

**HETEROSIS AND COMBINING ABILITY IN
OKRA [*Abelmoschus esculentus* (L.) Moench]**

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ABSTRACT

HETEROSIS AND COMBINING ABILITY IN OKRA
[*Abelmoschus esculentus* (L.) Moench]

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ABSTRACT

The present investigation on okra entitled as Heterosis and Combining ability in okra [*Abelmoschus esculentus* (L.) Moench] was undertaken to obtain information on the magnitude of heterosis and combining ability of parents and F₁'s for fruit yield and yield attributing traits. The experimental material comprised eight diverse lines, three testers, 24 resultant cross combinations and one standard check (GJOH-4) were evaluated in randomized block design with three replications at Agronomy Instructional Farm, C.P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar during *kharif* 2021.

Analysis of variance for individual indicated significant differences among genotypes (Parents + F₁s) for all the characters for yield and yield contributing traits except fruit length. Significant mean square for various traits indicating the presence of considerable genetic diversity in the material studied.

On the basis of mean value of hybrids Parbhani Kranti x GAO-6 followed by JOL-75-5 x Pusa Sawani and NLO-17-9 x GAO-6 and female parent *viz.*, JDNOL-18-2, Parbhani Kranti and NLO-17-9 recorded the highest fruit yield per plant, whereas, male parents GAO-6 and GAO-5 recorded the highest fruit yield per plant.

The best hybrids on the basis of significant and desirable heterosis over mid parent and better parent were Parbhani Kranti x GAO-6 (15.81% and 14.83%, respectively), JOL-75-5 x Pusa Sawani (17.91% and 16.97 %, respectively) for fruit yield per plant. The cross Parbhani Kranti x GAO-6 (9.44%) exhibited significant and positive heterosis over standard check for fruit yield per plant.

Combining ability analysis revealed that non-additive variances were significant for fruit yield per plant and its related traits indicated their involvement in the expression of various traits. The magnitude of non-additive variance was higher for fruit yield per plant and its contributing traits indicated the predominant role of non-additive gene action in the inheritance of the traits.

None of the parents were good general combiner for all the traits under study. Among female parents, NLO-17-9, JOL-75-5 and Parbhani Kranti and male parent GAO-6 were classified as good general combiners for fruit yield per plant and related

traits. The parents with high *per se* performance had high gca effects for most of the traits indicated that selection for good combiners for different characters could also be made on the basis of *per se* performance of the parents. The hybrids on the basis of sca effects for fruit yield per plant were Parbhani Kranti x GAO-6, JOL-75-5 x Pusa Sawani, Arka Anamika x GAO-6.

On the basis of *per se* performance, gca effects of parents, exploitable heterosis, sca effects of hybrid for fruit yield per plant and its component characters, NLO-17-9, Parbhani Kranti (female) and GAO-6 (male) parents and among hybrids Parbhani Kranti x GAO-6, JOL-75-5 x Pusa Sawani and Arka Anamika x GAO-6 were found to be most promising for exploitation in practical breeding programme.

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CERTIFICATE – I

Date: 22/09/2022

This is to certify that the thesis entitled, “**HETEROSIS AND COMBINING ABILITY IN OKRA** [*Abelmoschus esculentus* (L.) Moench].” submitted for the degree of **MASTER OF SCIENCE** in the subject of **GENETICS AND PLANT BREEDING** is a record of bonafide research work carried by **PATEL KRUTIKKUMAR BHARATBHAI** under my guidance and supervision and that no part of this thesis has been submitted for any other degree, diploma, associateship, fellowship or other similar title. The assistance and help received during the course of investigation have been fully acknowledged.


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LIST OF SYMBOLS AND ABBREVIATIONS USED

Symbols

=	is equal to
x	Multiply
()	Bracket
;	semi colon
%	Per cent
/	per

Abbreviations

SDAU	Sardarkrushinagar Dantiwada Agricultural University
ANOVA	Analysis of Variance
a.m.	After Meridian
p.m.	Past Meridian
C.D.	Critical Difference
C.V.	Co-efficient of Variation
S.Em \pm	Standard error of mean
<i>et al.</i>	and his co-workers
$^{\circ}$ C	Degree Celsius
cm	Centimeters
g	Gram
GCA	General Combining Ability
SCA	Specific Combining Ability
Max.	Maximum
Min.	Minimum
<i>viz.;</i>	Namely
R.B.D.	Randomized Block Design
MP	Mid Parent
BP	Better Parent
SC	Standard Check
H ₁	Relative Heterosis
H ₂	Heterobeltiosis
H ₃	Standard Heterosis
<i>vs.</i>	Versus
No.	Number

JAU	Junagadh Agricultural University
DF	Days to Flowering
DFP	Days to first picking
FL	Fruit length
FG	Fruit girth (cm)
NBP	Number of branches per plant
IL	Internodal length
PH	Plant height
FYP	Fruit yield per plant
TNFP	Total number of fruits per plant
TNSF	Total number of seeds per fruit
DLP	Days to last picking

INTRODUCTION

I. INTRODUCTION

Okra (*Abelmoschus esculentus L.*) has occupied a prominent position among vegetables and commonly known as bhendi or lady's finger in India, being native of tropical Africa. It is the choicest fruit vegetable grown extensively in the tropical, subtropical and warm areas of the world like India, Africa, Turkey and other neighboring countries. Major areas of cultivation in India are Uttar Pradesh, Bihar, Orissa, West Bengal, Andhra Pradesh, Gujarat, Karnataka and Assam. Tender green fruits are cooked in curry and soup, while crop has not adapted in India as leafy vegetable as in Far East countries. Okra is now commonly available as a boiled or fried vegetable dish at restaurants, salad bars and cafeterias.

Tender green fruits are cooked in curry and are also used in soups. The fruits of okra are rich source of vitamin A, vitamin C and minerals *viz.*; Ca, Mg, I and Fe. The seeds of okra are good source of vegetable oil (14%). The greenish yellow edible oil has a pleasant taste and odor and is high in unsaturated fats such as oleic acid and linoleic acid (Franklin, 1982). The oil content of the seed is quite high (18-20 per cent) and the oil yield from okra crop is 794 kg/ha (Mays *et al.* 1990). Okra fruit is a good source of nutrients and minerals as each 100 g edible portion contains 1.9 g protein, 0.2 g fat, 0.7 g minerals, 0.4 g carbohydrates, 66 mg calcium, 43 mg magnesium, 1.5 mg iron, 6.9 mg oxalic acid, 88 I. U. vitamin A, 63 I.U. vitamin B, 13 mg vitamin C, 0.07 mg thiamine, 0.1 mg riboflavin and 0.6 mg nicotinic acid (Annon. 1963; Babel and Yadav, 1971 and Rekhi, 1976). The average nutritive value (ANV) of okra is 3.21 per cent, which is higher than tomato, brinjal and cucurbitaceous vegetables (Sharma and Arora, 1993). Mature fruits and stems are used in paper industry; root and stems are used for cleaning the cane juices. Okra contain special fiber which contain sugar levels in blood under control. Apart from its commercial uses, it is said to be very useful against genito-urinary disorders, spermatorrhoea and chronic dysentery.

In India, among fresh vegetables, 60% share of export goes to Okra (Rewale *et al.*, 2003^a). Our major targets have been our neighboring countries in the Gulf and South-East Asia, particularly Singapore, Mauritius, Malaysia, Sri Lanka, Bangladesh, which require vegetable supply round the year. Middle East countries

like Bahrain, Qatar, Kuwait, Saudi Arabia, Muscat, Tehran and Abu Dhabi are upcoming potential markets for export of vegetables from India.

In India okra is grown commercially in the states *viz.*, Andhra Pradesh, Assam, Madhya Pradesh, Bihar, West Bengal, Maharashtra, Gujarat, Karnataka and Uttar Pradesh. In India, okra occupies an area of 5,19,000 ha with the production of 63,71,000 MT (Annon. 2019-20). It also an important vegetable crop in Gujarat state and is mainly grown in Banaskantha, Bhavnagar, Junagadh, Navsari, Surat, Tapi and Vadodara. The area under okra cultivation in Gujarat is about 85,145 ha with the production of 10,19,422 MT (DOH, 2020-21).

Okra is a polyploid, belonging to the family Malvaceae with $2n = 8x = 72$ or 144 chromosome and a self-pollinated crop, occurrence of out crossing to an extent of 4–19% with the maximum of 42.2% is noticed with the insect assisted pollination (Kumar *et al.*, 2006). Genetical studies of okra can be completed within short time span due to its fast growth, short duration and photo-insensitive nature that enables plant breeders to raise two crops in a year. Moreover, its large flowers and monadelphous nature of the stamens make emasculation and pollination processes easier. With the ease in fruit set and good number of seeds per pod, okra can be well exploited for hybrid vigour. Presently accepted binomial of okra is *Abelmoschus esculentus* (L.) Moench, formerly referred as *Hibiscus esculentus* L. The genus *Abelmoschus* consists of nine different species *viz.*, *Abelmoschus angulosus* Wall ex. W. & A. ($2n=56$), *Abelmoschus tuberculatus* Pal and Singh ($2n=58$), *Abelmoschus manihot* L. Medikus ($2n=66$), *Abelmoschus moschatus* Medikus ($2n=72$), *Abelmoschus ficulneus* L. W. & A. ex. Wight ($2n=72$), *Abelmoschus tetraphyllus* (Roxb. ex.Hormen) R. Graham var. *tetraphyllus* ($2n=138$), *Abelmoschus crinitus* Wall ($2n=138$), *Abelmoschus caillei* Sterv. ($2n = 186-198$) and *Abelmoschus esculentus* [L.] Moench ($2n = 130$). (Annon., 1991).

To exploit the heterosis of potential yield components, knowledge of genetic architecture of fruit yield and its attributes is important in crop improvement. For developing promising varieties through hybridization, the choice of parents is a matter of great concern to the plant breeder. A high yielding genotype may or may not transmit its superiority to its progenies. Hybrid vigour provides the means to an increase in the crop yield, disease and insect resistance and to combining ability characters, it is one of the important objectives in the plant breeding. Hence, an attempt has been made to study the 'line \times tester' analysis (Kempthorne, 1957) to

know the heterosis and combining ability for interested traits in Okra (Solankey *et al.*, 2013).

The combining ability is the important genetic tool, which provides a guideline for an assessment of the relative breeding potential of the parents or identifying the best combiners, which may be hybridized either to exploit heterosis or to accumulate fixable genes. In order to identify potential crosses for further exploitation, it is important to have prior information about heterosis and nicking ability of the parents involved, since it helps in the identification of superior parents with good general combining ability and crosses with high and desirable specific combining ability effects (Singh *et al.*, 1991). Several approaches are available for assessing the parents and cross combinations with respect to combining ability. Among these, a line x tester analysis as proposed by Kempthorne (1957) is popular and has been found to be more suitable in many respects. It helps in testing a large number of genotypes to assess the heterosis, gene action and combining ability.

Hence, the proposed study was envisaged to investigate the possibility of developing experimental hybrids and study the heterosis and combining ability of the hybrids for yield and yield contributing traits in okra.

Keeping all the facts in view, the present investigation using line × tester mating design involving 24 genetically diverse genotypes of okra was undertaken over two consecutive seasons with the following objectives:

Objectives of the study:

1. To assess the nature and magnitude of heterotic expression for various characters
2. To study the general combining ability and specific combining ability variances and effects for different traits
3. To study the combining ability effects of parents & hybrids for different traits

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Present investigation was planned to study the magnitude of heterosis, combining ability of parents and crosses and gene action involved for various traits in okra [*Abelmoschus esculentus* (L.) Moench]. The relevant and important published work available on these aspects has been reviewed and is presented in this chapter under the following heads:

2.1 Heterosis

2.2 Combining ability and gene action

2.1 Heterosis

Heterosis or hybrid vigour indicates the superiority of hybrid over its parents and the expression of heterosis may be due to factors such as heterozygosity, allelic interaction such as dominance or over-dominance, non-allelic interaction or epistasis as well as maternal interactions, it was first reported in plants by Koelreuter (1766). Shull (1908) explained the cause of heterosis independently. Later on, Shull (1914) proposed the term 'heterosis' to describe superiority of a hybrid in respect to average performance of parents involved. Fonseca and Patterson (1968) coined a new term 'heterobeltiosis' to describe an improvement in heterozygote in relation to better parent. The term standard heterosis was given by Meredith and Bridge (1972) to explain superiority of F₁ in respect to well adapted hybrid/variety. Exploitation of heterosis on commercial scale in crops have resulted in the development of a number of high yielding hybrids and proved to be the most important genetic tools enhancing the yield potential. The review of literatures pertaining to heterosis in okra for various characters are given below.

The literature pertaining to heterosis in okra has been reviewed as under;

Pathak and Shymal (1997) studied heterobeltiosis in six lines and three testers of thirteen crosses of okra showed high heterobeltiosis for pod yield per plant. They suggested that heterosis for pod yield could be due to manifestation of high heterosis of important yield component characters.

Panda and Singh (1999) studied heterotic effects of six characters in twenty crosses of okra. The highest value of heterosis was observed for pod yield and number of pods per plant. The extent of heterosis was 45.62 per cent for pod yield and 28.30 per cent for number of pods per plant.

Nichal *et al.* (2000) reported heterobeltiosis in okra from a set of 7 x 7 diallel cross excluding reciprocals. They recorded observations on days to first flowering, plant height, number of primary branches on main stem, number of fruiting nodes on main stem, number of fruits per plant, average fruit weight, fruit length and yield per plant. The best performing hybrids were VRO-3 x Arka Abhay, VRO-3 x JNDO-5, VRO-3 x AKO-73, JNDO-5 x Arka Abhay, Arka Abhay x Arka Anamika and AKO-16 x Pusa A-4, which gave 129.22, 106.24, 92.00, 69.85, 43.83 and 18.37 per cent higher yield than the better parent involved in the cross, respectively.

Saha and Kabir (2001) studied economic heterosis of different yield component characters of six commercial hybrids with respect to average performance of four different cultivars *i.e.* Pusa Sawani, Parbhani Kranti, Arka Anamika and Sevindhari. All the commercial hybrids exhibited significant economic heterosis for yield (62.70% to 98.75%) and for all the yield component characters except number of branches per plant.

Sood and Sharma (2001) studied heterosis for fruit yield and associated traits in a diallel cross among cultivars; P-7, Parbhani Kranti, Pusa Sawani, Arka Abhay and Arka Anamika, and two promising breeding lines (IC-9856 and IC-39135) of okra. P-7 x Arka Abhay had the highest heterosis for fruit yield over the better parent (68%) and produced 80% more fruits than the check cultivar, Pusa Sawani. Its yield advantage could be due to heterosis for number of fruits per plant, plant height and number of nodes per plant.

Chauhan and Singh (2002) studied line x tester analysis using twenty lines and four testers was carried out to study the extent of heterosis for yield and yield contributing characters in okra. The study revealed that heterosis over the better parent (BP), standard check 1 (Parbhani Kranti) and standard check 2 (Pusa Sawani) was recorded for all the traits studied. The cross-combination DC-97 x P-7 showed the highest magnitude of heterosis for yield over better parent and over standard checks. Among other cross combinations, Arka Anamika x Arka Abhay, Shagun x Varsha Uphar, EMS-8 x P-7, DC-97 x Varsha Uphar, PSB-1 x Varsha Uphar, K-21 x P-7 and Punjab Padmini x Varsha Uphar exhibited higher heterosis over the better parent and standard check 1, while Arka Anamika x Arka Abhay also exhibited higher heterosis over standard check 2. Thus, these can be considered as promising cross combinations for yield and can be tested further.

Singh *et al.* (2002) had reported heterobeltiosis in okra ranging from -141 percent for fruit length (5709 x 6308) to 185 percent for number of fruits per plant (6305 x 6901). The maximum beneficial heterobeltiosis for yield per plant was observed in 6302 x 6308 (67.51%). It was further revealed that most of the high heterotic cross combinations for different characters showed high inbreeding depression in F₂ generation. This may be due to the fact that the most part of heterobeltiosis was accounted for dominance and dominance x dominance type of epistatic interactions and less for additive x dominance type of gene effect.

