAO-5 × AOL-12-59 (1.16) were recorded as top three ranking cross combination which exhibited significant positive sca effects for fruit length.

For fruit girth, GAO-5 × AOL-12-59 (1.17), JDNOL-11-01 × HRB-55 (1.13) and AOL-12-59 × Arka Anamika (0.47) depicted significant and positive sca effect, thus proved to be good specific cross combinations. Out of total twenty one hybrids, AOL-10-22 × VRO-6 (3.30) and AOL-10-22 × GAO-5 (2.82) depicted significant positive sca effect for internodes per plant. AOL-10-22 × GAO-5 (9.09), JDNOL-11-01 × Arka Anamika (6.44) and AOL-10-22 × VRO-6 (5.91) were recorded as top three superior cross combination which exhibited significant positive sca effects for photosynthetic rate.

Similarly for leaf area, AOL-10-22 × GAO-5 (13.31), AOL-10-22 × VRO-6 (10.20) and HRB-55 × AOL-12-59 (10.17) were the top three superior specific cross combinations. Among twenty one hybrids, AOL-10-22 × GAO-5 (14.93), HRB-55 × AOL-12-59 (7.85) and JDNOL-11-01 × AOL-10-22 (6.74) were the top three superior specific cross combinations for chlorophyll content.

AOL-10-22 × GAO-5 (25.20), AOL-10-22 × GAO-5 (16.59) and JDNOL-11-01 × Arka Anamika (15.22) were the top three superior specific cross combinations for stomatal conductance trait. Among the hybrids AOL-10-22 × VRO-6 (1.68), AOL-10-22 × GAO-5 (1.65) and VRO-6 × GAO-5 (1.13) depicted significant and positive sca effect, thus this combination proved to be best for transpiration rate.

The above results confirmed the finding obtained by Pawar *et al*. (1999) [13], Rajani *et al.* (2001) [17], Bendale *et al.* (2004) [3], Aliu *et al.* (2008) [1], Sharma *et al.* (2008) [19], Pal and Sabesan (2009) [11], Murugan *et al*. (2010) [9], Rai *et al.* (2011) [16], Raghuvanshi *et al.* (2011) [15], Prakash *et al.* (2012) [14], Obiadalla- Ali *et al.* (2013) [10], Wakode *et al.* (2016) [20], Kayande *et al*. (2018) [5].

Table 1: Analysis of variance for combining ability of okra

Sources of variation	d. f.	Days to 50% flowering	Plant height (cm)	Primary branches per plant	Fruits per plant	Fruit yield per plant (g)	Fruit weight (g)	Fruits length (cm)
Gca	6	11.64**	36.93	0.20**	0.82	172.99	0.22	0.78
Sca	21	7.56**	156.57**	0.13**	3.98**	1489.79**	1.65**	0.99**
Error	54	2.59	19.65	0.01	0.97	108.94	0.43	0.39**
σ^2gca		1.01	1.92	0.02	-0.02	7.12	-0.02	0.05
σ^2sca		4.98	136.92	0.12	3.01	1380.85	1.22	0.65
σ^2gca/ σ^2sca		0.20	0.02	0.17	-0.01	0.01	-0.02	0.07

Sources of variation	d. f	Fruit girth (cm)	Internodes per plant	Photosynthetic rate(μ mole/m²)	Leaf area (cm²)	Chlorophyll content (SPAD reading)	Stomatal conductance (μmole/m²/sec)	Transpiration rate
gca	6	0.43**	0.77	3.96	18.54	12.12**	122.06**	0.38**
sca	21	0.39**	2.75**	21.84**	58.27**	48.48**	15.91**	1.09**
Error	54	0.05	0.99	3.02	9.78	1.17	20.80	0.11
σ^2gca		0.04	-0.03	0.11	0.97	1.22	11.25	0.03
σ^2sca		0.34	1.75	18.83	48.49	47.31	145.11	0.98
σ^2gca/ σ^2sca		0.13	-0.02	0.01	0.02	0.03	0.08	0.03

* Significant at 5% level, ** Significant at 1% level

Table 2: General combining ability effect of parents for various characters in okra

Sources of variation	Days to 50% flowering	Plant height (cm)	Primary branches per plant	Fruits per plant	Fruit yield per plant (g)	Fruit weight (g)	Fruit length (cm)	Fruit girth (cm)	Internodes per plant	Photosynthetic rate (μ mole/m²)	Leaf area (cm²)	Chlorophyll content (SPAD reading)	Stomatal conductance (μmole/ m²/ sec)	Transpiration rate
JDNOL-11-01	G	P	P	P	P	P	G	P	A	P	P	P	P	P
AOL-10-22	P	G	G	A	A	P	P	P	P	A	A	P	P	P
VRO-6	A	A	G	A	A	P	A	G	P	P	A	A	G	G
GAO-5	A	A	P	P	P	A	A	G	A	P	P	A	P	P
HRB-55	P	P	P	A	A	P	P	P	A	A	P	G	A	A
AOL-12-59	G	P	P	P	A	A	P	A	A	A	A	G	G	G
Arka Anamika	P	P	P	P	P	P	P	P	P	P	P	P	P	P

G = Good combiner, A = Average combiner and P = Poor combiner

Table 3: Estimation of specific combining ability (sca) effect of crosses for various characters in okra

