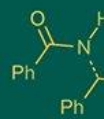


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Exploitation of heterosis for fruit yield and yield attributes in okra [*Abelmoschus esculentus* (L.) Moench]

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Abstract

The present investigation was conducted to evaluate the extent and magnitude of heterosis in okra [*Abelmoschus esculentus* (L.) Moench] using a line $\times$ tester mating design. The experimental material consisted of six lines and five testers, generating 30 hybrids, along with one standard check hybrid (GJOH-4). All the genotypes were evaluated during *kharif* 2024 at the Vegetable Research Station, Junagadh Agricultural University, Junagadh, using a randomized block design with three replications. Analysis of variance revealed highly significant differences among the genotypes for all the studied traits, indicating substantial genetic variability. Heterobeltiosis for fruit yield per plant ranged from-19.35% (KS-404 $\times$ VRO-6) to 100.29% (JOL-21-109 $\times$ HRB-108-2), while standard heterosis varied from-34.85% (JOL-22-106 $\times$ GJO-3) to 21.78% (JOL-21-109 $\times$ HRB-108-2). The hybrid JOL-21-109 $\times$ HRB-108-2 emerged as the most promising, exhibiting superior performance over both the better parent and the standard check. These findings suggest that selected hybrids hold considerable potential for future genetic improvement and commercial hybrid development in okra.

Keywords: Heterosis, Line $\times$ tester analysis, okra

Introduction

Okra [*Abelmoschus esculentus* (L.) Moench] is one of the world's oldest and important vegetable and medicinal crop belonging to the family Malvaceae. It is a tropical and subtropical semi woody herbaceous annual with indeterminate growth habitat. The chromosome number varies greatly ranging from polyploid to diploid from $2n = 66$ to 144 and the highest reporting 200 in *Abelmoschus manihot* var. *caillei*.

Okra is commonly referred to as Lady's finger, gumbo, bamieh, quin gumbo with origin being India (Lamont, 1999) ^[11]. It is a seed propagated hot weather crop sensitive to frost, low temperature (below 15 °C), water-logging as well as drought conditions. It is grown in tropical and sub-tropical regions and also in warmer parts of temperate regions. The crop thrives well in hot humid climates. The best plant growth and fruiting are observed at around 25 °C average temperatures with high relative humidity (65-85%). Seed germination is fast at 30-35 °C temperatures. Temperature slower than 25 °C slowdown germination, while above 42 °C slow down plant and fruit growth and cause drying/desiccation and dropping of flower buds.

Okra has been called "a perfect villager's vegetable" because of its robust nature, dietary fiber and distinct seed protein balance of both lysine and tryptophan amino acids. The fruit of okra is a capsule which is very popular and well known for culinary vegetable in India. The edible immature seed pods are harvested while they are still soft and the seeds are only partially developed. The color of immature pods varies from pale to dark green, red or purple. While, the mature pods dehisce releasing round very hard dark green and brown seed (Lamont, 1999) ^[11]. *Abelmoschus* is a highly nutritive vegetable which contains moisture of 90.19 g, protein 2.0 g, carbohydrates 7.45 g, vitamins (ascorbic acid 23 mg, niacin 1 mg, thiamine 0.2 mg), minerals (calcium 82 mg, potassium 299 mg, magnesium 57 mg, zinc 0.58 mg, iron 0.62 mg), sugars 1.48 g and fibers 3.2 g per 100 gm of edible portion (Kumar *et al.*, 2013) ^[9].

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Materials and Methods

The present investigation was carried out using a set of six female lines of okra JOL-22-103, JOL-22-106, JOL-21-106, JOL-21-109, HRB-55, and KS-404 and five male testers GAO-8, GO-6, GJO-3, VRO-6, and HRB-108-2 (Table 1). A total of 30 F₁ hybrids were developed through a line × tester mating design, along with one standard check hybrid, GJOH-4. All the genotypes, including parents, hybrids, and the check, were evaluated during the *kharif* 2024 season at the Vegetable Research Station, Junagadh Agricultural University (JAU), Junagadh.

