E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating: 5.20
www.agronomyjournals.com
2025; 8(3): 330-333
Received: 02-12-2024
Accepted: 10-01-2025

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Evaluation of heterosis for morphological traits in interspecific hybridization of okra (*Abelmoschus esculentus* (L.) Moench)

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DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i3e.2651

Abstract
The study, "Evaluation of Heterosis for Morphological Traits in Interspecific Hybridization of Okra **(***Abelmoschus esculentus* (L.) Moench) " was conducted at the Instructional-Cum-Research Farm, Department of Horticulture, VNMKV, Parbhani, during *Kharif* 2022-23 (F_1) and Summer 2023-24 (F_2). The research aimed to evaluate heterosis for Plant growth characters, including Petiole length and Stipule length using interspecific crosses between cultivated okra and wild relatives (*Abelmoschus tetraphyllus*, *Abelmoschus moschatus*, and *Abelmoschus manihot*). A Line × Tester mating design was adopted, comprising 10 lines and 3 testers in F_1 generation and 7 lines and 2 testers in F_2 generation. Experiments were laid out in a Randomized Block Design (RBD) with two replications. The study evaluated heterosis for petiole length and stipule length in *Abelmoschus* crosses across F_1 and F_2 generations. Significant positive heterosis was observed, with Punjab 8 × *A. tetraphyllus* (45.91%) showing the highest petiole length in the F_1 generation, and Parbhani Kranti × *A. manihot* (19.69%) in the F_2 generation. For stipule length, Phule Vimukta × *A. tetraphyllus* (213.76%) displayed the highest heterosis in F_1, while Parbhani Kranti × *A. manihot* (123.96%) in F_2. These traits are pivotal for improving yield potential in crop breeding programs.

Keywords: Okra, heterosis, better parent, standard check, Morphological traits

1. Introduction

Okra (*Abelmoschus esculentus* (L.) Moench) is a widely cultivated vegetable grown during the summer and rainy seasons. It has become a popular choice in tropical regions due to its ease of cultivation, high nutritional value, year-round export potential, resilience to pests, and adaptability to various moisture conditions (Haq *et al*., 2023; Ibitoye and Kolawole, 2022) [4, 5]. Global okra production reached 11.23 million tons across 2.80 million hectares, reflecting a 5.90% increase from the previous year and a 13.40% rise over the past decade. India is the leading producer, contributing 61.20% of global okra production (FAOSTAT, 2022) [2]. Okra fruits, known for their plump, green, and delicate appearance, are rich in calcium and various nutrients, serving as a staple in tropical diets. They are typically consumed fresh, dried, or preserved (Thamburaj and Singh, 2018) [8]. Despite its benefits, existing okra cultivars often have limited yield potential, which affects farmers' productivity and profitability, particularly in regions where okra is a crucial income source. Hybrid breeding offers a solution by overcoming yield limitations and harnessing hybrid vigour. Selecting parents solely based on their individual performance is often ineffective. A comprehensive assessment of the genetic transformation and prepotency of potential parents is crucial for successful hybridization (Yadav *et al*., 2023) [9]. Studies on heterosis and combining ability are essential to identify the best parent combinations and crosses for further genetic improvement.

Heterosis enables breeders to develop hybrids with better growth, higher fruit production, and greater yield potential by combining complementary traits from genetically diverse okra genotypes (Fujimoto *et al*., 2018) [3]. Such research streamlines the breeding process, ensuring more accurate predictions of hybrid performance and accelerating the development of new cultivars. Superior okra hybrids not only improve productivity and reduce input costs but also promote sustainability by optimizing resource use. The findings from this study aim to improve breeding strategies by identifying superior parent combinations, understanding hybrid vigour. Ultimately, these advancements will contribute to the development of more productive, resilient, and market-competitive okra cultivars, supporting farmers' profitability and food security. The study focuses on evaluating heterosis for morphological traits, with the goal of discovering superior hybrids.

2. Materials and Methods

The study, "Evaluation of Heterosis for Morphological Traits in Interspecific Hybridization of Okra (*Abelmoschus esculentus* (L.) Moench) "was conducted at the Instructional-Cum-Research Farm, Department of Horticulture, College of Agriculture, VNMKV, Parbhani, during *Kharif* 2022-23 (F_1 generation) and Summer 2023-24 (F_2 generation). The objective was to explore the heterosis of morphologicals traits. The experimental material consisted of 10 lines and 3 testers during *Kharif* 2023 and 7 lines and 2 testers during summer 2024, in a Line × Tester mating design within a Randomized Block Design (RBD) with two replications. The treatments included 45 entries in the F_1 generation (30 hybrids, 13 parents, and 2 checks) and 25 entries in the F_2 generation (14 hybrids, 9 parents, and 2 checks).For hybrid seed production, cultivated okra flowers (female) were emasculated in the evening, and wild male flowers were used for pollination the following morning. Emasculated buds were bagged, labeled, and allowed to mature for seed development. The crop was grown at a spacing of 60 × 30 cm, with the application of farmyard manure (15 t/ha) and fertilizers at 100:50:50 kg NPK/ha. Nitrogen was applied in splits, with one-third at sowing and the remaining in two equal top-dressings.