Rewale *et al.* (2003^a) recorded significant heterotic effects in the positive direction for all the yield and yield contributing characters of okra. Most of the high heterotic combinations were between geographically diverse parents. The crosses SOH-02 x Parbhani Kranti and SOH-02 x Gold Finger exhibited desirable negative and significant heterotic effects for days to initiation of flowering, days to initiation of fruit and days to maturity for green fruit. The cross DVR-3 x Green Gold recorded significant heterobeltiosis for fruit yield per plant, fruits per plant, nodes per plant, branches per plant and plant height. The crosses JNDO-5 x Parbhani Kranti (153.43%) and NOL-101 x Green Gold (147.79 %) also showed a higher magnitude of heterosis over better parent.

Bhalekar *et al.* (2004) had studied the extent of heterosis for yield and yield attributes in okra. Significant heterosis was found for fruits per plant and yield per plant in Varsha Uphar x Lorm 1, Arka Anamika x Parbhani Kranti and Arka Anamika x Lorm 1. Okra No. 6 x Arka Anamika, A.A.D.F.1 x Arka Anamika for yield per plant and A.A.D.F.1 x Parbhani Kranti for fruit diameter showed significant heterosis over better parent. The highest heterosis over better parent for yield was in A.A.D.F.1 x Arka Anamika (19.29%) followed by Varsha Uphar x Lorm 1 (15.13%), Arka Anamika x Lorm 1 (14.85%) and Arka Anamika x Parbhani Kranti (13.96%), which also had the best *per se* performance.

Singh *et al.* (2004) studied on ten diverse cultivars of okra to estimate heterosis over superior and economic parents in 45 F₁'s and inbreeding depression in 45 F₂ progenies. Considerable heterosis was observed for fruit yield and its components. The best five crosses, KS405 x KS404, PK x KS404, PK x KS405, PS x PK and PK x KS401, were recommended to exploit for increasing yield over standard cultivar Parbhani Kranti.

Tripathi *et al.* (2004) studied heterosis in F₁ over standard parent Azad Bhindi-1 popularly known as Azad Ganga and inbreeding depression in F₂ for yield and yield attributing traits by using a diallel mating design involving four parents (Azad Bhindi-2, BO-2, Azad Bhindi-1 and Parbhani Kranti) of okra. A significant amount of useful heterosis for days to flowering, plant height, number of branches per plant, number of nodes per plant, internode length, fruit length, fruit width, number of fruits per plant and yield per plant. However, the maximum heterosis with respect to fruit width was observed in cross Azad Bhindi-1 x Parbhani Kranti (131.57%). Significant and desirable heterosis along with significant inbreeding depression was also reported for all the characters in most of the crosses, which indicated that the most part of heterosis was due to dominance and dominance x dominance type of interaction.

Desai *et al.* (2005) evaluated 28 hybrids of okra made by crossing eight genetically diverse genotypes in half diallel fashion. Among these hybrids, the hybrid Parbhani Kranti x Gold Finger recorded superior performance for plant height, number of nodes per plant, fruit weight, number of fruits per plant and fruit yield per plant. While the hybrid Long Green Smooth Finger x Green Gold also showed superior performance for these characters except fruit weight. Fruit yield per plant exhibited highest heterosis of 558 per cent over mid parent and 447 per cent over better parent. Considering the high magnitude of heterosis and *per se* performance, these hybrids were identified as promising hybrids in okra.

Vermani *et al.* (2006) studied a line x tester involving fourteen lines and two testers in okra. They recorded no single cross-combination could express significant desirable heterobeltiosis for all the characters simultaneously. The cross Pusa Makhmali x P-8 revealed desirable maximum heterobeltiosis for fruit yield per plant (27.11 %), nodes per plant (19.30 %) and plant height (26.32 %). The cross-combination Dhira x Arka Anamika revealed heterobeltiosis for inter-nodal length (-22.78 %), fruits per plant (20.96 %) and fruit length (39.29 %).

Mamidwar *et al.* (2006) studied fourteen lines (females), three testers (males) in okra. The mean value of crosses and heterosis over the better parent was estimated for the 42 crosses. The highest level of heterosis over the better parent for fruit yield per plant was recorded for VRO-6 x Parbhani Kranti (55.57 %), followed by Daftari-1 x Arka Abhay (54.31 %).

Desai *et al.* (2007) conducted an experiment by using 28 okra hybrids and observed that Parbhani Kranti x Gold Finger recorded superior performance for plant height, nodes per plant, fruit weight, fruits per plant and yield per plant. The hybrid, Long Green Smooth Finger x Green Gold also showed superior performance for these traits except fruit weight. Yield per plant exhibited the highest heterosis of 558 per cent over mid parent and 447 per cent over better parent. Considering the high magnitude of heterosis and *per se* performance these hybrids were identified as promising hybrids in okra.

Shobha and Mariappan (2007) studied five lines and two testers in okra. The observations recorded for plant height, days to first flowering, number of nodes per plant, fruit length, fruit girth, number of fruits per plant, single fruit weight, number of seeds per fruit, 100-seed weight, crude fibre content, protein content and yield per plant. The results revealed highly significant differences for all the characters among the parent and genotypes indicated wider range of variability. Among all the crosses evaluated, the cross-combination IC 169340 x IC 112475 exhibited highest heterosis for all the characters studied.

Mehta *et al.* (2007) studied forty-two hybrids of okra generated by crossing three testers with fourteen lines were studied along with parents for studying heterosis and gene action for days to first flowering, days to 50 per cent flowering, fruit weight, fruit length, plant height, number of seeds per fruit, 100-seed weight and fruit yield per plant. The most heterotic combinations were VRO-6 x Parbhani Kranti, VRO-4 x Parbhani Kranti, Daftari-1 x Arka Abhay and Kaveri Selection x Ankur Abhaya for fruit yield per plant. The sca variances for days to fruit flower, days to 50 per cent flowering, fruit weight, fruit length, plant height, number of seeds per fruit and 100-seed weight were higher than gca variance so there was a preponderance of non-additive gene action. The gca variances was greater than sca variances for fruit yield per plant indicating preponderance of additive gene action for this trait. Overall, the results discussed above were quite indicative of the fact that hybrid okra had great potentialities of maximizing fruit yield.

Kumar and Pathania (2007) carried out heterosis studies involving ten lines and three testers of okra in line x tester model for characters like first flowering node, internodal length, fruit length, fruit diameter, plant height, fruits per plant, fruit yield per plant and fruit weight and found significant heterosis over better and

standard parents for all these characters. ANOVA exhibited significant differences for most of the traits studied.

Yadav *et al.* (2007) studied heterosis in okra through line x tester mating system to determine heterosis over standard parent (Parbhani Kranti) for yield and yield components in okra. This study revealed heterosis over standard parent for yield and yield contributing characters (days to flowering, plant height, number of branches per plant, internodal length, fruit length, fruit width and number of fruits per plant). The magnitudes of heterosis for plant height, number of branches per plant, number of nodes per plant and number of pods per plant were significant and positive heterosis over standard parent was observed in KS-455 x Parbhani Kranti. Whereas, the hybrid KS-455 x Parbhani Kranti also exhibited highly significant and positive heterosis for fruit length, while, KS-445 x KS-404 exhibited highly significant and positive heterosis for width of fruits. The estimates of heterosis for various yield components of the heterotic hybrids indicated that significant yield increase was largely attributed to increased plant height, number of branches per plant, number of fruits per plant and number of nodes per plant.

Hosamani *et al.* (2008) studied twenty-four F₁ hybrids of okra developed from three lines ('IC-111478', 'IC-90044' and Arka Anamika) and eight testers ('EC-316046', 'IC-111479', 'IC-90203', 'IC-90273', 'IC-90263', 'Parbhani Kranti', 'VRO-65' and 'IC- 89936') in a line x tester fashion. The parents were selected based on better adaptation and desirable agronomic characters. Parents and F₁'s were evaluated along with a private commercial hybrid as check 'MHB-10' in randomized block design. Observations were made on five randomly selected plants in parents, hybrids and a standard check in each replication for nine economic characters *viz.*, plant height, branches per plant, internodal length, first fruiting node, fruit length, fruit diameter, fruit weight, fruits per plant, and fruit yield per plant. The data was subjected to line x tester analysis and the heterosis for Mid Parent (MP), Better Parent (BP) and Standard Check (SC).

Pandey *et al.* (2008) studied heterosis in okra and observed for all the characters over both better parents and economic parent in several cross combinations *viz.*, number of branches per plant ranged from -45.22 (BO-2 x VRO-6) to 33.04 (Pusa Sawani x Azad Bhindi-2) per cent over better parent and 43.24 (BO-2 x VRO-6) to 45.13 (BO-2 x Azad Bhindi-1) per cent over economic parent, length of fruits from -18.38 (VRO-6 x Arka Abhay) to 30.36 (Pusa Sawani x VRO-6) per cent and from

-36.58 (Azad Bhindi-2 x Azad Bhindi-1) to 15.85 (Azad Bhindi-1 x VRO-6) per cent and number of fruits per plant ranged from -29.89 (Pusa Sawani x Azad Bhindi-1) to 9.23 (Punjab-7 x BO-2) per cent and from -35.15 (Azad Bhindi-2 x Arka Abhay) to 21.33 (Parbhani Kranti x Arka Abhay) per cent, respectively. In general, hybrids showed a wide range of heterotic effect for each character.

Jaiprakashnarayan *et al.* (2008) studied line x tester analysis to assess the magnitude of heterosis for earliness and yield parameters in okra. Maximum heterosis over better parent 12 and standard parent in desirable direction were found for days to 50 per cent flowering, fruit length, fruit weight, number of fruits per plant and total yield per plant.

Weerasekara *et al.* (2008) estimated heterosis in okra for yield and yield components in okra for different characters like days to 50 per cent flowering, number of branches per plant, number of fruits per plant, fruit weight and fruit yield per plant in a line x tester crossing programme comprising 24 hybrids produced by crossing eight lines and three testers and found significant heterosis over mid and better parents. The analysis of variance indicated highly significant differences for all most all the characters.

Dabhi *et al.* (2009) studied heterosis for fruit yield and its components in okra in a set of twelve lines and four testers cross over better parent and standard check (Arka Anamika). For fruit yield, maximum heterosis of 20.04 per cent (PB-266 x Arka Abhay) and 32.08 per cent (KS-404 x Arka Abhay) was observed over better parent and standard check, respectively. Out of 48 hybrids, four hybrids showed significant positive heterosis over better parent, while 31 hybrids exceeded the standard check for fruit yield over the environments. The highest standard heterosis was depicted by the hybrid KS-404 x Punjab-7 of 49.62 per cent for number of fruits per plant.

Singh *et al.* (2009) studied heterobeltiosis and inbreeding depression and observed that the maximum beneficial heterobeltiosis for weight of fruit per plant (yield per plant) was observed in 6302 x 6308 (67.51%). In general, hybrids showed a wide range of heterotic effects for each character. It was further revealed that most of the high heterotic cross combinations for different characters showed high inbreeding depression in the F₂ generation. This may be due to that most part of heterobeltiosis accounted for dominance and dominance x dominance type of epistatic interactions and less for additive x dominance type of gene effect.

Kumar and Sreeparvathy (2010) studied heterosis in okra with using six bhendi genotypes *viz.*, Girija Vikas, MDU 1, Hissar Unnath, Arka Abhay and EC 305623 were crossed in full diallel fashion (including the reciprocals). The eight characters observed included days to 50 per cent flowering, plant height, number of branches per plant, number of fruits per plant, fruit length, fruit girth, individual fruit weight and fruit yield per plant. The results revealed that the standard heterosis for fruit yield per plant was maximum in the hybrid MDU 1 x Hissar Unnath, with a value of 65.23 per cent. This hybrid recorded high standard heterosis for all the characters except number of branches per plant and individual fruit weight.

Patel *et al.* (2010) studied the relative heterosis and heterobeltiosis for fruit yield and their attributes in six crosses of okra. They found ample amount of heterosis over mid and better parent for all the traits. Significant and positive heterobeltiosis was observed in KS-404 x HRB-108-2 and VRO-5 x GO-2 for fruit length and fruit yield per plant. Similarly, significant and positive relative heterosis was depicted in KS-404 x HRB- 108-2 for number of nodes per plant, number of fruits per plant and fruit length.

Singh and Sanwal (2010) reported heterosis in okra for yield and contributing traits *viz.*, number of primary branches per plant, internodal length, first flowering node, fruit length, fruit diameter, fruit weight, number of fruits per plant and fruit yield per plant in line x tester programme involving six lines and four testers and observed significant heterosis over better parent.

Kumar and Pathania (2011) carried out heterosis studies involving ten lines and three testers in a line x tester model. The study revealed EC-169476 x Arka Abhay and LB Local x P-8 as promising cross combinations over better parent for fruit yield per plant along with node at which first flower appeared, internodal length, fruits per plant and internodal length. Whereas, EC-7194 x P-8, EC-329424 x Arka Abhay, EC- 329424 x Varsha Uphar were the top-ranking combinations exhibiting significant standard heterosis for fruit yield per plant along with its components.

Vachhani *et al.* (2011) studied 45 hybrids of okra derived from 10 x 10 diallel crosses excluding reciprocals in F₁ and F₂ generations for heterosis and inbreeding depression of fruit yield and yield components and reported that analysis of variance revealed significant differences among parents, F₁'s and F₂'s for most of the characters indicating considerable amount of genetic variability present in the

material studied. High magnitude of heterotic effect was detected for fruit yield per plant, number of fruits per plant, 10-fruits weight and internodal length.

Khatik *et al.* (2012) evaluated 36 crosses using twelve lines and three testers and revealed that heterosis analysis of variances was highly significant for all the traits under study. The study revealed that cross combination KS-423 x P.K., KS-453 x P.K., KS-439 x P.K., KS-427 x KS-410, KS-453 x KS-410, BO-2 x KS-404 and KS-439 x KS-404 were significant increase over mid parent the cross combinations for yield and its contributing traits. Therefore, these hybrids may be advanced and exploited in future breeding programmes for improving yield and its components in okra.

Medagam *et al.* (2012) developed 45 F₁ hybrids from ten elite lines to study heterosis. The overall mean heterosis over mid parent and standard control for total yield per plant was 6.92% and -15.44%, respectively, while for marketable yield per plant were 6.64% and -22.18 %, respectively. Negative heterotic crosses like C19 (P3xP5) for days to 50% flowering and C4 (P1xP5) for first flowering and fruiting node (-15.22%), were important to exploit heterosis for earliness in okra.

Das *et al.* (2013) studied breeding of okra for higher productivity through a line x tester mating design for characters like nodes at first flowering, fruit length, fruit diameter, fruit weight, number of fruit per plant and fruit yield per plant. Significant heterosis observed over better parent for all these characters.

Jagan *et al.* (2013) crossed four lines and fifteen testers to identify heterosis for yield and yield components in okra studied by using line x tester mating design, comprising 60 hybrids produced by crossing four lines and 15 testers for characters like plant height, days to 50 per cent flowering, first flowering node, number of branches per plant, number of fruits per plant, length of the fruit, diameter of the fruit, pod weight, fruit yield per plant and found significant heterosis over mid and better parents for all these characters. The analysis of variance indicated highly significant differences for most of all the characters suggesting presence of genetic variability.

Javia (2013) studied line x tester analysis for heterosis in okra with using 13 genetically diverse parents collected from the different parts of the country and their 36 crosses generated by using a line x tester mating design, was undertaken to study the heterosis and heterobeltiosis for fruits yield and its contributing characters in okra. Majority of the hybrids exhibited significant and positive heterosis over mid-

parental value and over better parent for most of the traits. Seventeen hybrids showed significant and positive heterobeltiosis for fruit yield per plant. The cross combination Parbhani Kranti x D-1-87-5 exhibited the highest heterobeltiosis (184.27%) for fruit yield per plant. Manifestation of heterosis by this particular cross combination was also realized for all the characters except for days to flowering and number of nodes per plant. The heterosis over better parent for yield per plant was mainly due to longer and thicker fruits coupled with more number of fruits per plant.

