Research Article Electronic Journal of Plant Breeding, Vol.17 (2): 152-161

Combining ability and exploitation of heterotic potential of Okra under the Central Indian Plains

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https://doi.org/10.37992/2026.1702.019

Abstract

This study quantified heterosis and partitioned general (GCA) and specific (SCA) combining ability for earliness, yield, plant architecture, and quality traits in Okra to identify superior parents and hybrids for breeding. Fifteen diverse parents (10 lines, 5 testers) were crossed in a Line × Tester design to generate 50 F_1s, with Arka Anamika as the standard check. Crosses were produced in *kharif,* 2024 and evaluated in *summer,* 2025 at AKS University, Satna, India, using an RCBD with three replications. ANOVA revealed highly significant differences among genotypes, parents, crosses, and Line × Tester interactions for all traits, evidencing ample genetic variability and the joint action of additive and non-additive effects. Parbhani Kranti and Ankur 40 emerged as strong general combiners for yield and quality, and Akola 2 for earliness/plant stature; high SCA was observed in Parbhani Kranti × PDKV Pragati, Parbhani Kranti × Akola 2, and Ankur 40 × Akola Bahar for yield components, with desirable negative heterosis for earliness in IC 42451 × Akola Bahar and Ankur 40 × Akola Bahar. The best-yielding cross, Parbhani Kranti × PDKV Pragati, exhibited 10.91 % better-parent and 9.40% standard heterosis. These parents and hybrids constitute actionable candidates for developing early, high-yield, and nutritionally enhanced Okra, warranting multi-location validation for stability and deployment.

Keywords: Okra (*Abelmoschus esculentus*), Heterosis, General Combining Ability (GCA), Specific Combining Ability (SCA), Line × Tester analysis

INTRODUCTION

Abelmoschus esculentus (L.) Moench, commonly known as Okra, stands as one of the most popular vegetable crops cultivated across tropical and subtropical regions during summer and rainy seasons due to its adaptability, nutritional richness, and economic significance. Okra's ease of cultivation, reliable yields, export potential, resilience against moisture variability, and broad tolerance to pests and diseases have made it a preferred choice for farmers throughout the tropics (Haq *et al*., 2023; Ibitoye and Kolawole, 2022).

Globally, Okra production reached approximately 11.23 million tons from 2.80 million hectares in 2022, marking a 5.9 % increase from the previous year and a 13.4 % rise compared to a decade earlier. India leads the world, accounting for nearly 61 % of global Okra output, with Nigeria and Mali comprising the next largest shares. Together, the top three nations contribute about 85 % of the world's Okra supply, underscoring the crop's regional and international importance. The tender, green Okra fruits are prized for culinary use and are key dietary sources of calcium, vitamins, and minerals for millions (Thamburaj and Singh, 2018). Hybrid breeding, leveraging heterosis and integrating traits for yield, nutrition, and stress resilience, has emerged as a crucial strategy to overcome stagnating productivity and enhance crop quality (Labroo *et al*., 2021; Ranga *et al*., 2024). However, reliance on *per se* performance alone is insufficient; genetic insight into parents' combining ability and hybrid vigor is needed for targeted improvement (Yadav *et al*., 2023).

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How to cite this artilce: Shivnath Ramdas Sangle and Bineeta Singh. 2026. Combining ability and exploitation of heterotic potential of Okra under the Central Indian Plains. *Electronic Journal of Plant Breeding*, 17(2): 152-161. doi:10.37992/2026.1702.019

Received: 16.12.2025 **Revised**: 17.04.2026 **Accepted**: 21.04.2026

Heterosis and combining ability studies guide breeders in identifying optimal parental combinations and promising hybrids by distinguishing additive and non-additive genetic contributions to complex traits (Fujimoto *et al*., 2018). This study aims to advance Okra improvement by evaluating heterosis and combining ability for a set of biometrical and biochemical traits, guiding the selection of superior parents and hybrids for future breeding, and better aligning varietal development with farmer and market priorities.

MATERIALS AND METHODS

Experimental site

The present research was conducted at the Instructional Farm of AKS University, Satna, Madhya Pradesh, India (latitude 24°33′N, longitude 80°50′E), under the

Department of Genetics and Plant Breeding, during the *kharif*, 2024 (crossing program) and subsequent evaluation during the summer, 2025. The experimental site is characterized by a subtropical climate with hot summers, moderate rainfall, and mild winters. The chosen site and management strategy were selected to provide optimal and representative conditions for evaluating combining ability, heterosis, and hybrid performance in Okra.

Planting material

The experimental materials in this study comprised 15 genetically diverse parents, including ten lines and five testers, selected for variation in biometrical and quality attributes (**Table 1**). All parental genotypes were sourced from regional and national breeding institutes with proven track records in Okra improvement. The crossing programme was conducted during *Kharif, 2024*, wherein the parental lines and testers were grown in three staggered sowing to ensure uniform and synchronized flowering for hybridization. The resulting 50 F_1 hybrids along with 15 parents and one standard check (*Arka Anamika*) were evaluated during *summer, 2025* using a Randomized Complete Block Design (RCBD) with three replications. Each experimental plot consisted of two rows of 3.0 m length, accommodating appropriate plant population at a spacing of 60 cm × 30 cm. Standard agronomic practices were followed to raise a healthy crop. Observations were recorded on ten randomly selected plants per plot for all traits except yield, which was recorded on a plot basis.

Experimental observations were recorded on a set of 14 traits encompassing phenological and quality attributes. For yield, data was recorded at the plot level, while for all remaining traits, data from ten randomly selected and tagged plants per genotype per replication were averaged. Standard physiological and biochemical methodologies were employed for trait measurement. Protein content was determined using the Lowry method (Lowry *et al*., 1951), and vitamin C and crude fiber contents were estimated according to established protocols by Sadasivam and Manickam (2008). Data acquisition and analysis adhered to procedures recommended in current Okra breeding literature and national guidelines for horticultural research.

Statistical analysis

The statistical analysis for the present investigation was performed using R software (version 4.3.0) and its integrated data analysis packages. The Analysis of Variance (ANOVA) and F-test were conducted under the Randomized Complete Block Design (RCBD) framework following the procedure described by Panse and Sukhatme (1985). Heterosis was evaluated by estimating the percentage increase or decrease in the mean performance of F_1 hybrids relative to their better parent and the standard check using the method suggested by Fonseca and Patterson (1968). The statistical significance of heterotic effects was tested using the *t*-test and standard error, as explained by Wynne *et al*. (1970). Combining ability analysis for the Line × Tester mating design was carried out following Kempthorne's (1967) methodological framework. The General Combining Ability (GCA) and Specific Combining Ability (SCA) effects were estimated using the agricolae, metan, and plant breeding packages in R, which provide tools for variance component estimation, mean square computation, and genetic interpretation of cross interactions (Kittiwachana *et al*., 2024; Su *et al*., 2025)

Table 1. List of Okra genotypes used for study

Parents/ Checks	Genotype name	Institute/ Organization developed
L1	IC 42451	ICAR-NBPGR
L2	IC 42456	ICAR-NBPGR
L3	Ankur 40	Ankur Seeds Pvt. Ltd., Nagpur (Maharashtra)
L4	EC 329384	ICAR-NBPGR
L5	Parbhani Kranti	VNMKV, Parbhani
L6	Varsha Upahar	IIHR, Bengaluru
L7	EC 329386	ICAR-NBPGR
L8	Kokan Bhendi	Konkan Krishi Vidyapeeth
L9	Korchi	Regional research, Vidarbha
L10	EC 329395	ICAR-NBPGR
T1	Akola Bahar	PDKV, Akola
T2	Akola 1	PDKV, Akola
T3	Akola 2	PDKV, Akola
T4	Akola 3	PDKV, Akola
T5	PDKV Pragati	PDKV, Akola
C1	Arka Anamika	IIHR, Bengaluru
C2	Arka Nikita	IIHR, Bengaluru

RESULTS AND DISCUSSION

Analysis of variance for combining ability

Analysis of variance (ANOVA) for combining ability **(Table 2)** revealed highly significant differences among genotypes for all studied traits, indicating the existence of wide genetic variability and substantial potential for genetic improvement in Okra (Rasheed *et al*., 2024; Pathania *et al*., 2025). The mean squares due to genotypes were highly significant for all measured characters, including days to 50% flowering, days to first picking, number of branches per plant, internodal length, plant height, fruit length and girth, total number of fruits per plant, total number of seeds per plant, days to last picking, crude protein content, crude fiber content, vitamin C content, and fruit yield per plant.