The experiment was laid out in a Randomized Block Design (RBD) with three replications. Each genotype was planted at a spacing of 60 cm between rows and 30 cm between plants. All recommended agronomic practices for the region were followed to ensure optimal crop growth and health. The observations on five randomly selected plants were recorded for 14 characters viz, days to first flowering, days to first picking, fruit weight (g), fruit length (cm), fruit girth (cm), plant height (cm), number of branches per plant, number of nodes per plant, internodal length (cm), number of fruits per plant, days to last picking, number of pickings, fruit yield per plant (g) and fruit borer infestation (%).

Mean data were used for statistical analysis. The variance analysis for each character was performed using the method described by Panse and Sukhatme (1995)^[14]. Heterosis was estimated in term of two parameters, i.e. heterobeltiosis (heterosis over better parental value) as suggested by Fonseca and Patterson (1968)^[12] and standard heterosis (heterosis over standard check) as suggested by Meredith and Bridge (1972)^[12].

Results and Discussion

The analysis of variance showed highly significant differences among the genotypes for all the traits. The genotypic variance was further partitioned into parents (lines, testers and L. vs T.), hybrids and parents vs. hybrids. The differences among parents and hybrids were found highly significant for all the traits studied except fruit girth, number of fruits per plant and fruit yield per plant for parents. Differences due to parents vs. hybrids were also found highly significant for all the characters under investigation except for number of nodes per plant and fruit weight. The mean squares due to lines and testers were found significant for all the traits. This indicated the presence of wide genetic variability in the material used. The mean squares due to lines vs. testers were significant for all the traits. Magnitude of variability was higher with testers for days to first flowering, fruit weight, fruit girth, plant height, number of branches per plant, number of fruits per plant, days to last picking, number of pickings, fruit yield per plant and fruit borer infestation in comparison to lines. This indicated that the more contribution of testers in total variance for these characters, while, the magnitude of variability was higher with female for the rest of the traits under studied to the total variance (Table 2). Similar results observed by Khatik *et al.* (2012)^[7], Javia (2013)^[5], Satish *et al.* (2017)^[25], Gavint *et al.* (2018)^[3], Pithiya *et al.* (2019)^[19], Rynjah *et al.* (2020)^[22], Nanthakumar *et al.* (2021)^[13], Sood *et al.* (2022)^[26], Chaudhary *et al.* (2023)^[1], Sakriya *et al.* (2023)^[23], Ranga *et al.* (2024)^[21] and Patel *et al.* (2024)^[17].

Many crosses depicted significant heterosis over better parent and standard check in favorable direction for days to

first flowering (13, 6), days to first picking (9, 8), fruit weight (g) (1, 3), fruit length (cm) (1, 2), fruit girth (cm) (18, 1), plant height (cm) (4, 6), number of branches per plant (2, 3), number of nodes per plant (7, 1), internodal length (cm) (7, 1), number of fruits per plant (17, 2), days to last picking (11, 13), number of pickings (9, 4), fruit yield per plant (g) (15, 2) and fruit borer infestation (%) (21, 5), respectively (Table 3).

Performance of crosses in respect of heterosis over better parent and standard check (GJOH-4) revealed that the high magnitudes of heterobeltiosis and standard heterosis in desirable direction were found for days to first flowering, days to first picking, plant height, number of fruits per plant, days to last picking, number of pickings, fruit yield per plant and fruit borer infestation. While, the low amount of heterobeltiosis was noticed for fruit weight (g), fruit length (cm) and number of branches per plant and the low magnitude of heterosis over standard check was noticed for fruit girth (cm), number of nodes per plant and internodal length (cm). Similar observations were also made by Nama *et al.* (2017), Sapavadiya *et al.* (2019)^[24], Patel *et al.* (2020)^[15], Karadi and Hanchinamani (2021)^[6], Kharat *et al.* (2022), Chaudhary *et al.* (2023)^[1], Sakriya *et al.* (2023)^[23], Ranga *et al.* (2024)^[21] and Patel *et al.* (2024)^[17].