Kumar *et al.* (2013) studied estimation of combining ability by line x tester analysis and magnitude of heterosis in okra. The data on nine characters *viz.* plant height, number of primary branches, days to first flowering, total number of fruit per plant, fruit length, fruit girth, fresh fruit weight, internodal length and yield per plant were utilized for the present study. The study revealed significant and positive heterosis for plant height, number of branches per plant, number of fruits per plant, internodal length, and fruit length over better parent and standard parent. The most promising crosses showing significantly positive Standard heterosis for fruit yield were Arka Abhay x Parbhani Kranti, Hissar Unnat x Punjab Padmini, VRO-6 x Parbhani Kranti and VRO-6 x Arka Anamika. These crosses should be exploited for further advancement in breeding programme for high yielding varieties and early maturity, simultaneously.

Patel (2013) studied the set of 45 genotypes including eight females, four males, their 32 resultant hybrids and one commercial check variety (GAO-5). Significant standard heterosis and high *per se* performance with regards to fruit yield per plant were recorded by the crosses *viz.*, JOL-09-8 x Pusa Sawani, JOL-10-17 x GJO-3, JOL-09-7 x Pusa Sawani and AOL-10-18 x VRO-6. The crosses *viz.*, JOL-09-8 x Pusa Sawani, JOL-10-17 x Pusa Sawani, JOL-09-7 x Pusa Sawani and AOL-10-18 x VRO-6 showed high heterosis and best *per se* performance for fruit yield and major yield related component like number of fruits per plant.

Paul (2013) observed that the crosses JOL-09-8 x JOL-09-7, JOL-09-8 x AOL-09-17 and JOL-09-12 x AOL-09-2 showed significant and desirable heterosis for fruit yield per plant over better parent. The crosses HRB-55 x AOL-09-17, JOL-09-8 x AOL-09-17 and AOL-09-17 x JOL-09-7 showed significant and desirable heterosis for fruit yield per plant over standard check. In majority of the cases, these crosses also exhibited significant and desirable heterosis for days to initiation of

flowering, number of primary branches per plant, plant height, internodal length, fruit length and fruit diameter, number of ridges on fruit, fruit weight and number of fruits per plant.

Solankey *et al.* (2013) recorded appreciable heterosis over better parents of 51 F₁'s of okra for various horticultural traits and quality traits over both the seasons. It was confounded that rainy season was more yield productive season than summer. The high fruit yield potential and quality attributing traits recorded in the F₁ hybrid Arka Abhay x Arka Anamika has been directly attributed to increased number of fruits per plant during both climatic change's years.

Reddy *et al.* (2013) studied exploitation of heterosis in okra with using ten elite, optimally divergent and nearly homozygous lines of okra selected from the germplasm were crossed in all possible combinations excluding reciprocals during summer 2009. The resultant 45 F₁'s along with their 10 parents and one commercial check (Mahyco Hybrid No.10) were evaluated in a Randomized Block Design with three replications during mid *kharif* (July - October), 2009. Heterosis over mid parent, better parent and standard check were studied for 17 quantitative characters pertaining to pod yield and its associated characters. For total yield per plant, the crosses as a whole manifested 7.17% and -15.22% average and standard heterosis, respectively. For marketable yield per plant, the crosses as a group manifested 6.77% and -22.64% average and standard heterosis, respectively. The crosses C16 (P2 × P9) and C4 (P1 × P5) manifested significantly negative commercial heterosis, for days to 50% flowering (-5.13%), first flowering and fruiting nodes (-16.55%), respectively, indicating their earliness. The highest heterobeltiosis of 38.87% for total yield per plant and 37.95% for marketable yield per plant was manifested by the cross C23 (P3 × P9). The extent of standard heterosis for total yield per plant (9.32%) and marketable yield per plant (-6.69%) appears to be sufficient for exploitation of heterosis commercially. The crosses C 42 (P7×P10), C 31 (P5×P6) and C 35 (P5×P10) were statistically at par with the standard check in their mean performance and are as promising as that of the standard check (Mahyco Hybrid No. 10).

Badiger *et al.* (2014) undertook the investigation to estimate the heterosis of conventional and genetic male sterility (GMS) based hybrids. The magnitude of heterosis over the commercial check hybrid was high in the desirable direction for all the 12 traits studied. The results revealed that the crosses IIHR-294 x JNDO-5,

GMS-1 x Varsha Uphar and GMS-1 x Parbhani Kranti were potential heterotic crosses. They also stated that GMS based hybrids have got great commercial significance of saving 70% of the time and labour required for hybrid seed production.

Gajera and Vaddoriya (2014) studied heterosis for quantitative traits in okra. Eight genotypes were crossed in diallel fashion (excluding reciprocals) to develop 28 F₁ hybrids and were evaluated during summer-2012. Heterosis was worked-out over better parent and standard check variety, GJOH-3. The standard heterosis for fruit yield per plant ranged from -37.05 to 24.66 per cent. The crosses, Arka Anamika x JOL-09-7, JOL- 09-7 x JOL-04-8 and GO-2 x JOL-09-7, were the best heterotic combinations for fruit yield per plant, which recorded 24.66 per cent, 23.31 per cent and 20.32 per cent standard heterosis, respectively and could be utilized for commercial exploitation of heterosis after large scale testing. The heterosis for fruit yield per plant was associated with the heterosis expressed by its component characters.

Pathak and Prabhat (2014) studied heterosis. The 28 lines of okra originating from diverse eco-geographical regions were crossed in various combinations to generate 52 F₁ hybrids. All the hybrids along with parental lines and a standard check namely Punjab-8 was evaluated for yield and its attributing traits. Positive heterosis ranged from 1.09 to 66.07% for marketable fruit yield. The top five hybrids viz; KS-442 x POS-17 (66.07%), Arka Abhay x VRO-6 (59.81%), PB-266 x VRO-22 (52.14%), Arka Abhay x VRO-21 (51.96%), and KS-442 x POS-27 (49.1%) exhibited the highest positive heterotic effects for marketable yield. For number of fruits, hybrid PB-266 x VRO-22 exhibited the highest positive and significant (63.61%) heterosis over better parent. Most of the hybrids exhibited significant heterosis for fruit yield recorded significant heterosis for number of fruits also. Only two crosses namely Arka Abhay x POS-27 (-9.04%) and Arka Abhay x POS-17 (-9.04%) exhibited significant heterosis over better parent for early picking.

Chaubey *et al.* (2014) crossed eight okra genotypes in a line x tester mating design. Highly significant and maximum negative heterosis over better parents (-12.27 %) and mid-parent (-9.17 %) was observed in HRB-9-2 x VRO-5 for days to 50 per cent flowering. Whereas, DOV-91-4 x VRO-5 displayed highly significant and positive heterosis for fruit length over mid-parent and better parent.

Nagesh *et al.* (2014) conducted in okra to estimate the magnitude of heterosis and to identify the good combiners for yield and quality parameters. 54 F₁'s hybrids generated by line x tester mating design these F₁'s along with 21 parents and commercial check were evaluated in a randomized block design with two replications. Appreciable heterosis was found over better parent and commercial check for all the traits studied in desirable direction. The maximum positive heterosis was observed in the cross KON-8 x IC90174 over better parent (107.90 %) and the commercial check (92.42 %) for total yield per hectare. The crosses KON-8 x IC90174 (92.42 %), KON-5 x AAN (45.83 %), KON-16 x AAN (40.52 %), KON-12 x AAN (35.07 %) and KON-7 x IC90174 (27.11 %) showed significant heterosis over the commercial check in order of merit for total yield per hectare. The present study reveals good scope for commercial exploitation of heterosis in okra.

Katagi *et al.* (2015) reported heterosis in okra for fruit yield per plant and its associated components. Magnitude of heterosis over better parent (the best parent) was highly significant for total yield per plant. Out of 15 crosses, three crosses over better parent exhibited positive and significant heterosis for fruit yield per plant. They reported that the hybrid which exhibited the maximum heterosis BH – 1 x BH – 3, BH – 1 x BH – 4 and BH – 1 x BH – 5, these hybrids can be commercially exploited after assessing its stability for yield.

Tiwari *et al.* (2015) studied heterosis for various horticultural traits of okra in late *kharif* 2013 and summer 2014 by involving five diverse parents in a diallel mating including reciprocals. The analysis of variance reflected considerable variability for yield and other component traits. VRO-6 was excellent over other parents in *per se* performance for majority of traits under investigation except average fruit weight, fruit stalk length and ascorbic acid. The cross-combination VRO-6 x GJO-3 was the only F₁ exhibiting significant heterobeltiosis as well as standard heterosis for yield per plant. Whereas, hybrids Arka Anamika x AOL-12-52, Arka Anamika x GJO-3 and VRO-6 x Arka Anamika also displayed significant heterosis over better parent for this character. The cross-combination VRO-6 x GJO-3 also recorded significant and desirable heterotic gain over standard check for other traits like first flowering node, days to first flowering, number of branches per plant and average fruit weight.

Kumar and Reddy (2016) studied heterotic potential of single cross hybrid in okra with using 15 half-diallel crosses developed by crossing six newly developed inbred lines in a half-diallel fashion during *kharif* 2012, along with three standard checks were evaluated to study their heterotic potential for yield and its components. The crosses RNOYR-17 × RNOYR-18, RNOYR-15 × RNOYR-16 and RNOYR-16 × RNOYR-17 were the top three heterotic hybrids, manifesting significantly positive average heterosis of 82.23, 79.21 and 64.42%, respectively and heterobeltiosis of 71.43, 65.84 and 54.71%, respectively for marketable fruit yield per plant. The cross RNOYR-15 × RNOYR-16 manifesting significant standard heterosis of 20.57% over check 'No. 64' for marketable yield per plant was the top most heterotic hybrid, while the other two crosses RNOYR-16 × RNOYR-17 and RNOYR-17 × RNOYR-18 exhibiting positively non-significant standard heterosis over all the three standard checks.

Patel and Patel (2016) studied heterosis in okra with using set of 45 genotypes including eight females, four males, their 32 resultant hybrids and one commercial check variety (GAO-5) were sown during *kharif* 2012 at Vegetable Research Scheme, Regional Horticultural Research Station, Navsari Agricultural University, Navsari to study the magnitude of heterosis using line x tester analysis for twelve characters. Significant differences were observed among parents and hybrids indicating considerable genetic variation among these genotypes. Significant standard heterosis and high *per se* performance with regards to fruit yield per plant were recorded by the crosses *viz.*, JOL-09-8 x PUSA SAWANI, JOL-10-17 x GJO-3, JOL-09-7 x PUSA SAWANI and AOL-10-18 x VRO-6.

Gavint *et al.* (2017) carried out line x tester analysis with the objective of to find out the superior combinations of parents giving high degree of useful heterosis for fruit yield and its contributing characters and for future use in the breeding programme. Significant and desired directional heterosis was observed for majority of the yield attributing traits for fruit yield per plant in okra. Experimental material comprising 12 parents and their 32 hybrids along with one standard check (GJOH-3) were evaluated in randomized block design with three replications during *kharif* 2016 at the college farm, Navsari Agricultural University, Navsari. The highest heterobeltiosis was observed in crosses KS-404 x GAO-5 followed by JOL-11-12 x GAO-5 and AOL-03-1 x GAO-5 and the highest standard heterosis with cross JOL-11-12 x GAO-5. High heterosis for fruit yield per plant in these hybrids was due to,

positive heterotic response in other yield related characters *viz.*, plant height, fruit yield per plant and fruit dry weight.

Satish *et al.* (2017) studied heterosis in okra with using a set of 66 genotypes including ten females, five males, their 50 resultant hybrids and one commercial check variety (GJOH-3) were sown during *kharif* 2014 at Seed Spices Research Station, S. D. Agricultural Universtiy, Jagudan to study the magnitude of heterosis using line x tester analysis for ten characters. Significant differences were observed among parents and hybrids indicating considerable genetic variation among these genotypes. Significant standard heterosis and high *per se* performance with regards to fruit yield per plant were recorded by the crosses *viz.*, JDNOL-11-1 x Pusa Sawani, JDNOL-11-1 x GO-2, JDNOL-11-12 x Arka Anamika and AOL-07-9 x VRO-6.

Hadiya *et al.* (2018^a) studied assessment of heterosis with using 21 crosses from 7 × 7 diallel excluding reciprocals were studied to assess the magnitude of heterosis over standard check (SC) for fruit yield and its components in Okra [*Abelmoschus esculentus* (L) Moench]. Analysis of variance for genotypes manifested highly significant differences for different characters, which indicating the considerable genetic diversity among the material studied. For total fruit yield per plant, standard heterosis ranged from -31.36 to 35.01 per cent and total four hybrids showed positive direction heterosis over standard check. The cross AOL-10-22 x GAO-5 exhibited the highest magnitude of heterosis to the extent of 35.01 per cent over standard check for fruit yield per plant. Other best performing crosses on the basis of merit were AOL-10-22 x VRO-6 (34.15%), HRB-55 x AOL-12-59 (7.94%) and JDNOL-11-01 x Arka Anamika (2.78%) and these crosses can be used for exploitation of hybrid vigor on commercial scale. The study revealed good scope for exploitation of heterosis in okra for high yield.

Makdoomi *et al.* (2018) studied heterosis in okra during *kharif* 2012 at three locations. The basic material consisted of ten diverse genotypes of okra [*Abelmoschus esculentus* (L.) Moench] *viz.*, SKBS-11, Pant Bhindi, IC-117018, Azad Ganga, Parbhani Kranti, Lam-1, GO-2, Red Bhindi, Aka Anamika and Pusa Sawani. The selected ten genotypes were crossed in all possible combinations and produced 45 crosses. The results revealed wide range of heterotic pattern for different traits. The heterosis over better parent ranged from -11.38 to 8.82% for days to first flowering, -12.80 to 5.53% for days to first pod picking, -24.46 to

20.28% for plant height, -7.26 to 17.26% for number of nodes, -29.62 to -24.36% for internodal distance, -23.65 to -33.32% for pod length, -30.24 to 3.22% for pod girth, 33.69 to -9.38% for average pod weight, 30.41 to -4.78% for number of pods plant⁻¹, 57.13 to -0.43% for pod yield plant⁻¹ and 55.00 to -0.38% for pod yield ha⁻¹. The superior crosses identified through heterosis analysis and through farmers' participatory mode of plant breeding were SKBS-11 x IC-117018, SKBS-11 x Parbhani Kranti, IC-117018 x Pusa Sawani, Pant Bhindi x Pusa sawani and Pant Bhindi x Azad Ganga.

Prakash *et al.* (2019) studied heterosis in yield and its components in okra in which, 45 F₁s were developed by crossing ten elite lines of okra in a half diallel fashion during summer 2016. Significance of mean squares due to genotypes revealed the presence of considerable genetic variability among the material studied for almost all yield and yield attributes. The overall maximum positive significant heterosis for total yield per plant was observed in cross IIHR-875 x IIHR-478 (112.89%) over relative heterosis, (83.78%) over heterobeltiosis and (168.55%) over standard heterosis. Negatively heterotic crosses like IIHR-562 x IIHR-444 for days to 50% flowering (-8.70%) and IIHR-567 x IIHR-107 for fruiting nodes (-9.03%) respectively, are important to exploit heterosis for earliness in okra.

Patel *et al.* (2020) analysed 35 genotypes in four distinct situations using a line x tester mating of ten different parents and a commercial hybrid check named 'OH-102'. In terms of higher heterotic effect for fruit yield/plant, AOL-16-04 x Parbhani Kranti was consistent across the environments, while cross AOL-16-04 x Arka Anamika was consistent in terms of heterotic effects in environments E₁, E₂, and E₃, and cross NOL 17-09 x Arka Anamika was consistent in terms of fruit yield/plant in environments E₁, E₃, and E₄.

