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Heterosis studies in Okra (*Abelmoschus esculentus* (L.) Moench) for yield and yield attributing traits

SM Kadam, GR Munde, SD Deshmukh, KG Kute and BD Gore

SM Kadam
Department of Horticulture (Vegetable Science), College of Agriculture, Latur. VNMKV Parbhani, Maharashtra, India

GR Munde
Officer Incharge, Custard Apple Research Center, Ambajogai, VNMKV Parbhani, Maharashtra, India

SD Deshmukh
Department of Horticulture (Vegetable Science), VNMKV Parbhani, Maharashtra, India

KG Kute
Department of Agricultural Botany, VNMKV Parbhani, Maharashtra, India

BD Gore
Department of Genetics and Plant Breeding, College of Agriculture, Latur, VNMKV Parbhani, Maharashtra, India

Corresponding Author:
SM Kadam
Department of Horticulture (Vegetable Science), College of Agriculture, Latur. VNMKV Parbhani, Maharashtra, India

Abstract
The present study on heterosis in okra (*Abelmoschus esculentus* (L) Moench) conducted using a half diallel method with seven parents, twenty-one hybrids, and one standard check. The analysis of mean squares showed significant differences due to treatment for all the studied traits. Heterosis was estimated as percentage values over the better parent (BP) and standard hybrid checks (SH) for various characters. The study identified specific cross combinations that exhibited significant positive heterosis for traits such as plant height, fruit yield, length of fruit, and number of branches per plant. The results also highlighted the potential of certain hybrid derivatives for the improvement of growth and yield-related characteristics in okra. The results indicated significant positive heterosis in several cross combinations for different traits, with specific hybrids showing potential for further exploitation in the development of hybrid okra varieties. The paper concludes by identifying promising hybrid derivatives and highlighting their potential for enhancing traits like yield, plant growth, and quality in okra cultivation.

Keywords: Okra, fruit yield, heterosis, better parent, standard check, hybrids

Introduction
Okra (Abelmoschus esculentus L. Moench) holds significant economic importance as a rapidly growing annual vegetable crop, commanding a prominent position among various vegetables. Originating in Tropical Africa, the Subtropics, and India, okra thrives in warm tropical and subtropical climates and has become a major global crop due to its nutritional richness, market demand, and therapeutic value. In India, the crop is extensively cultivated for its tender and versatile fruits, which are highly sought after as a vegetable. The green, ripe, and tender okra fruits are particularly valued, and the okra cortex has been identified as a potential source of mucilages (Benchasri, 2012) [1].

Rich in nutrients, especially in its edible fruit, okra boasts high levels of vitamin C (66 mg/100 g), calcium (0.35 mg/100 g), and iron (0.35 mg/100 g). The fruit is also a good source of protein and minerals, with 88% moisture, 7.7% carbohydrates, 1.1% fiber, 0.7% minerals, 0.08% phosphorus, and a caloric content of 41 kcal. Additionally, the levels of vitamin A, Vitamin B, Nicotinic acid, and Riboflavin contribute to its nutritional value. Okra is consumed as a cooked vegetable, either fresh, soaked, or frozen, and has historical uses in various domestic and medical applications.

Efforts in okra crop improvement should prioritize traits such as plant height, higher yield, early flowering, number of branches, fruit length, diameter of fruit, internodal length, number of fruits per plant, disease and pest resistance, and overall high yield. Hybrid vigor exploitation, understanding the genetics of traits, and enhancing quality aspects, particularly with an eye on the export market, are critical considerations in the ongoing okra improvement programs. The utilization of heterosis in okra breeding has been recognized as a practical approach for enhancing yield and other essential traits. The success of breeding programs hinges on the careful selection of parents, ensuring the transmission of desirable traits to the offspring and the development of promising varieties through hybridization.

