Eco. Env. & Cons. 30 (2) : 2024; pp. (467-473)
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ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2024.v30i02.006

Combining Ability for Yield and Yield Components Through Line X Tester in Okra (*Abelmoschus esculentus* (L.) Moench)

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(Received 22 September, 2023; Accepted 4 November, 2023)

ABSTRACT

The current investigation was carried out to evaluate eight lines and three testers as parents along with 24 hybrids through a Line× Tester mating design to study mean performance, gene action, general and specific combining ability effects for various yields and their contributing traits. The mean squares due to lines, testers and line × tester were significant for all the traits except testers, which were non-significant for fruit length, indicating significant variance between the genotypes. The ratio of GCA to SCA variation was less than unity, exhibited a prevalence of non-additive gene action for almost all the variables under study. Among the lines, EC 305613, IC 22232 and IC 18532 as well as the testers Varsha Uphar and Hissar Unnat recorded the best mean value and significant *gca* effects in the desired direction for the majority of the yield-attributing traits. The estimates of *sca* effects revealed that the three crosses EC 305613 × Varsha Uphar, IC 22232 × Varsha Uphar and IC 18532 × Hissar Unnat were found to be most promising for fruit yield and its contributing traits which could be used as heterotic hybrids.

Key words: *Combining ability, GCA, Line X Tester, SCA*

Introduction

Okra (*Abelmoschus esculentus* (L.) Moench) is a warm-season annual vegetable crop that is grown in tropical and subtropical areas of the world. It has the chromosomal number 2n=130 and belongs to the Malvaceae family. It occupies a significant position among vegetables because of its broad range of adaptability, year-round production, exportability and high nutritional content. Compared to most vegetables, it has a greater average nutritional value (3.21) (Arvind *et al.*, 2021). It is a great source of protein, minerals, carbohydrates and vitamins A, B and C.

Okra is prized for its immature green, soft and delectable fruit, which is cooked, preserved and consumed in many ways throughout the nation. India's total area is 10,436 mha, with a productivity of 17.96 tonnes per hectare and a production of 1,87,474 metric tonnes (Anonymous 2019). The major states in India that produce okra are Tamil Nadu, Uttar Pradesh, West Bengal, Odisha and Bihar (Kousalya *et al.*, 2021). Although India is the world's greatest producer of okra, production is fairly poor due to a lack of suitable location-specific high-yielding cultivars. Therefore, selecting the right parents for hybridization is important for producing heterotic hybrids.

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The combining ability is a significant genetic tool that serves as a benchmark for finding better cross-combinations that may be utilized commercially to exploit heterosis, in the choice of appropriate parents for hybridization and the assessment of inbreds on the basis of their genetic value. Additionally, it offers details on what kind of gene action that regulates the expression of certain traits and might help in forecasting whether selection would be successful. The present research aimed to investigate the combining ability and gene expression by utilizing Kempthorne's (1957) line × tester mating technique to detect the most suited parents and their crosses for genetic enhancement in okra.

Materials and Methods

The experimental material consisted of 8 lines *namely,* IC 14909, IC 18532, IC 22232, IC 22237, EC 305613, EC 305675, EC 305736 and EC 306720, and three testers, Hissar Unnat, Varsha Uphar and Arka Abhay. The eight lines and 3 testers have been crossed by using the Line × Tester mating technique to produce 24 F_1s during February 2022 at the "Plant Breeding Farm", Annamalai University, Faculty of Agriculture, Annamalai Nagar, Tamil Nadu. The 24 F_1s and their eleven parents (8 lines & 3 testers) have been evaluated in a RBD (Randomized Block Design) with 3 replications in June 2022. Each entry was raised in a row of 3.0 m length. Plants were spaced 30 cm apart from one another, with a row spacing of 45cm. The proposed agronomic and cultural approaches, along with the horticultural protection methods depending on plant requirements, were all effectively implemented. The observations were made on five randomly chosen plants and they included variables like days to first flowering,plant height (cm), number of branches per plant, number of fruits per plant, fruit length (cm), fruit girth (cm), fruit weight (g) and fruit yield per plant (g). According to the model proposed by Kempthorne (1957), combining ability's study along with the type of gene action for the traits mentioned above was calculated.

