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Research Article

Improvement in pod yield related characters of okra (*Abelmoschus esculentus* L. Moench.) genotypes through biparental crosses

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Abstract

Okra is the most labour-intensive monsoon vegetable crop, and it faces significant threats from weather patterns. A total of sixteen F_1 crossings were employed in this study, following a mating strategy of L × T, where four lines and four testers were used. The objective was to assess the combining ability and heterosis for nine variables related to pod yield quality. Additionally, the study aimed to identify the most promising combinations for future breeding endeavors. The results revealed statistically significant variations across all the variables examined, except for pod diameter in the lines. Significant values were observed for various traits in the case of tests, including plant height, days to first flowering, days to first fruit set, days to first fruit picking, number of pods per plant, pod length, average weight of pods, and pod yield per plant. The parental lines, namely EC 169470, IC 128024, Kashi Pragati, and Arka Anamika, were determined to be effective general combiners in terms of single plant yield. Therefore, it is possible to exploit these parents through the practice of pedigree breeding to achieve improved recombinants through selective breeding in subsequent generations. The hybrids IC 128024 × Kahi Lalima, IC 128024 Kashi Kranti, and IC 128028 × Kashi Pragati were determined to be the most favorable combiners based on the outcomes of standard heterosis, GCA and SCA effects. These hybrids exhibit promising potential for utilization in future breeding endeavors.

Keyword: Okra, GCA, SCA, Heterosis, Gene action

INTRODUCTION

Okra (*Abelmoschus esculentus* L. Moench.), is also known as “Bhindi”, “Lady’s finger”, “gumbo” and “bamia” in India, England, USA, and Ethiopia, respectively (Gemede *et al*., 2015) It is an excellent dietary fiber, vitamin, and mineral source (Ahiakpa *et al*., 2017; Abd El-Fattah *et al*., 2020). Okra, is a polyploid with 2n=130 and is linked to hibiscus and cotton (Wang *et al*., 2023), belongs to Malvaceae family. Although Ethiopia is widely accepted as birthplace of okra, West Africa, India, and Southeast Asia are hotspots for the crop’s genetic diversity (Gemede *et al*., 2016). It is a fast-growing annual herb widely cultivated as a vegetable crop throughout the world’s subtropical areas during the summer and rainy season. It takes 50-100 days from sowing the seed to harvesting the fruit (Amina *et al*., 2023). The stem is strong and straight, with just a few twigs. The flower is self-fertile due to the presence of hermaphrodites with entomophilous traits (Animasaun *et al*., 2023). Despite okra’s reputation as a self-fertile crop, reports indicate that it is often cross-pollinated, with rates as high as 42.2% (Oyetunde and Ariyo, 2014).

According to FAOSTAT (2021), globally okra is cultivated in 5.31 lakh hectares area with a production of 6.46 lakh metric tonnes with a productivity of 12,177 kg per hectare. Though it is a versatile crop, its output remains disappointingly low. The widespread import of seed that is not well suited to local circumstances, the cultivation of outdated varieties, and a lack of readily available better lines are all possible causes (Nkongho *et al*., 2022). The majority of the crop is grown in India using conventional techniques, with little to no involvement of a breeding plan. In contrast to the genetic features utilized in scientific plant breeding, farmers actively choose varieties based on phenotypic qualities (Armand, 2021; Glenn *et al*., 2017). To successfully breed and create high-yielding varieties, it is often necessary to have a thorough understanding of genetic diversity (Hazra and Basu, 2000; Animasaun *et al*., 2021). In the okra hybridization program, selecting the best parents and then the transgressive segregants is a crucial breeding approach (Khan *et al*., 2023; Prakash *et al*., 2011). Several approaches were proposed for measuring combining ability, but line × tester analysis emerged as the clear frontrunner (Fasahat *et al*., 2016). One additional benefit of using this approach is the ability to assess a large cohort of inbred all at once. This research aimed to measure the general combining ability (GCA), specific combining ability (SCA) and heterosis of okra genotypes and their offspring populations, and to select the best offspring populations for high yield and related traits, which is essential for creating superior varieties of okra.