Sidapara *et al.* (2021) developed 45 F₁ during the 2017 kharif by crossing ten elite okra lines in a half diallel method. Fruit yield per plant heterosis ranged from -21.85 % (AOL 13-144 × Phule Prajatika) to 37.09 % (GAO 5 × Kashi Kranti) for better parent and -9.45 % (AOL 13-144 JF 108-02) to 75.51 % (GAO 5 × Kashi Kranti) for standard check. GAO 5 × Kashi Kranti (28.26 %), AOL 12-59 × JF 5 (25.88 %), and Phule Prajatika × JF 5 (19.32 %) showed higher heterobeltiosis. The superior crosses identified through heterosis analysis were GAO 5 × Kashi Kranti, Phule Prajatika × Red One Long, and Phule Prajatika × JF 5, as these crosses had

high per se performance as well as significant and higher estimates of standard heterosis for fruit yield per plant and yield attributing other characters.

2.2 COMBINING ABILITY AND GENE ACTION

Hybridization is the most important technique for breaking yield barriers and evolving varieties having high yielding potential. Selection of suitable parents is one of the most essential steps in hybridization programme. Selection of parents on the basis of phenotypic performance alone is not a sound procedure, since phenotypically superior lines may not lead to expected degree of heterosis. Therefore, selection of potential parents, based on genetic information and knowledge of their combining ability is very important. Combining ability is the capacity of an individual to transmit superior performance to its offspring. It is the phenomenon with which inbred lines were crossed gave rise to hybrid vigour. In this way, the ability of a strain to produce superior progeny upon hybridization with other strain is called combining ability.

The general combining ability (GCA) is the comparative ability of the line to combine with other lines. Specific combining ability (SCA) was defined as the deviation in the performance of specific cross from the performance expected on the basis for general combining ability effects of parents involved in the crosses. However, the concept of general and specific combining ability which was provided first by Sprague and Tatum (1942) as a measure of gene effect has become very important to plant breeders. According to them, general combining ability (GCA) measures the average performance of a line in hybrid combinations while specific combining ability (SCA) measures the deviation of certain expected combinations on the basis of average performance of the line involved and explained that GCA as the result of additive effect and SCA of non-allelic interaction effects. Griffing (1956) presented statistical concept of general and specific combining ability.

The general combining ability involves additive and additive x additive interaction, whereas, specific combining ability measures dominance, dominance x dominance and additive x dominance interactions. Griffing (1956) described two models, each with four methods, for working out the general and specific combining ability estimates in a set of diallel crosses and showed the relationship of diallel crossing methods to Fisher's method of covariance between relatives as expressed in terms of additive and non-additive genetic variance.

The literature pertaining to combine ability and gene action in okra has been reviewed as under;

Chaudhary *et al.* (1991) carried out line x tester analysis involving five lines and three testers in okra. The results revealed that the genotypes Pusa Makhamali and Punjab Padmini were good general combiners for yield and yield components.

Kulkarni *et al.* (1991) studied combining ability through a 10 x 10 diallel set in okra and reported highly significant variances due to general and specific combining ability for number of pods per plant, green pod yield per plant, pod length, pod girth, dry seed yield per plant and 100-seed weight. The GCA variances were higher in magnitude than SCA variances, suggesting the preponderance of additive type of gene action for all above mentioned characters.

Srivastava (1991) estimated gene action in okra through 10 x 10 diallel set, including reciprocals and found that the characters; earliness, age of edible fruits and plant height were predominantly governed by additive type of gene action.

Chavadhal and Malkhandale (1994) reported that both gca and sca variances were significant for all the characters. However, the predictability ratio showed the predominance of non-additive gene action for all the characters except days to 50% flowering.

Poshiya and Vashi (1995) reported that both GCA and SCA mean squares were influenced by environments. The higher magnitude of gca than their respective sca counter parts for number of nods per plant, internodal length, plant height, fruit length, fruit girth, number of fruits per plant and fruit yield per plant indicated preponderance of additive gene action in the expression of these traits. The *per se* performance of the parents may give a good indication of their GCA effects.

Shinde *et al.* (1995) reported that both general and specific combining ability variances were significant for pod yield, plant height, number of nodes on main stem and pod length. The hybrids Japan okra x Parbhani Tillu, Parbhani Tillu x No.-168 were found most promising. They expected that these crosses could be exploited for green pods per plant.

Sivakumar *et al.* (1995) studied combining ability in okra and reported that the parent Punjab-7 was the best general combiner for fruit yield. The hybrid Punjab-7 x A.E.-129 exhibited the highest sca effects for fruit yield, earliness and plant height. Non-additive gene action appeared to be important for fruit length: fruit girth ratio and fruit yield.

Patil *et al.* (1996) reported non-additive gene action for the number of nods per plant, internodal length, plant height, pod diameter and pod weight. Line PI 489782 was the best general combiner for marketable yield, total number of pods per plant and plant height. They also reported high positive significant SCA effect for marketable yield in crosses, IHR4 x PI 489782, Pusa Sawani x Smooth green, Pusa Sawani x PI 496620 and IHR4 x Green velvet.

Singh *et al.* (1996) studied combining ability through 8 x 8 diallel in okra. The results revealed that non-additive gene action was predominant for all the characters studied like, plant height, first fruiting node, length of internode, number of branches per plant, length of fruit, number of fruits per plant and fruit yield per plant. The best specific combinations were Punjab Padmini x Punjab-7, Punjab-7 X P-5 and Punjab Padmini X P-5 for fruit length and fruit yield.

Ahmed *et al.* (1997) studied 8 x 8 diallel analysis in okra and reported that gca and sca variances were highly significant for days to 50% flowering, internodal length, plant height, fruit girth, average pod weight, seed number and fruit yield per plant. The parent SB-5 was proved to be the best general combiner for height at first fruiting node, fruit girth, average pod weight, seed number and fruit yield per plant.

While studying combining ability through line x tester analysis in okra, Ramesh *et al.* (1998) observed Arka Abhay, Pusa Makhamali, Parbhani Kranti and Punjab Padmini as good combiners for yield per plant. They also reported significant and positive SCA effects for yield per plant in crosses; IC-9275 x HB-55, Arka Abhay x Punjab Padmini, Arka Abhay x HB-55, Parbhani Kranti x HB-55, D-2 x EC-16511, P7 x Punjab Padmini, Pusa Makhmali x Punjab and Pusa Makhmali x EC-16511.

Pawar *et al.* (1999) studied combining ability in okra. The mean squares due to general as well as specific combining ability were significant for pod length, pod girth, internodal length and plant height. Both additive and non-additive genetic variances were important for all the characters under investigation.

During the study of combining ability through 7 x 7 diallel analysis, Pal and Hossain (2000) reported the importance of both additive and non-additive gene actions in the inheritance of yield per plant and all the yield contributing characters. The variety Punjab Padmini was the best general combiner for pod length, pod girth, number of seeds per pod and seed weight per plant.

Singh *et al.* (2001) crossed 15 diverse genotypes of okra in a diallel fashion excluding reciprocal. The analysis of variance revealed the predominance of non-

additive gene action for plant height, first fruiting node, length of internode, number of branches per plant, length of fruit, number of fruits per plant and fruit yield per plant. Lines 7310 and 6313 were good combiners for plant height, length of internode and number of fruits per plant. The crosses 6305 x 6308, 6305 x 6308, 6305 x 6325, 6302 x 6308, 6325 x 7312, 6308 x 6325, 6313 x 7312 and 67308 x 7312 showed significant and positive specific combining ability effects for fruit yield per plant.

Dhankhar and Dhankhar (2001) studied combining ability in okra through a line x tester analysis involving 20 lines (female) and four testers (male). The combining ability analysis revealed that variances due to treatments, crosses, lines, testers, and parents *vs.* crosses were significant for fruit yield, number of fruits per plant, days to 50 per cent flowering, number of branches per plant, plant height, and number of effective nodes on stem, but not for internodal length of stem for tester

Thippeswamy (2001) evaluated 30 F₁ hybrids obtained from crossing five lines and six testers for yield and yield components in okra. The estimation of GCA effects of all 11 parents revealed that IIHR-MS-5 and IIHR-MS-2 showed the highest positive significant effects and were good combiner for number of fruits per plants, total yield per plant and fruit weight. IIHR-MS-5 had highest GCA for number of branches per plant and fruit length. Among the testers the magnitude of GCA effects for total yield per plant and node at which first flower appearance was high in the Arka Anamika. Parbhani Kranti had high GCA for fruit weight and fruit length. Significant SCA effect in desirable direction was noticed in the cross combinations in IIHR-MS-5 x 120-11-8-1 for days to first flower appearance. The hybrid, IIHR-MS-2 x Arka Anamika and IIHR-MS-5 x Parbhani Kranti can be exploited commercially for marketable yield, more number of fruits per plant and earliness. In majority of crosses, high SCA effect was due to high x high, high x low and low x low cross combinations, indicating the importance of additive x additive and additive x dominance or dominance x additive type of interaction.

Prakash *et al.* (2002) studied combining ability for yield and yield components in 21 F₁ hybrids developed from ten okra cultivars grown in Annamalainagar, Tamil Nadu, India. The estimates of general (GCA) and specific (SCA) combining ability and their ratio indicated the predominance of non-additive gene action for days to flowering, first fruiting node, stem hairiness, plant height, number of branches, number of nodes, fruit weight, fruit length, fruit girth, and number of

fruits per plant. Pusa Makhmali, Arka Anamika, Punjab Padmini, and Dharmapuri local were found the good general combiners for fruit yield per plant. Punjab Padmini x Pusa Makhmali and Dharmapuri local x Parbhani Kranti exhibited favourable SCA effects for plant height, number of branches, number of nodes, fruit weight, fruit length and number of fruits per plant and can be exploited in breeding for improved yield.

Rewale *et al.* (2003^b) carried out combining ability analysis in okra by crossing nine lines and seven testers in a line x tester fashion. DVR-4 and SOH-02 among the lines and Arka-Anamika among the testers showed good GCA effects for plant height, branches per plant, fruits per plant, fruit length, fruit weight, seeds per fruit, test weight and fruit yield per plant.

Combining ability analysis in okra was carried out by Shushmita and Das (2003) with 10 x 10 diallel cross, excluding reciprocals. The parent Ankur-40 was found as good general combiner for six characters, *viz.*, days to 50% flowering, number of nodes per plant, fruit length, plant height, number of fruits per plant and fruit yield per plant. The crosses Parbhani Kranti x Indam-9821, Indam-9821 x Ankur-40 and Ankur-40 x Pankaj Dwar were observed to be the most promising hybrid combinations for earliness, fruit yield and other characters.

Bendale *et al.* (2004) conducted combining ability studies with eight parents of okra and their 28 crosses prepared in a half diallel fashion. Among the parents, Gold Finger was found to be a good general combiner and among the hybrids, the cross Parbhani Kranti x Gold Finger showed the highest positive significant specific combining ability value for fruit yield per plant.

Rajendra *et al.* (2005) evaluated six hybrids of okra for their combining abilities and recorded significant general and specific combining ability variances for 10 characters examined. Cultivar AB-2 was a good general combiner for number of days to flowering, number of fruits per plant and yield per plant. Cultivar AB-1 was a good general combiner for number of days to flowering, number of first fruiting node, number of fruits per plant and yield per plant, whereas Parbhani Kranti was a good general combiner for plant height and fruit length and width. Most of the superior specific combinations for different attributes also had a good *per se* performance.

Kumar *et al.* (2006) carried out a line x tester analysis in okra with six lines and three testers to estimate the combining ability and variance effects. The combining

ability and variances indicated the preponderance of non-additive gene action for all the traits. Lines, Mohanoor local, TCR 2056, Gobi local and testers Parbhani Kranti and Punjab Padmini were adjudged as the superior performer for seed yield per plant based on general combining ability effects. The hybrid Mohanoor local x Parbhani Kranti found to be superior when SCA effects were considered for many of the traits.

Naphade *et al.* (2006) estimated combining ability using a line x tester analysis. The parents Tot-1494 and Tot-1502 proved to be good general combiners for fruit weight, number of primary branches, number of seeds per fruit and fruit yield per plant. The parent Tot-1494 also proved to be good general combiner for fruit length. While, Parbhani Kranti x Tot-1494 was found to be the best specific combiner for fruit yield followed by AKO-73 x Tot-1502 and Parbhani Kranti x Tot-1502.

Singh *et al.* (2006) studied experimental material comprised of 60 crosses of okra were produced by crossing of fifteen lines and four testers for characters *viz.*, days to 50 per cent flowering, green pod weight, green pod length, green pod diameter, plant height, internodal length, number of branches per plant, number of fruits per plant and fruit yield per plants. ANOVA revealed highly significant difference among all the parents, hybrids, lines, line x tester for all the characters and testers for all the traits except fruit diameter.

Mehta *et al.* (2007) evaluated 42 crosses using fourteen lines and three testers and revealed that the SCA variances for days to first flower, days to 50 per cent flowering, fruit weight, fruit length, plant height, number of seeds per fruit and 100-seed weight were higher than GCA variance so, there is a preponderance of non-additive gene action. The GCA variances were greater than SCA variances for fruit yield per plant indicated preponderance of additive gene.

Weerasekara *et al.* (2008) estimated combining ability effects for different traits in a line x tester crossing programme comprising 24 hybrids produced by crossing eight lines and three testers. Parents and hybrids differed significantly for GCA and SCA effects, respectively. Among the lines, KAO-25 and KAO-61 and among the testers, KAO-23 and KAO-AA were found to be the best general combiners. Three cross-combiners *viz.*, KAO-53 x KAO-18, KAO-35 x KAO-AA and KAO-17 x KAO-AA were found to be the best specific crosses for yield per plant. Results

showed that non-additive gene action was an integral component of the genetic architecture of different traits in the material used in okra.

Srivastava *et al.* (2008) reported that ratio of $\sigma^2_{gca}/\sigma^2_{sca}$ were more than unity indicated preponderance of additive gene for expression of characters under study. Among the parents, IC-73352, Okra No. 6, Pb-8, VB-9101 and Punjab Padmini for days to 50% flowering; Punjab-8, IC-73352, BO-1, Okra No.-6 and IC-69117 for plant height; BO-1, Okra No.-6, IC-73352, Punjab-8, IC-69117, Arka Abhay and VRO-3 for number of branches per plant; Punjab-8, Punjab Padmini, IC-69117, Arka Abhay for number of fruits per plant; Punjab Padmini, VRO-3, Arka Abhay, Punjab-8 and IC-69117 for pod yield per plant were found good general combiners. Where in specific combining ability study, the cross VRO-3 x Arka Abhay and Punjab Padmini x Arka Abhay for pod yield per plant; VRO-3 x IC-69117 for plant height; Punjab-8 BO-1 for number of branches per plant; IC-73352 x Punjab Padmini for number of pods per plant; VRO-3 x IC-73352 for pod length; Punjab-8 x IC-68364 for pod diameter; Punjab-8 x IC-69117 for pod weight exhibited high specific combining ability.

Khanpara *et al.* (2009) evaluated eight lines and four testers for general and specific combining ability through a line x tester mating method. The parents Pant Bhindi and D-1-87-5 were good general combiners for fruit yield per plant, number of nodes per plant and number of fruits per plant; KS-404 and BO-13 for early flowering and picking. Similarly, BO-13 and IC-990049 for shorter internodal length, Chhodawadi and Parbhani Kranti for tall plant, Parbhani Kranti for fruit length, Chhodawadi and Pant Bhindi for fruit girth were found good general combiners.

Pal and Sabesan (2009) studied combining ability for fruit yield and its components in okra using a 12 x 12 diallel mating design and found that both GCA and SCA variances were highly significant for all traits like plant height, number of nodes per plant, number of branch per plant, internodal length, number of fruits per plant, fruit yield per plant, indicating the importance of both additive and non-additive gene action. The cross combinations *viz.*; Satdhari x Ratna 78, VRO 5 x Sagun, Ratna 78 x Punjab 8, Ankur 40 x Pankaj Dwarf, Satdhari x Varsha Uphar, Arka Anamika x Punjab 5 showed significant SCA effects in desirable direction for fruit yield per plant and associated traits and were expected to produce transgressive segregates.

