Research Article

Combining Ability and Genetic Analysis of Morphological and Yield Related Traits in *Abelmoschus esculentus* L.

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Abstract | The present study was conducted to assess combing ability and genetic analysis in Okra. Twenty-eight okra genotypes (5x5 diallel crosses) and checks were screened for high yield and early maturity in a randomized complete block design. Highly significant differences were observed for most traits, except stem diameter and marketable fruit diameter. Among genotypes, G10 flowered earliest (41.5 days), G22 had longest internodes (3.59cm), G16 had heaviest fruits (9.65g), and G14 had longest and thickest marketable fruits (13.8 cm, 1.74cm). Combing ability analysis revealed that non-additive gene action was involved in controlling all traits. Non-additive gene action was important for all traits, and P2 and P3 were good general combiners. G8 and G14 were superior crosses due to high per se performance and significant SCA effects. Heritability analysis suggested that the selection of the studied traits should not be based on phenotypic performance. A heterosis study revealed that most of the crosses outperform the checks, and hence could be used in future okra breeding programs. The estimated inbreeding depression revealed that the majority of the traits showed negative inbreeding depression due to selfing, thus least affected by selfing. Thus from our study G8, G14 and G23 could be identified as the best-performing crosses for yield-associated traits. Hence should be involved in a variety of development programs to improve the quantitative and related traits of *Abelmoschus esculentus* L.

Received | November 10, 2023; **Accepted** | December 14, 2023; **Published** | January 15, 2024
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Citation | Rasheed, S.M., T. Ali, S. Jan, F. Rehman, M.A. Shah, Z. Hussain and A. Waheed. 2024. Combining ability and genetic analysis of morphological and yield related traits in *Abelmoschus esculentus* L. *Sarhad Journal of Agriculture,* 40(1): 11-21.
DOI | https://dx.doi.org/10.17582/journal.sja/2024/40.1.11.21
Keywords | Okra, Diallel crossing, Combining ability, Heterosis, Heritability, Inbreeding depression

Introduction

Okra is a vegetable widely grown in hot and subtropical regions. It is a major crop in Pakistan, but average yields are low compared to other countries (Bhatt *et al*., 2015). Farmers begin growing the Kharif crop in January as an off-season early crop in order to gain high prices, despite the fact that it is a warm season. For the Kharif crop to function at its best, high soil temperatures as well as high daytime and night-time temperatures are necessary (Suganthi *et al*., 2020). From February through November, okra can be grown and pods can be harvested, but the summer is when harvesting is most plentiful. Every other day during fruiting, and several times more if the crop gets cut and allowed to regenerate, okra fruit can be harvested (Khan and Rab, 2019).

Okra variations are divided into two categories: those that are native to the area and those that are imported. Farmers will make more money if they plant or choose types that are suited for their area and soil conditions. The seed production per acre ranges from 400 to 600 kg (Ashraf *et al*., 2020). Okra is Pakistan's top vegetable crop. It is also produced in Khyber Pakhtunkhwa Province; however, the province's average pod yield is rather low. In Pakistan, the area used for okra farming has been gradually increasing. Okra crop is now cultivated on 15500 hectares, with a yield of 7.52 tons per acre on average and a total production of 117900 tons (Khan and Rab, 2019). However, Pakistan's average okra production is lower than that of many comparable nations (Abd El-Fattah *et al*., 2020). Poor cultural practices, insects, pests, and disease, as well as a lack of excellent quality seed, might indeed contribute to Pakistan's lower yield (Budania and Dahiya, 2018).

In Pakistan, crop growth and yield are adequate, but average yields are still low when compared to other nations across the world. Okra yields are low for a number of reasons. For best development and output, okra requires sufficient nutrients, moisture, and daylight (Karadi and Hanchinamani, 2021). Due to limited land holdings and increasing fertilizers prices, farmers strive to raise plant population per unit area in order to enhance productivity (Amiteye, 2021).

Any okra breeding program's ultimate objective is to maximize commercial production. Yield is the end product of the multiplying interaction between the components that make up the yield, and there is no distinct gene system for yield (Kumar, 2019). Because the vegetative qualities of okra plants are significantly linked to production, therefore choosing okra species for breeding projects, factors such as pod size must be given priority in order to boost output (Rynjah *et al*., 2020).

In plant breeding, combining ability analysis is becoming more and more crucial. Sprague and Tatum (1942) proposed the ideas of general combining ability (GCA) and specific combining ability (SCA). (Sprague and Tatum, 1942). It has been determined that parallel analysis is a crucial statistical tool for assessing how ability and genetic factors that underlie the inheritance of biometric features are combined (Priyanka *et al*., 2018). The utilization of heterosis or hybrid vigour in plant breeding efforts has been the most significant advancement in recent decades. agricultural production has made considerable use of the heterosis phenomenon, which has played a significant role in the evolution of agricultural plants (Rynjah *et al*., 2020). The perspective of the heterosis have a big impact on how it can be used. Depending on the criteria used to measure the performance of a hybrid, heterosis is represented as relative heterosis, heterobeltiosis, and standard heterosis (Reddy *et al*., 2014). Previous studies have shown that combining ability analysis and heterosis can be useful tools for improving crop yields. This study aims to apply these concepts to okra breeding in Pakistan to develop high-yielding genotypes.