Earliness is desirable character in okra and days to first flowering is component which effects on earliness. The heterobeltiosis for this trait was ranged from-12.57% (JOL-22-106 × VRO-6) to 5.10% (JOL-21-109 × GJO-3). The standard heterosis varied from-8.23% (HRB-55 × GO-6) to 7.59% (JOL-22-106 × GO-6). (Table 3). Similar observations were also reported by Ivin and Anbuselvam (2021)^[4], Sakriya *et al.* (2023)^[23] and Patel *et al.* (2024)^[17]. In okra, earliness in days to first picking is a desirable trait and the heterobeltiosis for this trait was ranged from-10.67% (HRB-55 × GO-6) to 4.73% (JOL-21-109 × VRO-6). The standard heterosis varied from-9.66 percent (HRB-55 × GO-6) to 4.55 percent (KS-404 × GAO-8). Similar findings were reported by Pithiya *et al.* (2019)^[19], Kumar *et al.* (2023)^[10] and Patel *et al.* (2024)^[17].

The estimated heterosis over better parent varied from-32.58% (JOL-21-106 × HRB-108-2) to 20.44% (KS-404 × VRO-6) for fruit weight. The standard heterosis varied from-24.15% (JOL-22-103 × GO-6) to 15.81% (KS-404 × VRO-6). Positive estimation of heterosis in this trait was also reported by Patel and Patel (2016)^[16], Sapavadiya *et al.* (2019a)^[24], Rynjah *et al.* (2020)^[22] and Sood *et al.* (2022)^[26].

More fruit length generally directly responsible for high yield and hence, their positive values found beneficial in okra. The heterobeltiosis was ranged from-28.12% (JOL-21-109 × GO-6) to 8.61% (JOL-21-106 × HRB-108-2). The standard heterosis varied from-18.17% (JOL-21-109 × GO-6) to 13.31% (JOL-22-106 × GO-6). These results are agreed with the results obtained by Patel and Patel (2016)^[16], Pithiya *et al.* (2019)^[19], Chaudhary *et al.* (2023)^[1] and Ranga *et al.* (2024)^[21].

The estimation of heterosis over better parent varied from-26.55% (JOL-21-109 × HRB-108-2) to 12.26% (KS-404 × GJO-3) for fruit girth. The range of standard heterosis was noted from-11.00% (HRB-55 × GO-6) to 19.92% (KS-404 × GJO-3). These results are agreed with the results obtained by Kishor *et al.* (2013a)^[8], Sapavadiya *et al.* (2019)^[24] and Chaudhary *et al.* (2023)^[1].

More plant height generally directly responsible for high yield and hence, their positive values found beneficial in okra. The heterobeltiosis was ranged from-18.39% (JOL-21-109 × VRO-6) to 21.92% (JOL-21-106 × GO-6). The minimum and maximum values of heterosis over standard check were-5.30% (JOL-21-109 × VRO-6) to 35.16% (JOL-22-106 × GO-6). These results are agreed with the results obtained Gavint *et al.* (2018) ^[3], Ivin and Anbuselvam (2021) ^[4], Kharat *et al.* (2022) and Patel *et al.* (2024) ^[17].

For number of branches per plant, the estimates of heterobeltiosis ranged from-48.00% (KS-404 × GJO-3) to 30.95% (JOL-21-109 × GO-6). The range of standard heterosis was noted from-52.94% (JOL-21-109 × GAO-8) to 23.53% (JOL-22-103 × HRB-108-2). Similar results for number of primary branches of plant in okra were also observed by Patel and Patel (2016) ^[16], Pithiya *et al.* (2019) ^[19], Ivin and Anbuselvam (2021) ^[4] and Sakriya *et al.* (2023) ^[23].

More number of nodes generally directly responsible for high yield and hence, their positive values found beneficial in okra. The heterobeltiosis was ranged from-32.59 (JOL-22-106 × HRB-108-2) to 32.17 percent (JOL-21-109 × HRB-108-2). The standard heterosis varied from-29.53 (KS-404 × GJO-3) to 14.43 percent (JOL-21-109 × HRB-108-2). Similar results for number of nodes per plant in okra were also observed by Sapavadiya *et al.* (2019) ^[24], Kharat *et al.* (2022) and Sakriya *et al.* (2023) ^[23].