Mean squares for crosses were likewise significant across all traits, confirming the presence of genetic divergence among hybrids and indicating ample scope for heterosis exploitation. The partitioning of variance among parents, lines, testers, and their interaction highlighted significant differences, demonstrating that both additive and non-additive genetic effects were important for trait expression (Kumar *et al*., 2019).

Notably, the Line × Tester interaction was significant for several traits, underlining the crucial role of specific combining ability in the manifestation of these characters (Sidapara *et al*., 2021). The contrast between crosses and parents was also significant for all measured traits, demonstrating notable heterotic effects among F_1 hybrids compared to their parents (Rynjah *et al*., 2020).

General Combining Ability (GCA) Effects

The estimates of general combining ability (GCA) effects for 14 yield and quality traits among parental genotypes are presented in **Table 3**. Days to 50% flowering, a critical earliness trait showed significant negative GCA effects for EC 329386 (-0.83), PDKV Pragati (-0.68), IC 42451 (-0.42), IC 42456 (-0.17), and EC 329384 (-0.14), highlighting their utility in developing early flowering hybrids. This observation aligns with findings by Valluru Manju Vani *et al*. (2017), who reported significant *GCA* effects for earliness traits in Okra. Likewise, days to first picking exhibited strong negative *GCA* in genotypes such as Kokan Bhendi (-1.52) and Varsha Upahar (-1.03), reinforcing early harvest potential similarly noted by Singh *et al*. (2012) for days to 50% flowering.

The number of branches per plant was positively influenced by Parbhani Kranti (0.57), Akola 3 (0.38), and Kokan Bhendi (0.29), consistent with results from Parmar *et al*. (2012), where branching correlated with fruit yield enhancement. Internodal length, associated with compact plant architecture, showed significant negative *GCA* effects in Akola 2 (-1.01) and EC 329386 (-0.42), affirming the role of desirable number of branches per plant as reported by Kayande *et al*. (2015).

Plant height varied widely, with Akola 2 (4.43) and Ankur 40 (4.31) exhibiting strong positive *GCA* effects, in agreement with Rewale *et al*. (2013) for plant height, who emphasized heterogeneous height as an important breeding target pertaining to yield stability. Crude protein content was the highest in Parbhani Kranti (1.34) and Varsha Upahar (0.88), which complements Archana Mishra *et al*. (2015) who described protein content variability as a crucial protein in Okra breeding. Similarly, lower crude fiber content observed in EC 329384 (-1.47) and IC 42451 (-1.00) illustrates improved crude protein content with previous genetic studies (Valluru Manju Vani *et al*., 2017).

Table 2. ANOVA for combining ability of various traits

Source of variation	DF	DFF	DFP	NBP	IL	PH	FL	FG	TFP	TSP	DLP	CPC	CFC	VC	FYP
Replication	2	0.8	1.12	0.06	0.03	2.4	0.14	0.016	13.59	4.12	3.59	0.02	0.08	0.29	902.9
Genotypes	64	6.60**	5.27**	0.53**	1.61**	101.87**	2.11**	0.106**	101.88**	10.50**	40.60**	10.70**	11.79**	2.89**	7653.2**
Crosses	49	4.30**	4.54**	0.57**	1.94**	63.96**	1.81**	0.102**	99.99**	11.91**	14.28**	4.81**	6.22**	2.63**	7107.9**
Parents	14	4.89**	5.70**	0.31**	0.45**	39.08**	2.84**	0.100**	66.49**	6.25**	24.42**	1.13**	2.07**	2.82**	5163.1**
LINES	9	4.03**	4.56**	0.33**	0.40**	53.49**	3.99**	0.137**	41.45**	3.88**	29.14**	1.20**	1.91**	3.46**	5258.5**
TESTS	4	7.97**	4.47**	0.15**	0.64**	12.67**	0.70**	0.039**	126.74**	12.96**	14.05**	1.25**	2.70**	1.83**	5859.5**
L x T	1	0.24	20.79**	0.74**	0.18**	15.07**	1.03**	0.010**	50.85**	0.79*	23.47**	0	1.01**	1.05**	1519.1**
Crosses Vs Parents	1	142.97**	35.15**	1.55**	1.70**	2838.33**	6.83**	0.388**	690.08**	0.76*	1556**	433.6**	421.2**	16.67**	69235.9**
ERROR	128	0.09	0.07	0.002	0.004	0.56	0.01	0.001	0.43	0.17	0.69	0.02	0.01	0.04	21.6
TOTAL	194	2.24	1.8	0.18	0.53	34	0.7	0.036	34.03	3.62	13.89	3.55	3.9	0.98	2548.3

* Significant at 5 per cent probability level, ** Significant at 1 per cent probability level

DFF = Day to 50% flowering; DFP = Day to first picking; NBP = Number of Branches per plant; IL = Internodal length; PH = Plant height; FL = Fruit length; FG = Fruit Girth; TFP = Total number of fruit per plant; TSP = Total number seed per plant; DLP = Day to last picking; CPC = Crude protein content; CFC = Crude fiber content %; VC = Vitamin C; FYP = Fruit yield per plant

Table 3. Estimates of general combining ability effects (*GCA*) for 14 traits in Okra

Genotypes	DFF	DFP	NBP	IL	PH	FL	FG	TFP	TSP	DLP	CPC	CFC	VC	FYP
Lines														
IC 42451	-0.42 **	-0.76 **	-0.18 **	-0.29 **	0.08	-0.06 **	-0.05 **	-7.45 **	-0.80 **	-1.86 **	-0.93 **	-1.00 **	0.06	-79.61 **
IC 42456	-0.17 *	0.08	0.02	0.14 **	-0.94 **	-0.18 **	-0.09 **	-2.46 **	-0.45 **	-0.4	-0.31 **	-0.31 **	0.13 *	-20.77 **
Ankur 40	-0.03	0.01	0.25 **	0.10 **	4.31 **	0.78 **	0.17 **	3.85 **	1.54 **	1.44 **	0.11 **	1.33 **	-0.06	39.53 **
EC 329384	-0.14 *	-0.41 **	-0.39 **	-0.21 **	-2.44 **	-0.68 **	-0.12 **	-4.14 **	0.73 **	-0.51 *	-0.93 **	-1.47 **	0.79 **	-57.42 **
Parbhani Kranti	1.32 **	1.14 **	0.57 **	0.65 **	3.71 **	0.80 **	0.16 **	5.94 **	1.31 **	2.30 **	1.34 **	1.95 **	-0.70 **	68.70 **
Varsha Upahar	0.24 **	-1.03 **	-0.03	0.40 **	0.51 **	-0.12 **	0.11 **	2.13 **	-0.21 *	-0.27	0.88 **	0.25 **	-0.80 **	0.73
EC 329386	-0.83 **	0.96 **	-0.27 **	-0.42 **	-2.94 **	-0.23 **	-0.02 **	-1.31 **	0.74 **	-1.27 **	-0.01	0.21 **	1.04 **	9.03 **
Kokan Bhendi	-0.11	-1.52 **	0.29 **	0.18 **	-0.32	-0.21 **	-0.02 *	2.69 **	-1.36 **	0.95 **	0.36 **	0.86 **	-0.19 **	19.25 **
Korchi	0.04	0.76 **	-0.22 **	-0.34 **	-3.62 **	-0.35 **	-0.14 **	-1.48 **	-2.82 **	-0.62 **	-0.55 **	-0.90 **	-1.17 **	-2.99 *
EC 329395	0.1	0.78 **	-0.05 **	-0.22 **	1.65 **	0.25 **	0.01	2.23 **	1.33 **	0.23	0.04	-0.91 **	0.90 **	23.56 **
Testers														
Akola Bahar	-0.12 *	0.23 **	-0.19 **	-0.33 **	-2.29 **	-0.43 **	0.08	1.11 **	0.34 **	1.58 **	0.23 **	1.04 **	-0.43 **	3.37 **
Akola 1	0.37 **	0.10 *	0.04 **	0.91 **	0.67 **	0.01	-0.04 **	2.01 **	0.51 **	-0.63 **	0.09 **	-0.79 **	-0.05	12.63 **
Akola 2	0.55 **	0.30 **	-0.20 **	-1.01 **	4.43 **	0.15 **	-0.12 **	0.72 **	0	-0.79 **	0.36 **	-0.89 **	0.13 **	-13.09 **
Akola 3	-0.12 *	-0.34 **	0.38 **	-0.02	1.54 **	0.39 **	-0.03 **	-4.14 **	-0.40 **	-1.05 **	-0.25 **	0.93 **	0.19 **	-17.50 **
PDKV Pragati	-0.68 **	-0.28 **	-0.03 *	0.44 **	-4.36 **	-0.12 **	0.18 **	0.30 *	-0.46 **	0.90 **	-0.42 **	-0.29 **	0.15 **	14.59 **
SE (gca for line)	0.07	0.068	0.017	0.012	0.185	0.022	0.008	0.173	0.105	0.218	0.021	0.021	0.054	1.275
SE (gca for tester)	0.05	0.048	0.012	0.008	0.131	0.016	0.006	0.122	0.074	0.154	0.015	0.015	0.038	0.901