Results and Discussion

Analysis of variance (ANOVA)

The results of an ANOVA for the combining ability for eight traits of okra are displayed in Table 1, which shows that the mean squares due to testers and lines were significant for all the traits except testers, which were non-significant for fruit length. The mean squares due to the line × tester were also significant for all the traits, indicating significant variance between the parents. The magnitude of the SCA and GCA variance showed that the ó²SCA was greater than the corresponding ó²GCA for all the traits, which include fruit yield per plant, plant height, days to first flowering, number of branches per plant, fruit length, fruit girth, fruit weight andnumber of fruits per plant. This revealed the predominance of non-additive gene action. For all of the traits, the ratio of ó²GCA to ó²SCA was less than unity, signifying dominant gene action (non-additive) regulating the traits. It was clear from the results that non-additive gene action had a major in-

Table 1. Analysis of variance for combining ability analysis for yield and its component characters in okra

Source of Variations	D.f.	DFF	PH	NBPP	NFPP	FL	FG	FW	FYPP
Replication	2	0.16	2.46	0.02	0.99	0.05	0.02	0.08	86.38
Hybrid	23	23.73**	156.38**	1.95**	23.07**	5.46**	0.45**	3.33**	3950.37**
Lines	7	34.85**	259.51**	2.22**	51.81**	11.19**	0.65**	1.83**	7301.57**
Testers	2	64.54**	312.01**	2.00**	34.95**	1.02	0.29**	7.46**	5798.66**
L × T	14	12.34**	82.58**	1.80**	7.00**	3.22**	0.37**	3.49**	2010.72**
Error	46	0.94	2.61	0.02	0.31	0.21	0.02	0.18	104.69
GCA		0.26	1.70	0.01	0.37	0.05	0.01	0.02	44.66
SCA		3.80	26.66	0.60	2.23	1.00	0.12	1.10	635.34
GCA/SCA		0.07	0.06	0.01	0.17	0.05	0.08	0.01	0.07

** Significant at 1 *per cent* level

DFF - Days to first flowering
PH - Plant height (cm)
NBPP - Number of branches per plant
FL - Fruit length (cm)
FG - Fruit girth (cm)
NFPP - Number of fruits per plant
GCA- General combining ability
SCA- Specific combining ability
FW - Fruit weight (g)
FYPP - Fruit yield per plant (g)

fluence on the expression of all characters studied. The current study's findings, which describe the nature as well as magnitude of gene action, are crucial for selecting the parents to be utilized in hybridization programmes and for choosing the optimal breeding practices for the genetic enhancement of various traits in okra. Similar findings were previously achieved by Punia and Garg (2018), Sapavadiya *et al.*, (2019), Devi *et al.*, (2020), Kousalya *et al.*, (2021), and Narkhede *et al.*, (2021).

Per se performance

Per se performance was considered the most significant factor for the evaluation of parents and their

Table 2: Mean performance of the parents and hybrids for yield and its attributing characters