MATERIALS AND METHODS

A total of 16 F_{1S} hybrids generated by crossing four high-yielding lines, namely IC 128024, IC 128028, EC 169459, and EC 169470, with four testers in line × tester fashion (Kempthorne, 1957), during rainy season of 2022, were evaluated along checks Kashi Pragati, Kashi Lalima, Kashi Kranti, and Arka Anamika during spring season of 2023 at Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab. Summer temperatures exceeded 40 degrees Celsius, and winter temperatures drop below 10 degrees Celsius. The field was mostly characterised by sub-humid conditions. The hybrids, as well as the parental lines, were raised in a randomised complete block design with three replications. Two seeds were planted in a raised bed with a spacing of 60 cm × 30 cm in a single row. To ensure optimal crop growth, adherence to recommended agronomic practises and implementation of plant protection measures were ensured. A total of nine biometric and pod quality variables namely plant height, days to first flowering, days to first fruit set, days to first fruit picking, number of pods per plant, pod length, pod diameter, average weight of pods, and pod yield per plant, were observed.

The investigation of combining ability was conducted using the line × tester mating design (Kempthorne, 1957). In this mating system, a representative sample of 'L' lines is selected, and each line is paired with every 'T' tester, as explained by Singh *et al*. (2023). The technique of line × tester analysis was employed to determine the variances of general combining ability (GCA) and specialized combining ability (SCA), as well as their respective impacts (Kuselan *et al*., 2017). These estimations were based on the observations collected from the F_1 progeny. The estimation and testing of standard heterosis were conducted following the methodology outlined by Karadi and Hanchinamani (2021).

RESULTS AND DISCUSSION

The utilisation of combining ability analysis has been extensively employed for the purpose of germplasm screening and the identification of superior donor parents in several crops, including okra (Patil *et al*., 2016; Pachiyappan and Saravanan, 2018). The line tester component of variances exhibited statistical significance for all the observed traits, with the exception of pod diameter. This suggests that there was a substantial

Table 1. Names of the selected genotypes and tester for hybridization

S.No.	Genotype	Symbols	Sources	Characters
Female Parent (Lines)				
1	IC 128024	L1	NBPGR, New Delhi, India	Indigenous collection
2	IC 128028	L2		Indigenous collection
3	EC 169459	L3		Exotic Collection
4	EC 169470	L4		Exotic Collection
Male Parent (Tester)				
5	Kashi Pragati (VRO-6)	KP	IIVR, Varanasi, India	Pants are tall and high yield. Resistant to YVMV and OLCV.
6	Kahi Lalima	KL		Redish purple fruits tolerant to YVMV and OLCV, Medium fruit yield. Rich in anthocyanin and phenolics.
7	Kashi Kranti (VRO-22)	KK		Early maturity variety, high yielding, and resistance to YVMV and OLCV
8	Arka Anamika	AA	IIHR, Bengaluru, India	Plants are high yielding and moderately resistance to YVMV

interaction between the female and male parents in the experimental population. The present findings align with the results published by Yadav *et al*. (2023) in their study on okra, whereby they also observed a substantial interaction between female and male parents. GCA plays a crucial role in the identification of superior parents, whereas SCA is vital in identifying superior cross combinations, with a significance level of $p \leq 0.01$. The variances attributed to GCA and SCA for different traits are furnished in **Table 2**. Except for pod production per plant, the SCA variance exceeded the GCA variance for all the studied features, suggesting that non-additive gene action predominates in the inheritance of these traits (Das *et al*., 2020). The variations of GCA/SCA ratios were found to be smaller than one for the traits, indicating a prevalence of non-additive gene effects. Previous studies conducted by Arvind *et al.* (2021) and Manivelan *et al.* (2022) have shown the significance of both additive and non-additive gene effects in the heritability of pod yield components in okra. Heterosis breeding can be applied to traits that exhibit non-additive gene activity (Singh *et al*., 2023). The current investigation identified IC 128024, IC 128028, Arka Anamika, and Kashi Kranti as effective cultivars for maximising single pod yield per plant (**Table 3**).