Estimation of Heterosis

Per cent heterosis of derived F_1 over better parent (BP) and checks was calculated. Standard checks Radhika, Parbhani Kranti were considered for calculating standard heterosis for all the character. Heterosis for each trait was computed by using following formula.

Percent heterosis over

$$\text{Better parent (Heterobeltiosis)} = (\overline{F_1} - \overline{BP} / \overline{BP}) \times 100$$

$$\text{Standard checks (Standard heterosis)} = \frac{(\overline{F_1} - \overline{\text{Std. Checks}})}{\overline{\text{Std. Checks}}} \times 100$$

Where,
F_1: Average mean of F_1 hybrid
BP: Mean value of better parent of that particular F_1 cross
Std checks: Mean value of standard checks

a. Calculation of standard error

- S.E. for testing heterosis over better parent:

S.E. (H1) = ± (2Me/r)1/2

- S.E. for testing heterosis over standard check:

S.E. (H3) = ± (2Me/r)1/2

Wherein,
Me = Error due to mean sum of square
r = Number of replications

b. Test of significance for heterosis

In order to test the significance for different estimates of heterosis, t-test were conducted as follows:

1. 't' calculated values for heterosis over BP = (F_1-BP)/SE(H1)
2. 't' calculated values for heterosis over MP = (F_1-MP)/SE(H1)
3. 't' calculated values for heterosis over SC = (F_1-SC)/SE(H2)

The 't' test calculated values for heterosis over better parent (BP) and standard check cultivar (SC) were compared with 't' tabulated values at error degree of freedom and P= 0.05. 't' calculated value ≥ 't' tabulated value were marked as significant

3. Results and Discussion

3.1 Plant Growth characters

3.1.1 Petiole length

Among the 30 crosses evaluated, 8 cross combinations exhibited significant positive heterosis for Petiole length over the better parent, 12 and 9 cross combinations showed significant positive heterosis over the standard hybrid check 1 (Parbhani Kranti) and standard hybrid check 2 (Radhika) respectively during the F_1 generation (Table 1).

In the F_2 generation during summer 2023-24 (Table 2) 14 crosses were evaluated, 5 crosses displayed significant positive heterosis over the better parent, while 14 and 14 cross combinations showed significant positive heterosis over the standard hybrid check 1 (Parbhani Kranti) and standard hybrid check 2 (Radhika) respectively.

F_1 generation during *Kharif* season (2022-23), the cross combination Punjab 8 × *Abelmoschus tetraphyllus* displayed the highest significant positive heterosis over the better parent (45.91%), while in the F_2 generation during Summer season (2023-24), the cross Parbhani Kranti × *Abelmoschus manihot* recorded the highest significant positive heterosis over the better parent (19.69%).

Cross Parbhani Kranti × *Abelmoschus manihot* (36.27%) and Parbhani Kranti × *Abelmoschus manihot* (30.34%) showed significant positive heterosis over the standard hybrid check 1 (Parbhani Kranti) and standard hybrid check 2 (Radhika) respectively F_1 generation during *Kharif* season (2022-23).

Whereas in the F_2 generation during Summer season (2023-24), Cross Parbhani Kranti × *Abelmoschus manihot* (58.75%) and Parbhani Kranti × *Abelmoschus manihot* (56.70%) showed significant positive heterosis over the standard hybrid check 1 (Parbhani Kranti) and standard hybrid check 2 (Radhika) respectively Meyer *et al*. (2004) [7] and KOUASSI *et al*. (2024) [6].

Petiole length is an important trait influencing overall yield, as optimal petiole length ensures efficient photosynthesis and nutrient distribution significant and positive heterosis for plant height is a desirable characteristic in crop breeding programs. Significant and positive heterosis for these traits is desirable in crop breeding programs to enhance yield potential.

3.1.2 Stipule length

Among the 30 crosses evaluated, 27 cross combinations exhibited significant positive heterosis for Stipule length over the better parent, 10 and 6 cross combinations showed significant positive heterosis over the standard hybrid check 1 (Parbhani Kranti) and standard hybrid check 2 (Radhika) respectively during the F_1 generation during *Kharif* season (2022-23) (Table 1).

