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HETEROSIS STUDIES IN OKRA HYBRIDS FOR YIELD AND ITS CONTRIBUTING TRAITS

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ABSTRACT

This study was conducted at the Department of Biotechnology and Crop Improvement, College of Horticulture, Bangalore, Karnataka, India, during the (March – June) 2024 Summer season to evaluate heterosis in okra hybrids for various agronomic traits and their implications for yield and quality. Five hybrids, KOK1 to KOK5, were analyzed across different crosses, revealing varying degrees of heterosis for traits such as total yield per plant, number of fruits, average fruit weight, and fruit dimensions. KOK5 exhibited high positive heterosis for total yield per plant and average fruit weight, indicating its potential for improving productivity. KOK1 demonstrated significant standard heterosis for fruit diameter and plant height, while KOK3 showed high positive heterosis for the number of seeds per plant and fruit length. KOK4 and KOK2 displayed distinct advantages, with KOK4 excelling in branch number and KOK2 in fruit diameter. Negative heterosis observed for some traits suggested a delay in maturation compared to earlier parent varieties, potentially due to recessive alleles for early maturity. Qualitative traits also highlighted the hybrids' unique value. KOK1, KOK3, and KOK5 shared desirable consumer traits, such as dark green fruit color and high tenderness. In contrast, KOK2 and KOK4 exhibited distinct morphological features, including weak pubescence and deeply lobed leaves. These findings underscore the potential of specific hybrids to enhance okra production by improving both yield and quality, catering to market demands and environmental adaptability.

Key words : Heterosis, Better parent, Standard Heterosis, Hybrids, Mid Parent Heterosis.

Introduction

Okra (*Abelmoschus esculentus* L.), a widely cultivated vegetable crop, holds significant economic and nutritional importance globally. Global okra production has reached 11.23 million tons, cultivated over 2.80 million hectares. This marks a 5.90% increase from the previous year and a 13.40% rise over the past decade. India leads global production, contributing 61.20% of the total output (FAOSTAT, 2022). Enhancing okra yield while optimizing yield-attributing traits is a paramount objective for breeders and farmers ((Haq *et al*., 2023; Ibitoye and Kolawole, 2022). Hybrid breeding has accelerated productivity growth by overcoming yield limitations. The whole genetic transformation and prepotency of possible parents must be taken into consideration when choosing the ideal parents for hybridization (Yadav *et al*., 2023). It has enabled the exploitation of hybrid vigor, advanced the understanding of the genetic foundation of various traits, and improved key quality attributes such as nutritional content (*e.g.*, elevated levels of vitamins, minerals, and antioxidants), texture and shelf life (Fujimoto et al., 2018). However, current cultivars often fail to consistently meet consumer preferences or market demands, which can limit their market appeal and profitability (Labroo *et al*., 2021, Patel *et al*., 2022). Okra is predominantly self-pollinated (Souza *et al*., 2001), but exhibits significant outcrossing rates, from 18.75% (Purewal and Randhawa, 1947) to 42.2% (Mitidieri and Vencovsky, 1974 and Purquerio *et al*., 2010), aided by insect pollinators like *Apis mellifera*. This reproductive variability requires immediate protection of emasculated flowers to prevent contamination. Gametocides can induce male sterility (Deepak *et al*., 2007). Hybrid seeds are widely utilized as they offer one of the quickest methods to boost yields (Paterniani, 1974). The potential of heterosis in okra has been recognized and harnessed for decades (Singh and Singh, 1978). Recent studies further highlight the heterotic potential of hybrid okra seeds in achieving higher productivity (Mehta *et al*., 2007; Weerasekara *et al*., 2007; Jaiprakashnarayan *et al*., 2008; Jindal *et al*., 2009, Suma *et al*., 2023). While hybrid seeds are costlier than traditional varieties, their higher productivity leads to increased profitability for growers (Medagam *et al*., 2012, Animasaum *et al*., 2023), potentially reducing hybrid seed production costs. In India, hybrid seed production relies on traditional methods involving manual emasculation and crosses, which are labor-intensive and costly (Nascimento, 2014 and Maurya *et al*., 2024). High costs limit hybrid exploitation and seed availability for growers. In recent years, has emerged as a promising approach to accelerate the development of high-yielding okra cultivars.

