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RESEARCH ARTICLE

Genetic analysis and combining ability in okra (*Abelmoschus esculentus* L.)

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Abstract

Okra a widely cultivated vegetable crop in tropical and subtropical regions of the world, that is valued for its significant nutritional and therapeutic properties. The current investigation was conducted with 21 F_1 hybrids developed through a half-diallel mating design by using seven diverse parental lines namely, Punjab-8, Hissar Unnat, Hoshiarpur Local, Anima, Green Gold, Ajeet 121 and AKO 107 which were evaluated during the rainy season, 2022 and spring-summer, 2023 in randomized block design with three replications. Significantly highest general combining ability (GCA) effect for fruit production per plant was displayed by parent Hissar Unnat in both seasons of investigation followed by Punjab 8. These two parents have a good scope in the yield improvement program. In terms of disease resistance substantial GCA impacts in the intended direction for tolerance to bhindi yellow vein mosaic virus (BYVMV) and okra enation leaf curl virus (OELCV) were shown by the parents AKO-107 and Ajeet 121, respectively in both seasons of investigation. Both Ajeet 121 and AKO 107 were established to be ideal general combiners for disease resistance. Maximum substantial specific combining ability (SCA) impacts in the positive direction for fruit production per plant along with tolerance to OELCV and BYVMV were observed in crosses Punjab 8 × Ajeet 121 and Hissar Unnat × AKO 107 during the investigation. These promising crosses, involving at least one ideal general combiner parent, offer significant potential for developing superior segregating lines. The predictability ratio confirmed the overwhelming influence of non-additive gene action for regulating all the evaluated traits.

Keywords: combining ability; gene action; general combining ability (GCA); specific combining ability (SCA)

Introduction

Bhindi [*Abelmoschus esculentus* (L.) Moench] commonly known as okra, is one of the world's popular vegetable crops, famous for its luscious and delicate fruits (1). This vegetable crop is grown during the rainy and summer seasons (2). It is a polyploid, having chromosomal number 2n=72 or 144 (3). Internationally, okra is cultivated on 1.12 million hectares, with an output of 8.71 million tonnes (mt) and a productivity of 7.8 tonnes per hectare (4). Okra was initially named *Hibiscus esculentus* but is now regarded as *Abelmoschus esculentus*, owing to the existence of attributes of the corolla, calyx and staminal column which are united at the base and fall as one piece immediately after anthesis (5).

Okra pods and leaves, as well as vegetative portions, are utilized in a variety of industries, including papermaking (6). The sticky substance obtained from roots, pods and stems was employed to filter sugarcane juice (7). Improvement program success is heavily dependent on identifying and selecting favourable gene combinations in lines with high combining ability, as well as isolating important germplasm (8). One of the key genetic factors in producing superior cultivars is combining ability (9). Selection efficiency depends on the genetic mechanisms in the parent, which influence their combining ability (10).

Several researchers have commonly use diallel mating to test the combining ability and action of genes for early maturity, yield and yield attributes in bhindi (11). For genetic enhancement of yield and its associated attributes, it is vital to choose the appropriate breeding strategies based on the general combining ability (GCA) of parents and the specific combining ability (SCA) of crosses (12). The combining ability assessment, featuring both GCA and SCA impacts, assists in determining ideal parents and superior hybrids. The GCA and SCA predictions for various quantitative characteristics were assessed using the half-diallel analysis, a biometric approach (13). The GCA analyses additive gene effects, whereas the SCA uncovers dominance (intra-allelic) and epistasis interactions (inter-allelic) (14).

The ratio of GCA and SCA predicts whether genes function additively or dominantly for each characteristic (15). Understanding gene activity can assist in determining whether to use recombination and heterosis breeding or selection (16).

The present study aims to identify elite parents and promising crosses for use in okra improvement programs.

Materials and Methods

The current study used 21 F_1s produced through half-diallel mating with seven parents namely, Punjab-8, Hissar Unnat, Hoshiarpur Local, Anima, Green Gold, Ajeet 121 and AKO 107. The seven parents were sown during the rainy season in 2022 and spring-summer in 2023 in a randomized block design with 3 replications at the teaching field, extended campus of BCKV, Burdwan. Data were obtained for 18 yield-contributing characteristics. Observations were obtained from 10 randomly marked plants in each replication.

Following the techniques described by earlier and the randomized block design (RBD) was subjected to analysis of variation (ANOVA) (17). Combining ability investigations were carried out by employing the approach (18). Griffing's method 2 and model 1 were regarded as the most ideal for the current investigation. The predictability ratio illustrates the relative significance of additive and non-additive genetic impacts on traits by displaying additive genetic variation as a percentage of overall genetic variance (19). Predictability ratio near unity (> 0.8) shows the prevalence of additivity, a ratio between 0.5 to 0.8 indicates both additivity and non-additive gene impacts and a ratio of less than 0.5 suggests a non-additive gene effect for the specified characteristic (19). The half-diallel mating approach for the current investigation is shown in Table 1.

Table 1. 7 × 7 Half-diallel mating design: 21 Hybrids + 7 Parents

		Male parents						
		P_1	P_2	P_3	P_4	P_5	P_6	P_7
	P_1	**P_1x P_1**	P_1x P_2	P_1x P_3	P_1x P_4	P_1x P_5	P_1x P_6	P_1x P_7
	P_2		**P_2x P_2**	P_2x P_3	P_2x P_4	P_2x P_5	P_2x P_6	P_2x P_7
	P_3			**P_3x P_3**	P_3x P_4	P_3x P_5	P_3x P_6	P_3x P_7
	P_4				**P_4x P_4**	P_4x P_5	P_4x P_6	P_4x P_7
Female parents	P_5					**P_5 x P_5**	P_5 x P_6	P_5 x P_7
	P_6						**P_6 x P_6**	P_6 x P_7
	P_7							**P_7 x P_7**

(P1= Punjab-8, P2= Hissar Unnat, P3= Hoshiarpur Local, P4= Anima, P5= Green Gold, P6= Ajeet 121, P7= AKO 107 and Bold= selfed)

Results and Discussion

In the current investigation seeds of 21 F_1s with 7 parents were sown in the field following randomized complete block design with 3 replications during the last week of June 2022 (kharif season) and last week of February 2023 (spring-summer season) to record different quantitative traits to assess the action of gene and combining ability.

Gene action of various traits

ANOVA (mean squares) of 18 studied traits of hybrids and parents were displayed in supplementary Tables S1-S6. The variance analysis for the parents was subdivided into three sections: parents, hybrids and parents vs. hybrids.

