Combining Ability and Gene Action Studies for Fruit Yield and its Component Traits in Okra [*Abelmoschus esculentus* (L.) Moench]

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Abstract

Background: Okra commonly known as Lady's finger is queen of vegetables. The study focuses on assessing the combining ability in okra (*Abelmoschus esculentus* L.) across 12 traits, encompassing characteristics like earliness and fruit yield. The choice of parents for hybridization plays a critical role in breeders efforts to enhance complex quantitative traits such as fruit yield and its components, necessitating thorough genetic evaluations of existing germplasm and newly developed lines. Criteria for parental selection hinge on the magnitude and nature of gene actions, aiming to breed recombinants with desirable traits post-hybridization.

Methods: In the study, 35 F_1 hybrids were developed from 12 genotypes of okra, involving 7 lines and 5 testers. Evaluation occurred in a randomized block design with 3 replications during *Kharif* 2023. Twelve quantitative traits were analyzed from five randomly selected plants of each parent and F_1 generation. Analysis included ANOVA for Line×Tester interaction and assessment of combining ability following Kempthorne suggestions in 1957. The effects of General combining ability (GCA) and specific combining ability were estimated (SCA).

Result: Non-additive gene activity prevailed in the study, with specific parents showing strong general combining abilities. Certain hybrid combinations displayed promising effects on fruit yield per plant, warranting further investigation. The analysis highlighted the significance of both additive and dominant genetic components in fruit yield, with dominance variance notably influencing certain traits. Overdominance and gene symmetry were observed, alongside a predominance of dominant alleles. High narrow-sense heritability was noted for most traits studied.

Key words: Earliness, GCA, Gene action, Non-additive, Okra, SCA, Yield.

Introduction

Okra [*Abelmoschus esculentus* (L.) Moench] is an annual herbaceous plant that is also referred to as ladys finger or bhendi in India. Although it is an oligopurpose crop, it is typically eaten in India as vegetables in various kinds of ways because of its green, soft fruits native to tropical Africa (Dholaria *et al.,* 2018). It makes up over 60% of fresh vegetable exports and has significant potential for foreign exchange. The world biggest producer of okra is India. Tropical African in origin, okra is native to Ethiopia and Sudan in northeastern Africa. Since then, it has spread to southern Europe, North, South and Central America, Asia and the Mediterranean (Abhilash *et al*., 2023). Many tropical and subtropical locations cultivate this warm-season vegetable crop worldwide. Originating from Tropical Africa, okra is highly valued for its young, green seed pods, which are frequently eaten either fresh or sundried (Ranga *et al*., 2019).

In India, there are eight species of Abelmoschus, with Abelmoschus esculentus being the only cultivated one, while Abelmoschus moschatus is also grown for its fragrant seeds (Gupta and Patra, 2021). However, despite its potential, substantial production and national consumption, Abelmoschus esculentus is overlooked due to the absence of high-yielding cultivars. The natural cross-pollination tendency of okra leads to extensive genetic diversity across various traits (Abhilash *et al*., 2024), highlighting the importance of this diversity in genetic advancements. Breeding programs focus on selecting better genotypes and hybrids to enhance crop productivity, especially in mineral-rich foods crucial for human diets (Shiri *et al*., 2024). The selection of appropriate breeding practices relies on understanding general combining ability (GCA) and specific combining ability (SCA) to capitalize on additive and non-additive gene actions, respectively, as outlined by Sprague and Tatum, (1942). While SCA reflects allele

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interactions, GCA elucidates additive gene effects, with SCA being the standard deviation of a cross's performance from the expected level based on parental GCA.

Line×Tester analysis technique suggested by (Kempthorne, 1957) stands as one of the most recognized and systematic methodologies for identifying superior parents and crosses. This approach serves as a fundamental prerequisite for success in any breeding initiative. Augmenting the potential for enhanced crop yields involves identifying optimal combinations of individual lines exhibiting high general combining ability, thereby facilitating the creation of more favourable recombinants for subsequent crop improvement endeavours. Considering all relevant factors, this investigation employed a Line×Tester mating method with twelve genotypes of okra that differ genetically. The study goals were to evaluate the impact of parents and crossing specific and general combining abilities on fruit yield and its various components, such as the type and level of the gene action involved in inheritance.