Within the parental genotypes, it was observed that EC 169470 exhibited favourable characteristics as a general combiner for a variety of parameters, including plant height, days to first flowering, days to first fruit set, days to first fruit picking, and average weight of pod (**Table 3**). The line IC 128024 shown a notable GCA with impact on pod length and pod production per plant. IC 128028 recorded superior GCA in terms of pod quantity per plant. Vani *et al*. (2020) and Olayiwola *et al*. (2020) both observed comparable outcomes regarding the notable effects of GCA on these traits.

The results of the study indicate that Kashi Pragati demonstrated noteworthy GCA effects on plant height, number of pods per plant, and average weight of pods. This was followed by Arka Anamika, which exhibited considerable GCA effects on days to first fruit set, days to first fruit picking, and pod yield per plant (**Table 3**). The variety Kashi Kranti exhibited the longest pod length, while the Kahi Lalima displayed the widest pod diameter and shortest time to first flowering, indicating superior general combining capacity compared to the other tested varieties. Earlier research conducted by Kishor *et al*. (2012) in the field of okra hybrids revealed noteworthy GCA effects in many plant characteristics, including plant height, early flowering, fruit set, pods per plant, pod length, diameter of pods, and average weight of pods. The genotypes, namely EC 169470, IC 128024, Kashi Pragati, and Arka Anamika, exhibit significant GCA impacts in terms of single plant production. These genotypes hold potential for utilisation in pedigree breeding programmes aimed at obtaining improved recombinants. The current findings align with the outcomes reported by Keerthana *et al*. (2021) and Das *et al*. (2020).

The assessment of a given cross's efficacy in harnessing heterosis is determined based on the effects of SCA. In the present study, the crosses IC 128024 × Kahi Lalima, IC 128028 × Kashi Pragati, EC 169459 × Arka Anamika, and EC 169470 × Arka Anamika exhibited a notably significant SCA for pod yield, as indicated in **Table 4**. Furthermore, it is worth noting that the cross IC 128024 × Kahi Lalima and IC 128028 × Kashi Pragati exhibit notable positive SCA effects in relation to plant height and days to first flowering, respectively. The hybrid IC 128028 × Kahi Lalima exhibited a positive significant combining ability effect for the number of pods per plant. Similarly, the hybrid IC 128028 × Kashi Kranti showed a positive significant combining ability effect for pod length and average weight of pod. Additionally, the hybrid EC 169459 × Kashi Pragati demonstrated a positive significant SCA effect for days to first fruit set and days to first fruit picking. Lastly, the hybrid EC 169459 × Kahi Lalima displayed a positive significant SCA effect for pod diameter.

Standard heterosis is a good indicator of performance of a hybrid. The hybrid combination of IC 128028 × Kashi Pragati exhibited the highest level of standard heterosis

Table 2. GCA and SCA variance for various character of okra germplasm

Characters	σ^2 GCA	σ^2 SCA	σ^2 GCA/ σ^2 SCA
Plant height (cm)	0.7094	13.4866	0.053
Days to first flowering	0.7145	4.6270	0.154
Days to first fruit set	0.3220	5.2549	0.061
Days to first fruit picking	1.5396	3.7187	0.414
Number of pods per plants	0.2533	3.6957	0.069
Pod length (cm)	0.1049	1.1132	0.094
Diameter of pods (cm	0.0003	0.0286	0.010
Av. weight of pod (g)	0.6844	1.5291	0.448
Pods yield per plant (kg)	0.0002	0.0001	2.000