The parents were quite significant for all the characteristics in the rainy season, 2022, except the per fruit count of ridges and length of fruit. The parents were also significant for all the traits in spring summer, 2023, except for ridges count per fruit, fruit length and primary branches. These very dissimilar parental lines demonstrated their potential for producing divergent hybrids. Substantial differences among hybrids for all the studied attributes except the ridges count per fruit, days to 1st harvest in the rainy season, 2022 and ridges count per fruit, days to 1st blooming, days to 1st harvest, number of primary branches in spring-summer, 2023 showed that different cross combinations performed differently for most traits.

Parents vs. hybrids variance was also substantial for all the traits under investigation except the ridges count and diameter of fruit in the rainy season, 2022 and node to 1st flowering, diameter of fruit, ridges count per fruit and weight of fruit in spring-summer, 2023 revealed that average heterosis was also highly substantial for such attributes. Thus, the presence of substantial genetic variation emphasizes the prospect of improving economic features in okra by hybridization proceeded by selection and heterosis breeding. Highly significant parents, hybrids and parents vs. hybrids variances for most traits in okra under study were also noticed in various studies (20-22).

The ANOVA for combining ability centered on Griffing's model 1 and method 2 that constituents of GCA and SCA mean squares were highly substantial for yield of fruit per plant as well as other attributes in the F_1 generation except for ridges count per fruit where GCA and SCA mean squares were non-significant during both the seasons (Tables 2-5). In spring-summer of 2023, traits like days to 1st blooming and days to 1st harvest showed non-significant GCA mean squares. This suggested that the inheritance of yield of fruit per plant, okra enation leaf curl virus (OELCV) and bhindi yellow vein mosaic virus (BYVMV) disease severity features were influenced by both additive and non-additive action of gene.

Several researchers also noticed quite substantial GCA and SCA variances for yield of fruit per plant and many other quantitative traits (23-25). Non-additive gene activity predominated, according to the predictability ratio in controlling all the studied traits (Tables 2-5). The relevance of non-additive gene activity in these characteristics suggests a reliance on heterozygous loci, emphasizing the function of cross-pollination in sculpting these features over evolution. Heterosis breeding would be an appropriate method to enhance these attributes.

Many researchers have demonstrated the genetics of various metric parameters in bhindi. The torrential response of non-additive gene activity for length of internode, height of the plant, days to 50% blooming, node at 1st blooming, per plant fruits count, fruit weight, yield of fruit per plant, percent disease index (PDI) of YVMV and 1000 seed weight were documented (26-29). Disagreements in earlier findings, if any, in estimating gene activity regulating distinct traits may result from changes in the genetic architecture of the parental lines, variation in the mating designs, environment and experiment accuracy.

Combining ability impacts

The diallel technique assists in identifying the most promising combining parents and crosses for the different quantitative characteristics under identification, along with assessing combining ability variances for the parameters to be improved. In addition, we sought to assess the parents' relative potential in terms of GCA impacts (g_i) and SCA impacts of hybrids (s_{ij}), as well as per se (mean) performance, to evaluate their utility in an effective breeding program.

Table 2. ANOVA (mean squares) for combining ability (Griffing's Model 1 and Method 2) of 18 traits in 7x7 half diallel cross of okra in rainy season 2022

Source of variation	Degrees of freedom (DF)	Number of primary branches	Number of nodes/ main stem	Internodal length	Plant height	Days to first flowering	Days to 50% flowering	Node to first flowering	Days to first harvest	Fruit length
GCA	6	0.480 **	19.448 **	4.703 **	187.498 **	12.444 **	12.037 **	0.783 **	14.226 *	2.785 **
SCA	21	0.407 **	22.633 **	2.111 **	185.480 **	9.039 **	8.669 **	0.442 **	9.743 *	3.559 **
Error	54	0.01	1.183	0.075	22.15	1.717	2.245	0.037	5.001	0.287
Additive variance (σ^2a)		0.105	4.059	1.029	36.744	2.384	2.176	0.166	2.05	0.555
Dominance variance (σ^2D)		0.396	21.45	2.037	163.331	7.322	6.424	0.404	4.742	3.272
Predictability ratio		0.209	0.159	0.336	0.184	0.246	0.253	0.291	0.302	0.145

**Significant at 0.01 level of probability.

Table 3. ANOVA (mean squares) for combining ability (Griffing's Model 1 and Method 2) of 18 traits in 7x7 half diallel cross of okra in rainy season 2022

Source of variation	DF	Fruit diameter	Number of ridges per fruit	Fruit weight	Number of fruits	Number of seeds per fruit	1000 weed weight	Fruit yield per plant	YVMV PDI at 90 DAS	OELCV PDI at 90 DAS
GCA	6	0.030 **	0.007	8.995 **	12.712 **	66.906 **	64.321 **	5139.39 **	114.347 **	80.476 **
SCA	21	0.021 **	0.007	6.213 **	20.355 **	138.140 **	87.107 **	10829.1 **	173.710 **	173.659 **
Error	54	0.005	0.03	0.429	0.707	8.626	8.558	186.039	0.689	0.257
σ^2a		0.006	-0.005	1.903	2.668	12.951	12.392	1100.745	25.257	17.827
σ^2D		0.016	-0.023	5.784	19.648	129.514	78.549	10643.08	173.02	173.402
Predictability ratio		0.262	0.182	0.248	0.12	0.091	0.136	0.094	0.127	0.093

**Significant at 0.01 level of probability.

Table 4. ANOVA (mean squares) for combining ability (Griffing's Model 1 and Method 2) of 18 traits in 7x7 half diallel cross of okra in spring summer 2023

Source of variation	DF	Number of primary branches	Number of nodes/ main stem	Internodal length	Plant height	Days to first flowering	Days to 50% flowering	Node to first flowering	Days to first harvest	Fruit length
GCA	6	0.270 **	13.626 **	3.933 **	100.170 **	4.043	6.729 **	0.379 **	7.438	6.212 **
SCA	21	0.394 **	17.874 **	1.704 **	146.169 **	7.789 **	7.203 **	0.307 **	7.289 *	4.012 **
Error	54	0.016	0.554	0.092	14.381	2.822	2.058	0.045	4.031	0.405
σ^2a		0.056	2.905	0.854	19.064	0.271	1.038	0.074	0.757	1.291
σ^2D		0.377	17.32	1.612	131.788	4.967	5.145	0.262	3.258	3.608
Predictability ratio		0.13	0.144	0.346	0.126	0.052	0.168	0.221	0.189	0.263