Materials and Methods

Field experiment was conducted at Bacha Khan University Agriculture Research Farm during 2021-22. Crosses were made among the superior parental genotypes in diallel fashion.

The sowing of selected diallel crosses (G) along with checks and parental (P) lines (Table 1) were carried out in the field area near Agriculture block. Sowing of the genotype were carried out in replicated trials. The normal row to row and plant to plant separation was kept to be 75 cm and 25 cm, respectively. Standard agricultural practices were maintained throughout the growing season (Anyaoha *et al*., 2022).

Five plants from each genotype from each plot were randomly selected at maturity to collect data on F1 plants for various agronomic parameters like Days to first flowering, days to first fruiting, stem diameter, Internode length, Individual fruit weight, Marketable fruit length (cm) and marketable fruit diameter (cm). Analysis of variance appropriate for RCB was performed on the experimental data using the statistical programme M Stat C (Gomez and Gomez, 1984). The data were further submitted to diallel analysis utilizing (Griffing, 1956) model (fixed effect) and Heterosis (Falconer, 1996) after substantial F-value.

Table 1: *List of the parental genotypes, F_1, and checks that were used in the study.*

	Parents		F_1 population		F_1 population
1.	BK-2 (P1)	1.	P-1 x P-1 (S)(G1)	14.	P-3 x P-4 (G14)
2.	BK-3 (P2)	2.	P-1 x P-2 (G2)	15.	P-3 x P-5 (G15)
3.	BK-4 (P3)	3.	P-1 x P-3 (G3)	16.	P-4 x P-1 (G16)
4.	BK-7 (P4)	4.	P-1 x P-4 (G4)	17.	P-4 x P-2 (G17)
5.	BK-8 (P5)	5.	P-1 x P-5 (G5)	18.	P-4 x P-3 (G18)
		6.	P-2 x P-1 (G6)	19.	P-4 x P-4 (S)(G19)
Checks		7.	P-2 x P-2 (S)(G7)	20.	P-4 x P-5 (G20)
1	Check 1 (G26)	8.	P-2 x P-3 (G8)	21.	P-5 x P-1 (G21)
2	Check 2 (G27)	9.	P-2 x P-4 (G9)	22.	P-5 x P-2 (G22)
3	Check 3 (G28)	10.	P-2 x P-5 (G10)	23.	P-5 x P-3 (G23)
		11.	P-3 x P-1 (G11)	24.	P-5 x P-4 (G24)
		12.	P-3 x P-2 (G12)	25.	P-5 x BK-8 (S)(G25)
		13.	P-3 x P-3 (S) (G13)		

Results and Discussion

In order to assess the yield differences between diallel hybrids and their respective parental lines and checks, the current study evaluated the performance of diallel crosses made from an inbred okra lines at Bacha Khan Research Farm for morphological and yield parameters.

Analysis of variance for different traits

When data were analyzed for days to first flowering, genotype differences were discernible (Table 2). It was revealed from Table 3 that maximum days to first flowering were attained by G17 and G21 (53.50 d) while minimum days to first flowering were attained by genotype Check II (41.0 d). followed by genotypes G10 (41.5 d). The effect of prevailing environmental conditions on flowering, pollination and subsequent pod development. Similarly, okra plants which bear the first flower on a lower node, and need fewer days to flowering will be earlier than those bearing the first flower on a higher node and need more days to flowering (Mohamed *et al*., 2016) analyzed data of days to first fruiting revealed significant differences among the studied genotypes. It is evident from Table 3 that genotype G6, G21, G25 took maximum (59) days to first fruiting while minimum days were observed for genotype G20 (46.0 d), followed by G10 (46.5 d). The results of several diallel crossings were not significantly different based on the analysis of stem diameter data (Table 2). Table 3 shows that G3 (1.94 cm) and G13 (0.98 cm) had stem diameters that were both higher and smaller than the average, respectively. Analyzed data of internode length showed significant differences among the performance of genotypes. Maximum (6.45) and minimum (3.59cm) internode length was observed for genotype G4 and G22, respectively (Table 3).

Table 2: *Mean sum of squares for different traits of diallel crosses, parents and checks studied during 2022.*

Taits	MS	CV %
Days to first flowering	32.63^{*}	9.38
Days to first fruiting	36.29^{*}	8.46
Stem diameter	0.069^{ns}	13.92
Internode length	1.19^{*}	15.34
Individual fruit weight	2.15^{**}	23.50
Marketable fruit length	4.47^{*}	20.28
Marketable fruit diameter	0.01^{ns}	6.67

Highly significant differences among the genotypes showed that they were significantly different from each other for fruit weight as evident from Table 2. Mean value for fruit weight ranged between 5.59 and 9.65 g, attained by genotype G23 and G16, respectively (Table 3). Data for marketable fruit length as shown in Table 2 revealed significant differences among the genotypes. Average values for fruit length varied between 7.40 and 13.85 cm. Maximum marketable fruit length (13.85 cm) was evident for genotype G14, while genotype G8 ranked second, whereas genotype G22 exhibited minimum marketable fruit length (7.40cm) (Table 3). The genotypes showed significant differences when data of diallel crosses and checks were analyzed for fruit diameter (Table 2). It is clear from Table 3 that maximum average fruit diameter of 1.74 cm was recorded for genotype G14, followed by G5 (1.70cm) while genotype G9 exhibited minimum marketable fruit diameter of 1.35cm.