* Significant at 5 per cent probability level, ** Significant at 1 per cent probability level
DFF = Day to 50% flowering; DFP = Day to first picking; NBP = Number of Branches per plant; IL = Internodal length; PH = Plant height; FL = Fruit length; FG = Fruit Girth; TFP = Total number of fruit per plant; TSP = Total number seed per plant; DLP = Day to last picking; CPC = Crude protein content; CFC = Crude fiber content %; VC = Vitamin C; FYP = Fruit yield per plant.

Significant variation was observed among the parental lines for general combining ability effects relating to total fruits per plant, total seeds per plant, and fruit yield per plant. Parbhani Kranti exhibited the highest positive and highly significant *GCA* effects (5.94 for total fruits per plant, 1.31 for total seeds per plant, and 68.70 for fruit yield per plant). Similarly, Ankur 40 displayed highly significant positive *GCA* values (3.85, 1.54, and 39.53 for fruits, seeds, and yield per plant). Similar finding was reported by Silva *et al*. (2021) for total fruits per plant, total seeds per plant, and fruit yield per plant. EC 329395 showed desirable positive *GCA* effects across traits (2.23, 1.33, and 23.56, respectively). Conversely, IC 42451 and IC 42456 were identified as poor general combiners, presenting notable negative *GCA* values (–7.45, –0.80, –79.61 and –2.46, –0.45, –20.77, respectively). Additional moderate positive effects were documented for Varsha Upahar (2.13 fruits per plant) and Akola 1 (2.01 fruits per plant), whereas Kokan Bhendi, though scoring 2.69 for total fruits per plant, showed negative *GCA* for total seeds (–1.36).

These findings align with recent research, which emphasizes the significance of superior general combiners for trait improvement like no of fruits per plant and fruit yield per plant in Okra breeding programs (Katariya *et al*., 2025). The current results corroborate earlier reports that the selection of parents with high *GCA* can accelerate genetic gains for yield and related components, reinforcing the utility of these identified lines for future hybrid developments in Okra (Katariya *et al*., 2025).

Specific Combining Ability (SCA) Effects

Specific combining ability (*SCA*) reflects the unique performance of particular parental combinations and mainly captures the contribution of non-additive gene action such as dominance and epistasis to trait expression in hybrids. As shown in **Table 4**, the top performing crosses based on *SCA* effects, revealed important genetic interactions crucial for targeted Okra breeding. For earliness traits, where lower values are desirable, significant negative *SCA* effects were observed for days to 50% flowering in crosses such as Korchi × PDKV Pragati (-2.16), Kokan Bhendi × Akola Bahar (-2.06), and Parbhani Kranti × Akola 1 (-1.82). Similar trends were seen for day to first picking, with EC 329384 × PDKV Pragati (-1.90) and Korchi × Akola 2 (-1.40) among the top negative combiners, indicating their potential to hasten maturity and harvest (Singh *et al*., 2012; Valluru Manju Vani *et al*., 2017).

Table 4. Estimates of specific combining ability effects (*SCA*) for 14 traits in Okra