**Significant at 0.01 level of probability.

Table 5. ANOVA (mean squares) for combining ability (Griffing's Model 1 and Method 2) of 18 traits in 7x7 half diallel cross of okra in spring summer 2023

Source of variation	DF	Fruit diameter	Number of ridges per fruit	Fruit weight	Number of fruits	Number of seeds per fruit	1000 weed weight	Fruit yield per plant	YVMV PDI at 90 DAS	OELCV PDI at 90 DAS
GCA	6	0.045 **	0.004	3.942 **	11.241 **	62.764 **	50.676 **	3265.13 **	80.037 **	88.066 **
SCA	21	0.028 **	0.004	3.595 **	22.072 **	123.421 **	95.862 **	8884.34 **	118.996 **	192.818 **
Error	54	0.006	0.041	0.359	1.062	6.552	7.14	171.894	0.726	0.393
σ^2a		0.009	-0.008	0.796	2.262	12.491	9.674	687.387	17.625	19.483
σ^2D		0.022	-0.037	3.236	21.01	116.868	88.722	8712.449	118.269	192.425
Predictability ratio		0.283	0.183	0.197	0.097	0.097	0.098	0.073	0.13	0.092

**Significant at 0.01 level of probability

The GCA impacts of the parents used in present study for 18 attributes were shown in the tables 6-11. The GCA impacts of the parents differed for most attributes studied. No single parent consistently showed good combining abilities for all characteristics. Hissar Unnat exhibited the most significant positive GCA effects for 10 traits in the rainy season (2022), 7 traits in the spring-summer season (2023) and 14 traits in the pooled analysis (Tables 10-11). Next to Hissar Unnat, the parent, Punjab 8 displayed substantial GCA impacts in the intended direction for 7 traits in the rainy season, 2022 (Tables 6-7), 6 traits in the spring-summer season, 2023 and 9 traits in a pooled analysis (Tables 10-11).

The significantly highest GCA impact for per plant fruit yield was displayed by parent Hissar Unnat in both seasons of investigation followed by parent Punjab 8. These parents hold strong potential for use in yield improvement programs. Substantial GCA impacts in the intended direction for tolerance to BYVMV were shown by the parent AKO-107 in both seasons of investigation. Similarly, parent Ajeet 121 displayed significant GCA effects in the desired direction for tolerance to OELCV in both seasons of investigation. Both Ajeet 121 and AKO 107 were identified as ideal general combiners for disease resistance. For yield improvement, parents Hissar Unnat and Punjab 8 were treated as the best general combiners.

Punjab 8 had the best average performance in terms of fruit production per plant, fruit count per plant and lower levels of OELCV and BYVMV disease severity, followed by Hissar Unnat. Parents Ajeet 121 and AKO 107 showed no incidence of diseases (BYVMV and OELCV) in both seasons of investigation. Substantial and positive GCA impacts for yield of fruit per plant, fruit weight, fruit count per plant, fruit length, nodes on main stem and height of plant were also recorded (16, 25, 29-31). While negatively substantial GCA impacts for internodal length, days to 1st blooming, days to 50% blooming and PDI of BYVMV were also noticed (30-32).

SCA effects include dominance and epistatic components of genetic variants that cannot be fixed, however, crosses with high SCA impacts including good general combiner parents can be used in future improvement initiatives. The SCA impacts for 21 cross combinations of 18 traits were presented in Tables 12-17. Substantial SCA impacts in the intended direction were displayed by 10 crosses for per plant fruit yield (in both seasons), for primary branches 13 crosses (in the rainy season, 2022) and 9 crosses (in spring-summer, 2023), substantial SCA impacts in the intended direction were displayed by 12 crosses (in both the seasons) for PDI of OELCV at 90 DAS. Substantial SCA impacts in the intended direction were displayed by 12 crosses (in the rainy season, 2022) and 11 crosses (in spring-summer, 2023) for PDI of BYVMV at 90 DAS. Substantial SCA impacts for the number of fruits were shown by 8 crosses (in rainy season, 2022) and 10 crosses (in spring-summer, 2023). Substantial SCA impacts for the nodes count per main stem were displayed by 7 crosses (in both seasons) and for plant height by 5 crosses (in both seasons), substantial SCA impacts for days to 1st blooming were shown by 5 crosses (in rainy season, 2022), 3 crosses (in spring-summer, 2023). Significant SCA impacts for days to 1st harvest were shown by 1 cross (in

Table 6. Estimates of GCA (g_i) effects in 7 parents over 21 F_1's of bhindi during the rainy season 2022

Parents	Number of primary branches	Number of nodes/ main stem	Internodal length	Plant height	Days to first flowering	Days to 50% flowering	Node to first flowering	Days to first harvest	Fruit length
Punjab-8	0.447 **	1.937 **	-0.502 **	-0.769	-0.7	-0.728	-0.513 **	-0.762	-0.147
Hissar Unnat	0.058	1.192 **	0.352 **	4.350 **	-1.534 **	-1.322 **	-0.034	-1.462 *	0.329
Hoshiarpur Local	-0.220 **	-1.853 **	-1.028 **	-5.720 **	-0.486	-0.471	0.198 **	-0.407	-1.201 **
Anima	-0.017	1.236 **	-0.659 **	-4.059 **	-0.622	-0.708	-0.179 **	-0.83	0.177
Green Gold	-0.053	-0.175	0.318 **	-3.319 *	0.288	0.119	0.098	0.024	0.355 *
Ajeet 121	0.038	-0.986 **	0.678 **	4.720 **	1.319 **	1.261 **	0.01	1.692 *	0.31
AKO 107	-0.253 **	-1.353 **	0.842 **	4.797 **	1.734 **	1.849 **	0.420 **	1.745 *	0.177
SE (g_i)	0.076	0.821	0.207	3.554	0.989	1.131	0.146	1.689	0.405

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 7. Estimates of GCA (g_i) effects in 7 parents over 21 F_1's of bhindi during the rainy season 2022