Table 3: *Means values of diallel crosses and checks for days to flowering, days to first fruiting, stem diameter, internode length, individual fruit weight, marketable fruit length and marketable fruit diameter.*

Genotypes	Days to flowering	Days to fruiting	Stem diameter (cm)	Internode length (cm)	Individual fruit weight (g)	Marketable fruit length	Marketable fruit diameter
G1	42.50	48.50	1.30	5.59	7.77	9.29	1.51
G2	47.50	52.00	1.48	6.37	7.72	11.54	1.67
G3	49.00	55.00	1.94	5.23	6.20	7.89	1.47
G4	49.50	55.50	1.44	6.45	5.76	11.70	1.58
G5	44.50	49.50	1.37	5.84	6.60	11.51	1.70
G6	53.00	59.00	1.32	6.02	6.43	12.00	1.55
G7	47.00	52.00	1.53	5.62	8.00	9.85	1.60
G8	46.00	51.50	1.33	4.54	8.29	12.71	1.48
G9	45.50	50.50	1.70	5,78	7.97	8.67	1.35
G10	41.50	46.50	1.58	5.67	5.77	10.50	1.48
G11	48.00	53.00	1.27	6.37	5.60	10.89	1.66
G12	50.00	54.50	1.43	6.08	6.23	9.12	1.61
G13	43.00	48.50	0.98	4.62	6.43	10.15	1.58
G14	45.00	50.00	1.41	6.28	8.25	13.85	1.74
G15	43.50	48.50	1.50	5.84	6.67	10.19	1.39
G16	47.50	52.50	1.42	6.03	9.65	10.67	1.66
G17	53.50	58.50	1.38	6.00	6.70	11.34	1.59
G18	53.00	58.50	1.42	5.53	6.45	12.00	1.56
G19	49.50	54.50	1.52	5.08	5.70	10.57	1.60
G20	42.50	46.00	1.14	4.80	7.95	10.00	1.64
G21	53.50	59.00	1.52	4.08	6.40	9.67	1.63
G22	47.00	52.00	1.47	3.59	7.40	7.40	1.43
G23	43.00	48.00	1.40	3.80	5.59	11.67	1.56
G24	43.00	48.00	1.39	5.25	6.17	9.50	1.49
G25	53.00	59.00	1.34	5.03	7.50	9.50	1.54
Check I	42.50	47.50	1.47	4.80	6.25	12.17	1.53
Check II	41.00	46.00	1.49	5.37	6.97	8.67	1.64
Check III	51.50	56.50	1.85	5.09	8.30	9.40	1.57

Table 4: *Mean squares for combining ability for days to flowering, days to first fruiting, stem diameter, internode length and individual fruit weight during 2022.*

SoV	Days to first flowering	Days to first fruiting	Internode length	Individual fruit weight	Marketable fruit length
Crosses	30.213*	34.153*	1.300*	2.229569**	4.427
Replication	162 **	204.02**	0.129	1.414562	0.332*
GCA	11.81*	12.44	2.306*	1.234544*	3.158
SCA	38.68*	43.792*	0.567	1.526578*	4.449*
Reciprocal	29.1*	33.2	1.632*	3.330571*	4.912*
Error	19.08	19.103	0.604	2.505	4.683
H^2	0.18	0.21	0.16	0.52	0.47
GCA/SCA variance	0.052	0.363	0.1363	0.61	0.89

Combining ability analysis

Days to first flowering, days to first fruiting, internode length, individual fruit weight and marketable fruit length showed significant differences, hence underwent combining ability analysis. Table 4 displays the results of mean squares for combining ability for days to first flowering. General combining ability (GCA), specific combining ability (SCA), and reciprocal effects all showed significant variations in the combining ability analysis. Similar findings were also reported by (Vekariya *et al*., 2020), indicating the involvement of both additive and non-additive gene activities. Parental line P1 might be regarded as an effective general combiner. When P4 and P5 were crossed, highly significant negative SCA were noted for days to flowering. When P5 and P1 were crossed, highly significant negative reciprocal effects were noted (Table 5). The ratio of GCA/SCA variance was found to be less than unity (0.052) due to the observation of higher SCA variance than GCA variance, indicating the preponderance of non-additive gene activity (Abinaya *et al*., 2020). In contrast to our findings (Abed *et al*., 2020) demonstrated that the additive genetic variance's was higher for the number of days till flowering. Mean values for these parameters are shown in Table 3.

Table 5: *Estimates of GCA (diagonal values), SCA (above diagonal values) and RE (below diagonal values) of 5x5 okra diallel crosses for days to first flowering.*

Genotypes	P1	P2	P3	P4	P5
P1	-5.76*	1.94	1.64 NS	0.14	2.04 NS
P2	-2.75*	-1.36 NS	1.09 NS	1.09	-2.76 NS
P3	0.5	-2.0 NS	-2.46 NS	2.04	-2.31 NS
P4	1.0	-4.0 *	-4.0 *	1.04	-4.31 *
P5	-4.5 **	-2.75 *	0.25 *	-0.25	

Table 6: *Estimates of GCA (diagonal values), SCA (above diagonal values) and RE (below diagonal values) of 5x5 okra diallel crosses for days to fruiting.*