S.No.	Crosses	DFF	DFP	NBP	IL	PH	FL	FG	TFP	TSP	DLP	CPC	CFC	VC	FYP
1.	IC 42451 × Akola Bahar	0.34 *	0.63 **	0.13 **	0.03	-0.16	0.19 **	-0.09 **	0.35	0.70 **	0.65	-0.22 **	0.41 **	-0.28 *	-17.90 **
2.	IC 42451 × Akola 1	-0.64 **	-0.52 **	0.06	-0.09 **	2.56 **	-0.1	0.05 *	0.82 *	0	-0.78	0.28 **	-0.09	0.1	1.76
3.	IC 42451 × Akola 2	0.52 **	0.26	-0.13 **	-0.05	-1.89 **	-0.28 **	-0.09 **	-1.85 **	-0.78 **	0.15	0.08	-0.84 **	0.21	11.91 **
4.	IC 42451 × Akola 3	0.24	0.22	-0.07	-0.01	0.25	0.01	-0.06 **	0.83 *	0.38	-1.98 **	-0.16 **	0.42 **	0.02	3.39
5.	IC 42451 × PDKV Pragati	-0.46 **	-0.60 **	0.01	0.13 **	-0.76	0.18 **	0.19 **	-0.15	-0.3	1.96 **	0.02	0.09	-0.06	0.83
6.	IC 42456 × Akola Bahar	-0.93 **	-0.74 **	-0.27 **	0.20 **	2.00 **	0.02	0.11 **	-1.03 **	0.37	-0.9	-0.12 *	0.03	-0.63 **	17.10 **
7.	IC 42456 × Akola 1	0.25	0.78 **	0	-0.38 **	1.04 *	0.18 **	-0.07 **	-2.93 **	0.28	-0.4	0.39 **	-0.08	-0.1	11.74 **
8.	IC 42456 × Akola 2	0.15	-0.94 **	0.25 **	-0.32 **	0.49	0.37 **	0.01	-0.58	0.98 **	-0.27	-0.14 **	-0.10 *	0.13	-11.13 **
9.	IC 42456 × Akola 3	1.09 **	0.55 **	0.18 **	0.28 **	-1.23 **	-0.54 **	0.10 **	4.19 **	-2.18 **	-0.31	0.08	0.10 *	-0.01	-13.37 **
10.	IC 42456 × PDKV Pragati	-0.56 **	0.36 *	-0.16 **	0.22 **	-2.31 **	-0.03	-0.15 **	0.34	0.55 *	1.88 **	-0.21 **	0.06	0.61 **	-4.34
11.	Ankur 40 × Akola Bahar	0.37 *	0.48 **	0.20 **	0.02	-2.85 **	-0.16 **	-0.18 **	-2.94 **	-0.91 **	0.43	-0.20 **	0.60 **	-0.19	18.88 **
12.	Ankur 40 × Akola 1	0.26	-1.04 **	-0.06	0.20 **	1.12 **	-0.94 **	0.15 **	4.93 **	1.37 **	0.18	0.54 **	-0.85 **	-0.48 **	6.68 *
13.	Ankur 40 × Akola 2	0.16	0.48 **	-0.11 **	0.06 *	-0.16	0.82 **	-0.04 *	2.65 **	-1.85 **	-0.49	0.41 **	0.25 **	0.23	19.24 **
14.	Ankur 40 × Akola 3	-1.28 **	-0.76 **	-0.05	0.27 **	0.03	0.08	-0.01	-7.01 **	1.38 **	1.65 **	-0.67 **	-0.09	1.36 **	-12.25 **
15.	Ankur 40 × PDKV Pragati	0.49 **	0.84 **	0.02	-0.55 **	1.86 **	0.21 **	0.08 **	2.36 **	0.01	-1.77 **	-0.08	0.10 *	-0.91 **	-32.55 **
16.	EC 329384 × Akola Bahar	0.22	-0.77 **	-0.11 **	-0.24 **	0.4	0.63 **	0.07 **	6.54 **	-2.38 **	-1.20 *	-0.15 **	-0.27 **	-0.71 **	23.00 **
17.	EC 329384 × Akola 1	0.90 **	0.12	0.08 *	0.31 **	0.18	0.38 **	0	-7.15 **	-2.24 **	-1.79 **	-0.90 **	0.69 **	0.31 *	12.10 **
18.	EC 329384 × Akola 2	-0.82 **	0.35 *	0.11 **	0.02	-0.91 *	-0.91 **	-0.02	-0.54	-0.16	-0.75	0.34 **	-0.53 **	-0.15	-21.66 **
19.	EC 329384 × Akola 3	-0.24	2.21 **	-0.16 **	-0.33 **	0.41	-0.06	-0.02	1.35 **	2.01 **	1.49 **	0.42 **	0.13 **	0.13	16.53 **
20.	EC 329384 × PDKV Pragati	-0.06	-1.90 **	0.08 *	0.25 **	-0.08	-0.04	-0.03	-0.21	2.77 **	2.25 **	0.29 **	-0.02	0.43 **	-29.97 **
21.	Parbhani Kranti × Akola Bahar	-0.14	-0.73 **	0.11 **	-0.39 **	-3.45 **	-0.57 **	-0.06 **	-3.89 **	1.34 **	0.32	0.29 **	-0.56 **	1.51 **	-16.04 **
22.	Parbhani Kranti × Akola 1	-1.82 **	-0.22	0.45 **	-0.02	0.90 *	0.38 **	0.04 *	6.61 **	0.79 **	3.47 **	0.63 **	-1.16 **	-0.09	-29.29 **
23.	Parbhani Kranti × Akola 2	-1.18 **	1.01 **	-0.13 **	0.58 **	-1.50 **	1.14 **	0.11 **	-2.01 **	1.83 **	0.52	-0.92 **	0.87 **	0.54 **	29.42 **
24 .	Parbhani Kranti × Akola 3	1.94 **	-0.96 **	0.05	-0.01	-0.51	-0.97 **	0.05 *	-3.44 **	-3.14 **	-0.06	0.27 **	0.31 **	-1.19 **	-12.17 **
25.	Parbhani Kranti × PDKV Pragati	1.19 **	0.90 **	-0.48 **	-0.16 **	4.56 **	0.02	-0.14 **	2.73 **	-0.82 **	-4.25 **	-0.28 **	0.54 **	-0.76 **	28.08 **
26.	Varsha Upahar × Akola Bahar	0.96 **	0.88 **	-0.40 **	0.15 **	-1.01 *	-0.11 *	-0.09 **	-1.73 **	0.11	-0.35	-0.08	-0.50 **	-0.83 **	-58.40 **
27.	Varsha Upahar × Akola 1	-0.48 **	0.01	-0.05	0.07 **	-1.79 **	-0.15 **	0.17 **	-3.62 **	1.24 **	-0.27	-0.19 **	0.51 **	0.17	21.64 **
28.	Varsha Upahar × Akola 2	-0.09	-0.92 **	0.39 **	-0.08 **	1.04 *	0.65 **	-0.08 **	-2.01 **	0.49 *	-1.63 **	0.20 **	0.43 **	-0.18	22.79 **
29.	Varsha Upahar × Akola 3	-1.60 **	-0.75 **	-0.11 **	0.20 **	3.34 **	-0.69 **	-0.06 **	4.45 **	0.92 **	1.23 *	0.17 **	-0.35 **	0.80 **	16.30 **
30.	Varsha Upahar × PDKV Pragati	1.22 **	0.78 **	0.17 **	-0.34 **	-1.59 **	0.30 **	0.07 **	2.90 **	-2.75 **	1.03 *	-0.11 *	-0.08	0.03	-2.33
31.	EC 329386 × Akola Bahar	1.21 **	-0.76 **	0.27 **	0.07 **	3.65 **	-0.50 **	0.04 *	1.79 **	-0.95 **	1.06 *	0.01	0.79 **	-0.34 **	20.71 **
32.	EC 329386 × Akola 1	-1.06 **	0.64 **	-0.18 **	-0.16 **	-2.04 **	0.53 **	-0.19 **	-5.38 **	-0.13	-0.57	-0.74 **	-0.49 **	0.26 *	-17.63 **
33 .	EC 329386 × Akola 2	-0.58 **	-0.63 **	-0.35 **	-0.37 **	-1.12 **	-0.06	0.01	6.72 **	-2.41 **	0.84	0.42 **	0.24 **	-0.36 **	0.35
34.	EC 329386 × Akola 3	0.65 **	0.38 *	0.14 **	-0.08 **	-2.13 **	0.67 **	0.23 **	-2.39 **	0.62 **	-2.66 **	0.49 **	-0.51 **	0.1	-24.84 **
35.	EC 329386 × PDKV Pragati	-0.21	0.36 *	0.13 **	0.55 **	1.64 **	-0.63 **	-0.09 **	-0.74	2.87 **	1.32 **	-0.18 **	-0.02	0.34 **	21.41 **
36.	Kokan Bhendi × Akola Bahar	-2.06 **	0.70 **	0.01	-0.09 **	-0.67	0.27 **	0	2.87 **	1.88 **	-0.83	-0.01	-0.39 **	1.08 **	24.57 **
37.	Kokan Bhendi × Akola 1	-0.72 **	0.77 **	0.19 **	0.14 **	4.44 **	-0.43 **	0.11 **	5.74 **	-0.09	-0.54	0.22 **	0.31 **	-0.62 **	-44.12 **
38.	Kokan Bhendi × Akola 2	2.13 **	0.45 **	0.43 **	-0.05	2.21 **	0.31 **	0.19 **	-8.01 **	-0.72 **	-1.35 **	0.28 **	-0.11 *	-0.58 **	-13.72 **
39.	Kokan Bhendi × Akola 3	-0.14	-0.69 **	0	-0.19 **	-3.11 **	-0.28 **	-0.12 **	-0.94 *	-1.31 **	0.85	-0.87 **	0.69 **	0.02	17.02 **
40.	Kokan Bhendi × PDKV Pragati	0.78 **	-1.23 **	-0.64 **	0.18 **	-2.87 **	0.13 *	-0.18 **	0.35	0.25	1.87 **	0.37 **	-0.49 **	0.11	16.25 **
41.	Korchi × Akola Bahar	0.47 **	0.06	0.37 **	-0.12 **	-1.24 **	0.32 **	0.03	-0.5	-0.31	0.33	0.54 **	0.16 **	0.61 **	-1.35
42.	Korchi × Akola 1	1.84 **	0.72 **	-0.41 **	-0.19 **	-7.01 **	-0.09	0.01	1.08 **	-0.25	1.39 **	0.33 **	0.45 **	0.42 **	27.89 **
43.	Korchi × Akola 2	0.41 *	-1.40 **	-0.32 **	0.27 **	2.86 **	-1.80 **	-0.03	-1.32 **	1.66 **	0.05	-0.57 **	0.25 **	-0.01	-37.09 **
44.	Korchi × Akola 3	-0.56 **	0.3	0.17 **	0.70 **	2.52 **	0.83 **	-0.03	5.01 **	-0.54 *	0.47	-0.18 **	-0.80 **	-0.65 **	9.10 **
45.	Korchi × PDKV Pragati	-2.16 **	0.32 *	0.19 **	-0.65 **	2.87 **	0.74 **	0.02	-4.27 **	-0.56 *	-2.24 **	-0.13 **	-0.06	-0.37 **	1.45
46.	EC 329395 × Akola Bahar	-0.44 **	0.24	-0.31 **	0.37 **	3.33 **	-0.06	0.19 **	-1.47 **	0.15	0.48	-0.08	-0.26 **	-0.24	-10.57 **
47.	EC 329395 × Akola 1	1.46 **	-1.28 **	-0.08 *	0.13 **	0.59	0.24 **	-0.27 **	-0.12	-0.97 **	-0.69	-0.57 **	0.71 **	0.04	9.22 **
48.	EC 329395 × Akola 2	-0.70 **	1.34 **	-0.15 **	-0.06 *	-1.02 *	-0.25 **	-0.06 **	6.95 **	0.96 **	2.94 **	-0.11 *	-0.44 **	0.18	-0.11
49.	EC 329395 × Akola 3	-0.1	-0.49 **	-0.15 **	-0.82 **	0.43	0.95 **	-0.07 **	-2.05 **	1.88 **	-0.68	0.45 **	0.09 *	-0.58 **	0.3
50.	EC 329395 × PDKV Pragati	-0.23	0.19	0.69 **	0.39 **	-3.33 **	-0.88 **	0.22 **	-3.32 **	-2.02 **	-2.05 **	0.31 **	-0.11 *	0.59 **	1.16
SE (sca effects)		0.157	0.153	0.038	0.026	0.414	0.049	0.019	0.386	0.235	0.487	0.046	0.046	0.12	2.85

* Significant at 5 per cent probability level, ** Significant at 1 per cent probability level

DFF = Day to 50% flowering; DFP = Day to first picking; NBP = Number of Branches per plant; IL = Internodal length; PH = Plant height; FL = Fruit length; FG = Fruit Girth; TFP = Total number of fruit per plant; TSP = Total number seed per plant; DLP = Day to last picking; CPC = Crude protein content; CFC = Crude fiber content %; VC = Vitamin C; FYP = Fruit yield per plant.