Materials and Methods

The present research was carried out during *Kharif* season 2023 at the Genetics and Plant Breeding Research Farm, School of Agriculture, Lovely Professional University, Phagwara, Punjab. The twelve genotypes of the study experimental material of okra (7 lines and 5 testers) and one standard check Punjab-8 (Table 1) evaluated in RBD with 3 replications by line×tester method developed 35 F_1s. The (7 lines are *viz*., Line I - Pusa Savani, Line II - Phule Vimukta, Line III - Phule Prajatiti, Line IV - Punjab Suhanani, Line V -GAO-8, Line VI - GO-6 and Line VII - Harita and 5 testers *viz*., Tester I - Arka Abhay, Tester II - GAO-5, Tester III - VRO-106, Tester IV - K-54 and Tester V -VRO-6) which are considered for their diversity in terms of several attributes. Ten plants in a single row plot were used to present each entry. Every advised agronomic practice and plant protection steps was adhered to properly and consistently. From each submission, five competitive plants were chosen at random for three replications.

Twelve quantitative traits were examine from five randomly selected plants of each parent and F_1 generation *viz.* DFF - Days to 50% flowering, DFP- Days to first picking, PH- Plant height (cm), NBP- Number of branches per plant, NNP- Number of nodes per plant, IL- Internodal length (cm), NFP- Number of fruits per plant, FL- Fruit length (cm), FG- Fruit girth (cm), FYP- Fruit yield per plant, TPP- Total number of picking per plant, NMFP- Number of marketable fruits per plant.

ANOVA for Line×Tester analysis for combining ability analysis and test of significance for different genotypes was carried out in accordance with (Kempthorne, 1957) and (Singh and Chaudhary, 1985). These traits were analysed for their performance, impacts on specific combining abilities, general combining abilities and gene action. There were two types of combining abilities: general (GCA) and specific (SCA) estimated by calculating the two-way table of female and male parents and then summing the values obtained over multiple replications given by Sprague and Tatum, (1942). The line, testers and the proportional contributions of their interactions to the overall variance are estimated in addition to the estimation of GCA and SCA accordance with (Panse and Sukhatme, 1967; Singh and Chaudhary, 1985).

Results and Discussion

A number of methods that enable quantitative genetic analysis and the choosing potential parents and crosses (line × testers) for potential abuse in the future are now available because of advancements in biometrical genetics. The parents that yield high-quality offspring after mating are extremely valuable to the plant breeder. A crop development programs potential to be successful depends on its ability to isolate successful cross combinations, which are identified as parents possessing strong combining ability. The significance of evaluating parents combining ability is emphasized since high-yielding parents often fail to combine well enough to create segregates of superior grade. Combining ability analysis is a useful technique for determining whether lines have a strong chance of passing on desirable qualities to their progeny. It also aids in identifying prospective crossings based on fruit yield and related characteristics. In addition, it makes the difference between additive and non-additive gene action apparent that contributes to character inheritance.

Analysis of variance

The analysis of variance showed significant differences among the parents (lines and testers), lines and testers, parents vs crosses and across most traits studied except for FG and FL in the comparison between lines and testers

Table 1: List of parents used in crossing programme with a standard check.

Lines (7)		Testers (4)		Standard Check
Pusa Savani	L_1	Arka Abhay	T_1	Punjab -8
Phule Vimukta	L_2	GAO-5	T_2	
Phule Prajatiti	L_3	VRO-106	T_3	
Punjab Suhanani	L_4	K-54	T_4	
GAO-8	L_5	VRO-6	T_5	
GO-6	L_6			
Harita	L_7			

Table 2: Analysis of variance (ANOVA) for Line × Tester for yield and its attributing traits.