In the F_2 generation during summer 2023-24 (Table 2) 14 crosses were evaluated, 13 crosses displayed significant positive heterosis over the better parent, while no cross combinations showed significant positive heterosis over the standard hybrid check 1 (Parbhani Kranti) and standard hybrid check 2 (Radhika) respectively.

F_1 generation during *Kharif* season (2022-23), the cross combination Phule Vimukta × *Abelmoschus tetraphyllus* displayed the highest significant positive heterosis over the better parent (213.76%), while in the F_2 generation during Summer season (2023-24), the cross Parbhani Kranti × *Abelmoschus manihot* recorded the highest significant positive heterosis over the better parent (123.96%).

Cross Parbhani Kranti × *Abelmoschus manihot* (37.92%) and Parbhani Kranti × *Abelmoschus manihot* (20.06%) showed significant positive heterosis over the standard hybrid check 1 (Parbhani Kranti) and standard hybrid check 2 (Radhika) respectively F_1 generation during *Kharif* season (2022-23), Whereas in the F_2 generation during Summer season (2023-24), Cross Parbhani Kranti × *Abelmoschus manihot* (28.74%) and Parbhani Kranti × *Abelmoschus manihot* (9.14%) showed significant positive heterosis over the standard hybrid check 1 (Parbhani Kranti) and standard hybrid check 2 (Radhika) respectively.

Appropriate stipule length aids in protecting buds and promoting healthy plant growth. Significant and positive heterosis for these traits is desirable in crop breeding programs to enhance yield potential. Similar results were obtained by Espósito *et al.* (2014) [1] and Yadav (2013) [10]

Table 1: Heterosis percentage over the better parent and standard checks in F_1 generation (*Kharif* season, 2022-23) of okra (*Abelmoschus esculentus* L.)

SN	Parents/Hybrids	Plant growth characters					
		PL(cm)			SL(cm)		
		1			2		
		BPH	Parbhani kranti	Radhika	BPH	Parbhani kranti	Radhika
1	Parbhani kranti X *Abelmoschus. manihot*	30.22 **	36.27 **	30.34 **	166.91 **	37.92 **	20.06 **
2	Parbhani kranti x *Abelmoschus moschatus*	4.54	12.63	7.72	122.30 **	14.87	0.00
3	Parbhani kranti x *Abelmoschus tetraphyllus*	-17.03	-13.17	-16.95	122.30 **	14.87	0.00
4	Arka Anamika X *Abelmoschus manihot*	1.92	11.60	6.74	148.62 **	0.74	-12.30
5	Arka Anamika x *Abelmoschus moschatus*	7.73	17.96 *	12.83	27.52	-48.33 **	-55.02 **
6	Arka Anamika x *Abelmoschus tetraphyllus*	13.54	24.33 **	18.91 *	188.52 **	30.86 **	13.92
7	Konkan Bhindi x *Abelmoschus manihot*	40.54 **	30.49 **	24.81 **	-18.30 *	-3.72	-16.18 *
8	Konkan Bhindi x *Abelmoschus moschatus*	-3.44	12.68	7.77	-4.10	13.01	-1.62
9	Konkan Bhindi x *Abelmoschus tetraphyllus*	34.33 **	16.45	11.38	-13.56	1.86	-11.33
10	Arka Abhay X *Abelmoschus manihot*	0.37	-6.80	-10.86	129.36 **	-7.06	-19.09 **
11	Arka Abhay X *Abelmoschus moschatus*	7.22	15.52	10.49	176.15 **	11.90	-2.59
12	Arka Abhay X *Abelmoschus tetraphyllus*	33.99 **	20.41 *	15.17	173.39 **	10.78	-3.56
13	Phule Vimukta X *Abelmoschus manihot*	20.03 *	14.39	9.41	183.49 **	14.87	0.00
14	Phule Vimukta x *Abelmoschus moschatus*	-2.85	13.36	8.43	146.72 **	11.90	-2.59
15	Phule Vimukta x *Abelmoschus tetraphyllus*	29.22 **	23.15 *	17.79 *	213.76 **	27.14 **	10.68
16	Phule Utkarsha X *Abelmoschus manihot*	-13.69	-3.72	-7.91	100.00 **	-7.81	-19.74 **
17	Phule Utkarsha X *Abelmoschus moschatus*	-0.38	16.25	11.19	156.45 **	18.22 *	2.91
18	Phule Utkarsha X *Abelmoschus tetraphyllus*	11.23	24.08 **	18.68 *	157.26 **	18.59 *	3.24
19	Varsha Uphar X *Abelmoschus manihot*	-2.46	24.03 **	18.63 *	150.48 **	-2.23	-14.89 *
20	Varsha Uphar X *Abelmoschus moschatus*	-8.55	16.30	11.24	132.79 **	5.58	-8.09
21	Varsha Uphar X *Abelmoschus tetraphyllus*	0.77	28.14 **	22.57 *	145.08 **	11.15	-3.24
22	Pusa Sawani X *Abelmoschus manihot*	3.33	0.34	-4.03	124.17 **	0.00	-12.94
23	Pusa Sawani x *Abelmoschus moschatus*	-8.68	6.56	1.92	140.98 **	9.29	-4.85
24	Pusa Sawani X *Abelmoschus tetraphyllus*	11.19	7.98	3.28	124.17 **	0.00	-12.94
25	Kashi Satdhari X *Abelmoschus manihot*	16.93	17.33	12.22	201.83 **	22.30 **	6.47
26	Kashi Satdhari x *Abelmoschus moschatus*	-3.94	12.09	7.21	128.69 **	3.72	-9.71
27	Kashi Satdhari X *Abelmoschus tetraphyllus*	14.63	15.03	10.02	196.33 **	20.07 *	4.53
28	Punjab 8 X *Abelmoschus manihot*	40.27 **	30.25 **	24.58 **	44.30 **	22.30 **	6.47
29	Punjab 8 X *Abelmoschus moschatus*	11.63	20.26 *	15.03	29.39 **	9.67	-4.53
30	Punjab 8 X *Abelmoschus tetraphyllus*	45.91 **	32.84 **	27.06 **	38.16 **	17.10 *	1.94
	SE±	0.91	0.91	0.91	0.10	0.10	0.10
	CD 95%	1.83	1.83	1.83	0.22	0.22	0.22
	CD 99%	2.44	2.44	2.44	0.29	0.29	0.29
		2.44	2.44	2.44	0.29	0.29	0.29