Table 3. GCA for pod yield related attributes of okra

Parents	Plant height (cm)	Days to first flowering	Days to first fruit set	Days to first fruit picking	Number of pods per plants	Pod length (cm)	Diameter of pods (cm)	Av. weight of pod (g)	Pods yield per plant (kg)
IC 128024 (L1)	0.38 ns	-0.78 **	0.05 ns	-0.84 **	0.92 **	0.86 **	-0.00 ns	-0.72 **	0.04 **
IC 128028 (L2)	-3.24 **	0.26 **	-2.81 **	-4.17 **	1.21 **	0.77 **	0.06 ns	-1.70 **	0.03 **
EC 169459 (L3)	0.62 *	-1.87 **	-0.19 **	-1.16 **	0.83 **	0.31 **	-0.00 ns	-0.01 ns	-0.03 **
EC 169470 (L4)	2.24 **	2.39 **	2.95 **	6.16 **	-2.96 **	-1.94 **	-0.06 ns	2.44 **	-0.03 **
Kashi Pragati (KP)	3.00 **	-0.70 **	-0.62 **	-0.76 **	0.88 **	-0.46 **	0.11 ns	2.90 **	-0.03 **
Kahi Lalima (KL)	0.91 **	3.95 **	-1.04 **	-1.13 **	-1.38 **	0.10 ns	0.15 *	0.79 **	-0.00 ns
Kashi Kranti (KK)	0.56 *	-2.47 **	0.74 **	1.13 **	0.47 **	0.23 **	-0.11 ns	-0.90 **	0.01 **
Arka Anamika (AA)	-4.47 **	-0.78 **	0.92 **	0.77 **	0.02 ns	0.13 ns	-0.15 *	-2.79 **	0.02 **

**Significant at p 0.01, *Significant at p 0.05, ns - non-significant.

Table 4. SCA for pod yield related attributes of okra

Cross	Plant height (cm)	Days to first flowering	Days to first fruit set	Days to first fruit picking	Number of pods per plants	Pod length (cm)	Diameter of pods (cm)	Av. weight of pod (g)	Pods yield per plant (kg)
L1 × KP	-1.29 *	-2.25 **	-2.34 **	-2.65 **	-1.56 **	0.61 **	-0.12 ns	0.95 **	0.00 ns
L1 × KL	3.71 **	2.04 **	-1.06 **	-0.06 ns	-0.22 ns	0.27 ns	-0.14 ns	-0.59 **	0.01 **
L1 × KK	-1.34 *	-0.02 ns	1.31 **	0.80 **	0.36 *	0.48 **	0.11 ns	-0.94 **	0.00 ns
L1 × AA	-1.08 *	0.23 ns	2.09 **	1.91 **	1.42 **	-1.36 **	0.14 ns	0.58 **	-0.02 **
L2 × KP	3.13 **	3.20 **	0.27 *	0.80 **	0.43 *	-0.04 ns	0.13 ns	-1.77 **	0.01 **
L2 × KL	-7.89 **	-0.30 ns	1.78 **	0.97 **	2.55 **	-1.23 **	-0.19 ns	0.36 **	-0.01 **
L2 × KK	1.74 **	-1.84 **	-0.82 **	-1.11 **	-1.16 **	0.75 **	0.14 ns	1.11 **	0.00 ns
L2 × AA	3.02 **	-1.06 **	-1.23 **	-0.66 **	-1.82 **	0.52 **	-0.09 ns	0.30 *	-0.00 ns
L3 × KP	1.23 *	-1.41 **	2.84 **	2.94 **	1.80 **	-1.12 **	-0.23 ns	1.53 **	-0.01 **
L3 × KL	2.86 **	0.19 ns	-1.80 **	-1.92 **	-0.02 ns	0.28 ns	0.31 *	0.54 **	0.00 ns
L3 × KK	-1.76 **	2.43 **	1.55 **	0.79 **	-0.02 ns	0.43 *	-0.14 ns	-0.42 **	-0.00 ns
L3 × AA	0.13 ns	-1.21 **	-2.59 **	-1.81 **	-1.77 **	0.40 *	0.06 ns	-1.66 **	0.01 **
L4 × KP	-0.62 ns	0.47 *	-0.76 **	-1.10 **	-0.68 **	0.54 **	0.22 ns	-0.71 **	0.00 ns
L4 × KL	1.33 *	-1.93 **	1.07 **	1.02 **	-2.31 **	0.68 **	0.02 ns	-0.31 *	-0.01 ns
L4 × KK	1.36 *	-0.57 **	-2.04 **	-0.48 **	0.82 **	-1.66 **	-0.11 ns	0.24 ns	-0.00 ns
L4 × AA	-2.07 **	2.04 **	1.73 **	0.56 **	2.16 **	0.44 *	-0.12 ns	0.78 **	0.01 *

