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Genetic Expression of Heterosis for Yield and its Related Traits in Okra (*Abelmoschus esculentus* L. Moench)

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ABSTRACT: In the summer-*kharif* season of 2021, a half-diallel study was executed, utilizing 10 parental lines and generating 45 F_1 hybrids. The primary aim was to assess the extent of heterosis compared to mid-parental, superior parental, and the standard commercial reference "GJOH 3". The degree of heterosis exhibited variability across different cross combinations for all the traits analyzed. The most notable positive and statistically significant heterosis in terms of fruit yield per plant was witnessed in the GAO 5 × Arka Abhay cross. This particular cross outperformed not only the mid-parental and superior parental references but also surpassed the standard benchmark. The hybrid combination GAO 5 × Arka Abhay demonstrated robust and consistent heterosis as well as inherent performance in fruit yield per plant, suggesting its potential for commercial utilization pending further comprehensive assessment. In the context of genetic expression of heterosis there are several challenges that researchers and breeders may encounter *i.e.*, Identifying specific genes and molecular mechanisms responsible for heterosis in yield is challenging due to the complex and non-additive nature of genetic interactions. Achieving and maintaining sufficient genetic diversity in crops, necessary for harnessing heterosis, can be difficult in cases where the genetic variability is limited. Ensuring the stability of heterotic effects across diverse environments and generations poses a challenge in the genetic expression of heterosis for yield. Developing and producing hybrid seeds on a large scale is logistically challenging, and addressing regulatory and ethical concerns related to genetically modified organisms is essential. High estimates of heterosis obtained in hybrid combinations revealed considerable genetic divergence among the parental lines and also reveals good scope for commercial exploitation of heterosis in okra.

Keywords: Heterosis, yield, *per se* performance, okra, half diallel, hybrid.

INTRODUCTION

Okra is scientifically known as *Abelmoschus esculentus* (L.) Moench, holds a significant position as a key vegetable crop extensively cultivated across the nation during both summer and rainy seasons. It has garnered remarkable popularity within tropical regions due to its uncomplicated cultivation methods, reliable yields, potential for year-round export, nutritional richness, adaptability to varying moisture levels and inherent resistance to diseases and pests (Martin and Ruberte 1978). Originating from tropical and subtropical Africa (Yawalkar, 1992), this plant has garnered various names across languages, such as "okra" or "ladyfinger" in English, "gombo" in French, "gluinogombo" in Spanish, "guibeiro" in Portuguese, "bhindi" in Hindi, and "bamiah" in Arabic. In India, it's commonly referred to as "Bhindi" or "Lady's finger", and in Sanskrit, as "Tridisha" and "Gandhmula".

Serving as a staple in Indian cooking, okra is highly regarded for its tender, flavourful green pods that are prepared, preserved, and consumed in diverse forms throughout the country. With its straightforward cultivation, consistent yield, adaptability, and year-round growth potential, okra stands as a favoured crop among Indian vegetables. The primary commercial cultivating states in India are Gujarat and Maharashtra, followed by Andhra Pradesh, Karnataka, Uttar Pradesh, and Tamil Nadu.

However, there are prominent challenges faced by the okra cultivation sector. These include the need for location-specific, high-yielding varieties that demonstrate tolerance or resistance to diseases, pests, and environmental stresses. An important focal point lies in developing a variety or hybrid that responds effectively to available resources while also exhibiting resistance to threats like the yellow vein mosaic virus. Harnessing the potential of heterosis in okra holds significance in enhancing crop improvement. Knowledge regarding the genetic makeup of pod yield and its related attributes is pivotal for this purpose. Okra is a prime example of a vegetable crop where heterosis has been successfully utilized. This exploitation of heterosis is acknowledged as a pragmatic tool, offering breeders a means to enhance yield and other crucial traits.

MATERIAL AND METHODS

Field experiment and Plant material. The present investigation titled "Heterosis, Combining Ability, and Stability Analysis in Okra [*Abelmoschus esculentus* (L.) Moench]" employed a half-diallel mating design to create 45 crosses. The primary objective was to explore the scope of heterosis. This cross-breeding initiative was conducted during the *kharif* season of 2020 at College Farm, College of Horticulture, S. D. Agricultural University, Jagudan. Subsequent evaluations were carried out in both the summer and *kharif* seasons of 2021 at College Farm, College of Horticulture in Jagudan (District: Mehsana) and Fruit Research Station in Dehgam (District: Gandhinagar).

The collection of experimental materials encompassed 56 distinct genotypes, including 10 diverse parental lines such as GAO 5, GO 6, Arka Abhay, Parbhani Kranti, Pusa Sawani, Arka Anamika, Varsha Upahar, Kashi Kranti, Phule Prajatika, and Kashi Pragati. Additionally, it incorporated 45 F_1 hybrids like and a commercial check, GJOH 3. The recommended cultural practices for successful okra cultivation were meticulously adhered to throughout the process.