Materials and Methods
The Okra heterosis study was conducted during the summer of 2021 at the Instructional-Cum-Research Farm, Department of Horticulture, College of Agriculture, Latur, using a Randomized Block Design with two replications. The experimental setup comprised seven parents, twenty-one hybrids developed through the half diallel method, and one standard check. Each entry was planted in six rows, each containing twenty plants, with a spacing of 45 x 20 cm adhering to the recommended package of practices.

The randomization of parents and hybrids was ensured within continuous blocks. Subsequently, five plants were randomly selected from each plot for the observation of traits, including Plant height (cm), Internodal length (cm), Number of branches per plant, Number of nodes per plant, Days required for 50% flowering, Length of fruit (cm), Weight of fruit (g), Diameter of fruit (mm), Number of fruits per plant, Fruit yield per plant (kg), and Fruit yield per plot (kg).

To assess the significance of differences among genotypes, including crosses and parents, the first step involved the diallel analysis of variance for the Randomized Block Design. The analysis of variance for all the studied traits followed the method proposed by Panse and Sukhatme (1985) [9]. Heterosis was evaluated using the F1 values averaged over replications. The magnitude of heterosis was calculated as a percentage increase or decrease of the F1 mean over the mean of the better parent (BP), as suggested by Turner (1953) [13]. Additionally, the percent superiority over the standard hybrid check was also computed for a comprehensive assessment of hybrid performance.

Results and Discussions

In the analysis of mean squares, significant differences were observed for all the characters under study, indicating treatment effects. Heterosis, expressed as percentage values over the better parent (BP) and standard hybrid checks (SH), was evaluated and is presented in Table 1. Negative heterosis was considered desirable for traits such as internodal length and days required for 50% flowering, while positive heterosis was considered desirable for other characters.

For the trait of plant height, among the 21 cross combinations studied, 4 and 8 crosses displayed significant positive heterosis over the better parent and standard check, respectively. Notably, the cross combination Arka Anamika x EC-305731 exhibited highly significant positive heterosis over the better parent, with a magnitude of 92.12%, followed by Arka Anamika x EC-305609 (85.40%) and Varsha Uphar x Arka Anamika (77.86%). Similarly, for this trait, the cross Arka Anamika x EC-305731 (14.87%) showed significant positive heterosis over the standard check. Conversely, crosses such as Phule Vimukta x EC-305687 (-41.14%), Varsha Uphar x Phule Utkarsha (-37.84%), and Varsha Uphar x EC-305731 (-37.73%) displayed significant negative heterosis over the standard check. The crosses Arka Anamika x EC-305731 and Arka Anamika x EC-305731 showed the highest percentage of significant positive heterosis over the better parent and standard check, respectively. Similar results were reported by Chavan *et al.* (2021) [2] and Sapavadiya *et al.* (2019) [11].

Regarding internodal length, the cross Phule Vimukta x EC-305609 exhibited negative heterosis over the better parent, while recording significant positive heterosis over the standard check. This finding aligns with results reported by Harne *et al.* (2014) [3] and Kerure *et al.* (2019) [6].

For the trait of the number of branches per plant, the crosses Phule Utkarsha x Phule Vimukta (12.24%) displayed the highest positive heterosis over the better parent, followed by EC-305609 x EC-305687 (3.85%). Additionally, the cross combinations Varsha Uphar x Arka Anamika (24.00%), Phule Utkarsha x Arka Anamika (24.00%), and Phule Vimukta x Arka Anamika (16.00%) exhibited the highest percentage of positive heterosis over the standard check for the number of branches per plant. The cross combination Phule Utkarsha x Phule Vimukta and Varsha Uphar x Arka Anamika showed significant positive heterosis over the better parent and standard check, respectively, indicating better per se performance. Similar results were reported by Kumar *et al.* (2017) [7] and Sapavadiya *et al.* (2019) [11].

