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UR Javiya
Department of Genetics and Plant Breeding, College of Agriculture Junagadh Agricultural University, Junagadh, Gujarat, India

DR Mehta
Department of Genetics and Plant Breeding, College of Agriculture Junagadh Agricultural University, Junagadh, Gujarat, India

MH Sapovadiya
Department of Genetics and Plant Breeding, College of Agriculture Junagadh Agricultural University, Junagadh, Gujarat, India

DJ Pansuriya
Department of Genetics and Plant Breeding, College of Agriculture Junagadh Agricultural University, Junagadh, Gujarat, India

Corresponding Author:
UR Javiya
Department of Genetics and Plant Breeding, College of Agriculture Junagadh Agricultural University, Junagadh, Gujarat, India

Selection of parents and breeding methods based on combining ability and gene action for fruit yield and its contributing characters in okra (*Abelmoschus esculentus* L. Moench)

UR Javiya, DR Mehta, MH Sapovadiya and DJ Pansuriya

Abstract
The experiment was undertaken to study the combining ability for fruit yield and its contributing traits in okra. The experimental material consisted of eleven parents (8 lines and 3 testers) and 24 F_1's produced from line x tester mating design and evaluated in randomized block design for seven characters. The analysis of variance for combining ability revealed that the SCA variances were higher than their respective GCA variances for all the characters (except number of fruits per plant) confirmed the preponderance of non-additive gene action for most of the traits emphasized the utility of hybrid breeding approach to exploit existing heterosis in okra. The parents EC 169513, EC 30563 and VRO-6 were identified as good general combiners for most of the characters including fruit yield per plant and can be exploited well in further breeding programme. The estimates of sca effects revealed that the two cross combinations EC 169513 × GO-6 and EC 30563 × VRO-6 were observed most promising for fruit yield and some of its related traits which could be used as heterotic hybrids.

Keywords: Combining ability, gca and sca effects, gene action, line x tester analysis, okra

Introduction
Okra [*Abelmoschus esculentus* (L.) Moench] is a versatile vegetable crop, native of tropical Africa, commonly known as bhendi or lady's finger in India. It belongs to the family *Malvaceae* (Shoemaker, 1942) [14] under the order *Malvales*, having a somatic chromosome number of cultivated species 2n=8x=72 or 144 and is considered to be an amphidiploid. Okra comprising of valuable nutrients and the composition of okra pod per 100 g edible portion (81% of the product as purchased, ends trimmed) is: water 88.6 g; energy 144.00 kJ (36 kcal); protein 2.10 g; carbohydrate 8.20 g; fat 0.20 g; fibre 1.70 g; Ca 84.00 mg; P 90.00 mg; Fe 1.20 mg; β-carotene 185.00 µg; riboflavin 0.08 mg; thiamin 0.04 mg; niacin 0.60 mg; ascorbic acid 47.00 mg (Gamede *et al.* 2015) [4]. It is grown successfully during both summer and rainy seasons for its green tender fruits. During recent past, exploitation of hybrid vigour and selection of parents on the basis of combining ability effects have opened a new line of approach in crop improvement. Application of biometrical techniques like line x tester analysis has appeared to be the best and vastly useful breeding tool, which gives generalized picture of genetic potentialities of the parents for hybrid breeding.

Combining ability studies are more reliable as they provide useful information for the selection of parents in terms of performance of the hybrids and elucidate the nature of various types of gene actions involved in the expression of quantitative traits. The general combining ability and specific combining ability effects are the foundations for any fruitful breeding programme (Wakode *et al.*, 2016) [19]. The knowledge of nature of gene action governing the expression of various traits could be helpful in predicting the effectiveness of selection. Hence, the present investigation was undertaken to study the combining ability and gene action through line x tester mating design to identify the best suitable parents and cross combinations for genetic improvement in okra.

Materials and Methods
The experimental material comprised of 36 entries including eight lines *viz.*, EC 169573, EC 30563, EC 305623, EC 169513, IC 90107, IC 111493, IC 90117 and IC 052273; three testers namely GO-6, GAO-5 and VRO-6; and their 24 crosses along with a check hybrid (GJOH-4). The experimental was evaluated in a randomized block design with three replications during *Kharif*-2019 at the Vegetable Research Station, Junagadh Agricultural University, Junagadh. Each entry was presented by a single-row plot of twenty plants, spaced at 60 x 30 cm.

The observations on five randomly selected plants in each genotype of three replications were recorded for number of branches per plant, internodal length, number of fruits per plant, fruit length, fruit girth, ten fruits weight and fruit yield per plant. The data were analyzed for combining ability following procedure suggested by Kempthorne (1957) [6].