Genotypes	P1	P2	P3	P4	P5
P1	-5.28 *	1.82	1.57	0.32	1.87
P2	-3.5 *	-1.28	0.97	1.22	-2.73
P3	1.0	-1.5	-2.28	2.22	-2.48
P4	1.5	-4 *	-4.25 **	1.22	-4.98 *
P5	-4.75 **	-2.75 *	0.25	-1	*

Days to first fruiting data were analyzed, and variations across replications and crosses were found to be highly significant at the 5% probability level. Only SCA effects showed significant differences in the combining ability ANOVA (Table 4) (Kudari *et al*., 2020). P1 demonstrated a highly significant negative value for GCA while P5 demonstrated a highly significant positive value, making P5 a good general combiner for this trait. For combinations of P4 x P5, the SCA effect was shown to be highly significant and in the negative direction (Table 6). P4 x P3 was shown to have the second-highest degree of significance for reciprocal effects (RE), followed by P5 x P1. Likewise, P4 x P2, P2 x P1, and P5 x P2 all displayed strong negative reciprocal effects. It is clear from the combining ability study that the GCA variance was lower than the SCA variance, leading to the character's value of 0.363. This showed the participation of additive genes for this trait, which was also supported by the results of (Wakode *et al*., 2016). The data showed that the range for the mean number of days till first fruiting was 46.0 to 59.

Table 4 makes clear that there were considerable variations in internode length between genotypes (crosses) in the data that were analyzed (Bhatt *et al*., 2015). Replication revealed no differences that were statistically significant. Internode length showed significant mean squares due to GCA and reciprocal effects, but SCA showed no significant differences (Table 7). P5 demonstrated a relatively substantial positive value for this feature, making it a good general combiner for this trait. Following P1 x P4 which demonstrated substantial differences for the SCA effect, P1 x P2 revealed highly significant positive differences. Highly significant differences reciprocal effects were observed when P5 was crossed with P1, P2 and P3. The genotypic variance was very low for internode length indicating that the major part of the total variation was not heritable (Priyanka *et al*., 2018). Referring to the GCA to SCA variance ratio, this parameter's value is less than one (0.136).

Table 7: *Estimates of GCA (diagonal values), SCA (above diagonal values) and RE (below diagonal values) of 5x5 okra diallel crosses for Internode length.*

Genotypes	P1	P2	P3	P4	P5
P1	-0.505	0.327**	0.172	0.273*	-0.269
P2	0.173	-0.019	-0.093	0.156	-0.372
P3	-0.567 *	-0.77 **	-0.544	0.408	0.056
P4	0.207	-0.11	0.374	-0.760	-0.078
P5	0.878 **	1.039**	1.02 **	-0.22167	0.665*

While replication indicated no significant differences, analysis of variance revealed very significant different mean squares (P<0.01) among crosses for individual fruit weight (Table 4). For GCA, SCA, and RE, the combining ability analysis showed a significant difference. For this character, P1 proved to be an effective general combiner. For this parameter, a good cross was P1 x P4. Highly substantial changes were seen in the cross between P4 and P1, which may be having reciprocal effects (Table 8). The fact that the SCA variance is bigger than the GCA variance, causes the ratio of the two variances to be less than one, illustrating the dominance of non-additive effects (Punia and Garg, 2019; Patel *et al*., 2021). Mean value for individual fruit weight ranged between 5.59 and 9.65 g (Table 3).

Table 8: *Estimates of GCA (diagonal values), SCA (above diagonal values) and RE (below diagonal values) of 5x5 okra diallel crosses for Individual fruit weight.*

Genotypes	P1	P2	P3	P4	P5
P1	0.716*	-0.237	-0.774	0.612*	-0.316
P2	0.642	0.425	0.323	-0.019	-0.492
P3	0.298	1.030	0.132	0.632	-0.313
P4	-1.945 **	0.632	0.898 *	-1.428	0.203
P5	0.099	-0.815	0.543	0.893 *	0.919

Table 9: *Estimates of GCA (diagonal values), SCA (above diagonal values) and RE (below diagonal values) of 5x5 okra diallel crosses for marketable fruit length.*

Genotypes	P1	P2	P3	P4	P5
P1	-1.11	1.51*	-1.43	0.34	0.68
P2	-0.23	-0.25	0.24	-0.69	-0.80
P3	-1.5 *	1.79 *	-1.08	1.66**	0.60
P4	0.52	-1.33 *	0.92	-0.71	-0.59
P5	0.92	1.55 *	-0.73	0.25	0.10

Among crosses, there were no statistically significant differences in the marketable fruit length. Table 4 clearly showed that SCA and reciprocal effects were significant for this parameter, but GCA showed no changes that were worth noting. The GCA value of P5 (0.10) demonstrated that it is a good general combiner for this attribute even if GCA was non-significant (Table 4). While P1 x P2 exhibited substantial changes for this character, SCA impacts for marketable fruit length were highly significant in the cross of P3 x P4 (Table 9). The ratio of GCA variance to SCA variance was found to be 0.114. This suggested that non-additive gene activity was responsible for fruit length. Unlike our findings (Reddy *et al*., 2013) observed additive gene action for fruit length. The mean values for this parameter ranged between 7.40 and 13.85 cm observed for G14 and G22, respectively (Table 4).