Continuing with the analysis of heterosis, for the character number of nodes per plant, the crosses Arka Anamika x EC-305731 and Arka Anamika x EC-305731 recorded the maximum significant positive heterosis over the better parent and standard check, respectively. Similar results were reported by Harne *et al.* (2014) [3]. Regarding the days required for 50% flowering, the cross combinations Arka Anamika x EC-305687 and Phule Utkarsha x Arka Anamika showed negative significant heterosis over the better parent and standard check, respectively. This could be attributed to the better per se performance of parents, indicating the importance of additive variance in heterosis breeding. Similar observations were reported by Reddy *et al.* (2012) [10], Kumar *et al.* (2017) [7].

For the length of fruit, from 21 crosses, 2 and 4 combinations recorded the highest significantly positive heterosis over the better parent and positive heterosis over the standard check, respectively. The cross Arka Anamika x EC-305731 (6.89) exhibited the highest positive significant heterosis over the better parent, followed by Phule Utkarsha x EC-305609 (6.08). Similarly, the cross combinations Arka Anamika x EC-305731 (3.67) reported the highest percentage of positive heterosis, followed by Phule Utkarsha x EC-305609 (2.57) over the standard check for the length of fruit. The maximum heterosis over the better parent and the standard check was obtained in the cross combination of Arka Anamika x EC-305731. These results align with previous findings by Jindal *et al.* (2010) [5] and Singh *et al.* (2015) [12]. The highest significant positive heterosis for the weight of fruit was observed in the cross Phule Utkarsha x Phule Vimukta over the better parent and Arka Anamika x EC-305731 over the standard check. This result suggests that dominance gene effects play a crucial role in further heterosis breeding, consistent with findings by Jindal *et al.* (2010) [5].

Regarding the diameter of fruit, the cross combination Phule Vimukta x EC-305609 exhibited the highest significant positive magnitude of heterosis over the better parent and positive heterosis over the standard check. This result could be attributed to better per se performance, indicating the presence of additive variance along with non-additive gene effects. Similar findings are in agreement with those of Harne *et al.* (2014) [3] and Sapavadiya *et al.* (2019) [11]. For the character number of fruits per plant, Varsha Uphar x Arka Anamika and Varsha Uphar x Arka Anamika crosses recorded the highest percentage of significant positive heterosis over the better parent and standard check, respectively. These results were consistent with earlier findings by Reddy *et al.* (2012) [10] and Nagesh *et al.* (2014) [8].

Out of the 21 crosses, 4 and 3 combinations reported significantly maximum positive heterosis over the better parent and positive non-significant heterosis over the standard check, respectively, for fruit yield per plant. The cross combinations Arka Anamika x EC-305731 (56.00) exhibited the maximum positive significant heterosis, followed by Arka Anamika x EC-305609 (48.00) and Varsha Uphar x Arka Anamika (44.00) over the better parent. Meanwhile, the cross combinations Arka Anamika x EC-305731 (5.41) showed the highest percentage of positive heterosis over the standard check for fruit yield per plant. For fruit yield per plant, the cross Arka Anamika x EC-305731 showed the highest percentage of significant positive heterosis over both the better parent and standard check, respectively. Similar results were obtained by Singh *et al.* (2015) [12], Kerure *et al*. (2019) [6], and Sapavadiya *et al.* (2019) [11].

Regarding the character of fruit yield per plot, 5 and 5 crosses reported significant maximum positive heterosis over the better parent and standard check, respectively. The crosses Arka Anamika x EC-305731 (50.00) showed the maximum positive significant heterosis, followed by Arka Anamika x EC-305609 (42.31) and Varsha Uphar x Arka Anamika (36.15) over the better parent. Meanwhile, the cross combinations Arka Anamika x EC-305731 (52.94) showed the significantly highest percentage of positive heterosis, followed by Phule Utkarsha x EC-305609 and Arka Anamika x EC-305609 (45.10), and Varsha Uphar x Arka Anamika (38.82) over the standard check for fruit yield per plot. The cross combination Phule Arka Anamika x EC-305731 exhibited significantly the highest positive heterosis over both the better parent and standard check.

Table 1: Per cent heterosis over better parent and standard hybrid check for different characters in 7x7 half diallel of okra.