S. No.	Characters	Best performing parent Parents	Mean	Best performing crosses Hybrids	Mean
1	DFF	EC 305613	36.47	EC 305613 × Varsha Uphar	33.67
		IC 22232	36.67	IC 22232 × Varsha Uphar	35.21
		IC 18532	37.23	IC 22237 × Hissar Unnat	35.76
		Hissar Unnat	40.30	IC 18532 × Hissar Unnat	36.21
		Varsha Uphar	40.73	EC 305613 × Hissar Unnat	36.56
2	PH	EC 305613	74.45	IC 22232 × Varsha Uphar	64.18
		IC 18532	76.02	EC 305613 × Varsha Uphar	64.25
		IC 14909	78.03	IC 18532 × Hissar Unnat	66.32
		Varsha Uphar	74.39	IC 22237 × Hissar Unnat	66.32
				EC 305613 × Hissar Unnat	68.46
3	NBPP	EC 305613	5.76	EC 305613 × Varsha Uphar	7.55
		IC 22232	5.01	IC 22232 × Varsha Uphar	7.14
		IC 18532	4.87	IC 18532 × Hissar Unnat	6.98
		Varsha Uphar	5.29	IC 22237 × Arka Abhay	6.89
		Hissar Unnat	4.92	IC 22237 × Hissar Unnat	6.58
4	NFPP	EC 305613	22.17	EC 305613 × Varsha Uphar	32.67
		IC 22232	21.23	IC 22232 × Varsha Uphar	29.67
		IC 18532	20.46	IC 18532 × Hissar Unnat	28.80
		Varsha Uphar	21.23	IC 22237 × Varsha Uphar	28.78
		Hissar Unnat	20.56	IC 22237 × Hissar Unnat	27.99
5	FL	EC 305613	16.55	EC 305613 × Varsha Uphar	20.45
		IC 22232	15.82	IC 18532 × Hissar Unnat	19.74
		IC 18532	15.79	IC 22232 × Varsha Uphar	19.65
		Varsha Uphar	16.90	EC 305613 × Hissar Unnat	18.98
		Hissar Unnat	16.85	EC 305675 × Arka Abhay	18.76
6	FG	EC 305613	6.81	EC 305613 × Varsha Uphar	6.58
		IC 22232	6.18	IC 22232 × Varsha Uphar	6.48
		IC 18532	6.15	IC 18532 × Hissar Unnat	6.33
		Varsha Uphar	6.35	IC 22237 × Hissar Unnat	6.29
		Hissar Unnat	6.31	IC 22237 × Varsha Uphar	6.21
7	FW	EC 305613	17.44	EC 305613 × Varsha Uphar	19.58
		IC 22232	16.48	IC 22232 × Varsha Uphar	19.51
		Varsha Uphar	16.89	IC 18532 × Hissar Unnat	19.44
		Hissar Unnat	16.83	IC 22237 × Hissar Unnat	19.43
				EC 305613 × Hissar Unnat	18.76
8	FYPP	EC 305613	341.84	EC 305613 × Varsha Uphar	421.89
		IC 22232	338.21	IC 22232 × Varsha Uphar	392.67
		IC 18532	335.60	IC 18532 × Hissar Unnat	380.87
		Varsha Uphar	326.25	IC 22237 × Varsha Uphar	380.62
		Hissar Unnat	322.89	EC 305613 × Hissar Unnat	370.87

DFF - Days to first flowering FL - Fruit length (cm) PH - Plant height (cm) FG - Fruit girth (cm)
NBPP - Number of branches per plant NFPP - Number of fruits per plant
FW - Fruit weight (g) FYPP - Fruit yield per plant (g)

hybrids (Table 2). Based on *per se* performance, the line EC 305613 was earlier than other genotypes for days to first flowering, while EC 305613 and IC 22232 recorded the greatest mean for fruit weight. Among the lines, EC 305613, IC 22232 and IC 18532 exhibited the highest mean for fruit yield per plant as well as other contributing traits *viz*.,fruit length, number of fruits per plant, number of branches per plantand fruit girth. Among the testers, Varsha Uphar and Hissar Unnat recorded the best *mean* for reduction in plant height (expect Hissar Unnat), fruit weight, fruit length, fruit girth,number of fruits per plant, number of branches per plant and fruit yield per plant. Hissar Unnat had taken fewer days to days to first flowering while Varsha Uphar has been highly dwarfed. Therefore, the lines EC 305613, IC 22232 and IC 18532 as well as the testers Varsha Uphar and Hissar Unnat have been observed to be the best parents based on the *per se* performance of various parental genotypes.