Less intermodal length is desirable trait in okra. The heterobeltiosis was ranged from-26.97% (JOL-21-109 × VRO-6) to 23.02% (JOL-22-103 × GO-6). The standard heterosis varied from-15.48% (JOL-21-106 × GJO-3) to 51.67% (JOL-22-106 × GO-6). Similar findings were reported by Patel *et al.* (2015a) ^[18], Karadi and Hanchinamani (2021) ^[6] and Chaudhary *et al.* (2023) ^[1].

Considering heterosis over better parent, the variation for number of fruits per plant was from-19.35% (KS-404 × VRO-6) to 100.29% (JOL-21-109 × HRB-108-2). Estimations of standard heterosis for number of fruits per plant was ranged from-34.85% (JOL-22-106 × GJO-3) to 21.78% (JOL-21-109 × HRB-108-2). Similar findings were also reported by Patel and Patel (2016) ^[16], Satish *et al.* (2017) ^[25], Patel *et al.* (2020) ^[15], Sood *et al.* (2022) ^[26], Poluru *et al.* (2023) ^[20] and Patel *et al.* (2024) ^[17]. The values of heterobeltiosis for days to last picking ranged from-11.85% (JOL-22-106 × VRO-6) to 9.45% (JOL-21-109 × GJO-3). The standard heterosis, the range was noted from-4.40% (HRB-55 × GO-6) to 9.75% (JOL-22-106 × GO-6). These findings are akin to those of results reported by Khatik *et al.* (2012) ^[7], Patel and Patel (2016) ^[16], Pithiya *et al.* (2019) ^[19] and Sakriya *et al.* (2023) ^[23].

More number of pickings generally directly responsible for high yield and hence, their positive values found beneficial in okra. The ranged of heterobeltiosis from-9.76 (JOL-22-103 × GO-6) to 31.43 percent (KS-404 × HRB-108-2). The standard heterosis varied from-10.26 (JOL-21-106 × GO-6 and KS-404 × GAO-8) to 20.51 percent (JOL-21-109 × HRB-108-2). These results are agreed with the results obtained by Pithiya *et al.* (2019) ^[19], Ivin and Anbuselvam (2021) ^[4], Kumar *et al.* (2023) ^[10] and Ranga *et al.* (2024) ^[21].

The heterobeltiosis ranged from-12.65% (KS-404 × VRO-6) to 79.95% (JOL-21-109 × HRB-108-2) for total fruit yield per plant. JOL-21-109 × HRB-108-2 (79.95%) followed by HRB-55 × HRB-108-2 (61.96%), KS-404 × HRB-108-2 (61.36%) and JOL-21-106 × HRB-108-2 (42.60%).-34.09% (JOL-22-106 × GJO-3) to 16.67% (JOL-21-109 × HRB-

108-2). The hybrid JOL-21-109 × HRB-108-2 exhibited the highest magnitude of standard heterosis (16.67%) in desirable direction followed by KS-404 × HRB-108-2 (11.48%). These results are in conformation to the findings of Khatik *et al.* (2012) ^[7], Kishor *et al.* (2013) ^[8], Nama *et al.* (2017), Patel *et al.* (2020) ^[15], Sood *et al.* (2022) ^[26], Chaudhary *et al.* (2023) ^[1], Sakriya *et al.* (2023) ^[23], Ranga *et al.* (2024) ^[21] and Patel *et al.* (2024) ^[17].

The heterobeltiosis ranged from-65.52% (JOL-21-109 × HRB-108-2) to 9.58% (JOL-21-106 × GJO-3) for fruit borer infestation. The heterosis over standard check ranged from-43.60 (JOL-21-109 × HRB-108-2) to 45.54 percent (JOL-22-106 × GJO-3) for fruit borer infestation.

The superior cross JOL-21-109 × HRB-108-2 was also exhibited significant standard heterosis in desired direction for the characters, viz., number of nodes per plant, number of fruits per plant, number of pickings, fruit yield per plant and fruit borer infestation suggesting the greater role of these traits towards the fruit yield per plant. This cross had also registered significant heterobeltiosis in desirable direction for fruit girth, number of nodes per plant, number of fruits per plant, fruit yield per plant and fruit borer infestation. (Table 4).