*, ** denotes significance at 5% and 1% respectively.Petiole length=PL; Stipule length=SL

Table 2: Heterosis percentage over the better parent and standard checks in F_2 generations (Summer season) of okra (*Abelmoschus esculentus* L.)

SN	Parents/Hybrids	Plant growth characters					
		PL(cm)			SL(cm)		
		1			2		
		BPH	**Parbhani kranti**	**Radhika**	**BPH**	**Parbhani kranti**	**Radhika**
1	Parbhani kranti X *Abelmoschus. manihot*	19.69 *	58.75 **	56.70 **	123.96 **	28.74	9.14
2	Parbhani kranti x *Abelmoschus moschatus*	14.96	40.47 **	38.66 **	96.55 **	2.40	-13.20
3	Parbhani kranti x *Abelmoschus tetraphyllus*	15.75	53.52 **	51.55 **	90.62 **	9.58	-7.11
4	Arka Anamika X *Abelmoschus manihot*	4.97	37.86 **	36.08 **	103.45 **	5.99	-10.15
5	Arka Anamika x *Abelmoschus moschatus*	13.78	50.91 **	48.97 **	80.81 **	7.19	-9.14
6	Arka Anamika x *Abelmoschus tetraphyllus*	22.32 *	43.08 **	41.24 **	103.03 **	20.36	2.03
7	Konkan Bhindi x *Abelmoschus manihot*	9.84	45.69 **	43.81 **	107.29 **	19.16	1.02
8	Konkan Bhindi x *Abelmoschus moschatus*	18.97 *	39.16 **	37.37 **	133.33 **	21.56	3.05
9	Konkan Bhindi x *Abelmoschus tetraphyllus*	13.78	50.91 **	48.97 **	113.54 **	22.75	4.06
10	Arka Abhay X *Abelmoschus manihot*	17.72 *	56.14 **	54.12 **	105.62 **	9.58	-7.11
11	Arka Abhay X *Abelmoschus moschatus*	4.92	39.16 **	37.37 **	115.46 **	25.15	6.09
12	Arka Abhay X *Abelmoschus tetraphyllus*	7.32	33.94 **	32.22 **	108.25 **	20.96	2.54
13	Phule Vimukta X *Abelmoschus manihot*	15.75	53.52 **	51.55 **	116.67 **	24.55	5.58
14	Phule Vimukta x *Abelmoschus moschatus*	19.06 *	49.61 **	47.68 **	20.69	-37.13 *	-46.70 **
	SE±	0.76	0.76	0.76	0.23	0.23	0.23
	CD 95%	1.64	1.64	1.64	0.51	0.51	0.51
	CD 99%	2.29	2.29	2.29	0.71	0.71	0.71

*, ** denotes significance at 5% and 1% respectively. Petiole length=PL; Stipule length=SL

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