By systematically crossing parents with complementary characteristics, we seek to uncover novel genetic combinations that can lead to significant improvements in fruit yield, plant architecture, and other agronomically important traits (Sagar *et al*., 2024 and Das *et al*., 2022). This study will contribute to the understanding of efficacy in okra breeding and provide valuable insights for developing high-yielding and resilient cultivars.

Materials and Methods

The experiment on variability and correlation studies in okra was conducted at the Department of Biotechnology and Crop Improvement, College of Horticulture, Bengaluru (Karnataka), India. The experimental field was located at an altitude of 930m above MSL. Soil of the experimental site was red sandy loam in nature with a pH of 6.4. Superior lines were selected based on field evaluation of 50 different genotypes at the same institution (Prakash et al., 2022). These selected lines were then subjected to crossing, and the resulting hybrids were subsequently evaluated. The hybrids were evaluated in the Randomized Complete Block Design (RCBD), with two replications. The commercial checks used are the Radhika and MH-10 along with the parents and hybrids.

The lines were OK-2017-010, OK-2017-006 and EC-169459 was crossed with the testers Pusa Sawani, Pusa A4 and Varsha Uphar.

List of hybrids and their respective crosses

Experiment ID	Cross
KOK1	OK-201-010 x Pusa Sawani
KOK2	OK-201-010 x Varsha Uphar
KOK3	OK-2017-006 x Pusa A4
KOK4	EC-69304 x Pusa A4
KOK5	EC-69304 x Pusa Sawnai

Statistical method followed for the calculation of the heterosis given by Kempthorne (1957).

1. Heterosis over better parent (%) {Heterobeltiosis}

$$= \frac{F_1 - BP}{BP} \times 100$$

Where, BP is the mean of superior parent involved in development of respective F_1 and F_1 is the mean of F_1 hybrid.

2. Heterosis over commercial check (%) =

$$\frac{F_1 - CC}{CC} \times 100$$

Where, CC is the mean of superior mean of commercial check (Radhika and MH-10) and F_1 is the mean of F_1 hybrid.

Results and Discussion

The mean performance of the hybrids, when compared to the parental lines OK-2017-010, Pusa Sawani, and Varsha Uphar, as well as the commercial checks Radhika and MH-10, revealed several notable observations are in Table 1.

Days to first flowering and the Days to 50% flowering was seen better in the hybrids KOK2, which show that earliness is one of the key trait in the yield similar findings were seen in Chaudary *et al*. (2023). Plant height was recorded highest for the KOK3 of 179.57 cm which results that height is one of the major trait in the yield contribution. Number of Branches: KOK4 exhibited the maximum number of branches (2.81 per plant), indicating that KOK4 has a superior branching ability, which may contribute to increased plant productivity (Patel *et al*., 2024). Total Number of Nodes: KOK1 was the best, with an average of 16.32 nodes per plant, indicating a well-developed structure that can improve growth and fruiting (Sidapara *et al*., 2021). Internodal Length: KOK1 had the shortest average internodal length (4.47 cm). The reduced length may enhance plant organization, leading to optimal growth as reported in the studies of (Singh *et al*., 2024). Number of Ridges per Fruit: KOK3 had the highest number of ridges per fruit (4.98), which affects fruit firmness and market quality (Adedoyin *et al*., 2024,

Table I : Mean Performance of Hybrids in comparison with their parents and the commercial check.