Results and Discussion

The analysis of variance for combining ability with respect to seven characters is presented in Table 1 revealed that the mean squares due to lines, testers and line x tester interaction were highly significant for all the characters (except mean square due to testers for intermodal length). This result indicated that both additive and non-additive genetic variances played an important role in the inheritance of all these traits under studied. The result was in accordance with the findings of Singh *et al.* (2006) [15], Sharma *et al.* (2008) [13], Solankey and Singh (2010) [16], Sharma and Singh (2012) [12], Kishor *et al.* (2013) [7], Jupiter *et al.* (2017) [5] and Padadalli *et al.* (2019) [10].

The estimated variance due to line component (σ^2_l) was significant for fruit girth, ten fruit weight and fruit yield per plant, while tester variance component (σ^2_t) was highly significant only for number of fruits per plant. On the other hand, variance due to line x tester interaction (σ^2_{lt}) was significant for all characters under study. The magnitude of GCA and SCA variances revealed that the SCA variances were higher in magnitude than their respective GCA variances for all the characters (except number of fruits per plant). This was further supported by the ratio of $\sigma^2\text{GCA}/\sigma^2\text{SCA}$ which was less than unity for most of the characters confirmed the preponderance of non-additive gene action for all the traits (except number of fruits per plant) emphasized the utility of hybrid breeding approach to exploit existing heterosis in okra (Cockerham, 1961) [3]. The lines were contributed higher than that of the testers for all the characters (except number of fruits per plant), while comparing attributes of lines, testers and line × tester interactions, lines contributed higher than testers and line x tester interaction only for fruit girth, ten fruit weight and fruit yield per plant. Only for number of fruits per plant testers contributed more than lines and line x tester interaction. For the characters like number of branches per plant, internodal length and fruit length, line x tester interaction contributed much higher proportion than lines and testers.

The information regarding general combining ability effects of the parents is of prime importance as it helps in successful prediction of genetic potentiality of crosses which is desirable in segregating population of often cross-pollinated crops. The analysis of general combining ability effects of the parents revealed that none of the parents was found good general combiner for all the characters under studied (Table 2). Line EC 169513 was found to be good combiner for fruit yield per plant and ten fruits weight. The female EC 30563 was identified as good combiner for number of fruits per plant, fruit length, ten fruits weight and fruit yield per plant. The female parent IC 90117 was manifested good gca effect for fruit length and fruit girth. On the other hand, among males, GO-6 was identified as good combiner for ten fruits weight, VRO-6 for number of fruits per plant and fruit yield per plant. Hence, these parents may be utilized for component breeding programme in okra.

The specific combining ability is associated with interaction effects, which may be due to dominance and epistatic component of variation that are non-fixable in nature. Hence, it can be utilized in generation like F_1 in evolving of best F_1 hybrids. In the present study, estimate of sca effects revealed that none of the crosses was consistently superior for all characters and the crosses exhibiting high sca effect for fruit yield per plant may or may not have high *sca* effect for its contributing characters. These findings are in accordance with the earlier findings of Poshiya and Shukla (1986) [11], Vijay and Manohar (1986) [18] and Balakrishnan *et al.*, (2009) [1].

The highest sca effect for fruit yield per plant was observed in the cross EC 305623 X VRO-6, which also expressed significant sca effects in desired direction for number of branches per plant, number of fruits per plant and ten fruits weight. This cross had poor x good general combining parents. The hybrid IC 052273 × VRO-6 showed highest sca effect for internodal length; IC 90117 × GO-6 for fruit length; EC 169573 × GAO-5 for fruit girth; EC 30563 × GAO-5 for fruit length and fruit girth and EC 169513 × GO-6 for ten fruits weight and fruit yield per plant (Table 3). These results are in accordance with the findings of Mehta *et al.* (2007) [8], Sharma *et al.* (2008) [13], Murugan *et al.* (2010) [9], Sharma and Singh (2012) [12], Bhatt *et al.* (2015) [2] and Verma *et al.* (2016) [17]. For number of branches per plant, number of fruits per plant and ten fruits weight two, five and four crosses showed significant and positive sca effects, respectively; for internodal length four crosses; for fruit length four crosses; for fruit girth six crosses; and for fruit yield per plant three crosses showed significant and positive sca effects.