Source of variation	DF	DFF	DTP	PH	NBP	NNP	IL	NFP	FL	FG	FYP	TPP	NMFP
Replications	2	2.19	3.12	3.30	0.55*	0.53	0.04	4.92	0.37	0.08	93.94	0.64	1.01
Treatments	46	15.11**	25.87**	372.16**	0.98**	7.11**	2.50**	53.09**	7.72**	0.78**	13574.42**	5.92**	14.63**
Parents	11	30.08**	25.80**	224.75**	1.13**	10.72**	1.31**	38.72**	5.05**	0.22*	17126.63**	3.79**	25.43**
Parents (Line)	6	21.36**	30.22**	181.53**	1.07**	8.11**	1.11**	48.26**	1.97*	0.18	24057.60**	3.21**	31.36**
Parents (Testers)	4	47.01**	21.89**	258.58**	1.47**	16.06**	1.72**	32.57**	9.12**	0.18	10813.57**	4.03**	22.52**
Parents (LvsT)	1	14.70*	14.97**	348.81**	0.06	5.20**	0.89**	6.08	7.22**	0.63*	792.96**	6.35**	1.45
Parentsvs crosses	1	15.32*	66.30**	20.58	1.06**	8.85**	5.77**	12.26**	24.97**	1.99**	2016.12**	41.03**	30.15**
Crosses	34	10.27**	24.70**	430.19**	0.93**	5.89**	2.79**	58.94**	8.08**	0.92**	12765.13**	5.58**	10.68**
Line effect	6	10.79	33.14	424.05	0.56	5.43	1.59	12.66	16.78*	2.04**	5087.24	9.62*	7.28
Tester effect	4	9.32	47.10	96.27	0.55	7.86	2.38	91.33	9.39	2.34**	14716.14	12.37*	4.40
Line*Tester effect	24	10.29**	18.86**	487.38**	1.08**	5.68**	3.16**	65.11**	5.69**	0.41**	14359.43**	3.43**	12.57**
Error	92	2.55	2.48	11.60	0.12	0.52	0.10	1.99	0.67	0.11	38.475	0.67	1.70

Note: *, **denotes significance at 5% and 1% respectively.

DF- Days to 50% flowering, DP- Days to first picking, PH- Plant height (cm), NBP- Number of branches per plant, NNP- Number of nodes per plant, IL- Internodal length (cm), NFP- Number of fruits per plant, FL- Fruit length (cm), FG- Fruit grith (cm), FYP- Fruit yield per plant, TPP- Total number of picking per plant, NMFP- Number of marketable fruits per plant.

(Table 2). These results similar findings reported by *viz.* (Sharma and Prasad, 2015; Singh *et al*., 2021; Ivin *et al.,* 2022).

Estimation of combining ability

The combining ability of the parents and crosses was used to classify them as good, average and bad combiners. Simple techniques like pedigree selection might be used to take advantage of crossings with strong SCA effects if their parents are also skilled general combiners, as long as the interaction additive×additive component was significant. (Table 3 and Table 4) showed the impact of hybrids Specific Combining Ability (SCA) lines and testers for 12 quantitative features during the *Kharif*-2023 evaluation. Good general combiners were defined as parents with strong GCA effects moving in the right direction average general combiners were defined as parents with positive GCA effects and parents with negative GCA affects were classified to be poor general combiners.

Pusa Savani emerged as the top general combiner for eight traits, followed by Punjab Suhanani. Other notable general combiners include GAO-8, GO-6, Harita, Phule Vimukta and Phule Prajatiti. Among the testers, VRO-6 and VRO-106 showed promise across multiple traits. Considering Phule Prajatiti as a parent in future breeding efforts could optimize genetic variability and streamline trait combinations.

In order to compare the lines in combinations for the traits combining ability was studied. Top twelve character combiners, both General and Specific for Line×Tester analysis of okra tabulated in (Fig 1). Data pertaining to DFF among female lines, single line is highly negative significant in GAO-8 and Phule Vimukta exhibited significant negative GCA effect whereas, among tester VRO-106 possess highest negative significant GCA effect. Maximum SCA effect found in GAO-8×Arka Abhay and GAO-8×K-54 which contributes DFF. Among female lines Phule Vimukta, whereas tester VRO-106 and Arka Abhay possess highest adverse major GCA impact for DFP, which are useful for earliness of the crop. Three crosses revealed that highly negative significant SCA effect *viz.* Phule Prajatiti×Arka Abhay, GAO-8×GAO-5and GAO-8 × K-54 which contributes DFP. In okra, earliness and small height are preferred. negative GCA effects are preferred for characteristics such as DFF and DFP. Desirable Combining ability *i.e.* GCA and SCA for DFF and DFP also resulted by Bhatt *et al*. (2015) and Singh *et al.* (2021).