Heritability estimates

Heritability estimates ranged from 16% for internode length to 52% for individual fruit length. Maximum heritability was observed for individual fruit weight followed by marketable fruit length (47%) and days to first fruiting with value of 21%. It was however very low for internode length followed by days to first flowering (9%). Very low heritability reveals the ineffectiveness of direct selection for these characters (Table 4). Breeders use heritability to determine how much confidence to put in an individual's phenotypic performance when selecting parents for next generation. In qualities with high heritability and a h^2 value more than 0.40, the phenotype serves as a reliable predictor of genetic quality or breeding value. When h^2 is less than 0.15, which denotes low heritability features, the performance is significantly less helpful in determining which people have the best genes for the trait (Cassell, 2009). This suggests that the genotypes cannot be improved through direct selection for these traits.

Inbreeding depression for different traits

Inbreeding depression is the term used to describe the phenotypical decline in genotype performance brought on by ongoing inbreeding. An excessive number of heterozygotes may indicate negative values of the inbreeding coefficient. Because of this, we advise removing variations with negative inbreeding coefficients. We do not advise eliminating positive results because they may originate from a mixing of various populations, even though positive values indicate that there are limited heterozygotes (Derek Caetno- Anolles). For some Okra traits, including days to first flowering (which implies early maturity), inbreeding depression is quite significant and desirable for us. The inbreeding values vary from -9.28 to 17.26 for days to flower commencement and was evident for P3 and P5 self. While 1.08% inbreeding was found in the P2 self. Negative inbreeding value to first fruiting was revealed for P3 (-5.27). While the most positive value of inbreeding (15.46) was possessed by P4 (Table 10). Similar results were also documented by (Neetu *et al*., 2015). Stem diameter desires positive inbreeding. According to Table 10, the stem diameter for P4 showed positive inbreeding (6.29). However, favored negative inbreeding depression of -19.01% was revealed by P3 self. Negative inbreeding is particularly beneficial for internode length because it increases yield. P3 had the most negative inbreeding (-22.74) while P5 had the lowest positive inbreeding (2.86) (Table 10). Zate *et al*. (2021) observed an inbreeding depression up to 25.81% for internode length, which is much higher than our value. The possible reason for this high value of inbreeding depression for internode length may be difference in genetic makeup of the genotypes used in the studies. The relevance of positive inbreeding for individual fruit weight in relation to yield cannot be underestimated. For self P4 and self P5, the inbreeding ranged from -11.63 to 22.75, as indicated in Table 10 confirming the past trends of (Singh *et al*., 2009) who showed evidence of beneficial inbreeding. Similar findings were observed by (Samindre *et al*., 2022) for fruit weight having inbreeding depression of 30.1%.

Positive in breeding depression is desperately needed for marketable fruit length. Negative inbreeding for all of the self's during the experiment were observed, although the highest value of (-8.65%) was shown by the self (P5), followed by P4 (-5.62) (Table 10). (Aakansha *et al*., 2015) also observed inbreeding depression upto -11.2%. Contrary to these finding (Samindre *et al*., 2022) observed 27.8% inbreeding depression for fruit length. Maximum and minimum inbreeding depression for marketable fruit diameter was observed for P2 (6.67) and P5 (-6.10), respectively (Table 10). Mix inbreeding depression for different traits were reported by (Kalpande *et al*., 2009). Whereas (Samindre *et al*., 2022) recorded positive inbreeding in okra fruit while evaluating F1's for this parameter. The estimated inbreeding depression revealed that majority of the traits showed negative inbreeding depression due to selfing, thus least effected by selfing. Hence again proved practically that self-pollinated crops are least effected by inbreeding depression.

Heterotic study of diallel crosses

Heterosis occurs when a cross performs better than either of its parents. Positive heterosis is not always more significant than negative heterosis. Depending on the study's aims. A breeder needs negative heterosis if he is interested in early maturity. However, positive heterosis is necessary to increase yield (Chavan *et al*., 2021). The importance of the non-additive gene in okra is suggested by the relationship between heterotic response and inbreeding depression (i.e., crosses showing high heterosis, their parental lines also show high inbreeding depression). The results for relative heterosis were also generally higher than the results for inbreeding depression in all characters (Samindre *et al*., 2022). For days to first flowering, breeders are more interested in negative heterosis. Maximum heterosis (-12.87) was noted for G17 x G21 (Table 11). While minimum/positive heterosis (12.45) was revealed by G10. These trends were in similarity with (Aware *et al*., 2014) and for negative heterosis. (Srikanth *et al*., 2019) also reported heterosis ranged from -1.67% to -8.65% for flowering days. It is cleared from Table 11 that negative heterobeltiosis (-11.32) for days to first fruiting was evident for G6, G21 and G25 and Positive (13.21) was shown by G20 followed by G10 (12.26). Those findings are in agreement with the findings of (Aakansha *et al*., 2015). Days to early fruiting was necessary for capturing of early market. Table 11 Indicating that maximum positive BPH (38.36) regarding stem diameter was revealed for G13 followed by G20 (28.30). Whereas, negative (-22.01) numbers was evident for G3. Heterosis was necessary for stem diameter as the plants with week stem do not resist the environmental hazards and lodged down (Chaudhary *et al*., 2023). Also the plants with week stem bend their top down when fruit develop at the tip of plant.