For specific combining ability effects if the crosses showing high sca effects involving either both or one good general combiner parents, they could be successfully exploited for varietal improvement and expected to throw stable performing transgressive segregants carrying fixable gene effects. The most of the cross combinations which were either due to good x good, good x average, good x poor, average x average, average x poor and poor x poor besides exhibiting favourable and high additive effect of parents and manifest the complementary interaction effects and thus leads to higher sca effects. Thus, it appears that the selection of crosses merely on the basis of *per se* performance and sca effects may not be helpful, but gca effects of the parents should be given due consideration. An ideal combination to be exploited is one with higher degree of sca effect with higher *per se* performance and at least one parent with good general combining ability.

Overall, both GCA and SCA variances were important for inheritance of all the traits under studied. However, the predominance of SCA variance suggested that there is a considerable scope for further improvement through hybrid breeding programme. The line EC 30563 and tester VRO-6 were found good combiners for fruit yield and its contributing traits. The crosses with high sca effects for fruit yield and its components traits involved good x good, good x average, good x poor, average x average, average x poor and poor x poor general combiners. This reflected the role of both additive and non-additive gene actions in the genetic control of these traits. The presence of additive gene action would enhance the chance for making improvement through simple selection. For exploitation of non-additive effects, it appears worthwhile to intermate the selected progenies in early segregating generations, which would be resulted in the accumulation of favourable genes in segregating generations. Hence, bi-parental progeny selection may be useful to get some desirable transgressive segregants from such crosses.

The two crosses namely EC 169513 × GO-6 and EC 30563 × VRO-6 had high *per se* performance and desirable sca effects for fruit yield and some of its related components. Hence, it would be advantageous to exploit these hybrids in practical plant breeding programme.

Table 1: Analysis of variance for combining ability in line × tester set for fruit yield and its contributing characters in okra

Source	df	Number of branches per plant	Internodal length (cm)	Number of fruits per plant	Fruit length (cm)	Fruit girth (mm)	Ten fruits weight (g)	Fruit yield per plant (g)
Replications	2	0.071	0.71*	0.08	2.08*	0.15	175.68	442.54
Lines (L)	7	0.07**	1.47**	7.33**	2.53**	21.46**+	2276.44**+	13214.34**+
Testers (T)	2	0.103**	0.28	45.9**++	4.71**	2.30**	582.60**	3530.72**
Line × Tester	14	0.06*	0.90**	5.71**	1.88**	6.22**	571.12**	3683.66**
Error	46	0.02	0.16	1.24	0.49	0.43	55.23	637.88
Variance components								
σ^2l		0.005	0.15	0.68	0.23	2.34*	246.8*	1397.38*
σ^2t		0.003	0.005	1.86**	0.18	0.08	21.97	120.53
σ^2lt		0.0113*	0.25**	1.49**	0.46**	1.93**	171.96**	1015.26**
σ^2GCA		0.004	0.04	1.54**	0.19*	0.69*	83.29**	468.77**
σ^2SCA		0.0113*	0.25**	1.49**	0.46**	1.93**	171.96**	1015.26**
σ^2SCA / σ^2GCA		2.83	6.25	0.97	2.42	2.80	2.06	2.17
Per cent contribution								
Lines		31.01	43.90	22.99	33.17	62.09	63.50	61.20
Testers		13.98	2.41	41.20	17.62	1.90	4.64	4.67
Line × Tester		55.00	53.69	35.81	49.21	36.00	31.86	34.12

*, ** Significant at 5% and 1% levels when tested against error mean squares, respectively
+, ++ Significant at 5% and 1% levels when tested against line × tester interactions mean squares, respectively

Table 2: Estimation of general combining ability effects of parents of line × tester set for various fruit yield and its contributing characters in okra

Parents	Number of branches per plant	Internodal length (cm)	Number of fruits per plant	Fruit length (cm)	Fruit girth (mm)	Ten fruits weight (g)	Fruit yield per plant (g)
Lines							
1. EC 169573	-0.087	-0.057	0.021	-0.207	2.431**	7.597**	15.239
2. EC 30563	0.035	0.003	1.932**	0.670**	0.399	13.042**	50.039**
3. EC 305623	0.090	0.210	-0.235	-0.413	-1.097**	-3.958	-8.072
4. EC 169513	0.068	0.456**	0.599	-0.169	-2.512**	26.597**	55.521**
5. IC 90107	0.024	0.506**	-0.857*	-0.188	-0.387	-14.514**	-38.805**
6. IC 111493	0.079	-0.754**	-0.235	-0.112	-0.458	3.708	0.761
7. IC 90117	-0.087	-0.167	-0.701	0.966**	1.659**	-10.403**	-30.317**
8. IC 052273	-0.121*	-0.196	-0.524	-0.548*	-0.035	-22.069**	-44.367**
SE(gi) ±	0.05	0.13	0.37	0.24	0.22	2.48	8.42
SE(gi − gj) ±	0.07	0.19	0.52	0.33	0.31	3.50	11.91
Testers							
1. GO - 6	0.012	-0.023	-1.353**	0.167	-0.355*	5.681**	-7.660
2. GAO-5	-0.071*	0.118	-0.061	0.336*	0.212	-2.569	-6.325
3. VRO-6	0.058	-0.095	1.414**	-0.502**	0.143	-3.111*	13.984**
SE(gj) ±	0.03	0.08	0.23	0.14	0.13	1.52	5.16
SE(gi − gj) ±	0.04	0.12	0.32	0.20	0.19	2.15	7.29