The combining ability studies were carried out by Dabhi *et al.* (2010) using a line \times tester (twelve lines and four testers) mating method over three environments for 11 traits in okra. The pooled analysis revealed that both additive and non-additive gene actions were involved in the genetic control of various traits studied. The preponderance of non-additive gene action in expression of days to first flower opening, number of nodes at first flowering, days to first picking, number of nodes per plant and fruit length, whereas additive type of gene action was predominant in expression of internodal length, plant height, 10-fruits weight, fruit girth, stalk length and fruit yield per plant. The lines *i.e.*, KS-404, JOL-06(K)-2, VRO-5, JOL-1, JOL-2K-19 and HRB-108-2, while the testers *viz.*, Arka Abhay and GO-2 were found as good general combiners for fruit yield per plant as they possessed high concentration of favourable genes indicated by significant and positive GCA effects. The parents JOL-06(K)-2, KS-404 and GO-2 were good general combiners for early flowering. Among the crosses, Pant Bhindi \times Red Bhindi, KS-404 \times Punjab-7, JOL-02-10 \times Punjab-7 and JOL-06(K)-2 \times GO-2 had high sca effects for fruit yield per plant and number of fruits per plant. The results revealed that most of the superior combinations involved at least one parent with high GCA effect for most of the traits.

Solankey and Singh (2010) studied a line \times tester analysis in okra with 20 parents (seventeen lines and three testers) and their 51 F₁s, in two different seasons. The combining ability variances indicated the preponderance of non-additive gene action for all the traits like, days to first flower, days to 50 per cent flowering, fruit weight, fruit length, plant height, number of seeds per fruit and 100-seed weight. The lines *viz.*, VRO-5, VRO-6, Arka Abhay, IC-218844 and testers like Arka Anamika proved to be the good general combiners and Arka Abhay \times Arka Anamika was the good specific combination for most of the yield and yield attributing traits.

Wammanda *et al.* (2010) studied the genetic basis of yield and its components using a 9 \times 9 diallel cross, 36 F₁'s and the nine parents. Combining ability analysis of parent also revealed that Mothol-AE2, Mothol-AE3, Gerio-AE1 and Mothol-AE1 gave consistently high general combining ability effects for most of the traits. Significant GCA (general combining ability) and SCA (Specific combining ability) variances were also obtained in all the traits, implying that both the additive and non-additive gene effects operated in the genetic expression of the traits.

Raghuvanshi *et al.* (2011) studied the combining ability for yield and its components by using a lines x tester mating fashion, involving six lines and five testers of okra. The GCA and SCA were significant for all the traits, indicated the importance of both additive and non-additive genetic components. Among the crosses, HRB-55 x Arka Abhay, HRB-9-2 x P-7 and HRB-9-2 x Arka Abhay were good specific combiners for yield per plant.

Kachhadia *et al.* (2011) studied the combining ability using a line x tester (ten lines and four testers) mating method over three environments for nine characters in okra and concluded that the pooled analysis of variance for combining ability revealed the preponderance of non-additive gene action in the expression of yield and all the yield contributing characters except fruit girth, which was governed by the additive gene action. The lines *i.e.* GO-2 and JOL-06-S-5, while the tester *viz.*, HRB-55 were found as good general combiners for fruit yield per plant and possessed concentration of favourable genes as indicated by significant and positive gca effects for fruit yield and other contributing traits *viz.*, number of nodes per plant, number of branches per plant and fruit length. The parents JOL-06-S-4, JOL-06-S-5, JOL-06-S-6 and Parbhani Kranti were identified as good general combiners for early flowering. Among the hybrids, JOL-06-S-5 x HRB-55, JOL-06-S-8 x JOL-06-S-1 and GO-2 x Parbhani Kranti had high sca effects for fruit yield per plant and other related traits, were also accompanied with high *per se* performance; hence, *per se* performance of the hybrids would be a good indicator for predicting sca effects.

Singh (2011) conducted an experiment on combining ability analysis for yield and yield contributing traits in okra with eight parents and 28 F₁s. The positive and significant sca effects for fruit yield was exhibited by the crosses Arka Abhay x Parbhani Kranti, Badshah x Parbhani Kranti and Parbhani Kranti x KS 383. The crosses Arka Abhay x Parbhani Kranti and Badshah x Parbhani Kranti had the high values for yield and most of the its contributing traits. First fruiting node length, Arka Abhay x KS 393 was found to be the best specific combiner, for plant height; Arka Abhay x Parbhani Kranti, for number of nodes per plant; Badshah x KS 383, for number of branches per plant, Badshah x Punjab Padmini, for length of the fruit; KS 373 x KS 383, for fruit thickness, Arka Abhay x Punjab Padmini, for tapering length, KS 373 x KS 383 and for the number of fruits per plant, Arka Abhay x Parbhani Kranti were found to be the best specific combiners.

Sharma and Singh (2012) estimated combining ability effects for different traits of okra in a line x tester mating design comprises six lines and four testers and their 24 F₁ hybrids. Lines *viz.*, VRO-3, VRO-4, VRO-5, VRO-6 and Parbhani Kranti and testers *viz.*, Hisar Unnat, Arka Anamika, BS-14 and BS-12 were the best general combiners for plant height, number of branches per plant, days to 50% flowering, number of seeds per fruit, average fruit weight, number of fruits per plant and fruit yield whereas, the best specific crosses were VRO-3 x BS-14, VRO-4 x Arka Anamika, VRO-5 x BS-12, Varsha Uphar x Hisar Unnat, Varsha Uphar x BS-14 and Parbhani Kranti x Hisar Unnat for plant height, number of branches per plant, node at which 1st flower appeared, internodal length, number of seeds per fruit, fruit length, number of fruits per plant and fruit yield. The cross *viz.*; VRO-3 x BS-14, VRO-4 x Arka Anamika, VRO-5 x BS-12, Varsha Uphar x Hisar Unnat, Varsha Uphar x BS-14 and Parbhani Kranti x Hisar Unnat showed highest specific combining ability for green fruit yield and its components and are potential source for screening of high yielding F₁ hybrid varieties. The crosses *viz.*; VRO-5 x BS-12, Parbhani Kranti x Hisar Unnat, VRO-5 x BS-14 and VRO-6 x Hisar Unnat were the very good performing crosses for number of fruits/plant. In these crosses involved the parents with high x low, low x low, high x high general combining ability effects indicated the presence of both additive and non-additive gene action for more number of fruits per plant.

Prakash *et al.* (2012) studied on combining ability through full diallel analysis in bhendi. A full diallel analysis involving six bhendi genotypes was used to study the combining ability for fruit yield and its component characters. The study revealed that the Kamini, Bakra and P7 were good general combiners. The cross combinations of Kamini x Bakra exhibited highly significant and positive specific combining ability and standard heterosis for fruit yield and other yield contributing traits.

Patel (2013) estimated the effect of gca and indicates that Pusa Sawani was good general combiner for fruit weight and number of seeds per fruit. JOL-09-8 was good general combiner for days to 50% flowering, plant height and 100-seed weight. JOL-08-8 was good general combiner for fruit weight and number of seeds per fruit and JOL-55-3 was good general combiner for number of branches per plant and fruit length. It is interesting to note that none of the parents was good general combiner for fruit yield per plant. In addition females *viz.*, AOL-10-3,

AOL-10-18, JOL-09-5 and JOL-09-7 were good general combiners for fruit weight, 100-seed weight, number of seeds per fruit and days to 50% flowering, respectively.

Paul (2013) estimated the general combining ability and observed that HRB-55, AOL-09-17, AOL-09-2 and JOL-09-7 to be good general combiners for fruit yield per plant. Moreover, the parent HRB-55 was observed as good general combiner for the maximum traits except days to initiation of flowering and number of ridges on fruit. Whereas, parent AOL-09-17 was good combiner for number of primary branches per plant, plant height, fruit length, fruit diameter, fruit weight and number of fruits per plant. The parent JOL-09-7 was found to be either good or average combiner for all the traits. The results of SCA effects revealed that the cross combinations JOL-55-3 x HRB-55, JOL-09-8 x JOL-09-7 and JOL-09-8 x AOL-09-17 showed the highest SCA effect for fruit yield per plant and also can be said as most promising for fruit yield and some of its related traits.

Kishor *et al.* (2013) evaluated 15 crosses using five lines and three testers of okra to estimate combining ability for characters *viz.*, days to first flowering, number of primary branches, plant height, number of fruits per plant, fruit weight, fruit length and yield per plant. Combining ability analysis showed preponderance of non-additive gene action for most of the characters. Good 29 general and specific combiner found for all these characters. Significant variation was observed among treatments and line x tester interaction for all the characters.

Reddy *et al.* (2013) evaluated 45 crosses using ten parents in a half diallel fashion. Combining ability analysis of parents revealed that the parental lines IC 45732, IC 89819 and IC 89976 were superior general combiners for total and marketable yield per plant and other traits. The crosses *viz.*; IC 29119-B x IC 99716, IC 27826-A x IC 111443, IC 89976 x IC 111443 and IC 90107 x IC 111443 were superior specific combiners for total as well as marketable yield per plant with the potential of being commercially exploited for the production of F₁ hybrids. The crosses IC 27826-A x IC 111443 and IC 89976 x IC 111443 involving one or both of the parents with positive and significant general combining ability effects for marketable yield per plant could be utilized in recombination breeding. Genetic analysis revealed a preponderance of non-additive gene action for plant height, internodal length, days to 50% flowering, first flowering and fruiting node, fruit length and weight, total number of fruits and number of marketable fruits per plant,

total yield and marketable yield per plant and yellow vein mosaic virus infestation on fruits and plants and a preponderance of additive gene action for number of branches per plant and fruit and shoot borer infestation on fruits and shoots.

Adiger *et al.* (2013) studied on selection of parents based on combining ability studies in okra. Combining ability effects were estimated for different characters in a line x tester crossing programme comprising 120 crosses produced by crossing of 40 lines and three testers and concluded that parents and hybrids differed significantly for GCA and SCA effects, respectively. Magnitude of specific combining ability (SCA) variance was higher than the general combining ability (GCA) variance. This showed the predominance of non-additive gene action for all the characters, which indicated the scope for heterosis breeding in crop improvement in okra. Majority of cross combinations recorded high SCA effects and *per se* performance due to low x low, low x high or high x low SCA status. The line 13 was found to be the good general combiner for the characters *viz.*, plant height, number of branches per plant, fruit length, fruit diameter, fruit weight, number of fruits per plant, fruit yield per plant and fruit yield per hectare followed by the lines 5, 25 and 38. The tester Parbhani Kranthi was found to be the good general combiner followed by Pusa Sawani. The hybrids 38 x 3, 3 x 1 and 13 x 3 had higher significant SCA effects for fruit yield and its component characters like; days to 50% flowering, plant height, number of branches per plant, internodal length, fruit length, fruit diameter, test weight, fruit weight and number of fruits per plant.

Kumar *et al.* (2014) carried out an experiment with twelve parental lines of okra along with 66 F₁ hybrids based on a half-diallel cross excluding reciprocals to the study of combining ability of okra with respect to 17 traits. The mean square due to GCA and SCA were significant for all 17 traits under study indicated the importance of both additive and non-additive genetic components for the traits under study. None of parents was good general combiner for all the traits whereas, Hisar Unnat, IC- 128891 and VRO-5 showed significant GCA for yield, earliness and different pod traits, respectively, which signified their suitability to be used for further breeding and crop improvement programme. Among the crosses, Larm-1 x IC-111527, IC-282280 x IC-111527 and IC-282280 x EC-329380 were most promising combinations for earliness and other desirable traits including yield per

plant. The results indicated the importance of heterosis breeding for effective utilization of non-additive genetic variance in okra.

Katagi *et al.* (2015) carried out combining ability analysis for fruit yield and its components in okra in a 6 x 6 diallel cross (excluding reciprocals). They found that the parents BH-5, BH-1 and BH-2 were found to be the best general combiners and close correspondence between *per se* performance of parents and their GCA effects were observed. The cross combinations *viz.*; BH-2 x BH-6, BH-1 x BH-3, BH-2 x BH-3, BH-2 x BH-4, and BH-1 x BH-5 showed significant SCA effects in desirable direction for fruit yield per plant and associated traits and were expected to produce transgressive segregants.

Arti *et al.* (2016) studied combining ability for fruit yield and contributing traits in okra with using desirable parents and F₁ hybrids in okra by involving eight diverse parents in a diallel mating design excluding reciprocals. Genotypes *i.e.*, P-20 and VRO-4 for earliness; 9801 for first fruit producing node, internodal length and fruit length; HU for average fruit weight; Tulsi-I for nodes per plant, fruit length and plant height were found good general combiners appeared to be worthy of exploitation in future breeding. It is suggested that involving these lines, new genotypes may be developed through multiple crossing for isolating high yielding varieties. The cross combinations VRO-4 x HU, Tulsi-I x SKBS-11, P-20 x Tulsi-I and P-8 x Tulsi-I showed high SCA effects as well as *per se* performance for yield per plant. The crosses showing high SCA effects and *per se* performance for yield per plant suggested that these hybrids may be exploited in further breeding programme.

Jupiter *et al.* (2017) studied on combining ability effects for eight characters *viz.*; days to first flowering, plant height, number of branches per plant, fruit length, fruit girth, number of fruits per plant, fruit weight and fruit yield per plant. The combining ability and variance indicated the preponderance of non-additive gene action for days to first flowering, plant height, number of branches per plant, fruit length, fruit girth, number of fruits per plant and yield per plant. On the basis of GCA effects across nine characters, the genotype Sivagangai Local (L2) was the best combiner for number of fruits per plant and fruit yield per plant followed by Pudukottai Local (L1) and Arka Anamika (T2) among testers were found to be good combiners for fruit yield per plant. Hence, these parents may be used as one of the parents in okra hybrid programme.

Tapas *et al.* (2017) studied estimation the magnitude of gene action involved in okra and to identify the good combiner for fruit yield and other yield attributing characters. They reported non-additive gene action for internodal length, fruit length, fruit diameter, number of fruits per plant and yield per plant, while additive gene action for plant height and number of branches per plant. The estimates of general combining ability effects suggested that parents HRB-55, AOL-09-17, AOL-09-2 and JOL-09-7 were good general combiners for fruit yield per plant and its related attributes. The estimates of specific combining ability effects indicated that cross combinations JOL-55-3 x HRB-55, JOL-09-8 x JOL-09-7 and JOL-09-8 x AOL-09-17 were most significant for fruit yield per plant and related traits. Present investigation indicated sufficient scope of exploitation of heterosis using the parents and crosses.

Reddy and Sridevi (2018) studied combining ability analysis for fruit yield and its components in okra in a 8 x 8 full diallel cross. Both general combining ability (GCA) and specific combining ability (SCA) variances were highly significant for all the characters indicating the importance of both additive and non-additive gene actions. The highest gca effect for fruit yield per hectare recorded in Arka Anamika followed by Arka Abhay. The highest significant positive sca effect was observed in the cross Arka Anamika x DBh-43 followed by DBh-47 x Arka Anamika and DBh-47 x DBh-30. Based on the total score values it is observed that among the parents Arka Anmika had higher *gca* scores and is a good combiner followed by Arka abhay and DBh-43. Among hybrids, Arka Anamika x DBh-43 had the highest *sca* score and is a good combiner followed by Arka Anamika x DBh-37 and DBh-30 x DBh-55 hybrids.

Hadiya *et al.* (2018) carried out an experiment to study the combining ability for yield and its contributing traits in okra. The study revealed that non-additive gene action for the days to 50% flowering, number of branches per plant, number of fruits per plant, fruit length, fruit girth and yield per plant. The mean squares due to *gca*, *sca* effects were significant for fruit yield and yield contributing traits studied. None of the parents was identified as good general combiner for fruit yield per plant but the parents AOL-10-22, VRO-6, HRB-55 and AOL-12-59 were identified as average general combiners for yield per plant and can be exploited well in further breeding programme. The estimates of *sca* effects revealed that the cross combinations AOL-10-22 x GAO-5, AOL-10-22 x VRO-6, JDNOL-11-01 x Arka

Anamika and HRB-55 × AOL-12-59 were observed most promising for fruit yield and some of its related traits could be used as heterotic hybrids.