Crosses	Plant height (cm)		Internodal length (cm)		Number of branches per plant		Number of nodes per plant		Days required for 50% flowering	
	1		2		3		4		5	
	BP	SH	BP	SH	BP	SH	BP	SH	BP	SH
Varsha Uphar x Phule Utkarsha	-36.02 *	-37.84 *	2.59	10.58	-22.45	-24.00	-15.67	-13.74	0.00	-2.25
Varsha Uphar x Phule Vimukta	16.04	-31.19 *	7.36	19.23*	-53.85 **	-64.00 **	-16.09	-16.41	7.13**	4.72 *
Varsha Uphar x Arka Anamika	77.86 **	6.34	32.16**	29.62**	-4.62	24.00	21.46*	14.50	2.30	0.00
Varsha Uphar x EC-305609	20.82	-29.00	24.90	17.69	-42.31 **	-40.00**	0.82	-6.11	4.83*	2.47
Varsha Uphar x EC-305687	31.03	-22.79	-5.59	7.12	2.56	-24.00	9.25	-5.34	-5.13*	-4.49*
Varsha Uphar x EC-305731	12.42	-37.73 *	-4.75	-7.50	-23.08	-40.00 **	-2.70	-17.56	-0.80	-3.03
Phule Utkarsha x Phule Vimukta	9.69	6.57	9.18	21.25*	12.24	10.00	11.57	14.12	0.80	-1.46
Phule Utkarsha x Arka Anamika	-28.39	-30.42 *	16.86	25.96**	-4.62	24.00	-24.63*	-22.90*	-5.40*	-7.53**
Phule Utkarsha x EC-305609	12.09	8.90	1.87	9.81	-30.77 *	-28.00 *	13.81	16.41	-2.30	-4.49*
Phule Utkarsha x EC-305687	-11.27	-13.80	3.39	17.31	-38.78 **	-40.00 **	5.97	8.40	1.56	2.25
Phule Utkarsha x EC-305731	-25.10	-27.23	-5.08	2.31	-65.31 **	-66.00 **	-15.30	-13.36	0.00	-2.25
Phule Vimukta x Arka Anamika	31.55	-21.35	-4.76	5.77	-10.77	16.00	-6.13	-6.49	4.94*	-4.49*
Phule Vimukta x EC-305609	4.40	-38.09 *	-17.75*	-8.65	-34.62 **	-32.00 *	1.92	1.53	0.00	-2.25
Phule Vimukta x EC-305687	-0.73	-41.14 **	-17.71*	-6.63	-28.21	-44.00 **	-20.69*	-20.99*	-2.90	-2.25
Phule Vimukta x EC-305731	9.50	-35.07 *	0.61	11.73	-7.69	-28.00 *	-26.44**	-26.72**	0.12	-3.26
Arka Anamika x EC-305609	85.40 **	10.85	28.04**	25.58*	-10.77	16.00	23.08*	16.03	-1.84	-4.04
Arka Anamika x EC-305687	39.09	-16.84	3.39	17.31	-21.54 *	2.00	-6.48	-11.83	-7.37**	-6.74**
Arka Anamika x EC-305731	92.12 **	14.87	21.37*	19.04*	-53.85 **	-40.00 **	26.32*	19.08*	1.28	-2.13
EC-305609 x EC-305687	27.80	-24.70	-2.37	10.77	3.85	8.00	-3.28	-9.92	-4.02	-3.37
EC-305609 x EC-305731	49.54	-12.12	18.81	15.38	-15.38	-12.00	-6.56	-12.98	-4.60*	-6.74**
EC-305687 x EC-305731	10.89	-34.66 *	-8.31	4.04	-8.11	-32.00*	-3.08	-16.03	-7.37**	-6.74**
S.E.D ±	7.41	7.41	0.48	0.48	0.29	0.29	1.20	1.20	0.89	0.89
C.D. At 5%	15.22	15.22	0.98	0.98	0.60	0.60	2.46	2.46	1.83	1.83
C.D. At 1%	20.55	20.55	1.33	1.33	0.81	0.81	3.32	3.32	2.47	2.47

* and ** significance at 5% and 1% level.