	DF	D50	PH	NBH	NON	IL	NR	FL	FD	SP	SG	WF	NF	TYP
KOK1	39.58	42.74	155.23	2.16	16.32	4.47	5.19	14.23	1.78	49.80	0.65	17.77	41.64	739.80
KOK2	36.55	40.50	133.77	2.35	15.94	5.59	5.03	13.72	1.48	47.98	0.56	19.36	35.77	692.46
KOK3	39.38	43.48	179.57	2.11	14.10	6.62	5.10	16.08	1.35	51.37	0.58	16.29	36.88	600.57
KOK4	41.04	40.66	136.52	2.81	14.96	5.61	5.19	13.52	1.53	45.88	0.56	18.25	36.38	663.37
KOK5	34.38	43.81	131.55	2.62	14.33	6.52	5.18	15.76	1.32	49.72	0.58	18.85	34.33	647.03
CC1	38.66	41.49	120.00	2.14	17.34	5.05	5.03	14.55	1.82	49.88	0.61	17.84	31.86	568.11
CC2	40.21	45.15	132.39	2.68	16.23	7.84	5.21	15.19	1.65	51.89	0.66	16.97	26.46	448.91
P1	41.35	48.96	137.10	1.80	16.29	7.11	5.48	18.22	1.67	49.69	0.64	18.30	29.91	547.04
P2	39.29	44.20	144.52	1.24	17.72	8.05	5.24	15.09	1.29	51.32	0.54	15.22	27.99	425.84
P3	41.04	46.05	134.20	1.67	17.16	9.10	5.21	17.24	1.91	47.44	0.66	14.75	25.88	381.65
P4	40.63	41.77	123.53	1.66	18.34	8.84	5.68	16.16	2.20	49.81	0.58	16.11	24.31	391.27
P5	42.59	48.11	109.76	2.11	17.75	6.86	5.41	16.20	2.17	44.76	0.75	15.36	30.26	465.14
P6	41.88	47.46	135.16	1.72	16.82	7.91	5.55	17.94	2.11	48.69	0.66	16.57	24.22	401.36
SEm	0.58	0.53	1.97	0.06	0.25	0.25	0.07	0.29	0.03	0.75	0.01	0.61	0.92	20.35
CD 5%	1.77	1.64	6.06	0.18	0.76	0.77	0.21	0.90	0.08	2.31	0.03	1.87	2.84	62.72
Sig	**	**	**	**	**	**	**	**	**	**	**	**	**	**
CV	2.05	1.70	2.04	3.96	2.13	5.14	1.86	2.63	2.09	2.16	2.09	5.03	4.18	5.37

DF: Days to first flowering, D50: Days to 50% flowering, NBH: Number of branches, NON: Number of nodes, IL: Internodal length (cm), NR: Number of ridges, FL: Fruit length (cm), FD: Fruit diameter (cm), SP: Seeds per fruit, SG: Stem girth, WF: Fruit weight (g), NF: Number of fruits per plant, TYP: Total yield per plant (g), PH: Plant height (cm), Sig: Significance levels (** at 1%, * at 5%), P1: OK-2017-010-201, P2: OK-2017-006, P3: IC-69304, P4: Pusa Sawani, P5: Varsha Uphar, P6: Pusa A4, CC1: Commercial check Radhika, CC2: Commercial check MH-10.

Habib *et al.*, 2024). Fruit Length: KOK3 produced the longest fruits, with an average length of 18.08 cm, showing its potential for fruit elongation. Fruit Diameter: The highest fruit diameter was observed in KOK2 (2.48 cm), indicating its ability to produce wider fruits similar results were seen in (Sidapara *et al.*, 2021 and Yadav *et al.*, 2023) for fruit length and diameter. Seed per Plant: KOK3 not only produced the largest seed yield but also averaged 51.37 seeds per plant, a key trait for maximizing seed and overall productivity (Samindre *et al.*, 2022). Stem Girth: The maximum stem girth was recorded in KOK1 (0.65 inches), which may provide better plant support and resistance. Fruit Weight: The highest average fruit weight was observed in KOK2 (19.36 g), indicating a potential for producing heavier fruits. Number of Fruits per Plant: KOK1 had the highest number of fruits per plant, with an average of 41.64, demonstrating its superior fruit production capability (Animasaum *et al.*, 2023). Yield per Plant: KOK1 also excelled in yield, producing an impressive 739.80 g per plant, highlighting its overall productivity due to high fnumber of nodes, less internodal length, high fruit length and diameter, wintermediate early flowering and moderate plant height and performance this findings were seen in the previous studies of Habib *et al*. (2024, Patel *et al*. (2021), Singh *et al*. (2024), Animasaum *et al*. (2023) and Suma *et al*. (2023) for yield.