**Significant at p 0.01, *Significant at p 0.05, ns - non-significant

in terms of plant height. On the other hand, the hybrid combination of EC 169470 × Arka Anamika shown superior performance in terms of early blooming, days to first fruit set, and fruit picking. These findings are summarised in **Table 5 and 6**. The hybrids IC 128024 × Kashi Kranti, EC 169459 × Kashi Kranti, and EC 169470 × Kashi Kranti exhibited superior mid-parent heterosis for the traits of number of pods per plant, pod length, and negatively significant pod diameter, respectively. The hybrid combination of EC 169459 × Kashi Pragati exhibited the highest level of heterosis in terms of average pod weight, whereas the hybrid IC 128024 × Kahi Lalima demonstrated superior performance in terms of pod output per plant.

In the current investigation, the varieties EC 169470, IC 128024, Kashi Pragati, and Arka Anamika were identified as highly effective general combiners in terms of pod yield per plant. Nevertheless, the parents in question did not produce noteworthy significant effects on their respective pairings. Therefore, these parents can be subject to exploitation through pedigree breeding in order to achieve

Table 5. Heterosis of F_1 hybrid combinations for plant height (cm), days to first flowering, days to first fruit set, days to first fruit picking and pods number per plant

Cross	Plant height (cm)		Days to first flowering		Days to first fruit set		Days to first fruit picking		Number of pods per plants	
	Mid parent	Better parent	Mid parent	Better parent	Mid parent	Better parent	Mid parent	Better parent	Mid parent	Better parent
L1 × KP	12.23 **	9.83 **	-13.85 **	-20.11 **	-11.14 **	-16.95 **	-6.92 **	-7.62 **	17.82 **	12.61 **
L1 × KL	12.16 **	6.88 **	-3.83 **	-3.84 **	-15.62 **	-15.75 **	-8.38 **	-12.46 **	31.09 **	6.04 **
L1 × KK	4.74 **	-1.61 *	-11.45 **	-19.27 **	-1.35 **	-8.51 **	3.83 **	1.36 *	24.27 **	23.30 **
L1 × AA	-1.14 ns	-7.86 **	-12.14 **	-15.74 **	-3.94 **	-6.90 **	0.76 ns	-1.03 ns	19.88 **	12.99 **
L2 × KP	20.66 **	10.69 **	1.53 *	-3.64 **	-9.57 **	-13.78 **	-11.12 **	-15.71 **	24.73 **	11.65 **
L2 × KL	2.22 **	-8.52 **	-3.87 **	-6.19 **	-13.85 **	-15.77 **	-16.00 **	-16.02 **	44.29 **	10.79 **
L2 × KK	10.80 **	-2.14 **	-10.64 **	-16.65 **	-8.35 **	-13.30 **	-9.75 **	-15.75 **	7.18 **	-0.68 ns
L2 × AA	5.62 **	-7.39 **	-10.35 **	-11.93 **	-12.78 **	-13.69 **	-13.18 **	-15.61 **	-6.56 **	-7.52 **
L3 × KP	9.53 **	8.91 **	-8.52 **	-9.94 **	1.98 **	-0.97 ns	-0.33 ns	-3.27 **	28.98 **	13.69 **
L3 × KL	8.59 **	6.26 **	-3.50 **	-9.19 **	-13.93 **	-17.39 **	-13.79 **	-15.81 **	17.82 **	-10.63 **
L3 × KK	1.85 **	-1.78 **	-2.44 **	-5.67 **	2.96 **	-0.82 ns	0.86 ns	-3.68 **	10.10 **	0.40 ns
L3 × AA	-2.20 **	-6.46 **	-11.49 **	-13.23 **	-8.83 **	-9.61 **	-8.01 **	-8.44 **	-10.25 **	-12.69 **
L4 × KP	7.05 **	2.08 **	3.47 **	1.07 ns	0.30 ns	-3.34 **	5.13 **	2.07 **	13.81 **	0.08 ns
L4 × KL	4.10 **	1.94 **	-0.12 ns	-5.29 **	-4.17 **	-7.31 **	2.32 **	-0.11 ns	-2.99 ns	-8.16 **
L4 × KK	2.25 **	1.63 *	-0.60 ns	-4.63 **	1.26 **	-3.19 **	11.05 **	6.10 **	18.12 **	0.55 ns
L4 × AA	-6.79 **	-7.01 **	2.84 **	1.62 *	3.83 **	3.77 **	7.66 **	7.19 **	15.63 **	-6.80 **