*, ** Significant at 5% and 1% levels, respectively

Table 3: Estimates of specific combining ability effects of hybrids for various fruit yield and yield contributing characters in okra

Sr. No.	Hybrids	Number of branches per plant	Internodal length (cm)	Number of fruits per plant	Fruit length (cm)	Fruit girth (mm)	Ten fruits weight (g)	Fruit yield per plant (g)
1	EC 169573 × GO-6	-0.012	0.318	1.342*	-0.714	-1.291**	-3.014	13.082
2	EC 169573 × GAO-5	-0.063	-0.611*	-0.117	0.873*	2.559**	4.903	8.180
3	EC 169573 × VRO-6	0.075	0.293	-1.225	-0.159	-1.268**	-1.889	-21.262
4	EC 30563 × GO-6	0.032	-0.449	-0.269	0.066	0.684	-11.792**	-28.552
5	EC 30563 × GAO-5	-0.051	0.206	-0.628	0.940*	1.367**	8.458	8.013
6	EC 30563 × VRO-6	0.019	0.243	0.897	-1.006*	-2.051**	3.333	20.538
7	EC 305623 × GO-6	-0.190*	0.093	-1.603*	-0.201	-0.629	-16.458**	-46.640**
8	EC 305623 × GAO-5	-0.040	0.015	-0.461	0.230	0.173	0.792	-8.442
9	EC 305623 × VRO-6	0.231*	-0.108	2.064**	-0.029	0.456	15.667**	55.083**
10	EC 169513 × GO-6	-0.101	-0.076	0.831	-0.649	1.138**	17.653**	41.800**
11	EC 169513 × GAO-5	0.049	-0.184	-1.328*	-0.778	-0.912*	-4.431	-29.322
12	EC 169513 × VRO-6	0.053	0.259	0.497	1.427**	-0.226	-13.222**	-12.478
13	IC 90107 × GO-6	0.143	-0.156	-0.581	0.103	-0.419	-3.236	-16.374
14	IC 90107 × GAO-5	0.026	0.243	0.328	-0.446	0.533	-1.986	4.491
15	IC 90107 × VRO-6	-0.169	-0.087	0.253	0.342	-0.114	5.222	11.883
16	IC 111493 × GO-6	0.121	-0.456	-0.369	0.131	-0.182	-0.792	-7.140

17	IC 111493 × GAO-5	-0.096	-0.487*	1.672*	0.299	-1.109**	-15.208**	-4.609
18	IC 111493 × VRO-6	-0.025	0.943**	-1.303*	-0.430	1.290**	16.00**	11.749
19	IC 90117 × GO-6	-0.079	0.341	1.497*	0.947*	-0.209	17.986**	54.404**
20	IC 90117 × GAO-5	0.204*	0.388	-1.028	-0.582	-1.130**	4.236	-6.764
21	IC 90117 × VRO-6	-0.125	-0.724**	-0.469	-0.364	1.339**	-22.22**	-47.640**
22	IC 052273 × GO-6	0.087	0.383	-0.847	0.317	0.908*	-0.347	-10.579
23	IC 052273 × GAO-5	-0.029	0.435	1.561*	-0.536	-1.482**	3.236	28.452
24	IC 052273 × VRO-6	-0.058	-0.818**	-0.714	0.219	0.574	-2.889	-17.873
$SE(S_{ij}) \pm$		0.09	0.23	0.64	0.41	0.38	4.29	14.58
$SE(S_{ij} - S_{kl}) \pm$		0.13	0.33	0.91	0.58	0.54	6.07	20.62
$SE(S_{ij} - S_{ik}) \pm$		0.22	0.57	1.57	0.99	0.93	10.51	35.72
No. of positive and significant crosses		2	1	5	4	6	4	3
No. of negative and significant crosses		1	4	3	1	7	5	2

*, ** Significant at 5% and 1% levels, respectively

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