The expression of favorable traits such as higher plant height, number of branches and fruit yield in hybrids like KOK1, KOK3 and KOK4 indicates that these hybrids inherited dominant alleles responsible for these traits from their parents. This could lead to better overall performance compared to either parent individually.

In fact, this negative better parent heterosis in okra for earliness (as illustrated by KOK2) could really denote that the hybrid is later than the earliest parent to maturity presented in Table 2 and Fig. 1. This is also likely due to the high frequency of late-maturing alleles in general, with early-maturing traits being recessive. Any delay in the maturity of hybrids invariably leads to good dominant alleles from one parent masking early maturing recessive alleles coming from the second parent, which also applies to heterosis studies. Detection was also reported by (Kumar *et al.*, 2023 and Chaudary *et al.*, 2023). Observations of better parent heterosis for days to first flower and fruit maturity in okra hybrids were recorded by Adedoyin *et al.* (2024). Based on their research, they concluded that late maturity in hybrids might result from a predominance of genetic components related to vegetative growth, which would postpone phase transition into reproductive stages. The greater the positive standard heterosis, as in KOK4 here, indicates that although this hybrid may not be as early as the better parent, it outperformed the standard you are comparing. It is probably due to a mixture of corresponding character qualities recovered from one or the other parent. Chaudary *et al*. (2023), for example, reported on increased standard heterosis as a consequence of combining early flowering capability with rapid fruit-setting in okra hybrids over the better-performing check variety.

The average heterosis values for plant height with positive and high extent of better parent (heterobeltiosis) observed in KOK1 suggests the hybrid represents an example where parental alleles combine favorably to bring about heightened growth vigor presented in Table 2 and Fig. 1. It has been proposed that this might be the result of transgressive segregation at loci determining plant height because dominant alleles from both parents can combine to facilitate increased growth in plants. This finding is consistent with that reported by Choudhary *et al*. (2023). The positive better parent heterosis for plant height in okra hybrids (Sidapara *et al*., 2021) suggested the contribution of growth-promoting genes from both parental lines. They argue that for height (as well as other growth-related traits), increased stature often derives from heterosis of the trait.

The high positive standard heterosis for plant height registered with KOK3 could be due to elevation in one of its parents (the shorter parent). While it may not outperform the taller parent, the hybrid still exceeds the height of the standard variety presented in Table 2 and Fig. 1. This may be because the hybrid combines some good traits from both parents, such as better nutrient uptake or stronger stem growth, allowing it to surpass the standard check (Karadi and Hanchinamani, 2021) also reported positive standard heterosis for plant height in okra hybrids due to better utilization of genetic traits from both parents favoring initial growth.

KOK4 had high positive better parent heterosis for the number of branches, indicating that the hybrid benefited from the additive genetic effects of branching-related genes from both parents presented in Table 2 and Fig. 1. This resulted in a hybrid with superior branching ability compared to its parents. The favorable alleles likely enhanced vegetative growth, allowing the hybrid to form more branches than either parent or the standard variety. (Patel *et al*., 2024) reported a similar trend in okra, where better parent heterosis for branches was due to the additive action of growth-promoting genes. For the number of nodes, high negative better parent heterosis in KOK4 and negative standard heterosis in KOK3 suggest fewer nodes, possibly due to genetic factors inhibiting nodal development. Keerthana *et al*. (2021) found similar results, linking suppressed nodal pathways to stronger, productive nodes.

The interplay between negative better parent heterosis and positive standard heterosis for internodal length confirms the complexity of gene interactions in okra hybrids presented in Table 2 and Fig. 1. While some genetic traits may appear recessive compared to a superior parent, they still contribute to improved growth relative to a standard variety. This is commonly observed in heterosis studies where hybrids combine traits that allow them to outperform standard varieties, even if they don’t exceed the best-performing parent in every aspect. Yadav *et al*. (2023) found a similar trend, with negative better parent heterosis for internodal length in okra hybrids but positive standard heterosis (Yohanna *et al*., 2023). These differences arose from dominant gene expression in hybrids, depending on parental combinations. In KOK1, a balance of dominance, recessiveness and epistatic interactions results in shorter internodes compared to the better parent but still advantageous over the standard variety.