For plant height female lines *viz.* Phule Vimukta and GAO-8 whereas tester GAO-5 possess highly positive significant GCA effect which contributes yield potential of the crop. GO-6×VRO-106, Punjab Suhanani×K-54 and Harita×VRO-6 exhibited maximum SCA effect. For NBP none of the parent among lines and testers found positive significant GCA effect. But, three crosses revealed that highly positive significant SCA effect *viz.* Phule Prajatiti×Arka Abhay, Phule Prajatiti×VRO-106 and GAO-8×K-54. For NNP female lines *viz.* Phule Prajatiti and Punjab Suhanani

Table 3: Estimates of specific combining ability (SCA) of crosses for twelve characters in Okra.

Crosses	DFF	DFP	PH	NBP	NPP	IL	NFP	FL	FG	FYP	TPP	NMFP
L1×T1	-0.50	-1.95*	-10.17**	-0.07	-0.08	0.84**	-0.81	1.04*	-0.36	-65.59**	-1.11	-1.11
L2×T1	0.12	-0.34	6.06**	-0.46*	-0.67	-1.05**	3.59**	0.34	-0.19	-70.82**	0.96	0.96
L3×T1	0.54	-3.72**	1.99	0.63**	1.60**	-1.02**	-1.93*	-0.59	0.16	108.46**	1.16	1.16
L4×T1	2.77**	-1.08	-10.87***	0.35	1.22**	-0.25	3.87**	0.54	-0.39	48.41**	-2.77**	-2.77**
L5×T1	-2.96**	4.47**	10.67**	-0.27	-1.72**	0.32	-1.83*	0.66	0.13	-61.75**	1.11	1.11
L6×T1	0.94	-0.57	-7.01**	0.43*	-1.23**	0.95**	-0.27	-2.41**	0.22	83.54**	0.67	0.67
L7×T1	-0.91	3.21**	9.32**	-0.61**	0.89*	0.20	-2.61**	0.40	0.42*	-42.26**	-0.01	-0.01
L1×T2	0.67	-0.15	9.82**	-0.23	1.44**	0.34	-3.77**	0.63	0.24	121.97**	-2.97**	-2.97**
L2×T2	-1.19	-1.97*	1.96	0.30	1.42**	0.28	-1.70*	-1.33**	-0.22	-47.58**	2.00*	2.00*
L3×T2	-2.07*	3.44**	-19.14**	-0.15	-2.72**	2.03**	5.50**	0.02	-0.04	-9.79**	0.97	0.97
L4×T2	-1.37	-0.17	13.36**	-1.24**	-1.58**	-1.51**	-2.66**	0.07	-0.26	-13.71**	2.89**	2.89**
L5×T2	3.58**	-3.95**	2.50	0.42*	0.60	-0.28	-1.99*	0.31	0.13	-73.07**	-1.27	-1.27
L6×T2	2.15*	2.86**	-5.14*	0.53*	1.13*	0.10	-0.44	1.41**	-0.17	-51.51**	-2.78**	-2.78**
L7×T2	-1.76	-0.04	-3.37	0.35	-0.30	-0.95**	5.08**	-1.13*	0.32	73.71**	1.15	1.15
L1×T3	-0.52	-0.07	2.67	0.18	0.75	-1.29**	-4.28**	-1.58**	0.58**	-69.17**	2.55**	2.55**
L2×T3	1.73	1.57	-21.14**	-0.21	-1.23**	0.16	7.59**	2.10***	-0.28	52.83**	-2.63**	-2.63**
L3×T3	-1.00	0.28	4.27*	0.68**	1.21**	-0.46*	-0.80	-0.73	-0.13	-61.71**	-2.36**	-2.36**
L4×T3	0.59	-0.66	-8.82**	0.14	0.16	1.34**	0.19	-0.68	0.31	26.77**	2.02*	2.02*
L5×T3	0.52	0.52	6.19**	-0.49*	-0.31	1.24**	3.03**	0.12	-0.65**	64.20**	-1.78*	-1.78*
L6×T3	-1.97	-0.43	19.90**	-0.81**	0.44	-0.65**	-3.71**	0.98*	0.06	15.97**	3.17**	3.17**
L7×T3	0.63	-1.20	-3.08	0.50*	-1.03*	-0.34	-2.02*	-0.22	0.10	-28.90**	-0.98	-0.98

Table 4: Estimates of specific combining ability (SCA) of crosses for twelve characters in Okra.