Parents	Fruit diameter	Number of ridges per fruit	Fruit weight	Number of fruits	Number of seeds per fruit	1000 seed weight	Fruit yield per plant	YVMV PDI at 90 DAS	OELCV PDI at 90 DAS
Punjab-8	0.012	-0.038	-0.127	1.697 **	1.434	1.044	27.528 **	-1.264 **	1.082 **
Hissar Unnat	0.058 **	-0.016	0.337	1.216 **	1.679	2.339 *	29.550 **	0.889 **	-2.483 **
Hoshiarpur Local	-0.106 **	0.006	-1.324 **	-0.367	-5.229 **	-5.487 **	-32.103 **	3.718 **	1.889 **
Anima	0.002	0.006	-1.377 **	0.600 *	-1.476	-1.219	-24.166 **	4.749 **	-0.167
Green Gold	-0.009	-0.016	0.516 *	-0.925 **	1.095	1.011	-7.388	-2.944 **	1.520 **
Ajeet 121	-0.025	0.05	0.962 **	-0.726 **	2.965 **	1.873 *	10.515 *	0.214	-5.320 **
AKO 107	0.068 **	0.006	1.014 **	-1.496 **	-0.468	0.44	-3.936	-5.362 **	3.479 **
SE (g_i)	0.053	0.130	0.495	0.635	2.218	2.209	10.300	0.627	0.383

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 8. Estimates of GCA (g_i) effects in 7 parents over 21 F_1's of bhindi during spring summer 2023

Parents	Number of primary branches	Number of nodes	Internodal length	Plant height	Days to first flowering	Days to 50% flowering	Node to first flowering	Days to first harvest	Fruit length
Punjab-8	0.282 **	1.908 **	-0.482 **	-0.067	-0.819	-0.825	-0.345 **	-0.854	0.146
Hissar Unnat	0.071	0.882 **	0.467 **	2.528 *	-0.643	-0.824	-0.056	-0.787	0.3
Hoshiarpur Local	-0.207 **	-1.515 **	-0.978 **	-5.501 **	-0.044	-0.079	0.134 *	-0.109	-1.850 **
Anima	-0.072	0.715 **	-0.573 **	-2.526 *	-0.199	-0.501	-0.089	-0.564	0.093
Green Gold	-0.029	-0.085	0.330 **	-0.982	-0.053	-0.134	0	-0.132	0.417 *
Ajeet 121	0.127 **	-0.813 **	0.534 **	4.091 **	0.779	1.009 *	0.034	0.856	0.559 **
AKO 107	-0.174 **	-1.092 **	0.702 **	2.457 *	0.98	1.354 **	0.322 **	1.590 *	0.336
SE (g_i)	0.097	0.562	0.229	2.864	1.268	1.083	0.161	1.516	0.480

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 9. Estimates of GCA (g_i) effects in 7 parents over 21 F_1's of bhindi during spring season 2023

Parents	Fruit diameter	Number of ridges per fruit	Fruit weight	Number of fruits	Number of seeds per fruit	1000 weed weight	Fruit yield per plant	YVMV PDI at 90 DAS	OELCV PDI at 90 DAS
Punjab-8	-0.031	-0.019	0.138	1.035 **	0.246	-0.4	20.814 **	-0.503	1.960 **
Hissar Unnat	0.033	0.026	0.293	1.136 **	3.744 **	2.022 *	24.951 **	0.478	-2.594 **
Hoshiarpur Local	-0.087 **	-0.019	-0.804 **	-0.296	-3.243 **	-3.833 **	-19.341 **	3.643 **	1.653 **
Anima	-0.02	-0.02	-0.818 **	0.612	-1.343	-2.188 *	-10.628 *	3.008 **	0.313
Green Gold	-0.051 *	0.003	-0.166	0.419	-0.627	1.189	2.914	-3.423 **	1.773 **
Ajeet 121	0.026	0.004	1.038 **	-1.083 **	3.286 **	2.926 **	5.652	1.016 **	-5.874 **
AKO 107	0.130 **	0.025	0.319	-1.823 **	-2.063 *	0.284	-24.362 **	-4.220 **	2.769 **
SE (g_i)	0.060	0.153	0.453	0.778	1.933	2.018	9.901	0.644	0.473

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 10. Estimates of GCA (g_i) effects in 7 parents over 21 F_1's of bhindi (pooled)

Parents	Number of primary branches	Number of nodes	Internodal length	Plant height	Days to first flowering	Days to 50% flowering	Node to first flowering	Days to first harvest	Fruit length
Punjab-8	0.365 **	1.923 **	-0.492 **	-0.418	-0.760 *	-0.776 *	-0.429 **	-0.808	0
Hissar Unnat	0.065 *	1.037 **	0.409 **	3.439 **	-1.089 **	-1.074 **	-0.045	-1.125 *	0.314 *
Hoshiarpur Local	-0.213 **	-1.685 **	-1.004 **	-5.611 **	-0.265	-0.274	0.166 **	-0.258	-1.526 **
Anima	-0.044	0.975 **	-0.616 **	-3.292 **	-0.411	-0.605	-0.134 **	-0.697	0.135
Green Gold	-0.041	-0.13	0.324 **	-2.151 *	0.118	-0.007	0.049	-0.054	0.386 **
Ajeet 121	0.082 **	-0.899 **	0.607 **	4.405 **	1.049 **	1.135 **	0.022	1.274 **	0.435 **
AKO 107	-0.213 **	-1.222 **	0.771 **	3.627 **	1.357 **	1.601 **	0.371 **	1.668 **	0.256
Gi-Gj 95%	0.081	0.512	0.199	2.505	1.042	0.97	0.137	1.304	0.44

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 11. Estimates of GCA (g_i) effects in 7 parents over 21 F_1's of bhindi (pooled)

Parents	Fruit diameter	Number of ridges per fruit	Fruit weight	Number of fruits	Number of seeds per fruit	1000 weed weight	Fruit yield per plant	YVMV PDI at 90 DAS	OELCV PDI at 90 DAS
Punjab-8	-0.009	-0.029	0.005	1.367 **	0.839	0.322	24.171 **	-0.883 **	1.520 **
Hissar Unnat	0.046 **	0.005	0.315 *	1.176 **	2.711 **	2.180 **	27.250 **	0.684 **	-2.538 **
Hoshiarpur Local	-0.096 **	-0.006	-1.064 **	-0.331	-4.236 **	-4.660 **	-25.722 **	3.681 **	1.771 **
Anima	-0.009	-0.007	-1.098 **	0.606 *	-1.409 *	-1.704 **	-17.397 **	3.878 **	0.073
Green Gold	-0.03	-0.006	0.175	-0.253	0.234	1.1	-2.237	-3.184 **	1.646 **
Ajeet 121	0	0.027	1.001 **	-0.905 **	3.126 **	2.399 **	8.084 *	0.615 **	-5.597 **
AKO 107	0.099 **	0.016	0.667 **	-1.660 **	-1.265 *	0.362	-14.149 **	-4.791 **	3.124 **
Gi-Gj 95%	0.051	0.144	0.437	0.707	1.697	1.69	10.918	0.409	0.431