Continue.. Table 1: Per cent heterosis over better parent and standard hybrid check for different characters in 7x7 half diallel of okra.

Crosses	Length of fruit (cm)		Weight of fruit (g)		Diameter of fruit (mm)		Number of fruits per plant		Fruit yield per plant (kg)	
	6		7		8		9		10	
	BP	SH	BP	SH	BP	SH	BP	SH	BP	SH
Varsha Uphar x Phule Utkarsha	-0.93	-10.22 **	-22.58 **	-33.88 **	-4.69	-11.31 **	-29.88 **	-12.44	-44.44 *	-59.46 **
Varsha Uphar x Phule Vimukta	-1.78	-11.90 **	-22.04 **	-33.41 **	-0.47	-7.37 *	-23.01 *	-13.43	-20.00	-56.76 **
Varsha Uphar x Arka Anamika	3.65	0.53	3.38	0.89	-1.20	-8.05 *	31.05 **	42.79 **	44.00 *	-2.70
Varsha Uphar x EC-305609	-7.73 *	-10.79 **	-30.84 **	-33.88 **	0.00	-6.94 *	-3.29	2.49	31.82	-21.62
Varsha Uphar x EC-305687	-3.84	-11.37 **	-20.49 **	-32.09 **	-2.80	-9.54 **	6.57	12.94	5.00	-43.24 **
Varsha Uphar x EC-305731	-0.78	-9.51 **	-13.49 **	-26.12 **	-0.53	-7.43 *	-6.57	-1.00	0.00	-45.95 **
Phule Utkarsha x Phule Vimukta	-1.17	-10.44 **	47.68 **	1.09	-0.20	-8.18 *	8.37	35.32 **	29.63	5.00
Phule Utkarsha x Arka Anamika	5.34	2.17	-26.84 **	-28.60 **	2.02	-6.13	4.38	30.35 **	-44.44 *	-59.46 **
Phule Utkarsha x EC-305609	6.08 *	2.57	7.14	2.44	0.34	-7.68 *	11.95	39.80 **	37.04 *	0.00
Phule Utkarsha x EC-305687	-1.20	-8.93 **	1.35	-24.02 **	-0.83	-7.81 *	-29.88 **	-12.44	-44.44 *	-59.46 **
Phule Utkarsha x EC-305731	1.07	-7.83 **	-15.68 **	-28.02 **	2.96	-5.27	-28.29 **	-10.45	-37.04 *	-54.05 **
Phule Vimukta x Arka Anamika	-9.21 **	-11.94 **	-34.00 **	-35.58 **	20.93 **	-0.12	-0.88	11.44	-24.00	-48.65 **
Phule Vimukta x EC-305609	4.67	1.19	6.74	2.06	23.41 **	5.51	-19.91 *	-9.95	-27.27	-56.76 **
Phule Vimukta x EC-305687	-1.39	-9.11 **	-2.07	-26.58 **	-0.37	-7.37 *	-36.73 **	-28.86 **	-17.65	-62.16 **
Phule Vimukta x EC-305731	1.45	-7.47 *	-19.82 **	-31.55 **	11.29 **	-8.09 *	-36.73 **	-28.86 **	-27.78	-64.86 **
Arka Anamika x EC-305609	4.47	1.33	3.66	1.16	16.96 **	1.00*	-1.83	6.97	48.00 *	1.00
Arka Anamika x EC-305687	-3.83	-6.72 *	-12.49 **	-14.59 **	-1.97	-8.86 **	-1.37	7.46	-8.00	-37.84 **