The second highest heterotic cross KS-404 × HRB-108-2 was recorded significant standard heterosis in fruit weight, number of nodes per plant, number of fruits per plant, number of pickings, fruit yield per plant and fruit borer infestation. This cross had also exhibited significant heterobeltiosis in desired direction for number of fruits per plant, number of pickings, fruit yield per plant and fruit borer infestation. (Table 4).

The third highest heterotic cross HRB-55 × HRB-108-2 was recorded significant standard heterosis in fruit borer infestation. This cross had also exhibited significant heterobeltiosis in desired direction for number of nodes per plant, number of fruits per plant, fruit yield per plant and fruit borer infestation (Table 4).

It is interesting to note that the high heterotic crosses for total fruit yield per plant did not show high heterosis for all the yield component traits (Table 4). However, the current study found that significant and positive heterosis for fruit yield was associated with significantly desirable heterosis for two or more yield-contribute traits. A similar cumulative heterotic effect of two or more yield components on fruit yield per plant was previously reported by Sood *et al.* (2022) ^[26], Chaudhary *et al.* (2023) ^[1], Sakriya *et al.* (2023) ^[23], Ranga *et al.* (2024) ^[21] and Patel *et al.* (2024) ^[17].

Table 1: List of genotypes utilized for study

No.	Genotypes	Source
Lines		
1	JOL-22-103	Vegetable Research Station, JAU, Junagadh
2	JOL-22-106	Vegetable Research Station, JAU, Junagadh
3	JOL-21-108	Vegetable Research Station, JAU, Junagadh
4	JOL-21-109	Vegetable Research Station, JAU, Junagadh
5	HRB-55	CCSHAU, Hisar, Haryana
6	KS-404	CSAUAT, Kanpur, UP
Testers		
1	GAO-8	Main Vegetable Research Station, AAU, Anand
2	GO-6	Vegetable Research Station, JAU, Junagadh
3	GJO-3	Vegetable Research Station, JAU, Junagadh
4	VRO-6	Indian Institute of Vegetable Research, Varanasi
5	HRB-108-2	CCSHAU, Hisar, Haryana
Standard Check		
1	GJOH-4	Vegetable Research Station, JAU, Junagadh

Table 2: Analysis of variance (mean square) for experimental design for different characters in okra

Source	d. f.	Days to first flowering	Days to first picking	Fruit weight (g)	Fruit length (cm)	Fruit girth (cm)	Plant height (cm)	Number of branches per plant
Replications	2	4.54	5.23	214.25	1.11	0.29	181.96	0.08
Genotypes	40	11.87**	11.25**	720.64**	3.61**	0.47**	400.54**	1.11**
Parents	10	6.82**	7.22**	901.05**	2.92**	0.21	286.07**	0.93**
Lines	5	8.90**	14.01**	603.72**	1.98**	0.50**	469.23**	0.82**
Testers	4	11.91**	5.96*	1314.96**	0.90*	0.79**	863.73**	1.45**
L vs T	20	14.19**	13.43**	574.81**	2.80**	0.29**	317.61**	1.13**
P vs H	1	30.46**	15.49**	40.49	45.69**	5.32**	1007.67**	2.62**
Hybrids	29	12.96**	12.50**	681.88**	2.40**	0.40**	419.08**	1.12**

Source	d. f.	Number of nodes per plant	Internode length (cm)	Number of fruits per plant	Days to last picking	Number of pickings	Fruit yield per plant (g)	Fruit borer infestation (%)
Replications	2	6.61	0.75	3.26*	4.79	1.93	376.04	1.58
Genotypes	43	12.45**	2.33**	8.63**	58.06**	4.22**	842.26**	12.90**
Parents	11	6.11**	2.08**	1.70	78.34**	6.27**	224.10	10.86**
Lines	7	21.23**	3.20**	3.07**	9.59**	1.58*	249.37**	5.59**
Testers	3	19.03**	3.14**	21.45**	39.81**	3.91**	1883.86**	31.48**
L vs T	1	12.73**	2.06**	4.72**	63.75**	2.55**	495.57**	7.17**
P vs H	1	0.05	2.56**	132.52**	56.92**	31.63**	12755.73**	110.24**
Hybrids	31	15.06**	2.41**	6.74**	51.11**	2.57**	644.61**	10.25**
Error	86	1.58	0.27	0.90	1.77	0.91	141.92	0.68