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 12. Estimates of SCA (g_{ij}) effects in 21 F_1's of bhindi for 18 traits during rainy season 2022

Cross combinations	Number of primary branches	Number of nodes	Internodal length	Plant height	Days to first flowering	Days to 50% flowering	Node to first flowering	Days to first harvest	Fruit length
Punjab-8 x Hissar Unnat	0.748 **	2.224 *	-0.611 *	9.150 *	-1.692	0.084	-0.042	1.057	-1.926 **
Punjab-8 x Hoshiarpur Local	0.425 **	1.269	0.782 **	7.323	2.26	2.233	-0.475 *	2.199	0.797
Punjab-8 x Anima	0.526 **	-1.42	0.39	-15.738 **	1.6	0.55	0.302	0.621	-0.981
Punjab-8 x Green Gold	-0.441 **	-0.809	0.013	0.022	-1.914	-1.557	-0.175	-2.132	-1.255 *
Punjab-8 x Ajeet 121	0.868 **	8.602 **	0.35	25.087 **	-3.245 *	-4.203 **	-0.084	-5.101 *	1.990 **
Punjab-8 x AKO 107	-1.441 **	-2.431 *	-1.211 **	-22.590 **	0.043	-0.087	0.004	-0.954	-0.278
Hissar Unnat x Hoshiarpur Local	-0.485 **	0.214	0.895 **	2.044	1.494	1.027	0.246	0.699	0.621
Hissar Unnat x Anima	-0.488 **	-1.175	0.246	-0.86	1.231	1.663	0.424 *	1.321	-0.554
Hissar Unnat x Green Gold	0.848 **	-0.264	0.366	3.063	1.623	0.567	0.346	1.268	1.799 **
Hissar Unnat x Ajeet 121	-0.943 **	-3.050 **	-1.011 **	-13.635 **	-2.814 *	-2.802 *	0.238	-2.201	-0.377
Hissar Unnat x AKO 107	0.848 **	9.514 **	-0.155	25.688 **	-4.126 **	-3.893 **	-1.177 **	-4.051	2.050 **
Hoshiarpur Local x Anima	0.09	-0.23	0.012	1.413	-0.487	-0.791	0.493 **	-0.234	1.046 *
Hoshiarpur Local x Green Gold	0.026	3.981 **	-0.868 **	0.672	-1.028	-0.615	-0.886 **	-0.587	1.002 *
Hoshiarpur Local x Ajeet 121	0.335 **	-3.709 **	-2.115 **	-10.063 *	-2.158	-1.457	0.203	-1.456	-3.957 **
Hoshiarpur Local x AKO 107	-0.574 **	-3.641 **	-2.675 **	-7.143	-2.174	-2.348	0.792 **	-2.309	-4.624 **
Anima x Green Gold	-0.077	2.892 **	0.43	3.112	-1.795	-1.775	0.492 **	-2.165	-0.88
Anima x Ajeet 121	-0.348 **	0.703	-1.060 **	-8.727	0.458	0.56	-0.420 *	0.366	-0.255
Anima x AKO 107	0.523 **	8.270 **	-1.114 **	17.696 **	-4.238 **	-3.711 *	-0.831 **	-3.886	-0.132
Green Gold x Ajeet 121	-0.032	6.514 **	-0.857 **	3.033	-2.133	-2.347	-0.700 **	-2.687	-0.212
Green Gold x AKO 107	-0.441 **	-2.119 *	-1.931 **	-20.044 **	-3.748 **	-3.858 **	-1.108 **	-3.66	-1.379 **
Ajeet 121 x AKO 107	0.568 **	-0.109	0.926 **	16.718 **	3.025 *	3.220 *	0.981 **	3.788	0.866
SE (s_{ij})	0.189	2.036	0.512	8.811	2.453	2.805	0.362	4.187	1.003

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 13. Estimates of SCA (g_{ij}) effects in 21 F_1's of bhindi for 18 traits during the rainy season 2022

Cross combinations	Fruit diameter	Number of ridges per fruit	Fruit weight	Number of fruits	Number of seeds per fruit	1000 weed weight	Fruit yield per plant	YVMV PDI at 90 DAS	OELCV PDI at 90 DAS
Punjab-8 x Hissar Unnat	-0.247 **	0.014	-2.006 **	1.261	-3.563	-0.852	-36.228 **	-7.635 **	-9.184 **
Punjab-8 x Hoshiarpur Local	0.118	-0.012	1.234 *	0.344	4.004	8.974 **	27.485 *	-10.464 **	-5.652 **
Punjab-8 x Anima	0.01	-0.012	0.311	0.677	-1.745	2.616	15.189	20.805 **	-1.416 **
Punjab-8 x Green Gold	-0.079	0.01	-2.585 **	-5.598 **	-21.968 **	-15.524 **	-145.750 **	-3.801 **	18.993 **
Punjab-8 x Ajeet 121	0.340 **	-0.059	1.849 **	8.403 **	11.151 **	9.514 **	212.627 **	-6.959 **	-6.347 **
Punjab-8 x AKO 107	-0.159 *	-0.012	1.104	-4.247 **	-1.064	2.027	-53.771 **	-1.384	14.924 **
Hissar Unnat x Hoshiarpur Local	0.112	-0.037	0.761	2.625 **	8.041 **	7.923 **	55.786 **	12.383 **	-1.981 **
Hissar Unnat x Anima	-0.036	0.164	0.827	-4.141 **	-2.606	2.491	-50.474 **	10.432 **	1.165 *
Hissar Unnat x Green Gold	0.098	-0.011	0.142	-2.617 **	1.215	2.082	-41.002 **	-5.955 **	-1.752 **
Hissar Unnat x Ajeet 121	-0.119	-0.074	1.382 *	-5.266 **	-8.035 **	-9.480 **	-70.979 **	-9.113 **	21.418 **
Hissar Unnat x AKO 107	0.078	-0.033	1.634 *	8.554 **	12.180 **	7.669 **	212.857 **	-3.537 **	-11.581 **
Hoshiarpur Local x Anima	0.032	-0.052	2.485 **	-1.558	3.984	2.538	28.179 *	-16.477 **	11.960 **
Hoshiarpur Local x Green Gold	0.039	-0.034	0.712	4.266 **	9.145 **	6.988 *	87.741 **	3.416 **	-10.493 **
Hoshiarpur Local x Ajeet 121	-0.255 **	-0.099	-3.854 **	-3.433 **	-21.055 **	-13.854 **	-138.902 **	40.359 **	-7.153 **
Hoshiarpur Local x AKO 107	-0.118	-0.055	-6.781 **	-3.662 **	-31.468 **	-25.821 **	-190.641 **	-6.366 **	34.050 **
Anima x Green Gold	0.152 *	-0.033	-2.355 **	1.2	-3.34	-4.284	-33.835 *	7.085 **	-5.937 **
Anima x Ajeet 121	-0.153 *	0.099	1.219	2.101 *	6.982 *	5.301	68.181 **	0.727	0.699
Anima x AKO 107	0.075	-0.057	-1.583 *	4.671 **	5.883 *	1.1	38.613 **	8.423 **	-6.977 **
Green Gold x Ajeet 121	-0.062	-0.077	-1.694 **	6.745 **	5.436	2.451	77.919 **	-5.279 **	0.016
Green Gold x AKO 107	-0.034	0.168	-0.505	0.395	3.752	-0.733	-1.385	0.296	13.416 **
Ajeet 121 x AKO 107	0.001	0.1	0.578	1.996 *	4.701	-1.545	49.955 **	-2.861 **	-8.744 **
SE (s_{ij})	0.132	0.322	1.227	1.574	5.499	5.477	25.536	1.554	0.949