The contrasting heterosis patterns for the number of ridges in KOK2 and KOK3 illustrate the complexity of genetic control for this trait presented in Table 2 and Fig. 1. The negative better parent heterosis in KOK2 suggests that ridge development is constrained by suppressive genetic interactions, while the positive standard heterosis in KOK3 indicates a beneficial combination of traits that enhances ridge number relative to a standard variety, though not necessarily surpassing the better parent. This pattern aligns with findings by Rehaman *et al*. (2024), who observed negative heterosis for ridge number in some okra hybrids due to genetic suppression. Conversely, Ranga *et al*. (2024) noted positive standard heterosis in other okra hybrids, attributing it to the additive effects of favorable genes from both parents enhancing ridge formation compared to a standard variety.

These observations reveal different genetic influences on fruit length in the hybrids. The negative extent better parent heterosis for KOK4 shows that certain genetic combinations in this hybrid result in reduced fruit length compared to the better parent. Conversely, the positive standard heterosis for KOK3 shows that despite not reaching the fruit length of the better parent, this hybrid has improved fruit length compared to the standard variety due to the advantageous gene combinations. Similar findings have been reported in the literature. For instance, Kumar *et al*. (2024) found negative better parent heterosis

Table 2 : Percent heterosis for all the fourteen characters over better parent (BP) and Commercial check in okra.

	Better parent heterosis					Standard heterosis CC1					Standard heterosis CC2				
	KOK1	KOK2	KOK3	KOK4	KOK5	KOK1	KOK2	KOK3	KOK4	KOK5	KOK1	KOK2	KOK3	KOK4	KOK5
DF	-2.6	-11.61	-6.97	0	-15.38	2.37	-5.46	1.85	6.16	-11.07	-1.57	-9.09	-2.06	2.08	-14.49
D50	2.32	-15.82	-8.37	-11.7	4.87	3.01	-2.39	4.78	-2	5.58	-5.33	-10.29	-3.7	-9.93	-2.97
PH	13.23	-2.43	-7.44	1.01	-1.97	29.36	11.48	49.64	13.77	9.63	17.25	1.04	35.64	3.12	-0.63
NBH	20	11.37	36.63	63.56	57.06	0.93	9.81	-1.4	31.07	22.2	-19.25	-12.15	-21.12	4.86	-2.24
NON	-11.01	-10.2	-5.23	-11.03	-21.89	-5.86	-8.05	-18.69	-13.7	-17.36	0.55	-1.79	-13.15	-7.83	-11.74
IL	-37.2	-18.51	-29.33	-29.03	-26.24	-11.58	10.69	30.99	11.09	29.11	-43.05	-28.7	-15.63	-28.44	-16.84
NR	-5.29	-7.12	-4.1	-0.38	-0.58	3.18	-0.1	-1.09	3.18	2.88	-0.38	-3.55	-4.51	-0.38	-0.67
FL	-21.88	-24.7	-23.55	-24.62	-8.58	-2.2	-5.74	10.48	-7.08	8.32	-6.29	-9.68	5.86	-10.96	3.79
FD	-19.09	-31.8	-29.86	-27.49	-40.23	-1.93	-18.46	-25.62	-15.7	-27.55	7.88	-10.3	-18.18	-7.27	-20.3
SP	-0.02	-3.44	-6.52	-5.76	-0.19	-0.15	-3.81	2.99	-8.01	-0.32	-4.02	-7.54	-1	-11.57	-4.18
SG	0.78	-26	-15.91	-15.15	-11.45	5.74	-9.02	-4.92	-8.2	-4.92	-1.53	-15.27	-11.45	-14.5	-11.45
WF	-2.87	5.82	16.84	10.17	17.01	-0.36	8.55	-8.66	2.33	5.69	4.75	14.12	-3.98	7.57	11.11
NF	39.22	18.21	27.82	40.55	32.63	30.7	12.29	15.76	14.19	7.75	57.35	35.19	39.36	37.47	29.72
TYP	35.24	26.58	62.61	65.28	65.37	30.22	21.89	5.71	16.77	13.89	64.8	54.25	33.78	47.77	44.13

DF: Days to first flowering, D50: Days to 50% flowering, NBH: Number of branches, NON: Number of nodes, IL: Internodal length, NR: Number of ridges, FL: Fruit length, FD: Fruit diameter, SP: Seeds per plant, SG: Stem girth, WF: Fruit weight, NF: Number of fruits per plant, TYP: Total yield per plant, PH: Plant height, ; Commercial check Radhika, CC2: Commercial check MH-10.