Yadav *et al.* (2020) investigated the Line x Tester crossing programme, evaluating a total of 24 crosses from twelve lines and two testers. In terms of fruit output, number of fruits per plant, and number of branches per plant, estimates of the gca impact revealed that Parbhani Kranti, K.S-325, and Pusa Sawni are good general combiners. The cross combinations Prabhani Kranti x A.B – 1, KS 325 x A. B 2, B. O 2 x A. B 2, and K.S-312 x A.B-2, among others, were shown to be the most promising for fruit output per plant, fruit length, number of fruit per plant, and plant height, according to the estimation of sca impacts.

Yogini and Saravanan (2020) studied the gca and sca effects of seven parents and forty-two hybrids under diallel mating. According to the gca impacts of parents, Srivilliputhur local was the best parent for features like earliness, fruit length, individual fruit weight, and fruit output per plant. Individual fruit weight, quantity of immature seeds, plant height, and fruit output per plant all demonstrated significant sca effects for Srivilliuthur local x Thunder, but Thunder Arka Anamika had a strong sca effect for earliness. The hybrids Srivilliputhur x Basanti and Srivilliputhur local x Arka Anamika demonstrated significant sca effects for various aspects.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

The details of the methods adopted and the materials used during the course of present investigation are described in this chapter under the following heads.

3.1 Experimental site

The Crossing programme was conducted in summer 2021 at Seed & Spices Research Station, Sardarkrushinagar Dantiwada Agricultural University, Jagudan and evaluation was carried out in *kharif* 2021 at Agronomy Instructional Farm, C.P.C.A., Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar.

3.2 Experimental materials

The experimental materials comprised of 36 genotypes, which involves eight females, three males and their 24 F₁ hybrids along with one commercial hybrid check (GJOH-4). The parents were obtained from Seed & Spices Research Station, Sardarkrushinagar Dantiwada Agricultural University, Jagudan and hybrid check was obtained from J.A.U., Junagadh.

Table 3.1. List of parents used in line x tester crossing programme

LINE (8)	TESTER (3)	CHECK
VRO -6	Pusa Sawani	GJOH – 4
NLO 17 – 9	GAO-5	
VRO 22	GAO-6	
JOL 75 – 5		
JOL 16 – 06		
JDNOL 18 – 2		
Parbhani Kranti		
Arka Anamika		

3.3 Experimental details

- 1. Experimental title** : HETEROSIS AND COMBINING ABILITY IN OKRA (*Abelmoschus esculentus L.*)
Field experiment: Seed and Spices Research Station, Jagudan.
- 2. Location** : **Evaluation:** Agronomy Instructional farm, S.D.A.U.
- 3. Year and season** : Crossing programme – summer 2021
Evaluation - *kharif* 2021
- 4. Number of** : 24 crosses + 8 lines + 3 testers + 1 check

- genotype**
5. **Experimental design** : Randomized Block Design
 6. **Number of replication** : 3
 7. **Spacing** : 60 cm x 45 cm
 8. **Materials were received from** : Seed and Spices Research Station, S.D.A.U., Jagudan and Vegetable Research Station, JAU, Junagadh
 9. **Agronomic practices** : As per recommendations
 10. **Plant Protection measures** : As and when required

3.4 Hybridization programme

Seeds of parents were sown during summer 2020 - 21 for attempting crosses in line x tester fashion. Sowing was done on 60 cm apart ridges at spacing of 45 cm between plants for easy movement. All packages of practices were followed to raise a healthy crop. A total of 24 hybrids were developed by crossing 11 parents in a line x tester fashion. Flower buds of male and female parents were selected on the previous evening prior to the day of their opening. The flower buds of female parents were emasculated and covered with butter paper bags to avoid out crossing. Pollination was carried out on the next day morning between 8 to 10 a.m. by using pollens of desired male parents. After pollination, the female flower buds were again covered with butter paper bags to avoid contamination and tagged with the name of male parent and date of pollination. Simultaneously, the male and female parents were selfed by bagging the flower buds with butter paper bag prior to the day of flower opening. Crossed and selfed fruits were harvested separately at full maturity stage. The seeds were hand threshed and preserved in butter paper bags labeled with the details of cross.

3.5 Evaluation of F₁S, Parents and Commercial check

The experiment consisted of 11 parents (8 lines and 3 testers) and 24 F₁ hybrids derived from line x tester fashion and one commercial check.

1. Treatments: 36 (24 crosses + 11 parents + 1 commercial checks)
2. Commercial check: GJOH-4
3. Replications: 3

4. Experimental design: RBD

5. Spacing: 60 cm x 45 cm

3.6 Procedure of recording the Experimental data

Five representative plants from each entry were selected and tagged at random for recording fruit yield and other traits in each replication and average values were computed for statistical analysis (except days to flowering, days to first picking and days to last picking). Total ten pickings were taken and 10th picking treated as last picking. The details of the recording of following different characters are given below:

1. Days to flowering

Number of days elapsed from the date of sowing to the date of first flower opening in 50 per cent plant was recorded on the plot basis.

2. Days to first picking

It was recorded by counting days from sowing to the first picking of the marketable fruits on the plot basis.

3. Fruit length (cm)

The fruit length was measured in centimeters from base of calyx to the tip of the pod during fifth picking.

4. Fruit girth (cm)

The middle portion of the pod was measured in centimeters and recorded as fruit girth during fifth picking.

5. Number of branches per plant

The total number of branches emerged on the main stem of plant was noted at the time of last picking.

6. Internodal length (cm)

The length of the internode between the fifth and sixth node was measured at 75 days after sowing in centimeter.

7. Plant height (cm)

The height of the plant was measured in centimeters from ground level to the tip of main shoot at the time of last picking.

8. Fruit yield per plant (g)

Yield of marketable fruits of five plants at each picking was summed for total number of pickings and the average was calculated in grams and taken as fruit yield per plant.

9. Total Number of fruit per plant

This observation was recorded by counting harvest fruits from each five selected plants at each picking. Sum total of all pickings was considered as total number of fruits per plant.

10. Total number of seed per fruit

This observation was noted on five randomly selected fruits from each genotype left over for seed and after last picking dry, it and separated number of seeds was taken for total number of seeds per fruit.

11. Days to last picking

Number of days taken from the date of sowing to the date of last harvest of green marketable green fruits on plot basis was recorded.

3.7 Statistical analysis

The following calculations were made using average of five plants per entry per replication.

3.6.1 The Analysis of variance for experimental design

3.6.2 Estimation of relative heterosis, heterobeltiosis, standard heterosis

3.6.3 Analysis of variance for combining ability (line x tester)

3.6.4 General and specific combining ability effects

3.7.1 Analysis of variance for experimental design

The analysis of variance to test the variation amongst parents and crosses was carried out using randomized block design separately for individual sowing based on the following model of Cochran and Cox, 1957.

$$Y_{ij} = \mu + g_i + r_j + \epsilon_{ij}$$

Where,

Y_{ij} = Values i^{th} genotype in j^{th} replication

μ = Population mean

g_i = An effect of i^{th} genotype

r_j = An effect of j^{th} replication

ϵ_{ij} = Uncontrolled variation associated with i^{th} genotype and j^{th} replication

To test the significance of the variation observed among different progenies, analysis of variance was carried out by the usual procedure.



PLATE 3.1. GENERAL VIEW OF EXPERIMENTAL FIELD

The orthogonal partitioning of the analysis of variance was done as below.

Table 3.2. Analysis of variance for experimental design

Sources of variation	d.f.	M.S.S.	E.M.S	Cal. F
Replications	(r-1)	M_r	$\hat{\sigma}_e^2 + g \hat{\sigma}_r^2$	M_r / M_e
Genotypes	(g-1)	M_g	$\hat{\sigma}_e^2 + r \hat{\sigma}_g^2$	M_g / M_e
Parents (p)	(p-1)	M_p	$\hat{\sigma}_e^2 + r \hat{\sigma}_p^2$	M_p / M_e
Hybrids (h)	(h-1)	M_h	$\hat{\sigma}_e^2 + r \hat{\sigma}_h^2$	M_h / M_e
p vs h	1	M_{ph}	$\hat{\sigma}_e^2 + r \hat{\sigma}_{ph}^2$	M_{ph} / M_e
Check vs hybrid	1	MF ₁ v/s M_{ch}	-	MF ₁ v/s M_{ch}/M_e
Error	(r-1)(g-1)	M_e	$\hat{\sigma}_e^2$	

Where,

r = Number of replications

g = Number of genotypes (p + h)

p = Number of parents (females + males)

h = Number of hybrids (females x males)

$\hat{\sigma}_r^2$ = Replication variance

$\hat{\sigma}_g^2$ = Genotype variance

$\hat{\sigma}_p^2$ = Parents variance

$\hat{\sigma}_h^2$ = Hybrid variance

$\hat{\sigma}_{ph}^2$ = Parent vs. Hybrid variance

$\hat{\sigma}_e^2$ = Environment variance

$$SEd = (2 M_e/r)^{0.5}$$

Where,

M_e = Error mean square in the analysis of variance

r = Number of replications

C.D. = $SEd \times t_{0.05}$ at error degrees of freedom at 5 % level of significance

3.7.2 Estimation of relative heterosis, heterobeltiosis, standard heterosis

Theoretically, heterosis is the deviation of F_1 from the mid parental value. But, an increase in F_1 over poor parent may not be of practical importance. Therefore, in the present investigation heterosis has been estimated over mid parent (H_1), which is referred as average or relative heterosis (H_1) and heterosis has been estimated over better parent (H_2), which is referred as heterobeltiosis as per Fonseca and Patterson (1968). Additionally, heterosis was also estimated over standard check variety (GJOH-4), referred to as standard heterosis or economic heterosis (H_3).

The formula used to estimate heterosis over better parent and standard check under individual environment are given as under;

$$\text{Relative heterosis (\%)} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

$$\text{Heterobeltiosis (\%)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

$$\text{Standard heterosis (\%)} = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$$

Where,

$\overline{F_1}$ = Mean performance of hybrid

\overline{BP} = Mean performance of better parent involved in a cross

\overline{SC} = Mean performance of standard parent involved in a cross

\overline{MP} = Mean performance of mid parent

Standard error of difference (S.Ed.) and critical difference (CD) for relative heterosis, heterobeltiosis and standard heterosis were calculated by following formulae;

$$\text{S.Ed. (Relative heterosis/Heterobeltiosis/Standard heterosis)} = (2 Me/r)^{0.5}$$

Where,

Me = Error mean square in the analysis of variance

r = Number of replications

CD = S.Ed. $\times t_{0.05}$ at error degrees of freedom at 5 % level of significance

3.7.3 Analysis of variance for combining ability

The combining ability analysis was carried-out according to the method suggested by Kempthorne (1957). This design is related to North-Carolina Design II (Comstock and Robinson, 1952) in terms of covariance of half-sibs and full-sibs.

The model for this design is as under:

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + r_k + \epsilon_{ijk}$$

Where,

Y_{ijk} = Phenotypic expression of the cross $i \times j$ in k^{th} replication

μ = General mean

g_i = General combining ability effect of i^{th} line

g_j = General combining ability effect of j^{th} tester

s_{ij} = Specific combining ability effect of cross between i^{th} line and j^{th} tester

r_k = An effect of k^{th} replication

ϵ_{ijk} = Random error effect associated with ijk^{th} individual

The combining ability analysis carried-out by using this design leads to following ANOVA structure.

Table 3.3: Analysis of Variance for Combining ability analysis

Sources of variation	d.f.	M.S.	E.M.S.
Replications (R)	(r-1)	-	-
Hybrids (H)	(h-1)	M_h	-
Lines (L)	(l-1)	M_1	$\sigma_e^2 + r\sigma_{1t}^2 + rt\sigma_1^2$
Testers (T)	(t-1)	M_2	$\sigma_e^2 + r\sigma_{1t}^2 + rl\sigma_t^2$
L x T	(l-1) (t-1)	M_3	$\sigma_e^2 + r\sigma_{1t}^2$
Error	(r-1) (h-1)	M_4	σ_e^2
Total	ltr-1	-	-

Where,

L = Number of lines,

T = Number of testers,

H = Number of hybrids,

- R = Number of replications,
 σ^2_1 = GCA variance component of lines,
 σ^2_t = GCA variance component of testers,
 σ^2_{lt} = SCA variance component of hybrids, and
 σ^2_e = Error variance.

From the expectation of mean squares, the covariance between half-sibs (Cov HS) and covariance between full-sibs (Cov FS) were estimated as under:

$$\text{Cov HS} = \frac{M_1 + M_2 - 2M_3}{r(1+t)} = \frac{(t \hat{\sigma}_1^2 + 1 \hat{\sigma}_t^2)}{(1+t)}$$

$$\text{Cov FS} = \frac{1}{3r} \left[(M_1 + M_2 + M_3 - 3M_4) + 6r \text{CovHS} - r(1+t) \text{CovHS} \right]$$

$$= \hat{\sigma}_t^2 + 2 \text{Cov HS}$$

The estimates of Cov HS and Cov FS were used to estimate the variances due to general combining ability ($\hat{\sigma}_{GCA}^2$) and specific combining ability ($\hat{\sigma}_{SCA}^2$) as under:

$$\hat{\sigma}_{GCA}^2 \approx \text{Cov HS}$$

$$\hat{\sigma}_{SCA}^2 \approx \text{Cov FS} - 2 \text{Cov HS}$$

The estimates of variance component due to lines, testers and hybrids were calculated as under:

$$\hat{\sigma}_1^2 = (M_1 - M_3)/rt$$

$$\hat{\sigma}_t^2 = (M_2 - M_3)/rl$$

$$\hat{\sigma}_{lt}^2 = (M_3 - M_4)/r$$

Where,

- σ^2_1 = GCA variance component of lines,
 σ^2_t = GCA variance component of testers,
 σ^2_{lt} = SCA variance component of hybrids, and
 M_1 = Mean square due to lines
 M_2 = Mean square due to testers
 M_3 = Mean square due to L×T

M_4 = Mean square due to error

To judge the significance of estimated variance, following hypothesis was tested;

Ho: $\hat{\sigma}_t^2 = 0$ and F test was used

$F(n_3, n_4) = M_3/M_4$.

If M_3 was significant, then test would be

$F(n_1, n_3) = M_1/M_3$ for $\hat{\sigma}_1^2 = 0$

$F(n_2, n_3) = M_2/M_3$ for $\hat{\sigma}_t^2 = 0$.

If M_3 was non-significant, then M_4 was used as denominator of M_1 and M_2 . Where n_1, n_2, n_3 and n_4 were degrees of freedom associated with M_1, M_2, M_3 and M_4 mean squares, respectively.

3.7.4 General and specific combining ability effects

General combining ability effects of lines and testers and specific combining ability effects of cross combinations were calculated as under:

i) General combining ability effect of lines

$$\hat{g}_i = (Y_{i..}/tr) - (Y_{...}/l t r)$$

Where,

\hat{g}_i = General combining ability effect of i^{th} line

$Y_{...}$ = The total of all hybrids in all replications

$Y_{i..}$ = The total of i^{th} line over all testers and replications

r = Number of replications

l = Number of lines

t = Number of testers

ii) General combining ability effect of testers

$$\hat{g}_j = (Y_{.j.}/l r) - (Y_{...}/l t r)$$

Where,

\hat{g}_j = General combining ability effect of j^{th} tester

$Y_{.j.}$ = The total of j^{th} tester over all lines and replications

iii) Specific combining ability effect of crosses

$$s_{ij} = (Y_{ij.}/r) - (Y_{i..}/tr) - (Y_{.j.}/lr) + Y_{...}/l t r$$

Where,

s_{ij} = Specific combining ability effect of $i \times j^{\text{th}}$ cross

$Y_{ij.}$ = The total of ij^{th} cross combination over all replications

The test of significance of gca and sca effects was done by using critical difference which was calculated as under:

$$SE \hat{g}_i = (Me/rt)^{0.5}$$

$$SE \hat{g}_j = (Me/rl)^{0.5}$$

$$SE s_{ij} = (Me/r)^{0.5}$$

Where,

Me = Error mean square in the analysis of variance

C.D. = SE x t_{0.05} value at error degrees of freedom

RESULTS AND DISCUSSION

IV. RESULTS AND DISCUSSION

The prime goal of any plant breeding programme is to increase yield potential of a crop, which is achieved by manipulating genes for its yield components. Okra [*Abelmoschus esculentus* (L.) Moench] is one of the most important vegetables grown throughout the country. Since, okra is an autogamous but often cross-pollinated crop, the breeding methods suitable for improving the self-pollinated crops can also be employed in this crop. Its fast growth, short duration and photo-insensitive nature enables the geneticist and plant breeder to grow two crops in a year, facilitating quicker genetic improvement. Moreover, its large flower and monadelphous nature of the stamens makes easy for manual crossing for large scale hybrid seed production. Success in seed set is also fairly high. The large numbers of the seeds are borne in a single fruit. Which enables for undertaking the studies on large number of crosses and also for raising sufficient population in F₁ and subsequent generations.