The superiority of the hybrids was influenced by the parents, which were chosen based on mean performance. Among the 24 crosses, EC 305613 × Varsha Uphar, IC 22232 × Varsha Uphar and IC 18532 × Hissar Unnat noted the *greatest mean* for fruit yield per plant. Additionally, these cross combinations were superior performers for the number of branches per plant, fruit girth, fruit weight, fruit lengthand number of fruits per plant. In terms of days to first flowering, EC 305613 × Varsha Uphar emerged as the earliest flowering cross, whereas the IC 22232 × Varsha Uphar cross resulted in a very dwarf plant with a low mean for plant height. The chosen cross combinations either had both the parents (high × high) or at least one parent (low × high or high × low) with desirable mean performance for most of the traits studied.More*et al.,* (2017),Vekariya *et al.,* (2020), Keerthana *et al.,* (2021), and Ivin *et al.,* (2022) also noted similar findings.

Combining ability

Combining ability in crosses signifies the capability of parents to combine during the crossing process so that desirable genes are passed on to their offspring. Specific combining ability is helpful in the identification of extraordinary cross combinations, whilst general combining ability is helpful in the identification of superior parents. The gca effects of the parents are presented in Table 3.

According to estimations of *gca* effects, the lines EC 305613, IC 22237, EC 305736 and IC 22232 showed good general combiners fordays to first flowering and fruit yield per plant, while the line EC 305613 was a top general combiner for fruit weight. However, it was discovered that the lines EC 305613, IC 22232 and IC 18532 were effective gen-

Table 3. Estimates of general combining ability effects for lines and testers for all the traits under study

Parents	DFF	PH	NBPP	NFPP	FL	FG	FW	FYPP
Lines								
IC 14909	2.50**	6.05**	-0.50**	-0.91**	-0.12	-0.45**	0.33*	-11.78**
IC 18532	0.82*	-5.42**	0.09*	1.06**	0.77**	0.21**	-0.23	-11.51**
IC 22232	-1.90**	3.72**	0.48**	1.16**	0.85**	0.11*	-0.69**	7.56*
IC 22237	-1.29**	-6.19**	0.85**	2.24**	-2.28**	0.42**	0.02	27.95**
EC 305613	-2.76**	-5.67**	0.20**	2.42**	1.23**	0.09*	0.77**	35.21**
EC 305675	1.96**	2.02**	-0.27**	-4.70**	-0.14	-0.05	-0.24	-26.62**
EC 305736	-0.93**	6.77**	-0.31**	0.63**	0.39*	-0.23**	0.28	24.26**
EC 306720	1.60**	-1.28*	-0.56**	-1.91**	-0.71**	-0.10*	-0.24	-45.08**
Testers								
Hissar Unnat	-1.00**	-0.28	0.24**	0.08	-0.24*	-0.03	0.50**	0.33
Varsha Uphar	-0.90**	-3.46**	0.08**	1.17**	0.14	0.12**	0.10	15.38**
Arka Abhay	1.89**	3.74**	-0.32**	-1.24**	0.09	-0.09**	-0.60**	-15.70**
S.E. for *gca* effects (lines)	0.32	0.53	0.40	0.19	0.15	0.04	0.14	3.41
S.E. for *gca* effects (testers)	0.19	0.33	0.03	0.12	0.10	0.03	0.09	2.09

*significant at 5 *per cent* level; **significant at 1 *per cent* level

DFF - Days to first flowering
FL - Fruit length (cm)
S. E- Standard Error
PH - Plant height (cm)
FG - Fruit girth (cm)
gca- General combining ability
NBPP - Number of branches per plant
NFPP - Number of fruits per plant
FW - Fruit weight (g)
FYPP - Fruit yield per plant (g)

eral combiners for number of fruits per plant, fruit length,fruit girthand number of branches per plant. The line, IC 22237 had a good general combiner for reduction in plant height, followed by EC 305613 and IC 18532. Among the testers, Varsha Uphar and Hissar Unnat showed the best general combiners for number of branches per plant anddays to first flowering, but Hissar Unnat alone showed a good general combiner for fruit weight. The tester, Varsha Uphar recorded the best general combiner for traits like fruit girth,number of fruits per plant and fruit yield per plant. Based on the *gca* effects of the parents, the testers, Varsha Uphar and Hissar Unnat and the lines EC 305613, IC 22232, IC 18532 were good general combiners with desirable gca effects. As a result, in the current study, these parents have been selected for hybridization as they exhibited the significant *gca* effects and maximum *per se* value for most of the traits studied. The results of Joshi *et al.,* (2019), Pithiya *et al.* (2020), Suganthi *et al.* (2020), Rajani *et al.* (2021) and Mundhe *et al.* (2023) recorded that high meanvalue and significant GCA effects would influence the selection of the best parents for hybridization.