Crosses	DFF	DFP	PH	NBP	NPP	IL	NFP	FL	FG	FYP	DTPP	NMFP
L1×T4	-1.469	2.77**	8.12**	0.37	-1.53**	-0.67**	4.73**	2.18**	-0.37	-44.59**	-0.16	-0.16
L2×T4	-0.475	0.58	8.13**	-0.18	0.64	-0.08	-4.43**	0.74	0.19	13.60**	-0.68	-0.68
L3×T4	1.751	1.54	8.96 **	-0.62**	-0.74	-0.99**	-5.92**	0.44	0.21	51.76**	-0.94	-0.94
L4×T4	-0.489	-1.28	18.62**	0.20	0.50	-0.09	5.87**	-0.18	0.15	-10.37*	-0.15	-0.15
L5×T4	-2.122*	-3.89**	-17.59**	0.86**	1.58**	-0.06	-4.05**	-1.60**	0.34	11.79**	0.47	0.47
L6×T4	0.411	0.15	-10.58**	-0.62**	-1.78**	0.29	0.90	-1.14*	0.19	-55.98**	0.23	0.23
L7×T4	2.391*	0.11	-15.67**	-0.06	1.34**	1.61**	2.89**	-0.45	-0.72**	33.77**	1.23	1.23
L1×T5	1.822	-0.58	-10.45**	-0.25	-0.57	0.78**	4.13**	-2.29**	-0.08	57.37**	1.70*	1.70*
L2×T5	-0.185	0.16	4.97 *	0.55*	-0.16	0.67**	-5.05**	-1.86**	0.51*	51.97**	0.35	0.35
L3×T5	0.775	-1.55	3.91	-0.54*	0.65	0.47*	3.15**	0.86	-0.20	-88.73**	1.15	1.15
L4×T5	-1.498	3.19**	-12.29**	0.53*	-0.30	0.51**	-7.28**	0.24	0.18	-51.11**	-1.98*	-1.98*
L5×T5	0.969	2.85**	-1.78	-0.52*	-0.15	-1.22**	4.85**	0.49	0.03	58.82**	1.47	1.47
L6×T5	-1.531	-2.00*	2.83	0.48*	1.44**	-0.70**	3.53**	1.15*	-0.30	7.98*	-1.30	-1.30
L7×T5	-0.351	-2.07*	12.80**	-0.23	-0.89*	-0.53*	-3.33**	1.40**	-0.13	-36.32**	-1.39	-1.39
SE± (sca)	0.99	0.93	2.02	0.21	0.43	0.19	0.80	0.47	0.20	3.11	0.47	0.79
CD @ 5% (sca)	1.97	1.86	4.03	0.42	0.86	0.38	1.60	0.94	0.39	6.21	0.94	1.58
CD @ 1% (sca)	2.62	2.48	5.35	0.56	1.15	0.51	2.13	1.26	0.53	8.25	1.26	2.10

Note: *, **denotes significance at 5% and 1% respectively.

whereas teste Arka Abhay possess highly positive significant GCA effect which contributes yield potential as (Fig 2) showed NFP will be more per nodes of the crop. Among eight positive significant, Phule Prajatiti×Arka Abhay, Pusa Savani×GAO-5 and GAO-8×K-54 exhibited maximum SCA effect (Narkhede *et al.,* 2021) found similar results.