For branching, positive significant *SCA* was the highest in EC 329395 × PDKV Pragati (0.69) and Parbhani Kranti × Akola 1 (0.45), reflecting the importance of enhanced branching for yield improvement, consistent with findings by Parmar *et al*. (2012). Shorter internodal length, desired for sturdy plant architecture, showed strong negative *SCA* effects in EC 329395 × Akola 3 (-0.82) and Korchi × PDKV Pragati (-0.65). Similar findings were reported by Kayande *et al*. (2015) branching per plant. Plant height, an important biomass determinant, exhibited the highest positive *SCA* in Parbhani Kranti × PDKV Pragati (4.56) and Kokan Bhendi × Akola 1 (4.44), paralleling earlier reports by Rewale *et al*. (2013) for plant height.

Extended fruiting period was marked by significant positive *SCA* in Parbhani Kranti × Akola 1 (3.47) and EC 329395 × Akola 2 (2.94), suggesting opportunities for prolonged harvesting, consistent with enhanced market value described in prior studies (Valluru Manju Vani *et al*., 2017). Nutritional quality traits including crude protein saw positive *SCA* in Parbhani Kranti × Akola 1 (0.63) and Korchi × Akola Bahar (0.54), whilst reduced crude fiber content, favorable for better digestibility, was evident in Parbhani Kranti × Akola 1 (-1.16) and Ankur 40 × Akola 1 (-0.85) (Archana Mishra *et al*., 2015). Vitamin C content was positively influenced by crosses such as Parbhani Kranti × Akola Bahar (1.51) and Ankur 40 × Akola 3 (1.36) indicating enhanced antioxidant potential *viz*., crude protein, crude fiber content and Vitamin C content (Singh *et al*., 2012).

Significant differences in *SCA* effects were recorded among Okra crosses for total number of fruits per plant, total seeds per plant, and fruit yield per plant. Crosses such as EC 329384 × Akola Bahar exhibited the highest positive *SCA* effects for fruit yield per plant (23.00) and total fruits per plant (6.54), while Kokan Bhendi × Akola Bahar (24.57 yield; 2.87 fruits) and EC 329386 × Akola Bahar (20.71 yield; 1.79 fruits) also demonstrated strong, statistically significant *SCA* values. Promising positive *SCA* impacts for fruit yield were observed in Ankur 40 × Akola Bahar (18.88), Varsha Upahar × Akola 1 (21.64), and Korchi × Akola 1 (27.89), highlighting these hybrids' potential for yield enhancement. Moreover, seed yield improvement was notable in crosses such as EC 329384 × Akola 3 (2.01), EC 329384 × PDKV Pragati (2.77), and EC 329386 × PDKV Pragati (2.87). Conversely, certain crosses displayed significantly negative *SCA* values for fruit yield, particularly Varsha Upahar × Akola Bahar (–58.40) and Kokan Bhendi × Akola 1 (–44.12), suggesting these combinations are less desirable for yield improvement. These findings confirm contemporary research that underscores the breeding value of *SCA* for identifying Okra hybrids with enhanced total fruits per plant, total seeds per plant and fruit yield per plant (Kumar *et al*., 2024).

Heterotic studies

The estimates of better parent heterosis (BPH) and standard heterosis (SH, relative to Arka Anamika) for 14 essential traits among Okra hybrids are sown in **Table 5 & 6**. The analysis of heterosis in this study revealed that for traits where lower values are desirable, such as days to 50% flowering and day to first picking, the most negative *SCA* effects highlight promising parental combinations. Notably, crosses *viz*., EC 329386 × PDKV Pragati (-4.39%) and EC 329386 × Akola 1 (-3.92%) exhibited the highest heterosis for early flowering, aligning with findings by Valluru Manju Vani *et al*. (2017), who reported significant heterosis for earliness traits in Okra. Similarly, for early harvest traits like days to first picking, crosses such as EC 329384 × PDKV Pragati (-1.90%) and Korchi × Akola 2 (-1.40%) demonstrated substantial heterotic effects, reinforcing the potential of these combinations to reduce maturity duration as observed by Singh *et al*. (2012).

Further, for traits related to plant architecture such as number of branches per plant and internodal length, where higher or shorter values are desirable, the heterotic crosses included EC 329395 × PDKV Pragati (0.69%) and IC 42451 × Akola 2 (-0.82%), as reported by Parmar *et al*. (2012), who emphasized the importance of heterosis in improving such traits. For plant height, crosses such as Parbhani Kranti × PDKV Pragati (4.56%) further exemplify the significant heterotic potential which correlates with boosts in biomass and yield, consistent with findings by Rewale *et al*. (2013).

Significant heterosis was recorded for fruit yield per plant, with several Okra hybrids showing notable positive better parent heterosis (BP) and standard heterosis (SH, Arka Anamika as the check). Kokan Bhendi × Akola Bahar showed the highest BP heterosis (18.23%), while Varsha Upahar × Akola 1 (13.16%), EC 329386 × Akola Bahar (8.89%), and Parbhani Kranti × PDKV Pragati (10.91%) also exhibited substantial BP values. Crosses such as Parbhani Kranti × PDKV Pragati (9.40%), Parbhani Kranti × Akola 2 (6.41%), and EC 329395 × Akola 1 (1.92%) demonstrated superior SH for fruit yield compared to Arka Anamika. The majority of crosses, however, displayed negative SH, highlighting the challenge of surpassing the standard variety.

These results align with earlier reports highlighting substantial heterotic effects for fruit yield and its contributing traits in Okra (heterosis for fruit yield and fruit number: Mohammed *et al*., 2022; heterosis for plant height and fruit weight: Iqbal *et al*., 2020; heterosis for seed yield and pod length: Mishra *et al*., 2021).These results underscore the considerable potential of certain Line × Tester combinations in Okra for commercial yield improvement, as similarly emphasized in recent heterosis studies (Patel *et al*., 2025; Yohanna *et al*., 2023; Rehaman *et al*., 2024).The magnitude of heterosis observed in these crosses confirms its utility in breeding programs aimed at developing high-yielding, early-maturing, and nutritionally superior Okra hybrids. This finding aligns with