Exploitation of heterosis in okra has been recognized as a practical tool in providing the breeders a means of improving yield and other important traits. The success of hybridization programme mostly depends on the choice of right type parents for hybridization. Further, success in genetic improvement of hybrids depends on the understanding of the nature of inheritance of yield and its component traits as well as identification of parents showing genetic prepotency for yield. This emphasized on the importance of testing the parents for their combining ability because many times the high-yielding parents may not combine well to give good segregation. Combining ability analysis following line x tester technique is frequently being used for testing the performance of lines in various combinations and also for characterizing the nature and magnitude of gene action involved in controlling various quantitative attributes. Besides, GCA helps in selection of superior parents and SCA for superior hybrids. Thus, heterosis and combining ability are basic requirements for a thorough knowledge of genetic architecture of yield and its components.

The present investigation entitled “Heterosis and combining ability in okra [*Abelmoschus esculentus* (L.) Moench]” was undertaken using line × tester analysis with eight lines, three testers and their 24 F₁ hybrids to get information on the

magnitude of heterosis, nature of gene action and combining ability in okra. The results obtained in the present investigation have been presented under following headings:

- 4.1** Analysis of variance for experimental design
- 4.2** Mean performance of parents and hybrids
- 4.3** Manifestation of relative heterosis, heterobeltiosis and standard heterosis
- 4.4** Analysis of variance for combining ability
- 4.5** General and specific combining ability effects

4.1 Analysis of variance for experimental design

The mean squares for 11 different characters are presented in Table 4.1. The mean squares due to genotypes, parents and hybrids (F_1) were highly significant for all the characters. This indicated that considerable amount of genetic variability was present in the material studied and the material were suitable for the study of manifestation of heterosis, combining ability and genetic parameters involved in the inheritance of different traits. The mean squares due to parents *vs.* hybrids were highly significant for plant height, number of branches per plant, days to last picking and total number of seed per fruit at 1%. Whereas, mean squares due to parents *vs.* hybrids significant only 5% for fruit length. Mean squares due to check *vs.* hybrids was also significant for all the characters except fruit length. Fruit length is non-significant for parents, hybrids and check *vs.* hybrids which indicated that considerable amount of genetic variability was not present for particular character.

4.2 Mean performance of parents and their hybrids

The mean values of all the characters studied are presented in Appendix B. Character-wise results of mean performance of parents and their hybrids are as under:

4.2.1 Days to flowering

The parent VRO-22 was the earliest (44.33 days) to flower, while the parent JDNOL-18-2 was late (49.67 days) in flowering. The cross JOL-75-5 x Pusa Sawani was earlier (with 41.33 days) in flowering whereas, JDNOL-18-2 x GAO-5 (51.33 days) were late in flowering. Overall mean for parents was 47.06 days and for crosses, it was 46.88 days.

Table 4.1. Analysis of variance for experimental design in respect to eleven characters in okra

Source of variation	d.f.	Days to flowering	Days to first picking	Fruit length	Fruit girth	Number of branches per plant	Inter-nodal length	Plant height	Days to last picking	Total number of seed per fruit	Total no. of fruits per plant	Total fruit yield Per plant
Replications	2	2.68	8.03	0.19	0.59	0.00	0.11	13.56	6.56	2.97	2.21	482.24
Genotypes	35	16.20**	13.60**	0.93*	1.49**	0.08**	1.03**	126.74**	36.69**	55.69**	11.66**	2762.76**
Parents	10	8.05**	8.81**	0.95	1.67**	0.08**	0.72**	54.78**	19.65**	33.91**	12.81**	2609.20**
Hybrids	23	20.46**	15.68**	0.79	1.28**	0.09**	1.09 **	146.81**	44.75**	48.28**	11.29**	2880.84**
Parent vs. Hybrid	1	0.78	7.18	3.01*	0.86	0.07**	0.02	79.88**	36.65**	214.86**	2.06	481.75
Check vs. Hybrid	1	14.99*	20.15**	1.96	5.26**	0.10**	3.68**	431.46**	21.79**	284.76**	18.06**	3863.38**
Error	70	2.63	2.55	0.58	0.22	0.01	0.04	8.32	2.21	1.08	1.02	184.81

*,** Significant at P=0.01 and P=0.05, respectively

4.2.2 Days to first picking

The parent VRO-22 was the earliest (48.33 days) to first picking, while the parent JDNOL-18-2 was late (53.67 days) in first picking. The crosses, Parbhani Kranti x GAO-6 was earlier (with 46.67 days) in first picking, whereas, the cross JDNOL-18-2 x GAO-5 (54.67 days) was late in first picking. Overall mean for parents was 50.91 days and for crosses, it was 51.47 days.

4.2.3 Plant height (cm)

The parent GAO-5 was tallest (78.90 cm) and parent Parbhani Kranti was shortest (63.64 cm). Mean performance for hybrids varied from 61.93 cm (Parbhani Kranti x GAO-6) to 88.45 cm (VRO-6 x GAO-5). Overall mean for plant height of hybrids (72.91 cm) was higher than the parents (71.04 cm).

4.2.4 Number of branches per plant

The mean values of number of branches per plant for parents ranged from 1.75 (NLO-17-9) to 2.35 (Arka Anamika). The range for hybrids was 1.71 (NLO-17-9 x Pusa Sawani) & (NLO-17-9 x GAO-5) to 2.40 (Arka Anamika x GAO-6). Overall mean for parents and hybrids were 2.05 and 1.99, respectively for number of branches per plant.

4.2.5 Total number of seed per fruit

The parent JOL-75-5 had the highest (40.63), while GAO-6 expressed the lowest (30.27) number of seed per fruit. The range in hybrids was from 33.17 (VRO-22 x GAO-6) to 47.53 (JOL-75-5 x Pusa Sawani). General mean of parents and hybrids was 36.54 and 39.62, respectively for this trait.

4.2.6 Internodal length (cm)

Parental means for internodal length varied from 3.41 cm (JOL-75-5) to 5.04 cm (NLO-17-9) and mean values for hybrids ranged from 3.36 cm (Parbhani Kranti x GAO-6) to 5.76 cm (NLO-17-9 x Pusa Sawani). Overall mean for parents was 4.22 cm and for crosses, it was 4.26 cm. Shorter internodal length is considered as desirable than longer one.

4.2.7 Number of fruits per plant

Among the parents, JOL-16-06 exhibited the lowest (16.10) number of fruits per plant, while Parbhani Kranti had the highest (23.65) number of fruits per plant. Mean performance of hybrids varied from 16.70 (JOL-16-06 x Pusa Sawani) to 25.48 (Parbhani Kranti x GAO-6). An overall mean for parents was lower (20.60) than the hybrids (20.90).

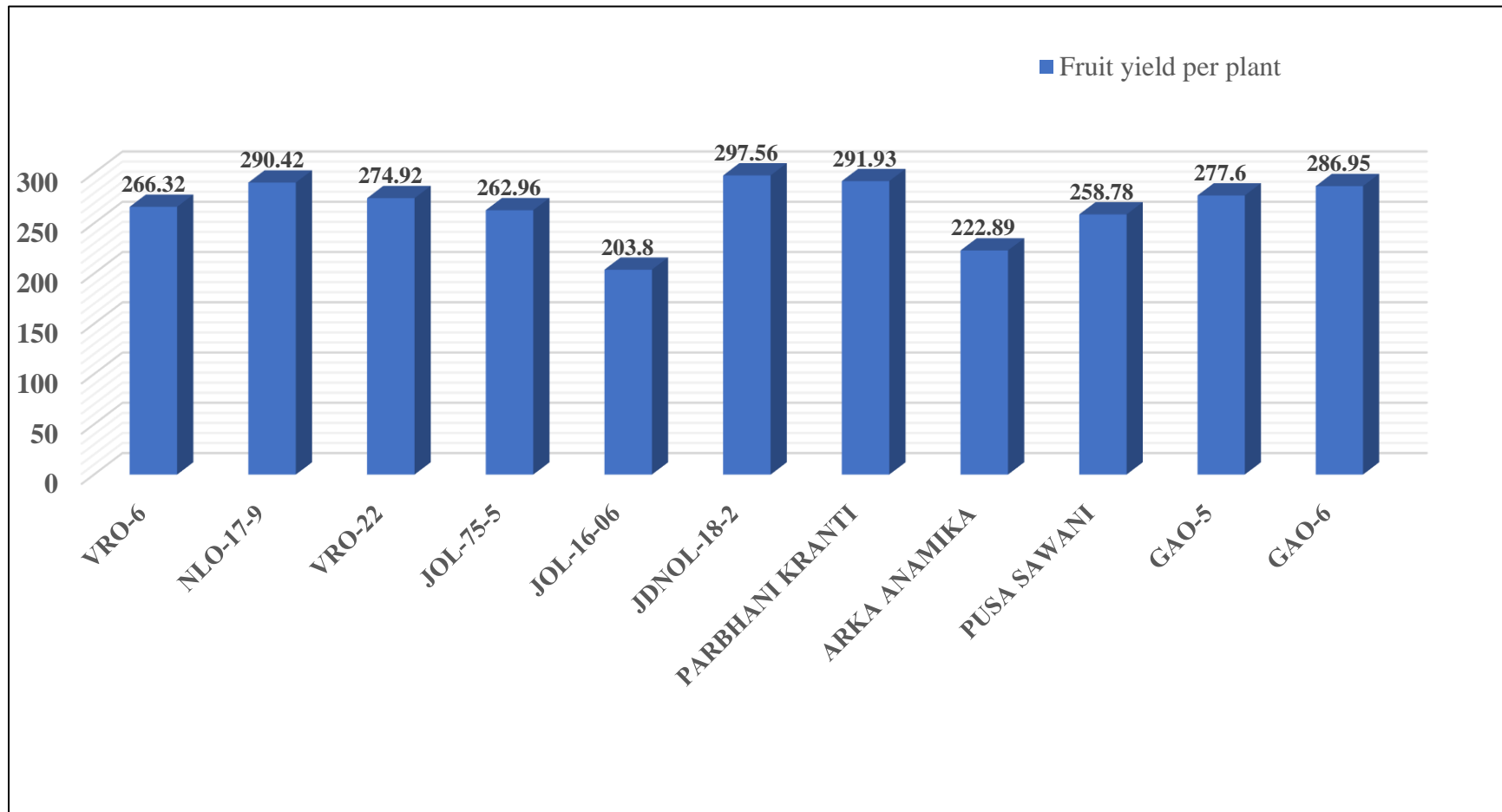


Fig. 4.1. Graphical representation of *per se* performance of parents for fruit yield per plant(g)

4.2.8 Fruit length (cm)

For fruit length, parents ranged from 10.33 cm (VRO-6) to 12.35 cm (GAO-6). Among the hybrids, the shortest fruit length (11.17 cm) was recorded by Parbhani Kranti x GAO-5 and the longest (13.55 cm) by JDNOL-18-02 x Pusa Sawani. On an average, fruit length in cross was longer (11.92 cm) than the parent (11.56 cm).

4.2.9 Fruit girth (cm)

Fruit girth varied from 4.55 cm (VRO-22) to 6.68 cm (Parbhani Kranti) in parents, whereas in crosses it ranged from 4.75 cm (JOL-16-06 x Pusa Sawani) to 7.18 cm (Parbhani Kranti x GAO-6). An overall mean was 5.54 cm and 5.74 cm for parents and hybrids, respectively.

4.2.10 Fruit yield per plant (g)

The parent JOL-16-06 manifested the lowest (203.80 g) and JDNOL-18-2 registered the highest (297.56 g) fruit yield per plant. Among the crosses, the cross combinations JOL-16-06 x Pusa Sawani recorded the lowest (204.05 g) yield per plant whereas, the hybrids Parbhani Kranti x GAO-6 expressed the highest (335.21 g) yield per plant. An overall mean of hybrids was higher (271.36 g) than the parents (266.74 g).

4.2.11 Days to last picking

The parent VRO-6 was the earliest (108.33 days) to last picking, while the parent JDNOL-18-2 was late (116.33 days) in last picking. The crosses, JOL-75-5 x Pusa Sawani was earlier (104.33 days) in last picking, whereas, the cross JDNOL-18-2 x GAO-6 (116.67 days) was late in last picking. Overall mean for parents was 111.61 days and for crosses, it was 110.33 days.

A perusal of data on mean values (Appendix B) revealed wide variation among the parents and also among the hybrids for all the characters. Similarly, wide difference observed between the mean value of parents and hybrids indicated the presence of considerable genetic diversity among parents and remarkable heterosis in the hybrids. For any hybrid to be acceptable for commercial purpose, it should possess significant superiority in fruit yield and other attributes over the best existing hybrids. Hence, in the present study, the performance of resultant hybrids was compared with GJOH-4. Mean values of parents and their cross combinations for various traits (Appendix B) revealed that several hybrids exceeded GJOH-4 in respect of fruit yield and various yield attributing characters. Considering *per se* performance of hybrids, Parbhani Kranti × GAO-6 recorded higher fruit yield per

plant than GJOH-4. The best *per se* performing hybrid for fruit yield per plant are given in Table 5.2. The cross combinations, NLO-17-9 x GAO-6, Parbhani Kranti x GAO-5, JOL-75-5 x Pusa Sawani and Arka Anamika × GAO-6 had high *per se* performance for fruit yield per plant. These crosses also manifested significant and desirable heterotic effects for one or more yield contributing traits.

4.3 Manifestation of relative heterosis, heterobeltiosis and standard heterosis

For a successful heterosis breeding programme in any crop, there are two important pre-requisites, first, there must be ample evidence of the presence of significant heterotic effect in the hybrids that can really be of practical utility and second, the production of economically feasible hybrid seed at the commercial scale. This is possible either through use of suitable male sterility systems (maintenance and restoration) or cheaper techniques to produce hybrids seed. Cotton is a unique example in which successful exploitation of hybrid vigour, in the absence of male sterility system made feasible by hand emasculation and pollination. Likewise, okra also belongs to family *malvaceae* having similar floral structure like cotton; hence there are enough chances to exploit heterosis on commercial scale.

The extent of heterosis expressed as per cent increase or decrease in the hybrids was obtained over mid parent (relative heterosis), better parent (heterobeltiosis) as well as over check variety (standard heterosis) for all the traits. The character-wise results pertaining to relative heterosis, heterobeltiosis and standard heterosis are presented as under:

4.3.1 Days to flowering

The relative heterosis range from -10.47 per cent (JOL-75-5 x Pusa Sawani) to 8.03 per cent (JOL-16-06 x Pusa Sawani). Five hybrids expressed the negative and significant relative heterosis for days to flowering.

Heterobeltiosis was calculated by taking earlier parent as better parent. The mean heterobeltiosis was range from -10.14% (JOL-75-5 x Pusa Sawani) to 10.37% (JOL-16-06 x GAO-5). The estimate of better parent heterosis was significant and negative (desirable) in six crosses while, two crosses observed to be significant heterosis and positive for days to flowering.

Standard heterosis for days to flowering ranged from -7.46% (JOL-75-5 x Pusa Sawani) to 14.93% (JDNOL-18-2 x GAO-5). Total 13 crosses showed significant and positive heterosis and only one cross showed significant and negative heterosis

(earlier) for days to flowering. Heterosis for earliness in okra was reported by Tripathi *et al.* (2004), Yadav *et al.* (2007), Kumar and Sreeparvathy (2010), Madgam *et al.* (2012), Paul (2013), Reddy *et al.* (2013) and Prakash *et al.* (2019).