The hybridization process was meticulously executed through manual emasculation and pollination, yielding F_1 hybrid seeds. To facilitate the experimentation, a Randomized Block Design (RBD) with three replications was employed. This approach ensured the establishment of a robust experimental framework for subsequent analyses.

Characters studied. The data was recorded for 13 contributing characters *viz*. number of node at which 1st flower appear, days to 50% flowering, internodal length (cm), number of pods per plant, plant height (cm), days taken from flower initiation to edible harvest, number of picking, pod yield per plant (g), pod yield per plot (kg), pod length (cm), pod thickness (cm), pod weight (g), number of ridges on pod, number of seeds per pod, crude protein content (%) and vitamin C content (mg/100 g).

RESULTS AND DISCUSSION

Heterosis. A substantial number of hybrid combinations exhibited important and statistically significant positive heterosis in comparison to both the mid-parent, superior parent, and the standard check for various traits. In terms of specific component traits, numerous hybrids displayed significant heterosis over the mid-parent, exemplified by four hybrid crosses in terms of days to 50% flowering, four crosses in plant height, one cross in the time taken from flower initiation to edible harvest, two crosses in the count of pickings, three crosses in pod yield per plant, one cross in pod yield per plot, one cross in pod thickness, two crosses in pod weight, two crosses in the number of seeds per pod, and one cross in vitamin C content.

Similarly, a considerable number of hybrids demonstrated significant positive heterosis over the better parent, evident in two crosses for the count of nodes at which the 1st flower appeared, four crosses in days to 50% flowering, one cross in the days taken from flower initiation to edible harvest, one cross in pod weight, and one cross in the number of seeds per pod.

Furthermore, for the standard heterosis, hybrids displayed significant heterosis effects on traits such as four crosses in days to 50% flowering, three crosses in internodal length, one cross in the days taken from flower initiation to edible harvest, one cross in the number of pickings, one cross in plant height, one cross in pod yield per plot, three crosses in pod thickness, one cross in pod weight, two crosses in the number of seeds per pod and one cross in crude protein content.

The effectiveness of the hybrid breeding strategy is rooted in the identification of the most productive and valuable cross combinations, thereby rendering the commercial cultivation of hybrids advantageous. The cross combinations that exhibit the highest degree of heterosis for pod yield per plant, when compared to the standard check, are presented in Table 1. This table also provides their average performance and the effects of heterosis across various characteristics. Significant desirable (negative and positive) heterotic effect for days to 50% flowering in crosses $P_1 \times P_9$ (-8.68%), $P_1 \times P_{10}$ (-7.06%) and $P_3 \times P_8$ (-6.86%), internodal length in $P_1 \times P_9$ (-15.16%), $P_1 \times P_{10}$ (-12.77%) and $P_3 \times P_8$ (-13.24%). significant positive heterotic effect for pod thickness in $P_1 \times P_9$ (14.50%), $P_1 \times P_{10}$ (12.92%) and $P_3 \times P_8$ (13.90%), for number of seeds per pod in $P_1 \times P_9$ (20.05%) and $P_3 \times P_8$ (14.56%). While significant desirable heterotic effects for characters like plant height (16.41%), days taken from flower initiation to edible harvest (-12.23%), number of picking (11.78%), pod yield per plant (21.70%) and pod weight (31.41%) in $P_1 \times P_9$ indicated that in different crosses pathways for releasing higher productivity varied from cross to cross. This study sustains the findings of Saha and Kabir (2001), Chauhan and Singh (2002); Mamta *et al.* (2002); Rewale *et al.* (2003); Singh *et al.* (2004); Tripathi *et al.* (2004); Weerasekara *et al.* (2008); Kumar and Sreeparvathy (2010); Parmar *et al.* (2011); Kerure *et al.* (2019); Keerthana *et al.* (2021); Yadav *et al.* (2023).

Table 1: Abstract table showing economic heterotic crosses, their mean performance and heterotic effects for different characters in okra (Data pooled over environments).

Traits		$P_1 \times P_9$	$P_1 \times P_{10}$	$P_3 \times P_8$
Days to 50% flowering	**A**	42.51	43.26	43.08
	B	-8.68%*	-7.06*%	-6.86*%
Internodal length (cm)	**A**	6.40	6.58	6.55
	B	-15.16*%	-12.77*%	-13.24*%
Plant height (cm)	**A**	87.44	83.81	84.68
	B	16.41*%	11.57%	12.73%
Days taken from flower initiation to edible harvest	**A**	5.44	5.87	5.85
	B	-12.23*%	-5.38%	-5.73%
Number of pickings	**A**	13.99	12.97	13.60
	B	11.78*%	3.6%	8.66%
Pod yield per plant (g)	**A**	210.78	189.29	191.68
	B	20.8 %	13.84%	15.32%
Pod thickness (cm)	**A**	1.57	1.55	1.56
	B	14.50*%	12.92*%	13.90*%
Pod weight (g)	**A**	17.60	15.08	15.92
	B	31.41**%	12.63%	18.86%
Number of seeds per pod	**A**	47.06	43.85	44.91
	B	20.05**%	11.86	14.56*%

A- Mean performance, B- Standard Heterosis (percent); *,** significant at 5 and 1 percent level, respectively.