Internodal length Punjab Suhanani and GAO-8 while tester Arka Abhay and VRO-106 possess highly positive significant GCA effect. Out of 9 highly significant, Phule Vimukta×Arka Abhay, Phule Prajatiti×GAO-5 and Harita×K-54 exhibited maximum SCA effect. Silva *et al*. (2021) and Syed Majid Rasheed *et al*. (2024). also found positive significant effect. For NFP female lines only Harita while among testers K-54 and VRO-6 possess highly positive significant GCA effect. Phule Prajatiti×GAO-5, Harita×GAO-5, Phule Vimukta×VRO-106 and GAO-8×VRO-106 exhibited positive highly significant SCA effect among 13 significant crosses, which contributes yield potential as NFP, will be more per nodes of the crop. Anyaoha *et al*. (2022) found similar results for these traits.

For fruit length among female lines Phule Prajatiti and Punjab Suhanani while tester VRO-106 possess highly positive significant GCA effect. Phule Prajatiti×GAO-5, Pusa Savani×K-54 and Harita×VRO-6 exhibited positive SCA effect which contributes to yield. For FG among female lines Pusa Savani and GO-6 while tester VRO-6 possess highly positive significant GCA effect. Only single cross Pusa Savani×VRO-106 revealed highly positive significant SCA effect for FG. For FG and FL, Kumar *et al*. (2004) and Reddy *et al*. (2013). found similar results in same direction. Data pertaining to yield plant female lines *viz.* Phule Prajatiti and GO-6 whereas tester GAO-5 and K-54 possess highly positive significant GCA effect.

For the trait total number of picking per plant female lines *viz.* Pusa Savani and Harita whereas tester Arka Abhay possess highly positive significant GCA effect. Three crosses revealed highly positive significant SCA effect *viz.* Punjab Suhanani×GAO-5, Pusa Savani×VRO-106 and GO-6×VRO-106 that contribute to yield. demonstrated that the capacity for both specific (SCA) and general combining ability (GCA). For NMFP female lines *viz.* GO-6 possess highly positive significant GCA effect which contributes yield potential of the crop. Out of 35 crosses, only two crosses revealed that highly positive significant SCA effect *viz.* Punjab Suhanani x GAO-5 and GO-6×VRO-106. Shiri *et al*. (2024) estimated the combining ability to related trait.

These single crossings or their numerous cross combinations could be used to create a population with a wide genetic base. Every acceptable combination of parents with high, low and medium combining abilities was present in the crosses with significant SCA effects seen. This suggested that the crosses impacts on SCA were unaffected by GCA in general. High SCA effects could be attributable to additive×additive gene expression in crossings where both parents were good general combiners. The desirable epistatic outcomes of the poor general combiner and the

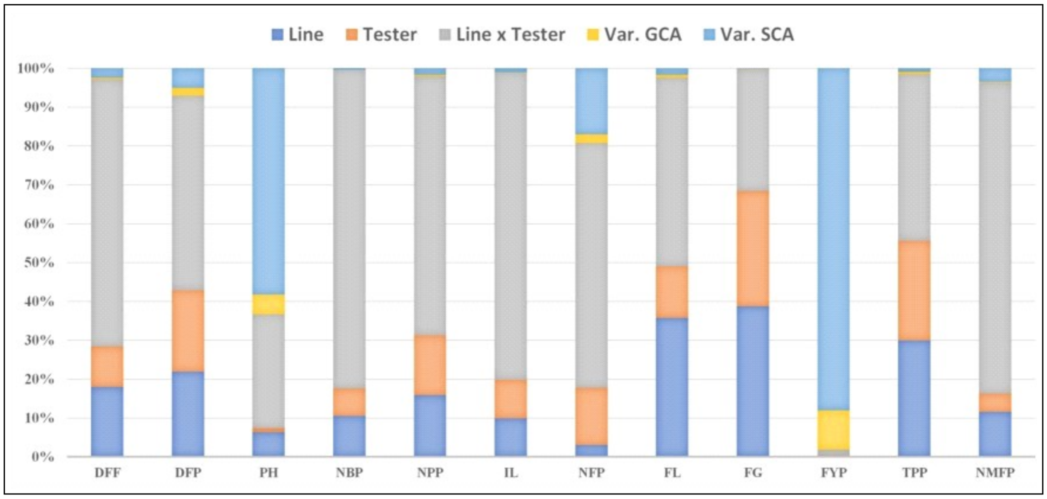

Fig 1: Contribution of lines, testers and line × tester for gene action.