The specific combining ability effects should be given much importance for the evaluation of a hybrid. The estimates of the *sca* effects of twenty four crosses are given in Table 4. Among the 24 cross combinations, IC 18532 × Hissar Unnat, EC 305613 × Varsha Uphar, IC 22232 × Varsha Uphar and IC 22237 × Hissar Unnat exhibited significant and negative sca effects forplant height and days to first flowering. The cross combinations showing positive *sca* effects for the number offruits per plant and number of branches per plant were EC 305613 × Varsha Uphar, IC 18532 × Hissar Unnat, IC 22232 × Varsha Uphar and IC 22237 × Arka Abhay. The crosses, IC 18532 × Hissar Unnat, EC 305675 × Arka Abhay, EC 305613 × Varsha Uphar, IC 22232 × Varsha Uphar,EC 306720 × Arka Abhay and EC

Table 4. Estimates of specific combining ability (*sca*) effects of hybrids for all the traits under study

Hybrids	DFF	PH	NBPP	NFPP	FL	FG	FW	FYPP
IC 14909 × Hissar Unnat	1.98**	0.04	0.33**	0.47	0.34	0.08	0.48	2.17
IC 14909 × Varsha Uphar	-1.16*	2.07*	-0.05	-0.50	-1.04**	-0.11	-1.08**	15.10*
IC 14909 × Arka Abhay	-0.82	-2.11*	-0.28**	0.02	0.69*	0.03	0.60*	-17.27**
IC 18532 × Hissar Unnat	-3.38**	-3.51**	0.75**	1.75**	1.43**	0.39**	1.16**	46.47**
IC 18532 × Varsha Uphar	1.09	2.84**	-1.53**	-1.58**	-0.57*	-0.62**	-1.53**	-15.28*
IC 18532 × Arka Abhay	2.30**	0.67	0.78**	-0.17	-0.87**	0.23**	0.37	-31.19**
IC 22232 × Hissar Unnat	1.62**	10.69**	-0.50**	-0.38	-0.83**	-0.14	-1.94**	-7.29
IC 22232 × Varsha Uphar	-1.75**	-11.62**	0.69**	1.43**	0.89**	0.50**	2.10**	24.77**
IC 22232 × Arka Abhay	0.14	0.92	-0.19*	-1.05**	-0.05	-0.36**	-0.15	-17.48**
IC 22237 × Hissar Unnat	-1.72**	-2.74**	-0.42**	-0.24	-0.75**	0.14	0.90**	-3.58
IC 22237 × Varsha Uphar	2.20**	5.36**	-0.04	-0.54	-0.16	-0.09	-0.26	-7.43
IC 22237 × Arka Abhay	-0.48	-2.62**	0.46**	0.77*	0.92**	-0.06	-0.65*	11.01
EC 305613 × Hissar Unnat	0.55	-1.12	-0.36**	-0.74*	0.22	-0.35**	-0.52*	-9.64
EC 305613 × Varsha Uphar	-2.44**	-2.15*	1.38**	3.17**	1.31**	0.62**	0.71**	26.33**
EC 305613 × Arka Abhay	1.88**	3.27**	-1.02**	-2.42**	-1.53**	-0.27**	-0.19	-16.69**
EC 305675 × Hissar Unnat	-0.17	0.28	0.46**	-0.84*	-0.85**	-0.08	0.27	-24.81**
EC 305675 × Varsha Uphar	-0.07	0.30	-0.27**	-0.86*	-0.18	-0.12	0.00	-13.08*
EC 305675 × Arka Abhay	0.25	-0.58	-0.19*	1.70**	1.04**	0.20*	-0.28	37.89**
EC 305736 × Hissar Unnat	0.28	-3.86**	-0.15	-0.08	0.73**	-0.05	-0.05	-1.36
EC 305736 × Varsha Uphar	1.84**	0.32	-0.20*	-0.26	-0.05	0.00	0.06	-15.36*
EC 305736 × Arka Abhay	-2.13**	3.54**	0.35**	0.34	-0.69*	0.05	-0.01	16.72**
EC 306720 × Hissar Unnat	0.84	0.22	-0.12	0.07	-0.29	-0.01	-0.32	-1.96
EC 306720 × Varsha Uphar	0.29	2.87**	0.02	-0.87**	-0.21	-0.17*	0.00	-15.06*
EC 306720 × Arka Abhay	-1.14*	-3.10**	0.10	0.8*	0.49	0.18*	0.31	17.02**
S.E. for *sca* effects (hybrids)	0.55	0.93	0.08	0.32	0.27	0.08	0.25	5.91