Heterobeltiosis, values for internode length varied from (-7.86) to (39.97), reported for G4 and G22, respectively (Table 11). Breeder were more interested in plants with shorter internodes to get maximum number of fruits from a plant. Therefore, plants with smaller internode length are given preference compared to larger one. For negative heterosis, taking similarity with (Mundhe *et al*., 2022)whose reported up to 9%.

Positive heterosis favored breeders for individual fruit weight because its enhanced yield directly. Maximum heterosis (23.63) was revealed for G23 followed by G11 (23.50). Whereas, negative value (-31.83) was

Table 10: *Estimates of Inbreeding depression (ID%) for days to flowering, days to first fruiting, stem diameter, internode length, individual fruit weight, marketable fruit length and marketable fruit diameter due to selfing.*

Genotypes	Days to flowering	Days to first fruit	Stem diameter	Internode length	Individual fruit weight	Marketable fruit length	Marketable fruit diameter
P1	-5.56	-2.02	-8.45	-1.76	10.68	-5.20	-1.31
P2	1.08	2.97	-3.77	-3.44	9.29	-3.43	6.67
P3	-9.28	-5.27	-19.01	-22.74	1.90	-5.14	-8.14
P4	5.32	2.83	6.29	-7.30	-11.63	-5.62	-5.33
P5	17.26	15.46	4.69	2.86	22.75	-8.65	-6.10

Table 11: *Heterosis study of days to flowering, days to first fruiting, stem diameter, internode length, individual fruit weight, marketable fruit length and marketable fruit diameter of okra diallel crosses during 2022.*

Genotypes	Days to flowering	Days to fruit	Stem diameter	Internode length	Individual fruit weight	Marketable fruit length	Marketable fruit diameter
G1	10.34	8.49	18.24	6.52	-6.15	17.05	12.21
G2	-0.21	1.89	6.92	-6.52	-5.46	-3.04	2.91
G3	-3.38	-3.77	-22.01	12.54	15.30	29.55	14.53
G4	-4.43	-4.72	9.43	-7.86	21.31	-4.46	8.14
G5	6.12	6.60	13.84	2.34	9.84	-2.77	1.16
G6	-11.81	-11.3	16.98	-0.67	12.16	-7.14	9.88
G7	0.84	1.89	3.77	6.02	-9.29	12.05	6.98
G8	2.95	2.83	16.35	24.08	-13.25	-13.48	13.95
G9	4.01	4.72	-6.92	3.34	-8.88	22.59	21.51
G10	12.45	12.2	0.63	5.18	21.17	6.25	13.95
G11	-1.27	0.00	20.13	-6.52	23.50	2.77	3.49
G12	-5.49	-2.83	10.06	-1.67	14.89	18.57	6.40
G13	9.28	8.49	38.36	22.74	12.16	9.37	8.14
G14	5.06	5.66	11.32	-5.02	-12.70	-23.66	-1.16
G15	8.23	8.49	5.66	2.34	8.88	9.02	19.19
G16	-0.21	0.94	10.69	-0.84	-31.83	4.73	3.49
G17	-12.87	-10.3	13.21	-0.33	8.47	-1.25	7.56
G18	-11.81	-10.3	10.69	7.53	11.89	-7.14	9.30
G19	-4.43	-2.83	4.40	15.05	22.13	5.62	6.98
G20	10.34	13.2	28.30	19.73	-8.61	10.71	4.65
G21	-12.87	-11.3	4.40	31.77	12.57	13.66	5.23
G22	0.84	1.89	7.55	39.97	-1.09	33.87	16.86
G23	9.28	9.43	11.95	36.45	23.63	-4.20	9.30
G24	9.28	9.43	12.58	12.21	15.71	15.18	13.37
G25	-11.81	-11.3	15.72	15.89	-2.46	15.18	10.47

evident for G16 (Table 11). Genotype G23 showed the highest heterosis compared to the best parents and the commercial standard for fruit weight (Chaudhary *et al*., 2023). This suggests that this cross can be utilized for future benefit. Positive heterosis is really important for marketable fruit length because its effects the yield directly. Positive heterobeltiosis (33.87) was documented for G22 cross. Whereas, negative (-23.66) value was estimated for G14 (Table 11). Contrary to our findings (Singh *et al*., 2009) revealed high negative heterobeltiosis for fruit length among crosses they made in okra genotypes. Whereas (Aware *et al*., 2014) recorded positive heterosis amounting to 11.53% for fruit length. This indicated the superiority of inbred lines used in our breeding program for this trait. For this parameter most of the crosses revealed positive values, with maximum value revealed for G9 (21.51). The only cross that showed negative value was G14 (-1.16) (Table 11). The crop could produce heterotic cross combinations, and these crosses could be utilised to advance the crop (Singh *et al*., 2013). Aware *et al*. (2014) revealed high useful heterosis of 62.61% for fruit diameter. Such high heterosis may be due to superior inbred lines used in the breeding program.

Conclusions and Recommendations

The study identified promising parental lines (P2 and P3) and hybrid crosses (G8 and G14) for breeding high-yielding okra varieties. Most traits studied showed low heritability, suggesting selection based solely on phenotype might not be effective. Many crosses exhibited heterosis, making them potential candidates for future breeding programs. Negative inbreeding depression observed in most traits indicates self-pollinated okra varieties are less susceptible to inbreeding effects. Hence again proved practically that self-pollinated crops are least effected by inbreeding depression. The performance of the promising lines and crosses will be evaluated under different environmental conditions to explore the economic viability of the lines for commercial production.