Table 5. Assessment of better parent heterosis (%) in Okra for various traits

S.No.	Crosses	DFF	DFP	NBP	IL	PH	FL	FG	TFP	TSP	DLP	CPC	CFC	VC	FYP
1.	IC 42451 × Akola Bahar	2.93 **	3.66 **	-7.25 **	-15.31 **	5.54 **	-6.28 **	-14.75 **	-4.83 **	-1.86 *	3.75 **	-14.16 **	-23.95 **	3.83 **	-0.31
2.	IC 42451 × Akola 1	3.12 **	1.29 **	-3.22 *	-0.14	14.68 **	-2.86 **	-1.85	0.59	3.70 **	0.7	-12.10 **	-37.77 **	4.17 **	1.31 **
3.	IC 42451 × Akola 2	0.95	-0.42	-5.66 **	-25.44 **	9.75 **	-4.42 **	-23.21 **	-18.97 **	-8.38 **	1.45	-14.00 **	-42.81 **	-1.04	-8.79 **
4.	IC 42451 × Akola 3	4.00 **	1.84 **	7.53 **	-11.57 **	8.79 **	-2.19 **	-14.66 **	-8.14 **	2.52 **	-1.16	-22.51 **	-24.55 **	5.89 **	-9.22 **
5.	IC 42451 × PDKV Pragati	1.08	0.42	-12.99 **	-3.51 **	1.04	-10.25 **	13.65 **	-6.24 **	-8.14 **	5.59 **	-16.58 **	-33.72 **	0.91	-8.31 **
6.	IC 42456 × Akola Bahar	0.59	-0.85 *	-13.04 **	2.89 **	6.63 **	-8.38 **	-13.38 **	0.12	-1.83 *	3.66 **	-9.03 **	-21.66 **	-3.70 **	5.44 **
7.	IC 42456 × Akola 1	6.06 **	1.62 **	0.97	11.75 **	12.19 **	-1.70 **	-22.73 **	0.92	-1.50 *	4.19 **	-5.42 **	-33.22 **	0.72	5.93 **
8.	IC 42456 × Akola 2	0.68	-1.09 **	8.09 **	-15.00 **	11.04 **	-0.45	-22.88 **	-11.37 **	-3.76 **	2.65 **	-11.68 **	-34.23 **	-1.1	-4.57 **
9.	IC 42456 × Akola 3	6.87 **	0.43	21.67 **	0.18	6.44 **	-7.13 **	-14.96 **	2.26 **	-9.12 **	3.81 **	-17.82 **	-21.96 **	2.41 **	-4.20 **
10.	IC 42456 × PDKV Pragati	1.71 **	0.19	-11.99 **	14.66 **	-1.35 *	-12.59 **	-16.83 **	1.3	-5.50 **	8.62 **	-12.09 **	-29.43 **	4.52 **	-2.08 **
11.	Ankur 40 × Akola Bahar	3.86 **	4.20 **	7.45 **	3.20 **	6.82 **	-11.35 **	-9.06 **	6.15 **	-0.21	7.25 **	-6.98 **	-3.70 **	-8.80 **	8.37 **
12.	Ankur 40 × Akola 1	7.70 **	1.17 **	6.04 **	19.70 **	13.38 **	-13.69 **	15.62 **	25.76 **	5.37 **	10.34 **	-0.82	-20.60 **	-8.42 **	8.02 **
13.	Ankur 40 × Akola 2	1.02	1.34 **	9.15 **	-6.72 **	15.39 **	-0.83 *	-10.86 **	0.19	-5.60 **	4.51 **	-6.14 **	-22.41 **	-4.32 **	6.12 **
14.	Ankur 40 × Akola 3	2.94 **	0.87 *	21.46 **	-0.6	12.57 **	-4.17 **	-2.01	-1.80 *	3.34 **	10.62 **	-19.66 **	-8.99 **	1.15	2.22 **
15.	Ankur 40 × PDKV Pragati	4.46 **	3.93 **	-0.91	6.36 **	7.42 **	-6.78 **	18.91 **	12.77 **	-2.31 **	9.24 **	-7.66 **	-7.27 **	-9.46 **	1.65 **
16.	EC 329384 × Akola Bahar	3.28 **	-2.44 **	-20.29 **	-8.25 **	1.78 **	-7.64 **	-10.91 **	8.19 **	-5.36 **	3.19 **	-14.33 **	-27.93 **	4.43 **	6.97 **
17.	EC 329384 × Akola 1	7.31 **	-1.11 **	-8.58 **	16.74 **	4.34 **	-3.95 **	-10.44 **	-5.02 **	-3.24 **	0.92	-19.52 **	-33.32 **	8.92 **	5.48 **
18.	EC 329384 × Akola 2	-1.39 **	-0.34	-10.44 **	-14.58 **	6.82 **	-13.80 **	-22.92 **	-13.37 **	-3.65 **	1.92 *	-12.56 **	-43.65 **	0.69	-10.14 **
19.	EC 329384 × Akola 3	3.55 **	1.81 **	-1.42	-13.09 **	5.36 **	-7.27 **	-16.05 **	-1.65 *	4.38 **	4.20 **	-19.40 **	-26.16 **	10.16 **	-5.00 **
20.	EC 329384 × PDKV Pragati	2.64 **	-5.36 **	-16.71 **	10.76 **	-0.67	-16.10 **	-1.79	-1.77 *	1.98 **	7.30 **	-15.50 **	-34.55 **	6.85 **	-9.31 **
21.	Parbhani Kranti × Akola Bahar	5.78 **	5.07 **	0.43	5.37 **	4.64 **	-16.89 **	-13.79 **	2.28 **	4.33 **	8.10 **	-2.62 **	-7.11 **	4.93 **	4.56 **
22.	Parbhani Kranti × Akola 1	5.56 **	5.78 **	14.88 **	24.59 **	11.50 **	-7.83 **	-11.17 **	17.12 **	3.77 **	12.41 **	-1.52 **	-20.92 **	-1.17	4.10 **
23.	Parbhani Kranti × Akola 2	1.03	4.31 **	-6.19 **	9.92 **	12.78 **	-1.94 **	-11.59 **	-2.94 **	1.98 **	6.65 **	-8.70 **	-15.09 **	-3.06 **	7.89 **
24 .	Parbhani Kranti × Akola 3	13.21 **	3.18 **	13.50 **	3.21 **	10.99 **	-14.17 **	-10.48 **	-3.97 **	-7.17 **	7.80 **	-7.78 **	-2.63 **	-5.49 **	2.60 **
25.	Parbhani Kranti × PDKV Pragati	9.19 **	7.14 **	-10.75 **	20.82 **	9.37 **	-11.01 **	-9.79 **	9.84 **	-4.66 **	5.18 **	-9.45 **	-6.84 **	-6.21 **	10.91 **
26.	Varsha Upahar × Akola Bahar	5.84 **	0.37	-18.24 **	6.62 **	2.90 **	-15.17 **	-7.37 **	5.45 **	-1.86 *	4.41 **	-1.73 **	-17.38 **	-3.53 **	1.79 **
27.	Varsha Upahar × Akola 1	6.64 **	-1.42 **	-1.95	22.17 **	4.92 **	-12.40 **	13.41 **	13.51 **	6.91 **	7.75 **	0.41	-18.80 **	0.19	13.16 **
28.	Varsha Upahar × Akola 2	1.07 *	-3.00 **	16.45 **	-7.07 **	11.04 **	-5.92 **	-15.18 **	-7.56 **	-4.31 **	1.24	-2.93 **	-27.78 **	-6.96 **	1.96 **
29.	Varsha Upahar × Akola 3	2.88 **	-3.56 **	11.09 **	2.62 **	10.49 **	-13.49 **	-6.94 **	12.23 **	3.98 **	8.09 **	-10.83 **	-17.39 **	5.46 **	1.91 **
30.	Varsha Upahar × PDKV Pragati	6.77 **	-0.73	-4.45 **	10.73 **	0.43	-10.19 **	15.46 **	11.14 **	-12.25 **	10.53 **	5.14 **	-17.63 **	-2.83 **	0.65
31.	EC 329386 × Akola Bahar	-0.05	0.74	-5.69 **	-2.78 **	6.30 **	-12.69 **	-7.53 **	5.56 **	-2.09 **	4.89 **	-6.51 **	-11.66 **	8.65 **	8.89 **
32.	EC 329386 × Akola 1	-3.92 **	3.00 **	-12.96 **	6.57 **	7.21 **	0.56	-14.75 **	0.17	0.91	3.50 **	-9.55 **	-30.75 **	9.94 **	5.32 **
33 .	EC 329386 × Akola 2	-2.50 **	1.07 **	-17.96 **	-20.43 **	7.63 **	-4.07 **	-17.26 **	-1.14	-8.58 **	2.92 **	-6.79 **	-29.14 **	0.88	0.3
34.	EC 329386 × Akola 3	-1.26 *	1.75 **	11.29 **	-12.53 **	3.71 **	1.40 **	0	-4.32 **	0.55	0.57	-13.96 **	-20.34 **	11.28 **	-2.01 **
35.	EC 329386 × PDKV Pragati	-4.39 **	1.81 **	-12.26 **	16.82 **	0.47	-17.12 **	0.82	1.38	2.24 **	7.49 **	-9.14 **	-24.79 **	7.66 **	4.37 **
36.	Kokan Bhendi × Akola Bahar	-1.84 **	1.80 **	3.04 *	-9.18 **	4.68 **	-6.78 **	-15.71 **	11.34 **	-0.47	5.27 **	-5.33 **	-14.14 **	3.33 **	18.23 **
37.	Kokan Bhendi × Akola 1	8.06 **	1.68 **	14.42 **	11.00 **	16.14 **	-6.48 **	-12.71 **	16.46 **	-1.4	8.89 **	-4.79 **	-21.11 **	-3.18 **	8.11 **
38.	Kokan Bhendi × Akola 2	5.18 **	-1.43 **	27.27 **	-17.95 **	13.25 **	-1.10 *	-12.86 **	-14.15 **	-9.48 **	2.96 **	-5.47 **	-27.34 **	-5.97 **	-0.16
39.	Kokan Bhendi × Akola 3	7.07 **	-1.80 **	24.31 **	-6.21 **	5.25 **	-5.38 **	-21.86 **	-0.95	-6.35 **	9.10 **	-19.40 **	-8.12 **	1.16	4.21 **
40.	Kokan Bhendi × PDKV Pragati	4.95 **	-2.69 **	-17.80 **	5.07 **	-1.30 *	-11.64 **	-15.71 **	6.82 **	-8.18 **	13.00 **	-6.90 **	-22.96 **	0.5	4.96 **
41.	Korchi × Akola Bahar	4.25 **	2.46 **	-1.08	-6.47 **	1.01	-7.44 **	-13.52 **	2.17 **	-8.70 **	4.79 **	-6.53 **	-20.48 **	2.04 *	2.71 **
42.	Korchi × Akola 1	9.05 **	3.42 **	-18.03 **	7.31 **	1.60 **	-4.99 **	-7.64 **	18.86 **	-3.36 **	9.32 **	-5.19 **	-28.21 **	-0.4	7.34 **
43.	Korchi × Akola 2	1.70 **	-0.65	-13.18 **	-10.99 **	10.75 **	-18.00 **	-24.26 **	-11.09 **	-7.48 **	2.77 **	-15.56 **	-35.66 **	-7.93 **	-5.54 **
44.	Korchi × Akola 3	2.43 **	1.87 **	13.94 **	-0.78	7.44 **	1.77 **	-17.44 **	7.83 **	-6.21 **	6.78 **	-20.61 **	-27.38 **	-3.82 **	0.61
45.	Korchi × PDKV Pragati	-2.53 **	2.02 **	-9.08 **	-2.77 **	0.98	-8.38 **	0.82	-3.71 **	-13.16 **	6.22 **	-4.89 **	-28.23 **	-6.60 **	0.66
46.	EC 329395 × Akola Bahar	0.01	-0.97 *	-16.27 **	3.67 **	4.33 **	-5.84 **	0.77	5.93 **	1.60 *	5.93 **	-6.72 **	-26.91 **	0.39	4.74 **
47.	EC 329395 × Akola 1	5.35 **	-3.82 **	-3.70 *	13.83 **	4.52 **	2.05 **	-20.25 **	12.07 **	-0.54	7.46 **	-7.79 **	-32.02 **	3.56 **	8.24 **
48.	EC 329395 × Akola 2	-0.58	1.05 **	-2.4	-13.45 **	6.45 **	-1.87 **	-19.05 **	3.43 **	0.12	7.05 **	-9.58 **	-39.81 **	2.77 **	1.96 **
49.	EC 329395 × Akola 3	0.79	-3.21 **	9.26 **	-20.06 **	5.15 **	7.05 **	-12.19 **	0.68	3.82 **	6.42 **	-13.93 **	-25.50 **	1.74 *	2.73 **
50.	EC 329395 × PDKV Pragati	-0.78	-1.95 **	9.08 **	15.93 **	-3.51 **	-15.43 **	12.56 **	2.71 **	-7.24 **	7.46 **	-5.50 **	-33.93 **	7.20 **	3.71 **