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 14. Estimates of SCA (g_{ij}) effects in 21 F_1's of bhindi for 18 traits during spring summer 2023

Cross combinations	Number of primary branches	Number of nodes	Internodal length	Plant height	Days to first flowering	Days to 50% flowering	Node to first flowering	Days to first harvest	Fruit length
Punjab-8 x Hissar Unnat	0.964 **	2.265 **	-0.673 *	8.534 *	1.251	0.235	-0.1	1.13	-3.190 **
Punjab-8 x Hoshiarpur Local	0.645 **	1.062	0.631 *	6.36	1.353	1.486	-0.289	1.853	-0.54
Punjab-8 x Anima	0.007	-0.766	0.357	-6.612	0.908	0.512	0.03	0.307	0.417
Punjab-8 x Green Gold	-0.336 **	-0.966	0.024	-1.756	-1.638	-1.158	-0.155	-1.325	-0.58
Punjab-8 x Ajeet 121	1.012 **	7.159 **	0.35	21.171 **	-4.467 **	-3.602 *	-0.393	-3.913 *	1.751 **
Punjab-8 x AKO 107	-0.791 **	-1.632 *	-1.039 **	-21.595 **	0.329	0.054	0.526 *	0.153	-0.026
Hissar Unnat x Hoshiarpur Local	-0.444 **	0.788	0.823 **	3.101	-1.027	-0.511	0.422 *	-0.215	2.110 **
Hissar Unnat x Anima	-0.282 *	-3.143 **	0.508	0.793	-0.669	-0.085	0.144	0.244	-1.336 *
Hissar Unnat x Green Gold	0.975 **	0.257	0.515	4.249	0.389	-0.455	0.556 **	0.008	0.93
Hissar Unnat x Ajeet 121	-0.881 **	-2.215 **	-0.999 **	-10.825 **	-1.95	-1.999	0.521 *	-2.18	0.974
Hissar Unnat x AKO 107	0.720 **	8.261 **	-0.057	18.010 **	-3.544 *	-3.647 **	-0.766 **	-3.914 *	1.801 **
Hoshiarpur Local x Anima	0.299 *	-0.146	-0.161	1.122	-1.187	-0.834	0.255	-0.438	0.614
Hoshiarpur Local x Green Gold	-0.047	2.854 **	-0.874 **	0.278	-1.813	-1.201	-0.630 **	-1.073	-0.11
Hoshiarpur Local x Ajeet 121	-0.206	-3.605 **	-2.092 **	-12.292 **	-2.041	-1.741	0.332	-1.858	-4.256 **
Hoshiarpur Local x AKO 107	-0.502 **	-3.522 **	-2.233 **	-4.962	-2.443	-2.685 *	1.044 **	-2.492	-4.529 **
Anima x Green Gold	0.118	3.027 **	0.355	1.704	0.345	0.021	0.589 **	-0.615	-0.95
Anima x Ajeet 121	-0.138	0.151	-0.949 **	-10.370 **	0.913	1.678	-0.442 *	1.597	-0.276
Anima x AKO 107	0.666 **	7.430 **	-0.968 **	16.667 **	-2.694	-2.467	0.067	-2.337	0.228
Green Gold x Ajeet 121	0.322 *	6.151 **	-0.552	9.886 **	-1.04	-1.689	-0.734 **	-1.835	-0.14
Green Gold x AKO 107	-0.380 **	-1.770 *	-1.871 **	-18.680 **	-3.434 *	-3.233 *	-0.821 **	-3.469	-1.196 *
Ajeet 121 x AKO 107	0.564 **	-0.042	1.155 **	16.806 **	0.727	0.22	0.244	0.642	1.091
SE (s_{ij})	0.24	1.393	0.567	7.1	3.145	2.686	0.398	3.759	1.191

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 15. Estimates of SCA (g_{ij}) effects in 21 F_1's of bhindi for 18 traits during spring summer 2023