Novelty Statement

Okra is an important vegetable crop, which is of great importance to farmers of the locality. Huge foreign exchange was utilized to import okra seed. This study aimed at the development of superior genotypes to reduce the seed import.

Author's Contribution

Syed Majid Rasheed: Designed the research and polishing article.
Tauseef Ali: Executed the field activity analysis and write up.
Faiz ur Rehman and Muhammad Ali Shah: Carried out statistical analyses.
Saad Jan and Zahid Hussain: Supervised the work.
Abdul Waheed: Helps in scientific writing.

Conflict of interest
The authors have declared no conflict of interest.

References

Aakansha, G., B. Singh and S. Anubhuti. 2015. Estimation of heterosis and inbreeding depression in okra (*Abelmoschus esculentus*). Indian J. Agric. Sci., 85: 448-455. https://doi.org/10.56093/ijas.v85i3.47201

Abd El-Fattah, B.E., A.G. Haridy and H.S. Abbas. 2020. Response to planting date, stress tolerance and genetic diversity analysis among okra (*Abelmoschus esculentus* (L.) Moench.) varieties. Genet. Resour. Crop Evol., 67: 831-851. https://doi.org/10.1007/s10722-019-00821-6

Abed, M., E. Ibrahim and A. El-Shoura. 2020. Development of Okra (*Abelmoschus esculentus* L. Moench) hybrids derived from selected inbreds under drought stress. J. Plant Prod., 11: 61-69. https://doi.org/10.21608/jpp.2020.79155

Abinaya, S., K. Saravanan, P. Thangavel, R. Madhubala and K. Pushpanathan. 2020. Studies and heterosis and combining ability analysis in okra (*Abelmoschus esculentus* moench.). Plant Arch., 20: 1340-1342.

Amiteye, S., 2021. Basic concepts and methodologies of DNA marker systems in plant molecular breeding. Heliyon, 7. https://doi.org/10.1016/j.heliyon.2021.e08093

Anyaoha, C.O., Oyetunde, O. and Oguntolu, O., 2022. Diallel analysis of selected yield-contributing traits in Okra (*Abelmoschus esculentus* (L.) Moench). Adv. Hortic. Sci., 36: 97-106. https://doi.org/10.36253/ahsc-12574

Ashraf, A., M.M. Rahman, M.M. Hossain and U. Sarker. 2020. Performance evaluation of some selected okra genotypes. Int. J. Plant Soil Sci., 32: 13-20. https://doi.org/10.9734/ijpss/2020/v32i330254

Aware, S., D. Deshmukh, S. Thakare and S. Zambre. 2014. Heteosis and inbreeding depression studies in okra (*Abelmoschus esculentus* (L.) Moench). Int. J. Curr. Microbiol. Appl. Sci., 3: 743-752.

Bhatt, J., K. Kathiria and S.C.R. Acharya. 2015. Combining ability studies in okra (*Abelmoschus esculentus* (L.) Moench) for yield and its component characters. Electron. J. Plant Breed., 6: 479-485.

Budania, Y.K. and H.S. Dahiya. 2018. Impact of microclimate modification on okra cultivation: A global review. Int. J. Curr. Microbiol. Appl. Sci., 7: 426-438. https://doi.org/10.20546/ijcmas.2018.710.045

Cassell, B.G., 2009. Using heritability for genetic improvement.

Chaudhary, P.L., B. Kumar and R. Kumar. 2023. Analysis of heterosis and heterobeltiosis for earliness, yield and its contributing traits in okra (*Abelmoschus esculentus* L. Moench). Int. J. Plant Soil Sci., 35: 84-98. https://doi.org/10.9734/ijpss/2023/v35i112949

Chavan, S., V. Jagtap, V. Dhakne, D. Veer and P. Sargar. 2021. Heterosis studies in okra (*Abelmoschus esculentus* (L) Moench). Pharma Innov. J., 10: 749-753.

Falconer, D.S., 1996. Introduction to quantitative genetics. Pearson Education India.

Gomez, K.A. and A.A. Gomez. 1984. Statistical procedures for agricultural research. John wiley & sons.

Griffing, B., 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci., 9: 463-493. https://

doi.org/10.1071/BI9560463

Kalpande, V., B. Dhonukshe and H. Kalpande. 2009. Heterosis and inbreeding depression in okra (*Abelmoschus esculentus* (L) Moench). Vegetable Sci. 36: 27-30.

Karadi, S.M., Hanchinamani, C., 2021. Estimation of Heterosis in Okra (*Abelmoschus esculentus* (L.) Moench) for fruit yield and its components through line× tester mating design. Bangladesh J. Bot., 50: 531-540. https://doi.org/10.3329/bjb.v50i3.55832

Khan, M.A. and A. Rab. 2019. Plant spacing affects the growth and seed production of okra varieties. Sarhad J. Agric., 35: 751-756. https://doi.org/10.17582/journal.sja/2019/35.3.751.756

Kudari, G.B., C. Hanchinamani, H. Hadimani, D. Satish, A. Bhavidoddi and V. Kantharaju. 2020. Assessment of genetic variability in F2 populations of okra (*Abelmoschus esculentus* (L.) Moench) for productivity traits. J. Pharmacogn. Phytochem., 9: 1574-1576.