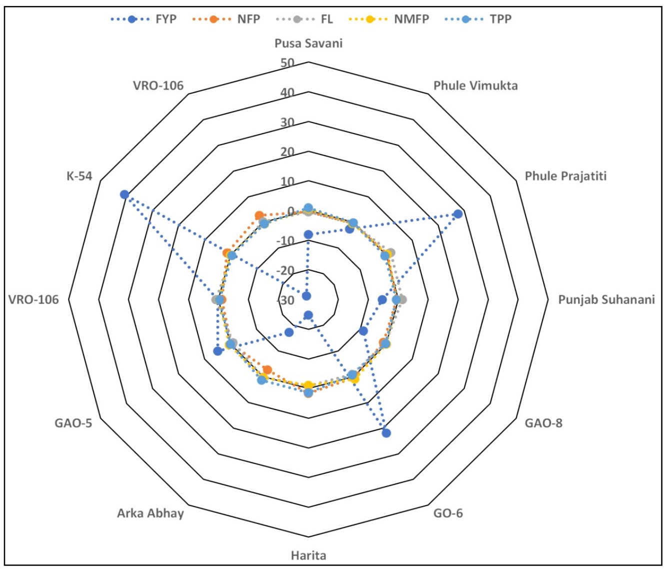

Fig 2: Estimates of general combining ability (GCA) for fruit yield attributes.

additive effects of the good general combiner parent, which augmented the desired plant feature, may be the cause of the crosses with the good×bad general combiner parents that have strong SCA effects. High SCA effects observed in low×low crosses may be explained by a non-allelic gene interaction of the dominance×dominance type that results in overdominance and is therefore unfixable. All things considered, the study indicates that choosing parents and crosses according to how well they combine is essential to improving okra yields and yield components.

Estimation of gene action

The gene action and the estimated variances of GCA and SCA (σ^2gca and σ^2sca), respectively. For every character, variance resulting from GCA is smaller than variance resulting from SCA *viz*., DFF, DFP, PH, NBP, NNP, IL, NFP, FL, FG, FYP, TPP and NMFP, indicating greater role of non-additive gene action in the control of these traits as reported earlier by Dholariya *et al.* (2018). This was also confirmed by the ratio of GCA to SCA variance will be less than unity for all the traits. This showed the fact that, although additive effects also play a major role in the features of okra, non-additive effects of the genes involved in their control are of a greater significance. The preponderance of non-additive gene action for DFF, DFP, PH, NBP, NNP, IL, NFP, FL, FYP, TPP and NMFP similar findings were recorded by Balat *et al.* (2022). Therefore, all the traits studied showed non-additive type of gene action. The trait of yield is under the control of multiple genes and is expressed in complex manner. Understanding the action of genes is essential for breeders to select the optimal breeding techniques and ultimately enhance the crops yield and yield-contributing characteristics. Character expression is determined by three types of gene actions, including additive, dominance and epistasis.

On the other hand, dominance and epistasis gene actions are associated with allelic and non-allelic gene interactions. In such situations, developing composite varieties or exploiting heterosis can prove beneficial. The earlier workers found similar results *viz.* (Arti and Varma, 2020; Singh *et al*., 2021; Balat *et al.,* 2022; Ivin *et al.,* 2022). On the predominant role of Gene action in the inheritance of traits that contribute to yield significant traits.

CONCLUSION

Significantly, certain parent combinations, such as Punjab Suhanani×GAO-5 and Phule Prajatiti×Arka Abhay, exhibit favourable GCA effects across multiple traits, highlighting their potential for improving overall crop performance. Noteworthy crosses, including GAO-8×Arka Abhay and Phule Prajatiti×Arka Abhay, exhibit prominent negative SCA effects, contributing to early flowering and picking. Conversely, several crosses demonstrate positive SCA effects on traits like plant height, indicating their potential to enhance crop yield. This detailed exploration of combining ability effects provides valuable insights for okra breeding programs, aiding in the selection of superior hybrids with desirable agronomic traits.

Conflict of interest

All author declar that they have no conflict of interest.

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