**Significant at p 0.01, *Significant at p 0.05, ns - non-significant.

Table 6. Heterosis of F_1 hybrid combinations for pod length, diameter of pods, pod weight and pods yield

Cross	Pod length (cm)		Diameter of pods (cm)		Av. weight of pod (g)		Pods yield per plant (kg)	
	Mid parent	Better parent	Mid parent	Better parent	Mid parent	Better parent	Mid parent	Better parent
L1 × KP	30.96 **	18.97 **	1.43 ns	-7.96 ns	18.05 **	12.67 **	28.44 **	-2.78 ns
L1 × KL	27.86 **	21.31 **	-0.69 ns	-12.22 ns	9.78 **	3.60 **	29.60 **	12.50 **
L1 × KK	46.02 **	24.84 **	-3.57 ns	-16.25 *	5.07 **	-7.82 **	20.90 **	12.50 **
L1 × AA	14.21 **	4.47 *	20.14 *	13.18 ns	9.28 **	-9.93 **	19.08 **	8.33 **
L2 × KP	26.58 **	18.34 **	18.31 *	8.89 ns	4.59 **	-6.17 **	29.73 **	-2.70 ns
L2 × KL	13.87 **	11.35 **	-1.27 ns	-11.52 ns	17.38 **	16.48 **	13.39 **	-2.70 ns
L2 × KK	53.73 **	34.97 **	0.67 ns	-11.39 ns	20.54 **	12.32 **	17.65 **	8.11 **
L2 × AA	39.31 **	31.18 **	6.52 ns	-1.10 ns	9.07 **	-5.00 **	20.30 **	8.11 **
L3 × KP	15.60 **	14.92 **	-3.03 ns	-14.07 ns	23.30 **	19.26 **	5.88 *	-6.25 *
L3 × KL	34.10 **	28.80 **	28.48 **	10.99 ns	18.90 **	10.76 **	12.87 **	7.55 **
L3 × KK	54.16 **	43.28 **	-16.37 *	-28.98 **	11.14 **	-3.65 **	7.27 **	-4.84 *
L3 × AA	41.43 **	41.20 **	17.87 ns	13.91 ns	-2.76 *	-20.72 **	21.50 **	10.17 **
L4 × KP	6.22 **	3.75 ns	21.21 **	7.41 ns	17.26 **	14.40 **	11.36 **	-3.92 ns
L4 × KL	9.70 **	7.20 **	7.68 ns	-6.98 ns	20.16 **	6.18 **	3.85 ns	1.89 ns
L4 × KK	-6.74 **	-14.72 **	-17.75 *	-30.15 **	21.87 **	0.69 ns	4.42 *	-4.84 *
L4 × AA	11.40 **	9.62 **	0.25 ns	-3.12 ns	20.61 **	-5.89 **	16.36 **	8.47 **

**Significant at p 0.01, *Significant at p 0.05, ns - non-significant.

improved recombinants by selection in subsequent generations. The identification of the best hybrids, namely IC 128024 × Kahi Lalima, IC 128024 × Kashi Kranti, and IC 128028 × Kashi Pragati, was based on the analysis of GCA, SCA, and heterosis effects. These hybrids exhibit promising characteristics and have potential for future breeding endeavours.

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