*, ** Significant at 5% and 1% levels, respectively

Table 3: Range of heterobeltiosis (H1) and standard heterosis (H2) as well as number of crosses with specific heterotic effects for various traits in okra

S. No	Characters				Range of heterosis (%)			Number of crosses with significant heterosis					
	Heterobeltiosis (H1) (%)				Standard heterosis (H2) (%)			+ Ve	H1	-Ve	+ Ve	H2	-Ve
1	Days to first flowering	-12.57	to	5.10	-8.23	to	7.59	1		13	3		6
2	Days to first picking	-10.67	to	4.73	-9.66	to	-9.66	1		9	2		8
3	Fruit weight (g)	-32.58	to	20.44	-24.15	to	15.81	1		12	3		6
4	Fruit length (cm)	-28.12	to	8.61	-18.17	to	13.31	1		24	2		9
5	Fruit girth (cm)	-26.55	to	12.26	-11.00	to	19.92	1		18	4		1
6	Plant height (cm)	-18.39	to	21.92	-5.30	to	35.16	4		2	6		0
7	Number of branches per plant	-48.00	to	30.95	-52.94	to	23.53	2		23	3		23
8	Number of nodes per plant	-32.59	to	32.17	-29.53	to	14.43	7		11	1		16
9	Internode length (cm)	-26.97	to	23.02	-15.48	to	51.67	4		7	8		1
10	Number of fruits per plant	-19.35	to	100.29	-34.85	to	21.78	17		1	2		23
11	Days to last picking	-11.85	to	9.45	-4.40	to	9.75	11		14	13		6
12	Number of pickings	-9.76	to	31.43	-10.26	to	20.51	9		1	4		2
13	Fruit yield per plant (g)	-12.65	to	79.95	-34.09	to	16.67	15		1	2		22

Table 4: Comparative study of three most heterotic crosses for fruit yield per plant and their heterotic effect for component characters in okra

Heterotic crosses	Fruit yield per plant (g)	Percent heterosis for fruit yield per plant over		sca effect for fruit yield per plant	Significant and desirable heterosis for component traits over	
		Better parent	Standard check (GJOH-4)		Better parent	Standard check (GJOH-4)
JOL-21-109 × HRB-108-2	146.83	79.95**	16.67**	18.29**	5, 8, 10, 12, 14	8, 10, 12, 13, 14
KS-404 × HRB-108-2	140.31	61.36**	11.48*	16.86**	10, 12, 13, 14	3, 8, 10, 12, 13, 14
HRB-55 × HRB-108-2	132.50	61.96**	5.28	-0.63	8, 10, 12, 13, 14	14

Where, *, ** Significant at 5% and 1% levels, respectively

1 = days to first flowering, 2 = days to first picking, 3 = fruit weight (g), 4 = fruit length (cm), 5 = fruit girth (cm), 6 = plant height (cm), 7 = number of branches per plant, 8 = number of nodes per plant, 9 = internodal length (cm), 10 = number of fruits per plant, 11 = days to last picking, 12 = number of pickings, 13 = fruit yield per plant (g) and 14 = fruit borer infestation (%).

Conclusion

From the ongoing discussion, it could be concluded that sufficient genetic variation was present in the experimental material for fruit yield and its component traits in okra. These crosses JOL-21-109 × HRB-108-2, KS-404 × HRB-108-2 and HRB-55 × HRB-108-2 manifested higher *per se* performance, heterobeltiosis, standard heterosis and sca effects for fruit yield and most of its component traits. These crosses also exhibited higher heterotic response and sca

effects in a desirable direction for fruit yield component traits. Therefore, these crosses could be exploited for heterosis breeding programme to boost the fruit yield in okra.

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