In the present investigation, the magnitude of heterosis varied from cross to cross for all the traits under study. Such types of results revealed that the selection of parents has an important bearing on performance of any cross. The superiority of crosses over better parent indicates the ability of the parental combination to give high level of transgressive segregation (Fonseca and Patterson 1968). As outlined by Mather and Jinks (1982), the phenomenon of heterobeltiosis can be attributed to specific scenarios, including: (i) the collective influence of beneficial dominant genes distributed between the two parents, (ii) the complementary interaction of additive dominant genes with recessive genes at distinct loci, and (iii) Favourable intra or inter locus interaction *i.e.*, manifestation of heterobeltiosis might be due to the non-additive gene effects in the parents. Consequently, the manifestation of hybrid vigour is intrinsically tied to the careful selection of parents, reinforcing the necessity to pair potentially robust combinations (Aldaji *et al.*, 2014). In the case of okra, a comprehensive analysis of pod yield per plant and its attributing traits for the five most heterotic crosses is presented in Table 2.

The overall results of heterosis analysis revealed that, among the top four crosses for pod yield per plant, the crosses $P_1 \times P_9$ and $P_4 \times P_7$ was found significant over mid parent heterosis while other crosses are non significant.

Considering the higher heterosis with high *per se* performance for pod yield per pod with other yield attributing characters. The crosses $P_1 \times P_9$, $P_3 \times P_8$ and $P_4 \times P_7$ were found superior. Therefore, these crosses should be included for further evaluation in generation advancement for getting good transgressive segregants.

Table 2: Four top ranking crosses on the basis of heterosis and *per se* performance for pod yield per plant in okra.

Sr. No.	Crosses	Mean	Standard Heterosis	Heterobeltiosis	Mid parent heterosis	Other traits found significant in desired direction for standard heterosis	Other traits found significant in desired direction for heterobeltiosis	Other traits found significant in desired direction for mid parent heterosis
1.	$P_1 \times P_9$	210.78	20.8	13.63	24.55**	DFF, IL, NPP, PH, DFIEH, PYP, PT, PW, NSP, CPC	NNWFA, DFF, DFIEH, PW, NSP	DFF, NPP, PH, DFIEH, NOP, PYP, PT, PW, NSP, VIT C
2.	$P_3 \times P_8$	191.68	9.85	8.81	13.45	DFF, IL, PT, NSP	DFF	DFF, NPP, DFIEH, PW, NSP
3.	$P_1 \times P_{10}$	189.29	8.48	20.4	7.61	DFF, IL, PT		
4.	$P_4 \times P_7$	185.60	6.37	8.22	20.70*		NNWFA, DFF	NNWFA, DFF, NPP, NOP

1.	NNWFA	:	No. of node at which 1st flower appear	9.	PYP	:	Pod yield per plot (kg)
2.	DFF	:	Days to 50 % flowering	10.	PL	:	Pod length (cm)
3.	IL	:	Internodal length (cm)	11.	PT	:	Pod thickness (cm)
4.	NPP	:	Number of pods per plant	12.	PW	:	Pod weight (g)
5.	PH	:	Plant height (cm)	13.	NSP	:	Number of seeds per pod
6.	DFIEH	:	Days taken from flower initiation to edible harvest	14.	CPC	:	Crude Protein Content (%)
7.	NOP	:	Number of picking	15.	VIT-C	:	Vitamin-C content (mg/100 g)
8.	PYP	:	Pod yield per plant (kg)				

CONCLUSIONS

In conclusion, the half-diallel study provided valuable insights into the extent of heterosis in okra. The GAO 5 × Arka Abhay hybrid emerged as a standout performer, exhibiting significant and consistent heterosis in fruit yield per plant, surpassing not only parental references but also the standard commercial benchmark. However, the genetic expression of heterosis in crop yield poses challenges, including the identification of specific genes and molecular mechanisms, maintaining sufficient genetic diversity, ensuring stability across environments, and addressing logistical, regulatory, and ethical concerns. Despite these challenges, the study highlights the promising potential for commercial exploitation of heterosis in okra through strategic breeding and further comprehensive assessments.

FUTURE SCOPE

— Molecular Mechanism Elucidation
—Genomic Approaches and Marker-Assisted Selection
— Enhancing Genetic Diversity
— Environmentally Resilient Heterosis

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