Cross combinations	Fruit diameter	Number of ridges per fruit	Fruit weight	Number of fruits	Number of seeds per fruit	1000 weed weight	Fruit yield per plant	YVMV PDI at 90 DAS	OELCV PDI at 90 DAS
Punjab-8 x Hissar Unnat	-0.017	-0.028	-1.103	5.486 **	7.793 **	10.576 **	58.645 **	-3.363 **	-11.299 **
Punjab-8 x Hoshiarpur Local	0.106	0.017	1.174 *	2.821 **	6.690 **	15.011 **	69.500 **	-9.228 **	-6.359 **
Punjab-8 x Anima	0.039	0.014	0.188	-6.090 **	-14.540 **	-8.097 **	-91.773 **	16.481 **	-2.159 **
Punjab-8 x Green Gold	-0.333 **	-0.003	-1.594 **	-7.093 **	-17.586 **	-14.738 **	-143.285 **	-2.161 *	22.154 **
Punjab-8 x Ajeet 121	0.287 **	-0.006	2.361 **	7.104 **	13.101 **	11.252 **	192.753 **	-6.600 **	-8.019 **
Punjab-8 x AKO 107	-0.137	-0.028	1.731 **	-5.955 **	-13.340 **	-11.606 **	-72.349 **	-1.365	17.339 **
Hissar Unnat x Hoshiarpur Local	0.056	-0.025	-0.001	-1.954 *	-1.795	-3.994	-34.940 **	4.992 **	-1.792 **
Hissar Unnat x Anima	-0.228 **	-0.028	0.3	-3.941 **	-3.178	-6.059 *	-54.913 **	7.507 **	0.349
Hissar Unnat x Green Gold	0.057	-0.048	1.381 *	1.005	7.306 **	6.757 *	51.206 **	-3.142 **	-1.996 **
Hissar Unnat x Ajeet 121	-0.076	-0.051	1.277 *	-4.497 **	-8.727 **	-10.060 **	-56.390 **	-7.581 **	24.335 **
Hissar Unnat x AKO 107	0.176 *	-0.073	1.983 **	6.440 **	12.129 **	10.752 **	166.328 **	-2.346 **	-12.107 **
Hoshiarpur Local x Anima	0.092	0.017	1.470 *	-1.759	5.085 *	1.819	2.983	-12.738 **	14.371 **
Hoshiarpur Local x Green Gold	0.233 **	-0.006	1.508 *	3.237 **	10.176 **	7.542 **	84.807 **	1.497	-11.260 **
Hoshiarpur Local x Ajeet 121	-0.233 **	-0.007	-4.326 **	-3.365 **	-21.683 **	-13.115 **	-136.371 **	37.274 **	-7.713 **
Hoshiarpur Local x AKO 107	-0.278 **	-0.028	-3.817 **	-0.244	-14.445 **	-12.552 **	-81.484 **	-5.510 **	31.445 **
Anima x Green Gold	0.156 *	-0.006	-1.155 *	3.326 **	3.593	2.588	21.124	4.411 **	-6.919 **
Anima x Ajeet 121	-0.13	-0.006	1.171 *	2.427 *	6.470 *	6.534 *	70.509 **	-0.291	0.628
Anima x AKO 107	0.115	-0.027	-1.560 **	5.371 **	3.832	2.466	47.690 **	5.844 **	-7.514 **
Green Gold x Ajeet 121	0.011	-0.029	-1.035	5.924 **	2.257	-2.12	72.437 **	-3.680 **	-0.033
Green Gold x AKO 107	-0.093	0.149	0.635	-3.839 **	-11.287 **	-13.191 **	-50.782 **	1.556	14.605 **
Ajeet 121 x AKO 107	0.08	0.152	0.33	2.962 **	7.633 **	3.069	57.363 **	-2.883 **	-8.828 **
SE (s_{ij})	0.148	0.379	1.122	1.929	4.792	5.003	24.546	1.596	1.174

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 16. Estimates of SCA (g_{ij}) effects in 21 F_1's of bhindi for 18 traits (pooled)

Cross combinations	Number of primary branches	Number of nodes	Internodal length	Plant height	Days to first flowering	Days to 50% flowering	Node to first flowering	Days to first harvest	Fruit length
Punjab-8 x Hissar Unnat	0.856 **	2.246 **	-0.642 **	8.844 **	-0.22	0.16	-0.071	1.093	-2.560 **
Punjab-8 x Hoshiarpur Local	0.536 **	1.165 *	0.704 **	6.842 **	1.807	1.859 *	-0.382 **	2.027	0.129
Punjab-8 x Anima	0.265 **	-1.093 *	0.373	-11.176 **	1.252	0.531	0.167	0.464	-0.28
Punjab-8 x Green Gold	-0.388 **	-0.886	0.018	-0.868	-1.775	-1.359	-0.165	-1.728	-0.918 *
Punjab-8 x Ajeet 121	0.940 **	7.880 **	0.35	23.129 **	-3.856 **	-3.901 **	-0.24	-4.508 **	1.870 **
Punjab-8 x AKO 107	-1.115 **	-2.032 **	-1.124 **	-22.095 **	0.185	-0.019	0.263 *	-0.402	-0.151
Hissar Unnat x Hoshiarpur Local	-0.465 **	0.501	0.858 **	2.575	0.234	0.258	0.334 *	0.242	1.367 **
Hissar Unnat x Anima	-0.385 **	-2.161 **	0.377	-0.033	0.281	0.79	0.285 *	0.783	-0.946 *
Hissar Unnat x Green Gold	0.912 **	-0.004	0.442 *	3.656	1.004	0.057	0.451 **	0.639	1.365 **
Hissar Unnat x Ajeet 121	-0.913 **	-2.633 **	-1.004 **	-12.231 **	-2.380 *	-2.401 *	0.379 **	-2.19	0.299
Hissar Unnat x AKO 107	0.783 **	8.888 **	-0.107	21.849 **	-3.836 **	-3.771 **	-0.969 **	-3.983 **	1.924 **
Hoshiarpur Local x Anima	0.196 *	-0.189	-0.072	1.267	-0.837	-0.813	0.374 **	-0.335	0.831
Hoshiarpur Local x Green Gold	-0.012	3.416 **	-0.872 **	0.474	-1.421	-0.907	-0.758 **	-0.831	0.445
Hoshiarpur Local x Ajeet 121	0.065	-3.656 **	-2.102 **	-11.179 **	-2.101 *	-1.599	0.266 *	-1.657	-4.106 **
Hoshiarpur Local x AKO 107	-0.539 **	-3.582 **	-2.454 **	-6.052 *	-2.306 *	-2.515 **	0.918 **	-2.401	-4.577 **
Anima x Green Gold	0.022	2.959 **	0.394 *	2.407	-0.725	-0.88	0.541 **	-1.39	-0.915 *
Anima x Ajeet 121	-0.244 **	0.427	-1.006 **	-9.548 **	0.685	1.119	-0.429 **	0.982	-0.264
Anima x AKO 107	0.594 **	7.851 **	-1.040 **	17.183 **	-3.466 **	-3.085 **	-0.383 **	-3.112 *	0.048
Green Gold x Ajeet 121	0.146	6.334 **	-0.706 **	6.460 **	-1.585	-2.018 *	-0.716 **	-2.261	-0.176
Green Gold x AKO 107	-0.411 **	-1.945 **	-1.900 **	-19.362 **	-3.589 **	-3.544 **	-0.965 **	-3.566 **	-1.287 **
Ajeet 121 x AKO 107	0.564 **	-0.074	1.042 **	16.763 **	1.874	1.72	0.612 **	2.217	0.978 *
Sij-Sik 95%	0.228	1.448	0.562	7.085	2.946	2.744	0.388	3.687	1.246