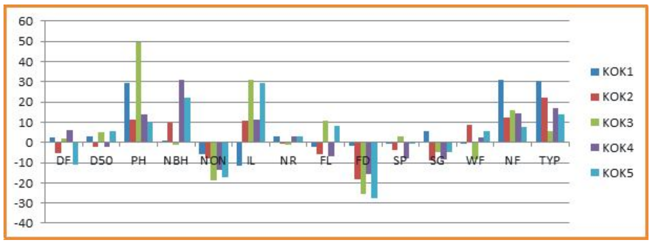
for fruit length in some okra hybrids, linking it to genetic factors that inhibit elongation. On the other hand, Singh and Yadav *et al*. (2023) documented positive standard heterosis for fruit length in okra hybrids, attributing it to the combined effects of favorable genes that enhance fruit length compared to standard varieties.

The contrasting heterosis patterns reveal the complex genetic influences on fruit diameter in okra hybrids. The negative better parent heterosis in KOK5 highlights challenges in achieving larger fruit diameter than the better parent, while the positive standard heterosis in KOK1 shows a genetic advantage over the standard variety, even if it doesn't exceed the better parent presented in Table 2 and Fig. 1. Similar findings have been reported in other studies. Abdelkader *et al*. (2024) noted negative better parent heterosis for fruit diameter, linking it to genetic suppression of size traits. In contrast, Ranga *et al*. (2024) observed positive standard heterosis in okra hybrids, attributing it to advantageous gene combinations that result in larger fruit compared to standard varieties (Sidapara *et al*., 2021).

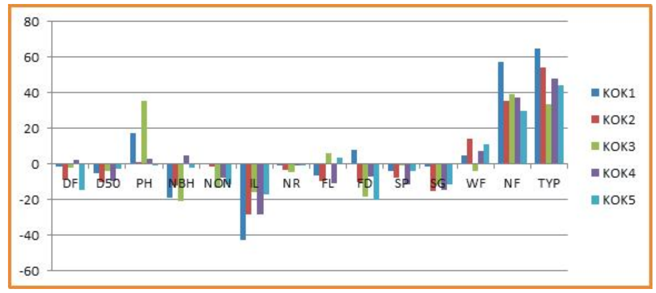
In contrast, KOK3 also exhibited high positive standard heterosis for seeds per plant, suggesting that while it does not surpass the better parent in seed number, it exceeds the standard variety presented in Table 2 and Fig. 1. This positive standard heterosis indicates that KOK3 benefits from a favorable combination of genes from both parents, enhancing seed production relative to the standard check. The higher number of seeds per plant in KOK3 reflects the additive effects of beneficial genes contributing to increased seed output. Similar patterns have been reported in other studies. For instance, Samindre *et al*. (2022) found negative better parent heterosis for seed number in some okra hybrids due to genetic factors that suppress seed production, while Rehaman *et al*. (2024) observed positive standard heterosis, attributing it to favorable gene combinations increasing seed output compared to standard varieties.

There were high inbreeding depression observed through the increasing of more than fifty percent from KOK 4 to KOK5 as average fruit weight, which demonstrated the hybrids with better morphological traits selected parents expressing larger fruits provided positive extent heterosis

1 A : Better parent heterosis.



1 B : Commercial check 1 (Radhika) standard heterosis.



1 C : Commercial check 2 (MH-10) standard heterosis.

Fig. 1 : Percent heterosis for all the fourteen characters over better parent (BP) and Commercial check in okra. DF: Days to first flowering, D50: Days to 50% flowering, NBH: Number of branches, NON: Number of nodes, IL: Internodal length, NR: Number of ridges, FL: Fruit length, FD: Fruit diameter, SP: Seeds per plant, SG: Stem girth, WF: Fruit weight, NF: Number of fruits per plant, TYP: Total yield per plant, PH: Plant height, : Commercial check Radhika, CC2: Commercial check MH-10.