Kumar, S.C.S., 2019. Exploitation of heterosis for yield and yield attributes in okra (*Abelmoschus esculentus* (L.) Moench). Int. J. Curr. Sci., 7: 853-857.

Mohamed, M.S., H. Ahmed and A.I. Ismail. 2016. Seed yield and quality of okra (*Abelmoschus esculentus* (L.) Moench) as influenced by sowing dates, harvest date and pod position. J. Plant Prod., 7: 1137-1145. https://doi.org/10.21608/jpp.2016.46953

Mundhe, S., S. Pole, P. Khandebharad and A. Patil. 2022. Heterosis studies for yield and yield component traits in okra (*Abelmoschus esculentus* (L.) Moench). Pharma Innov. J., 11: 837-842.

Neetu, A., A.K. Singh, R. Kumar and M. Pal. 2015. Heterosis and inbreeding depression in okra (*Abelmoschus esculentus* (L.) Moench). Seeds, 1: 2.

Patel, B., J. Vachhani, P. Godhani and M. Sapovadiya. 2021. Combining ability for fruit yield and its components in okra (*Abelmoschus esculentus* (L.) Moench). J. Pharmacogn. Phytochem., 10: 247-251.

Priyanka, V., T. Reddy, H. Begum, N. Sunil and M. Jayaprada. 2018. Studies on genetic variability, heritability and genetic advance in genotypes of okra (*Abelmoschus esculentus* (L.) moench). Int. J. Curr. Microbiol. Appl. Sci., 7: 401-411. https://doi.org/10.20546/ijcmas.2018.705.052

Punia, M. and D. Garg. 2019. General and specific combining ability effects and variances for fruit yield and its contributing traits in okra (*Abelmoschus esculentus* (L.) Moench). Int. J. Chem. Stud., 7: 1824-1830.

Reddy, M.A., O. Sridevi, P. Salimath and H. Nadaf. 2013. Combining ability for yield and yield components through diallel analysis in okra (*Abelmoschus esculentus* (L.) Moench). J. Agric. Vet. Sci., 5: 1-6. https://doi.org/10.9790/2380-0520106

Reddy, M.T., K. Haribabu, M. Ganesh and H. Begum. 2014. Exploitation of heterosis in okra (*Abelmoschus esculentus* (L.) Moench). Int. J. Agric. Food Res., 2. https://doi.org/10.24102/ijafr.v2i4.179

Rynjah, S., T. Arumugam, S. Mohankumar and A.K. Kannan. 2020. Exploitation of heterosis for yield and yield related traits in okra (*Abelmoschus esculentus* (L.) Moench). Int. J. Chem. Stud., 8: 886-893. https://doi.org/10.22271/chemi.2020.v8.i4f.9715

Samindre, S., V. Jagtap, P. Sargar, S. Deokar and S. Pisal. 2022. Heterosis and inbreeding depression analysis for fruit yield and its related attributes in Okra (*Abelmoschus esculentus* L. Moench). Pharma Innov. J., 11: 5754.

Singh, B., K. Deepak, K. Singh and C. Vinita. 2009. Heterobeltiosis and inbreeding depression in okra (*Abelmoschus esculentus* (L.) Moench). Adv. Plant Sci., 22: 273-275.

Singh, B., A. Goswami and M. Kumar. 2013. Estimation of heterosis in okra for fruit yield and its components through diallel mating system. Indian J. Hortic., 70: 595-598.

Sprague, G.F. and L.A. Tatum. 1942. General vs. specific combining ability in single crosses of corn 1. Agron. J., 34: 923-932. https://doi.org/10.2134/agronj1942.00021962003400100008x

Srikanth, M., S. Dhankhar, N. Mamatha and T. Ravikumar. 2019. Estimation of heterosis and Inbreeding depression in Okra (*Abelmoschus esculentus* (L.) Moench). Plant Arch., 19: 1195-1198.

Suganthi, S., R.S. Priya, A. Kamaraj, P. Satheeshkumar and R. Bhuvaneswari. 2020. Combining ability studies in bhendi (*Abelmoschus esculentus* (L.) moench) through diallel analysis for yield and yield attributing characters. Plant Arch., 20: 3609-3613.

Vekariya, R., A. Patel, K. Modha, C. Kapadiya, S. Mali and A. Patel. 2020. Estimation of heterosis, gene action and combining ability over environments for improvement of fruit yield and its related traits in okra (*Abelmoschus esculentus* (L.) Moench). Int. J. Curr. Microbiol. App. Sci., 9: 866-881. https://doi.org/10.20546/ijcmas.2020.909.109

Wakode, M., S. Bhave, V. Navhale, V. Dalvi, J. Devmore and S. Mahadik. 2016. Combining ability studies in okra (*Abelmoschus esculentus* L. Moench). Electron. J. Plant Breed., 7: 1007-1013. https://doi.org/10.5958/0975-928X.2016.00138.1

Zate, D., F. Khan, A. Rathod and L. Jawale. 2021. Heterosis, heterobeltiosis and inbreeding depression study in okra (*Abelmoschus esculentus* (L.) Moench). Pharma Innov. J., 10: 401-410.