*, ** Significant at 0.05 and 0.01 level of probability, respectively

Table 17. Estimates of SCA (g_{ij}) effects in 21 F_1's of bhindi for 18 traits (pooled)

Cross combinations	Fruit diameter	Number of ridges per fruit	Fruit weight	Number of fruits	Number of seeds per fruit	1000 weed weight	Fruit yield per plant	YVMV PDI at 90 DAS	OELCV PDI at 90 DAS
Punjab-8 x Hissar Unnat	-0.133 **	-0.008	-1.555 **	3.371 **	2.116	4.862 **	11.207	-5.499 **	-10.241 **
Punjab-8 x Hoshiarpur Local	0.113 *	0.001	1.203 **	1.584 *	5.348 **	11.994 **	48.492 **	-9.846 **	-6.009 **
Punjab-8 x Anima	0.024	0.002	0.248	-2.706 **	-8.143 **	-2.74	-38.292 **	18.643 **	-1.788 **
Punjab-8 x Green Gold	-0.205 **	0.003	-2.089 **	-6.346 **	-19.777 **	-15.129 **	-144.517 **	-2.981 **	20.573 **
Punjab-8 x Ajeet 121	0.311 **	-0.031	2.105 **	7.754 **	12.126 **	10.382 **	202.690 **	-6.780 **	-7.182 **
Punjab-8 x AKO 107	-0.148 **	-0.019	1.418 **	-5.101 **	-7.203 **	-4.788 **	-63.059 **	-1.374 **	16.131 **
Hissar Unnat x Hoshiarpur Local	0.084	-0.029	0.38	0.336	3.123	1.963	10.426	8.687 **	-1.887 **
Hissar Unnat x Anima	-0.131 **	0.069	0.564	-4.042 **	-2.893	-1.783	-52.692 **	8.970 **	0.757
Hissar Unnat x Green Gold	0.076	-0.03	0.761	-0.806	4.259 *	4.418 **	5.102	-4.548 **	-1.874 **
Hissar Unnat x Ajeet 121	-0.099 *	-0.065	1.330 **	-4.882 **	-8.381 **	-9.769 **	-63.686 **	-8.347 **	22.876 **
Hissar Unnat x AKO 107	0.129 *	-0.053	1.807 **	7.498 **	12.155 **	9.213 **	189.591 **	-2.941 **	-11.845 **
Hoshiarpur Local x Anima	0.061	-0.02	1.978 **	-1.659 *	4.535 **	2.179	15.579	-14.607 **	13.167 **
Hoshiarpur Local x Green Gold	0.137 **	-0.019	1.110 **	3.752 **	9.660 **	7.265 **	86.274 **	2.456 **	-10.876 **
Hoshiarpur Local x Ajeet 121	-0.244 **	-0.052	-4.089 **	-3.398 **	-21.369 **	-13.483 **	-137.637 **	38.816 **	-7.434 **
Hoshiarpur Local x AKO 107	-0.199 **	-0.042	-5.299 **	-1.955 **	-22.956 **	-19.188 **	-136.062 **	-5.938 **	32.748 **
Anima x Green Gold	0.155 **	-0.02	-1.756 **	2.264 **	0.128	-0.846	-6.355	5.749 **	-6.427 **
Anima x Ajeet 121	-0.142 **	0.047	1.195 **	2.266 **	6.726 **	5.916 **	69.345 **	0.217	0.665
Anima x AKO 107	0.096	-0.04	-1.572 **	5.021 **	4.859 **	1.783	43.152 **	7.133 **	-7.247 **
Green Gold x Ajeet 121	-0.025	-0.054	-1.363 **	6.335 **	3.848 *	0.164	75.180 **	-4.479 **	-0.008
Green Gold x AKO 107	-0.065	0.158	0.064	-1.722 *	-3.766 *	-6.962 **	-26.085 *	0.926 *	14.011 **
Ajeet 121 x AKO 107	0.041	0.126	0.453	2.479 **	6.167 **	0.765	53.659 **	-2.872 **	-8.786 **
Sij-Sik 95%	0.145	0.407	1.236	2.001	4.8	4.781	30.88	1.158	1.218

*, ** Significant at 0.05 and 0.01 level of probability, respectively

the rainy season, 2022) and by 2 crosses (in spring-summer, 2023). For fruit length significant SCA effects were displayed by 5 crosses (in rainy season, 2022) and by 3 crosses (in spring summer, 2023) were noticed.

In pooled data significant SCA impacts were noticed by 8 crosses for yield of fruit per plant, 12 crosses for PDI of OELCV at 90 DAS and PDI of BYVMV at 90 DAS each, 10 crosses for fruit count per plant and seed number per fruit each, 8 crosses for node number and fruit weight each, 9 crosses for primary branches count and 7 crosses for height of plant, days to 1st blooming, days to 50 % blooming and node to 1st blooming. The crosses Punjab 8 × Ajeet 121 and Hissar Unnat × AKO 107 showed the most substantial SCA impacts in the desired direction for both fruit yield per plant and tolerance to OELCV and BYVMV. Both crosses used one of the parents as an excellent general combiner for fruit yield per plant and other desired traits, suggesting that these crosses should be used further in segregated generations to identify favourable lines.

Based on the above findings, many cross combinations exhibited varied SCA impacts, with only a few crosses displaying consistently positive or negative SCA impacts for certain traits. Based on SCA impacts and mean performance, 2 cross combinations, Punjab 8 × Ajeet 121 and Hissar Unnat × AKO 107 could be identified as ideal specific combiners for future utilization in the okra improvement program. Substantial SCA impacts in favourable directions for various traits of okra involving various combinations of SCA effects of the hybrids were noticed by several earlier workers (22, 28, 31, 33).

Conclusion

In the current study, the predictability ratio shows the predominance of non-additive gene action in controlling all the studied traits. Heterosis breeding would be an appropriate method to improve the yield attributes. Based on GCA effects parents Hissar Unnat and Punjab 8 were identified as the best general combiners for yield improvement. Parents, Ajeet 121 and AKO 107 were considered as best general combiners for disease resistance. Based on SCA effects two crosses namely, Punjab 8 × Ajeet 121 and Hissar Unnat × AKO 107 were identified as most promising candidates for commercialization, pending critical evaluation.

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Authors' contributions

BM, SD and AC designed and executed the investigation and prepared the manuscript. UT and AM confirmed the analytical techniques. PH, CK and BN involved in the text editing. The final manuscript was reviewed and approved by every author.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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