* Significant at 5 per cent probability level, ** Significant at 1 per cent probability level

DFF = Day to 50% flowering; DFP = Day to first picking; NBP = Number of Branches per plant; IL = Internodal length; PH = Plant height; FL = Fruit length; FG = Fruit Girth; TFP = Total number of fruit per plant; TSP = Total number seed per plant; DLP = Day to last picking; CPC = Crude protein content; CFC = Crude fiber content %; VC = Vitamin C; FYP = Fruit yield per plant.

Table 6. Assessment of standard heterosis in per cent (Over Arka Anamika) in Okra for 14 traits

S.No	Crosses	DFF	DFP	NBP	IL	PH	FL	FG	TFP	TSP	DLP	CPC	CFC	VC	FYP
1.	IC 42451 × Akola Bahar	0.81	7.92**	-11.01**	23.84**	-7.72**	-16.35**	-56.26**	-20.48**	-3.64**	-2.48*	2.53*	-24.37**	-14.38**	-13.89**
2.	IC 42451 × Akola 1	-0.27	5.46**	-6.58*	46.02**	-3.00	-15.36**	-54.07**	-18.91**	-4.82**	-6.37**	5.00**	-38.11**	-11.14**	-10.61**
3.	IC 42451 × Akola 2	2.71	7.35**	-18.52**	9.03**	-3.58	-15.63**	-59.34**	-23.45**	-7.66**	-5.55**	5.51**	-43.12**	-9.86**	-12.37**
4.	IC 42451 × Akola 3	0.59	6.04**	-0.56	29.31**	-4.2	-12.14**	-56.43**	-25.95**	-5.98**	-8.09**	-0.42	-24.96**	-10.41**	-13.84**
5.	IC 42451 × PDKV Pragati	-2.24	4.56**	-9.88**	41.08**	-9.93**	-14.39**	-45.56**	-21.98**	-7.63**	-1.82	-0.35	-34.08**	-10.94**	-10.49**
6.	IC 42456 × Akola Bahar	-1.47	6.90**	-16.54**	35.89**	-6.76**	-18.23**	-52.55**	-16.35**	-3.61**	-2.56	7.58**	-22.51**	-15.57**	-3.25*
7.	IC 42456 × Akola 1	2.26	9.56**	-2.54	48.98**	-5.10**	-14.34**	-57.68**	-17.49**	-3.42**	-4.40**	10.13**	-33.94**	-11.70**	-2.81
8.	IC 42456 × Akola 2	2.43	6.64**	-1.98	12.25**	-2.44	-12.12**	-57.75**	-16.28**	-3.01**	-4.43**	8.35**	-34.71**	-9.92**	-8.32**
9.	IC 42456 × Akola 3	3.04	8.28**	12.53**	43.65**	-6.27**	-16.57**	-53.43**	-16.39**	-10.89**	-4.75**	5.61**	-22.80**	-10.22**	-9.07**
10.	IC 42456 × PDKV Pragati	-1.9	8.02**	-8.83**	51.43**	-12.06**	-16.62**	-54.44**	-15.71**	-4.97**	-0.34	2.37*	-30.19**	-7.75**	-4.41**
11.	Ankur 40 × Akola Bahar	1.73	9.11**	3.1	31.48**	-6.43**	-13.11**	-53.36**	-11.31**	-2.02*	0.81	9.99**	-9.51**	-14.50**	3.78*
12.	Ankur 40 × Akola 1	2.6	5.94**	2.37	59.59**	-0.68	-15.40**	-46.34**	-1.26	3.40**	-1.82	14.14**	-28.79**	-14.14**	3.45*
13.	Ankur 40 × Akola 2	2.78	9.24**	-5.73*	18.84**	1.37	-2.80*	-52.79**	-5.36**	-4.86**	-2.71	15.15**	-22.98**	-10.29**	1.95
14.	Ankur 40 × Akola 3	-1.94	5.62**	12.33**	42.54**	-0.87	-6.07**	-49.95**	-21.98**	1.41	-0.7	3.24*	-14.23**	-5.17**	-2.11
15.	Ankur 40 × PDKV Pragati	0.76	8.82**	2.65	35.49**	-4.24	-8.63**	-43.03**	-6.17**	-1.76	-2.27	6.26**	-20.28**	-15.11**	-0.78
16.	EC 329384 × Akola Bahar	1.15	5.91**	-23.51**	20.15**	-9.34**	-17.57**	-54.30**	-9.61**	-7.07**	-3.01	2.93*	-31.13**	-13.11**	-6.74**
17.	EC 329384 × Akola 1	3.79	7.35**	-11.74**	55.64**	-7.06**	-16.31**	-56.74**	-24.25**	-6.37**	-6.00**	-3.31*	-36.28**	-7.09**	-6.92**
18.	EC 329384 × Akola 2	0.33	8.18**	-17.67**	11.85**	-4.85*	-23.90**	-59.17**	-18.16**	-2.90*	-5.07**	7.27**	-44.06**	-8.28**	-13.66**
19.	EC 329384 × Akola 3	0.15	10.52**	-8.83**	24.63**	-6.15**	-16.71**	-57.14**	-21.56**	1	-2.96	3.57*	-29.44**	-6.79**	-9.84**
20.	EC 329384 × PDKV Pragati	-0.73	2.74*	-13.72**	45.03**	-11.45**	-19.97**	-52.55**	-18.27**	2.55*	-0.06	1.53	-37.46**	-5.70**	-11.47**
21.	Parbhani Kranti × Akola Bahar	3.61	8.95**	9.88**	34.31**	-7.42**	-15.71**	-50.76**	-10.02**	2.44*	1.61	22.08**	-12.72**	-9.96**	3.13*
22.	Parbhani Kranti × Akola 1	0.96	9.69**	25.68**	66.11**	-1.36	-6.53**	-49.24**	3.04*	1.59	2.61	23.46**	-27.02**	-15.20**	2.68
23.	Parbhani Kranti × Akola 2	2.79	12.44**	2.65	40.09**	-0.23	-0.55	-49.48**	-8.31**	2.77*	-0.71	14.45**	-15.70**	-11.70**	6.41**
24 .	Parbhani Kranti × Akola 3	8.27	7.41**	24.19**	48.00**	-1.81	-12.95**	-48.87**	-15.52**	-9.12**	-1.6	18.51**	-8.24**	-18.90**	1.2
25.	Parbhani Kranti × PDKV Pragati	5.32	11.10**	-2.34	54.00**	-2.5	-9.75**	-48.46**	-3.37*	-4.12**	-3.99*	13.51**	-14.03**	-17.22**	9.40**
26.	Varsha Upahar × Akola Bahar	3.66	7.89**	-21.54**	39.98**	-8.06**	-18.78**	-52.48**	-11.90**	-3.64**	-1.85	16.21**	-22.36**	-20.45**	-9.37**
27.	Varsha Upahar × Akola 1	1.55	5.97**	-5.36*	62.89**	-6.25**	-16.13**	-47.35**	-13.03**	-0.77	-4.13*	14.43**	-27.18**	-14.54**	0.75
28.	Varsha Upahar × Akola 2	2.83	4.56**	0.56	22.00**	-0.78	-9.93**	-55.08**	-12.67**	-3.56**	-5.75**	19.09**	-28.30**	-15.26**	-2.04
29.	Varsha Upahar × Akola 3	-2.03	3.66**	2.74	47.15**	-1.27	-17.17**	-52.48**	-10.84**	-3.49**	-2.97	14.59**	-22.15**	-10.76**	-3.27*