*significant at 5 *per cent* level; **significant at 1 *per cent* level

DFF - Days to first floweringPH - Plant height (cm)NBPP - Number of branches per plantNFPP - Number of fruits per plantFL - Fruit length (cm) FG - Fruit girth (cm)FW- Fruit weight (g)FYPP - Fruit yield per plant (g) *sca*- Specific combining abilityS.E- Standard Error

305736 × Arka Abhay exhibited maximum positive and significant *sca* effects for fruit yield per plant. In addition, the crosses EC 305613 × Varsha Uphar, IC 22232 × Varsha Uphar and IC 18532 × Hissar Unnat exhibited desirable *sca* effects for other yield-attributing characters like fruit weight, fruit length and fruit girth. Similar reports have also been discussed by Javiya *et al.* (2020), Patel *et al*. (2021), Kharat *et al.* (2022) and Shinde *et al.* (2023).

In the current study, the three hybrids, EC 305613 × Varsha Uphar, IC 22232 × Varsha Uphar and IC 18532 × Hissar Unnat have been the best specific combiners and had superior *per se* performance for most of the yield contributing traits, *viz*., plant height, days to first flowering, fruit yield per plant, number of branches per plant, number of fruits per plant, fruit girth, fruit weight and fruit length. The parents of this cross combination show high × high, low × high, high × low and low × low*gca* effects for the above-mentioned traits. This indicated that additive (additive × additive) and non-additive gene effects (dominance × dominance and additive × dominance) played a predominant role and these crosses were utilized for heterosis breeding. Shwetha *et al.* (2021) and Timmareddygari *et al.* (2021) noted similar results.

Conclusion

On the basis of the results, the lines EC 305613, IC 22232 and IC 18532 and the testers Varsha Uphar and Hissar Unnat have been observed to be good general combiners along with high *per se* performance for yield and its contributing characters, while the 3 crosses, EC 305613 × Varsha Uphar, IC 22232 × Varsha Uphar and IC 18532 × Hissar Unnat have been superior specific combinations as they showed desirable *sca* effects along with superior *mean* performance for fruit yield and its contributing traits. The three cross combinations either had both parents (high × high) or at least one parent (low × high or high × low) with desirable *gca* effects for most of the traits studied, showing the importance of both additive and non-additive gene actions. Thus, it is concluded that the three crosses (EC 305613 × Varsha Uphar, IC 22232 × Varsha Uphar and IC 18532 × Hissar Unnat) were the most promising and were adjudged to be the best hybrids and appropriate for the exploitation of the hybridization programme.

Acknowledgement

The authors acknowledge the "Department of Genetics and Plant Breeding at the Faculty of Agriculture, Annamalai University in Tamil Nadu", which helped them and gave them all the resources they required to conduct this study.
Conflicts of interest: The authors declare that there is no conflict of interest.

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