Crosses	Days to 50% flowering	Plant height (cm)	Primary branches per plant	Fruits per plant	Fruit yield per plant (g)	Fruit weight (g)	Fruit length (cm)
JDNOL-11-01 × AOL-10-22	-1.73	-0.02	0.01	0.19	21.74*	1.18*	0.65
JDNOL-11-01 × VRO-6	-0.29	1.42	-0.22*	-0.54	11.72	-0.28	0.52
JDNOL-11-01 × GAO-5	-0.32	-6.76	0.19	-0.71	-13.05	-0.29	-0.59
JDNOL-11-01 × HRB-55	0.86	5.52	0.25*	-1.22	-4.74	0.76	-0.78
JDNOL-11-01 × AOL-12-59	1.79	9.52*	-0.12	0.10	-4.98	0.30	0.19
JDNOL-11-01 × Arka Anamika	-2.77	-9.95*	0.05	0.74	38.75**	1.36*	1.67**
AOL-10-22 × VRO-6	-2.25	29.02**	0.53**	3.93**	78.17**	2.41**	0.47
AOL-10-22 × GAO-5	-2.29	32.60**	1.00**	4.76**	88.27**	2.40**	0.96
AOL-10-22 × HRB-55	-2.44	-6.12	-0.21*	-1.75*	-39.94**	-1.36*	-0.90
AOL-10-22 × AOL-12-59	0.82	-4.76	-0.18	-0.70	-1.15	0.79	0.67
AOL-10-22 × Arka Anamika	1.27	-6.66	-0.41**	-1.32	-27.10**	-0.36	0.55
VRO-6 × GAO-5	-3.18*	-1.4	0.17	1.83*	19.75*	0.61	0.69
VRO-6 × HRB-55	5.01**	-5.96	-0.10	-0.28	-29.75**	-0.81	0.24
VRO-6 × AOL-12-59	-0.73	0.46	0.06	-1.56	12.26	-0.07	-0.33
VRO-6 × Arka Anamika	-0.29	-7.08	0.17	-1.65	-25.74**	-0.81	0.02
GAO-5 × HRB-55	-3.36*	-2.98	-0.43**	-2.25*	8.40	-0.49	1.53**
GAO-5 × AOL-12-59	-0.44	0.98	-0.60*	-0.53	-5.33	0.32	1.16**
GAO-5 × Arka Anamika	-1.32	-0.10	0.11	-0.55	-25.19**	-1.22*	-1.43**
HRB-55 × AOL-12-59	-1.58	-8.89*	0.06	2.29**	34.01**	0.90	-0.49
HRB-55 × Arka Anamika	3.86**	9.19*	0.23*	0.34	2.49	0.16	-0.95
AOL-12-59 × Arka Anamika	-3.21*	0.71	0.06	-1.35	-28.43**	-1.10*	-1.11*

Crosses	Fruit girth (cm)	Internodes per plant	Photosynthetic rate (μ mole/m²)	Leaf area (cm²)	Chlorophyll content (SPAD reading)	Stomatal conductance (μmole/m²/sec)	Transpiration rate
JDNOL-11-01 × AOL-10-22	0.55**	0.56	5.19**	8.53**	6.74**	5.25	0.74*
JDNOL-11-01 × VRO-6	-0.72**	-0.26	-1.70	-1.73	-3.77**	-1.66	-0.38
JDNOL-11-01 × GAO-5	0.13	-1.21	-3.41*	-7.00*	-6.59**	-12.95**	-0.87**
JDNOL-11-01 × HRB-55	1.13**	-1.21	-2.37	-0.66	-2.25*	0.88	0.18
JDNOL-11-01 × AOL-12-59	0.06	0.46	3.02	2.48	-0.41	6.41	0.63*
JDNOL-11-01 × Arka Anamika	-0.37	0.61	6.44**	8.12**	6.22**	15.22**	0.72*
AOL-10-22 × VRO-6	-0.79**	3.30**	5.91**	10.20**	6.21**	16.59**	1.68**
AOL-10-22 × GAO-5	0.46*	2.82**	9.09**	13.31**	14.93**	25.20**	1.65**
AOL-10-22 × HRB-55	0.06	-2.18*	-7.16**	-12.21**	-11.65**	-18.75**	-1.77**
AOL-10-22 × AOL-12-59	-0.61**	-0.52	-0.91	-0.99	-1.30	-0.24	-0.25
AOL-10-22 × Arka Anamika	-0.24	-1.43	-3.04	-5.86*	-5.25**	-7.99	-0.83*
VRO-6 × GAO-5	0.39	0.06	5.31**	10.09**	1.89	9.78*	1.13**
VRO-6 × HRB-55	-0.21	-0.80	-2.84	-3.70	-3.94**	-9.98*	-0.69*
VRO-6 × AOL-12-59	0.33	-0.47	-1.54	-2.12	-2.59**	-3.23	-0.77**
VRO-6 × Arka Anamika	0.30	-0.92	-3.39*	-9.20**	-6.17**	-15.17**	-1.15**
GAO-5 × HRB-55	0.24	-2.33**	-2.20	-6.29*	5.36**	-12.81**	-0.78**
GAO-5 × AOL-12-59	1.17**	-0.55	-2.36	0.22	-2.88**	0.93	-0.26
GAO-5 × Arka Anamika	-0.86	-0.73	-3.28*	-6.55*	-6.32**	-13.32**	-0.97**
HRB-55 × AOL-12-59	-0.03	1.25	5.59**	10.17**	7.85**	13.81**	0.92**
HRB-55 × Arka Anamika	-0.06	-0.26	-1.24	3.26	-1.19	-0.67	-0.26
AOL-12-59 × Arka Anamika	0.47*	1.96*	-1.99	-3.11	-5.85**	-10.28*	-0.61*

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