30.	Varsha Upahar × PDKV Pragati	2.99	6.71**	-1.02	45.37**	-10.26**	-14.01**	-44.68**	-7.53**	-11.76**	-1.11	11.42**	-27.73**	-14.24**	-1.75
31.	EC 329386 × Akola Bahar	1.82	8.56**	-9.48**	22.20**	-7.06**	-22.07**	-52.55**	-11.81**	-3.87**	-1.41	10.56**	-14.98**	-10.41**	0.53
32.	EC 329386 × Akola 1	-2.13	11.00**	-15.98**	42.07**	-9.32**	-12.38**	-59.03**	-18.98**	-1.69	-5.51**	4.24*	-33.35**	-6.22**	-2.76
33 .	EC 329386 × Akola 2	-0.68	8.95**	-27.38**	0	-5.45*	-15.31**	-56.19**	-6.61**	-7.86**	-4.18*	14.36**	-29.66**	-8.11**	-3.64*
34.	EC 329386 × Akola 3	0.59	9.65**	2.94	25.42**	-8.67**	-8.91**	-48.94**	-22.61**	-2.04	-8.18**	10.56**	-23.33**	-5.84**	-6.99**
35.	EC 329386 × PDKV Pragati	-2.61	9.72**	-9.12**	46.81**	-10.44**	-20.94**	-51.54**	-15.64**	2.81*	-1.87	4.71**	-27.61**	-4.98**	1.88
36.	Kokan Bhendi × Akola Bahar	-3.86	6.61**	-1.13	30.95**	-8.47**	-16.79**	-53.50**	-6.00**	-2.28*	-1.05	13.02**	-18.14**	-9.62**	2.13
37.	Kokan Bhendi × Akola 1	0.25	6.48**	10.44**	60.04**	-1.77	-18.51**	-51.84**	-1.68	-6.26**	-3.11	13.65**	-24.78**	-15.31**	-4.61**
38.	Kokan Bhendi × Akola 2	7.01	6.26**	10.64**	18.31**	-0.51	-12.69**	-51.94**	-18.90**	-8.78**	-4.15*	15.97**	-27.87**	-14.35**	-4.08**
39.	Kokan Bhendi × Akola 3	0.45	2.83*	14.96**	35.24**	-7.32**	-15.00**	-56.90**	-16.37**	-10.97**	-2.07	3.57*	-12.40**	-11.51**	-1.09
40.	Kokan Bhendi × PDKV Pragati	1.23	1.9	-14.85**	51.49**	-12.02**	-15.71**	-53.50**	-9.81**	-7.66**	1.09	11.14**	-26.55**	-11.30**	2.46
41.	Korchi × Akola Bahar	2.11	9.75**	-5.08*	19.95**	-11.68**	-17.39**	-55.63**	-14.63**	-10.35**	-1.5	10.53**	-25.28**	-15.86**	-3.33*
42.	Korchi × Akola 1	6.28	10.78**	-20.89**	43.06**	-14.01**	-17.22**	-57.14**	-11.79**	-9.84**	-2.73	8.04**	-34.33**	-15.04**	1.03
43.	Korchi × Akola 2	3.47	7.09**	-25.01**	14.16**	-2.71	-27.61**	-59.88**	-16.01**	-6.76**	-4.32*	3.59**	-36.13**	-16.13**	-9.24**
44.	Korchi × Akola 3	-0.17	9.11**	5.36*	42.27**	-5.39*	-8.58**	-57.85**	-14.33**	-12.49**	-4.15*	2.02	-31.56**	-18.62**	-4.51**
45.	Korchi × PDKV Pragati	-5	9.27**	-5.81*	24.69**	-9.98**	-12.60**	-51.70**	-19.88**	-12.68**	-4.96**	1.27	-34.36**	-17.57**	-1.74
46.	EC 329395 × Akola Bahar	0.22	10.14**	-19.64**	31.94**	-3.51	-15.96**	-48.30**	-11.50**	-0.14	-0.43	10.30**	-27.77**	-10.59**	-1.37
47.	EC 329395 × Akola 1	5.57	6.96**	-7.06*	51.75**	-3.33	-11.08**	-59.98**	-8.91**	-2.24*	-4.04*	5.84**	-32.82**	-7.77**	1.92
48.	EC 329395 × Akola 2	1.15	12.38**	-15.69**	10.15**	-1.54	-13.37**	-57.14**	-2.3	0.9	-0.34	10.93**	-40.25**	-6.39**	-2.05
49.	EC 329395 × Akola 3	1	7.64**	1.04	14.62**	-2.74	-3.84**	-55.15**	-18.17**	2.04	-4.47**	10.61**	-26.37**	-9.39**	-2.5
50.	EC 329395 × PDKV Pragati	-0.57	9.05**	12.98**	47.54**	-10.76**	-19.33**	-43.50**	-14.54**	-6.72**	-3.86*	8.47**	-34.71**	-4.52**	1.23

*Significant at 5 per cent probability level, ** Significant at 1 per cent probability level

DFF = Day to 50% flowering; DFP = Day to first picking; NBP = Number of Branches per plant; IL = Internodal length; PH = Plant height; FL = Fruit length; FG = Fruit Girth; TFP = Total number of fruit per plant; TSP = Total number seed per plant; DLP = Day to last picking; CPC = Crude protein content; CFC = Crude fiber content %; VC = Vitamin C; FYP = Fruit yield per plant.

reports by Valluru Manju Vani *et al*. (2017) and Panda and Singh (1999), confirming heterosis as a critical genetic phenomenon that can be exploited for genetic gain in Okra improvement programs.

The investigation into combining ability and heterosis in Okra indicates substantial genetic variability among genotypes, allowing for genetic improvement through systematic breeding. The analysis of variance reveals notable diversity in parental lines, crucial for exploiting hybrid vigour. Both additive and non-additive gene actions impact yield and quality traits, implying that a mix of selection-based and hybrid breeding methods will enhance productivity. Key parental lines such as Parbhani Kranti and Ankur 40 demonstrate strong general combining ability (GCA), making them suitable for hybrid development. High specific combining ability (SCA) was noted in Parbhani Kranti × PDKV Pragati, leading to exploitation of heterosis and showed 10.91 % and 9.40 % better parent and standard heterosis, respectively. The potential cross could be exploited to develop high yielding hybrids in Okra.

ACKNOWLEDGEMENT

The authors express their sincere gratitude to AKS University, Satna (M.P.), for providing the necessary facilities and academic support to conduct this experiment as part of the Ph.D. research work.

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