Arka Anamika x EC-305731	6.89 *	3.67	5.49	2.95	13.81 **	-8.12 *	-6.39	1.99	56.00 **	5.41
EC-305609 x EC-305687	-4.39	-7.56 *	-26.75 **	-29.96 **	7.40 *	-0.15	-7.58	-2.99	-18.18	-51.35 **
EC-305609 x EC-305731	-5.86	-8.98 **	-22.81 **	-26.19 **	20.29 **	2.85	-14.22	-9.95	-18.18	-51.35 **
EC-305687 x EC-305731	4.27	-3.89	9.73 *	-6.33	-1.60	-8.52 **	-7.58	-2.99	38.89	-32.43 *
S.E.D ±	0.31	0.31	0.44	0.44	0.48	0.48	1.00	1.00	0.02	0.02
C.D. At 5%	0.65	0.65	0.90	0.90	0.99	0.99	2.06	2.06	0.04	0.04
C.D. At 1%	0.87	0.87	1.22	1.22	1.34	1.34	2.78	2.78	0.06	0.06

* and ** significance at 5% and 1% level

Continue.. Table 1: Per cent heterosis over better parent and standard hybrid check for different characters in 7x7 half diallel of okra.

Crosses	Fruit yield per plot (kg)	
	11	
	BP	SH
Varsha Uphar x Phule Utkarsha	- 46.18**	-41.96**
Varsha Uphar x Phule Vimukta	-25.85	-39.80 **
Varsha Uphar x Arka Anamika	36.15 **	38.82 **
Varsha Uphar x EC-305609	-28.00 *	-29.41 *
Varsha Uphar x EC-305687	0.48	-18.43
Varsha Uphar x EC-305731	-7.00	-24.51 *
Phule Utkarsha x Phule Vimukta	28.73 **	38.82 **
Phule Utkarsha x Arka Anamika	-45.09 **	-40.78 **
Phule Utkarsha x EC-305609	34.55 **	45.10 **
Phule Utkarsha x EC-305687	-45.09 **	-40.78 **
Phule Utkarsha x EC-305731	-39.27 **	-34.51 **
Phule Vimukta x Arka Anamika	-26.54 *	-25.10 *
Phule Vimukta x EC-305609	-37.60 **	-38.82 **
Phule Vimukta x EC-305687	-26.16	-46.86 **
Phule Vimukta x EC-305731	-35.66 *	-49.41 **
Arka Anamika x EC-305609	42.31 **	45.10 **
Arka Anamika x EC-305687	-11.54	-9.80
Arka Anamika x EC-305731	50.00 **	52.94 **
EC-305609 x EC-305687	-27.60 *	-29.02 *
EC-305609 x EC-305731	-31.00 *	-32.35 **
EC-305687 x EC-305731	24.69	-1.96
S.E.D ±	0.28	0.28
C.D. At 5%	0.57	0.57
C.D. At 1%	0.77	0.77

* and ** significance at 5% and 1% level.

Conclusion

The investigation into hybrid derivatives or crosses within the context of okra cultivation has yielded noteworthy findings. Specifically, the crosses involving Phule Utkarsha x Phule Vimukta, Phule Utkarsha x EC-305609, Varsha Uphar x Arka Anamika, and Arka Anamika x EC-305731 have demonstrated considerable promise in terms of various growth and yield-contributing characteristics. The growth parameters evaluated encompass plant height, number of branches, number of nodes per plant, and days required to reach 50% flowering. Notably, these hybrid combinations exhibit favorable traits, indicating potential improvements in plant development and maturity. Furthermore, the study delves into yield-contributing factors, including the number of fruits per plant, length, weight, and diameter of the fruit, as well as overall fruit yield per plant and per plot. Among the cross combinations, Arka Anamika x EC-305731, Phule Utkarsha x EC-305609, Varsha Uphar x Arka Anamika, and Phule Utkarsha x Arka Anamika stand out for recording significant positive heterosis across multiple parameters related to fruit yield. These findings suggest a valuable avenue for further exploration and exploitation in the development of hybrid okra varieties. The identified crosses present a promising foundation for future breeding efforts, aiming to enhance the overall productivity and quality of okra crops. The potential for positive heterosis in key characteristics underscores the significance of these crosses in contributing to the agricultural advancement of okra cultivation.

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