presented in Table 2 and Fig. 1. This indicates that the genetic bases associated with fruit weight expression is fully harnessed in these hybrids, thus making them superior to both better parent and standard variety. These results are consistent with previous reports. For instance, Samindre *et al*. (2022) noted that concrete agronomic practices improve the expression or intensification of heterosis effects, which could explain higher positive heterosis for fruit weight in okra hybrids, precipitated by favorable gene combinations from both parents responsible for boosting product development, as claimed by Patel *et al*. (2024). Positive significant heterotic, as well as better parent means for average fruit weight of the recently developed cross, resulted in a higher value of combining ability, as already mentioned by Keerthana *et al*. (2021), who connected this character with the additive effect supported by emphatic action growth-promoting genes tools.

A large segment of heterosis was recorded for the number of fruits in both KOK5 and KOK2, with high positive extent, indicating that these hybrids inherit good traits from their parents, thus increasing fruit count presented in Table 2 and Fig. 1. This underscores the capacity of hybrids to exploit the additive and interactive actions of fruit production-related genetic factors, resulting in higher yields compared to both the better parent and the check variety. These results are congruent with prior work. Kumar *et al*. (2023) reported an increased number of fruits in okra hybrids and a positive manifestation of high heterosis, attributed to the additive effects of fruit-setting genes. A similar pattern of better parent and standard heterosis for the number of fruits was also observed by Singh and Yadav *et al*. (2023), facilitated through the effective combining ability of desirable traits from the parental lines.

These observations demonstrate that different hybrids can exhibit various angles of total yield heterosis presented in Table 2 and Fig. 1. KOK5's high positive better parent heterosis for yield and yield-related traits indicates that its performance exceeds that of its parents, making it useful for commercialization. On the other hand, KOK1 high positive standard heterosis reflects enhanced traits over a good check cultivar, though not necessarily outperforming the best parent. Research supports similar findings. Kumar *et al*. (2023) observed high positive better parent heterosis for total yield in okra hybrids, linked to the effective combination of agronomic traits from both parents. noted positive standard heterosis for total yield, pointing to the additive effects of favorable genes that boost yield compared to standard varieties.

Table 3 : Qualitative characters of the hybrids developed by crosses.

Crosses	Fruit Color	Fruit Pubescence	Leaf lobing	Fruit tenderness	Fruit shape of apex
KOK1	Dark green	Weak	Medium	Smooth	Acute
KOK2	Green	Weak	Deep	Smooth	Narrow
KOK3	Dark green	Weak	Medium	Smooth	Acute
KOK4	Green	Weak	Deep	Smooth	Narrow
KOK5	Dark green	Weak	Medium	Smooth	Blunt

Quantitatively, KOK1 showed dark green fruit color with high tenderness and medium pubescence, similar to KOK3 and KOK5. These characteristics are linked to market-desirable traits, where dark green is often preferred, and less chewiness impacts texture and taste. Weak pubescence results in smoother fruits, appreciated by consumers (Kumar *et al*., 2024 and Prakash *et al*., 2022). On the other hand, KOK4 and KOK2 exhibit green fruit color, weak pubescence, narrow fruit apex, and deeply lobed leaves, which make them unique. While their pubescence is similar to KOK1, KOK3 and KOK5, their distinct fruit shape and leaf structure highlight their unique characteristics (Patel and Singh, 2022). This data is important for understanding the genetic base of hybrids and reflects various breeding objectives focused on market traits and environmental adaptability.

Conclusion

These findings highlight the interplay between genetics and breeding methods in enhancing quantitative and qualitative traits. KOK5 and KOK2 showed significant heterosis for yield and fruit weight, improving productivity and market competitiveness. KOK1, KOK3 and KOK5 excelled in fruit tenderness and dark green color, while KOK4 and KOK2 stood out with unique morphology like deeply lobed leaves. These hybrids combine high yield, superior fruit quality, and consumer-preferred traits, demonstrating the success of breeding programs in meeting agricultural and market demands.

Statements and Declarations

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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