4.3.2 Days to first picking

The relative heterosis range from -5.54 per cent (JOL-75-5 x GAO-5) to 7.59 per cent (Parbhani Kranti x GAO-5). Three hybrids expressed the negative and significant relative heterosis while, in five crosses observed to significant and positive for days to first picking.

Heterobeltiosis was calculated by taking earlier parent as better parent. The heterobeltiosis was range from -4.00% (JOL-75-5 x Pusa Sawani) to 11.64% (Parbhani Kranti x GAO-5). The estimate of better parent heterosis was significant and negative (desirable) in five crosses while, in one cross observed to significant and positive for days to first picking.

Standard heterosis for days to first picking ranged from -2.74% (Parbhani Kranti x GAO-6) to 12.33% (JDNOL-18-2 x GAO-5). None of the cross was found significant and negative direction for standard parent heterosis. While, 14 crosses exhibited significant and positive direction for days to first picking. Heterosis for earliness was earlier reported by Gajera and Vaddoriya (2014), Pathak and Prabhat (2014).

4.3.3 Fruit length

The relative heterosis range from -3.97 per cent (Arka Anamika x Pusa Sawani) to 13.75 per cent (JDNOL-18-2 x Pusa Sawani). Two crosses expressed the positive and significant relative heterosis while, none of the cross observed to significant and negative for fruit length.

Heterobeltiosis for fruit length ranged from -9.59% (Parbhani Kranti x GAO-5) to 11.53% (JDNOL-18-2 x Pusa Sawani). Only one cross had significant and positive heterosis over better parent for fruit length. While, none of the cross had significant and negative over better parent heterosis.

Standard heterosis range for this character was recorded from -11.54% (Parbhani Kranti x GAO-5) to 7.36% (JDNOL-18-2 X Pusa Sawani). None of the cross had significant and positive heterosis over standard heterosis. While, four crosses had significant and negative heterosis over standard heterosis. Above pronounced results regarding fruit length have been noticed by Hosamani *et al.*

(2008), Kumar and Sreeparvathy (2010), Khatik *et al.* (2012), Paul (2013), Kumar *et al.* (2013), Badiger *et al.* (2014) and Tiwari *et al.* (2015).

4.3.4 Fruit girth

The relative heterosis range from -18.45 per cent (JDNOL-18-2 x Pusa Sawani) to 23.32 per cent (NLO-17-9 x GAO-6). Only one cross expressed the negative and significant relative heterosis while, in three crosses observed to significant and positive for number of fruits per plant.

As regards to heterobeltiosis, nine crosses depicted significant and negative heterobeltiosis over their better parent, whereas, none of crosses showed significant and positive heterobeltiosis. The crosses JDNOL-18-2 X Pusa Sawani showed minimum significant and negative heterobeltiosis (-20.75%) followed by JOL-16-06 x Pusa Sawani (-18.63) for fruit girth.

The standard heterosis ranged from -32.35% (JOL-16-06 x Pusa Sawani) to 2.38% (Parbhani Kranti X GAO-6). Total 20 crosses showed significant and negative heterosis, while none of the crosses showed significant and positive heterosis over check variety for fruit girth. The present finding is in agreement with the findings of Pawar *et al.* (1999), Bhalekar *et al.* (2004), Tripathi *et al.* (2004), Yadav *et al.* (2007), Kumar and Sreeparvathy (2010), Paul (2013), Gavint *et al.* (2017), Makdoomi *et al.* (2018) and Hadiya *et al.* (2018^a).

4.3.5 Number of branches per plant

The relative heterosis range from -14.84 per cent (JDNOL-18-2 x GAO-5) to 7.15 per cent (Arka Anamika x GAO-6). Seven hybrids expressed the negative and significant relative heterosis while, in only one cross observed to significant and positive for number of branches per plant.

The heterobeltiosis was range from -18.02% (NLO-17-9 x Pusa Sawani) to 2.13% (Arka Anamika x GAO-6) for number of branches per plant. None of the crosses exhibit significant and positive direction while, 11 crosses observed to be significant and negative heterosis for number of branches per plant.

Standard heterosis for number of branches per plant ranged from -21.77% (NLO-17-9 x Pusa Sawani) & (NLO-17-9 x GAO-5) to 9.44% (Arka Anamika x GAO-6). Seventeen crosses exhibit significant and negative direction heterosis over standard check. While, only one cross exhibited significant and positive direction for number of branches per plant. Same type of findings for number of branches per plant in okra have been reported earlier by many researchers, Tripathi *et al.* (2004),

Desai *et al.* (2007), Kumar and Sreeparvathy (2010), Khatik *et al.* (2012), Paul (2013), Medagam *et al.* (2012), Kumar *et al.* (2013), Badiger *et al.* (2014), Tiwari *et al.* (2015), Hadiya *et al.* (2018) and Prakash *et al.* (2019).

4.3.6 Internodal length

The relative heterosis range from -17.26 per cent (NLO-17-9 x GAO-6) to 19.00 per cent (NLO-17-9 x Pusa Sawani). Eight hybrids expressed the positive and significant relative heterosis while, in eight crosses observed to significant and negative for internodal length.

As regards to heterobeltiosis, eight crosses depicted significant and negative heterobeltiosis over their better parent, whereas five crosses showed significant and positive heterobeltiosis. The extent of heterosis over the better parent ranged from -12.27% (Parbhani Kranti x GAO-6) to 29.49% (JOL-75-5 x Pusa Sawani).

The standard heterosis ranged from -37.43% (Parbhani Kranti x GAO-6) to 7.32% (NLO-17-9 x Pusa Sawani). Significant and positive heterosis over standard check was noticed in only one cross and significant and negative heterosis (desirable) was noticed in 22 crosses. Heterosis for internodal length in okra in desired direction (significant and negative) was reported by Rewale *et al.* (2003), Tripathi *et al.* (2004), Desai *et al.* (2007), Kumar and Sreeparvathy (2010), Khatik *et al.* (2012), Paul (2013), Kumar *et al.* (2013), Nagesh *et al.* (2014), Badiger *et al.* (2014) and Tiwari *et al.* (2015).

4.3.7 Plant height

The relative heterosis range from -12.24 % (Parbhani Kranti x GAO-5) to 17.16% (VRO-6 x GAO-5). Four hybrids expressed the negative and significant relative heterosis while, in seven crosses observed to be significant and positive for plant height.

The heterobeltiosis was range from -3.58% (JOL-75-5 x Pusa Sawani) to 22.69% (VRO-6 x GAO-5). The estimates of better parent heterosis was significant and positive direction in seven crosses while, four crosses observed to be significant and negative heterosis for plant height.

Standard heterosis for plant height ranged from -26.70% (Parbhani Kranti x GAO-6) to 4.69% (VRO-6 x GAO-5). None of the cross estimate of standard heterosis was significant and positive direction. While, 20 crosses exhibit significant and negative direction for plant height. Heterosis for plant height in okra in desired direction (significant and negative) was reported by Rewale *et al.* (2003),

Table 4.2: Estimation of relative heterosis(H_1), heterobeltiosis (H_2) and standard heterosis (H_3) in percentage for days flowering, days to first picking and fruit length

Hybrids	Days to flowering			Days to first picking			Fruit length		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
VRO-6 × Pusa Sawani	-7.14**	-6.47**	-2.99	-4.26	-3.31*	0.00	7.37	-0.67	-4.39
VRO-6 × GAO-5	-4.93*	-4.26*	0.75	-2.60	-0.66	2.74	9.92*	2.30	-2.84
VRO-6 × GAO-6	4.96*	4.96	10.45**	4.29	4.64	8.22**	4.42	-4.10	-6.17
NLO-17-9 × Pusa Sawani	3.50	6.47	10.45**	3.21	4.55	10.27**	-2.13	-3.74	-7.34
NLO-17-9 × GAO-5	0.69	2.10	8.96**	1.59	1.91	9.59**	-3.65	-4.59	-9.38
NLO-17-9 × GAO-6	2.08	4.26	9.70**	4.52*	6.58	10.96**	-3.83	-6.16	-8.18
VRO-22 × Pusa Sawani	4.41	6.77	5.97*	3.01	6.21	5.48*	0.59	-1.67	-5.35
VRO-22 × GAO-5	-2.90	0.75*	0.00	-1.32	2.76*	2.05	5.89	4.20	-1.04
VRO-22 × GAO-6	-4.38	-1.50*	-2.24	0.34	2.76	2.05	2.78	-0.33	-2.48
JOL-75-5 × Pusa Sawani	-10.47**	-10.14**	-7.46*	-5.26*	-4.00*	-1.37	4.30	1.48	-2.31
JOL-75-5 × GAO-5	-5.34*	-3.62*	-0.75	-5.54*	-3.33**	-0.68	3.04	0.91	-4.17
JOL-75-5 × GAO-6	3.23	4.35	7.46*	5.30*	6.00	8.90**	3.34	-0.26	-2.41
JOL-16-06 × Pusa Sawani	8.03**	9.63*	10.45**	5.61*	7.38	9.59**	0.60	-2.97	-6.60
JOL-16-06 × GAO-5	7.19**	10.37	11.19**	5.88**	8.72	10.96**	2.65	-0.38	-5.39
JOL-16-06 × GAO-6	-1.45	0.74	1.49	-0.33	0.67	2.74	-1.41	-5.64	-7.67
JDNOL-18-2 × Pusa Sawani	-0.69	2.88	6.72*	-2.22	0.00	5.48*	13.75**	11.53*	7.36
JDNOL-18-2 × GAO-5	5.48*	7.69	14.93**	3.14	4.46	12.33**	2.79	1.47	-3.63
JDNOL-18-2 × GAO-6	2.07	4.96	10.45**	1.60	4.61	8.90**	-0.76	-3.49	-5.57
Parbhani Kranti × Pusa Sawani	-4.29	-3.60	0.00	-1.33	1.37	1.37	-1.80	-6.60	-10.09*
Parbhani Kranti × GAO-5	2.11	2.84	8.21**	7.59**	11.64	11.64**	-2.67	-9.59	-11.54*
Parbhani Kranti × GAO-6	-7.80**	-7.80**	-2.99	-4.70*	-2.74*	-2.74	-3.90	-9.31	-11.27*
Arka Anamika × Pusa Sawani	-2.46	0.00	3.73	-4.18	-3.25*	2.05	-3.97	-6.44	-9.94*
Arka Anamika × GAO-5	-3.11	-2.10	4.48	0.00	0.00	7.53**	-1.77	-3.68	-8.53
Arka Anamika × GAO-6	2.44	4.26	9.70**	4.21	5.92	10.27**	0.75	-2.62	-4.72
Minimum	-10.47	-10.14	-7.46	-5.54	-4.0	-2.74	-3.97	-9.59	-11.54
Maximum	8.03	10.37	14.93	7.59	11.64	12.33	13.75	11.53	7.36
S.Em.±	1.13	1.30	1.30	1.13	1.30	1.30	0.55	0.63	0.63
No. of positive significant cross	4	2	13	5	1	14	2	1	0
No. of negative significant cross	2	6	1	3	5	0	0	0	4

Table 4.3: Estimation of relative heterosis (H_1), heterobeltiosis (H_2) and standard heterosis (H_3) in percentage for fruit girth, number of branches per plant and internodal length

Hybrids	Fruit girth			Number of branches per plant			Internodal length		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
VRO-6 × Pusa Sawani	9.53	-0.17	-17.01**	-2.68	-7.18*	-11.42**	-0.62	1.34	-15.70**
VRO-6 × GAO-5	7.59	-4.66	-15.53**	-12.68**	-16.40**	-20.85**	11.65**	14.72*	-9.56**
VRO-6 × GAO-6	-2.82	-14.47*	-23.04**	-0.75	-6.11	-8.83**	8.94*	14.25	-13.41**
NLO-17-9 × Pusa Sawani	4.03	-2.57	-19.00**	-10.84**	-18.02**	-21.77**	19.00**	24.12**	7.32*
NLO-17-9 × GAO-5	-8.64	-16.89**	-26.37**	-10.45**	-17.36**	-21.77**	7.51*	17.80	-7.14*
NLO-17-9 × GAO-6	23.32**	11.40	0.24	4.30	-4.86	-7.61**	-17.26**	-7.37**	-29.80**
VRO-22 × Pusa Sawani	10.56	-1.60	-18.19**	-3.91	-3.99	-8.37*	1.21	10.54	-19.30**
VRO-22 × GAO-5	-1.05	-14.32*	-24.09**	-7.21*	-7.51*	-11.87**	13.25**	17.77*	-14.03**
VRO-22 × GAO-6	-2.98	-16.53**	-24.89**	2.37	1.41	-1.52**	2.21	4.17	-23.96**
JOL-75-5 × Pusa Sawani	-5.66	-7.66	-23.23**	-2.80	-3.19	-7.61	9.72**	29.49	-17.69**
JOL-75-5 × GAO-5	-3.13	-8.04	-18.53**	-1.61	-1.61	-6.85*	-4.97	6.45**	-32.34**
JOL-75-5 × GAO-6	-3.25	-8.82	-17.96**	0.32	-0.94	-3.81*	13.85**	24.80	-20.67**
JOL-16-06 × Pusa Sawani	-10.38	-18.63**	-32.35**	-8.75**	-14.35**	-18.26	-1.65	2.90	-18.56**
JOL-16-06 × GAO-5	-7.14	-18.02**	-27.36**	-0.34	-6.11	-11.11**	0.90	1.10	-20.30**
JOL-16-06 × GAO-6	-2.65	-14.63*	-23.18**	3.20	-3.92	-6.70**	0.88	3.11	-21.85**
JDNOL-18-2 × Pusa Sawani	-18.45**	-20.75**	-30.17**	-12.13**	-12.76**	-16.74*	-15.01	-5.21**	-33.40**
JDNOL-18-2 × GAO-5	-4.84	-5.09	-15.91**	-14.84**	-15.11**	-19.63**	-10.49**	-5.04**	-33.27**
JDNOL-18-2 × GAO-6	-1.15	-2.16	-11.97*	-0.80	-2.35	-5.18**	-10.84**	-7.33**	-34.89**
Parbhani Kranti × Pusa Sawani	13.96*	6.74	1.62	-2.34	-4.43	-4.72	-11.88**	-2.52**	-30.48**
Parbhani Kranti × GAO-5	-1.32	-4.74	-9.31	-4.46	-6.87*	-7.15	-9.30*	-4.53**	-31.91**
Parbhani Kranti × GAO-6	10.57*	7.53	2.38	1.47	0.15	-0.15*	-14.94**	-12.27**	-37.43**
Arka Anamika × Pusa Sawani	4.28	-3.83	-20.05**	-3.98	-9.23**	-2.74	0.99	2.94	-10.99**
Arka Anamika × GAO-5	-6.49	-16.19*	-25.75**	-4.68	-10.23**	-3.81	14.69**	22.68*	-3.29
Arka Anamika × GAO-6	1.78	-9.40	-18.48**	7.15**	2.13	9.44**	-9.60**	-1.23**	-25.14**
Minimum	-18.45	-20.75	-32.35	-14.84	-18.02	-21.77	-17.26	-12.27	-37.43
Maximum	23.32	11.40	2.38	7.15	2.13	9.44	19.00	29.49	7.32
S.Em.±	0.33	0.38	0.38	0.06	0.07	0.07	0.15	0.17	0.17
No. of positive significant cross	3	0	0	1	0	1	8	5	1
No. of negative significant cross	1	9	20	7	11	17	8	8	22

Table 4.4: Estimation of relative heterosis (H_1), heterobeltiosis (H_2) and standard heterosis (H_3) in percentage for plant height, fruit yield per plant and total number of fruits per plant.

Hybrids	Plant height			Fruit yield per plant			Total number of fruits per plant		
	H_1	H_2	H_3	H_1	H_2	H_3	H_1	H_2	H_3
VRO-6 × Pusa Sawani	0.07	0.26	-14.78**	1.69	0.25	-12.84**	2.70	1.88	-8.70*
VRO-6 × GAO-5	17.16**	22.69**	4.69	-1.19	-3.19	-12.26**	-1.70	-5.43	-8.30*
VRO-6 × GAO-6	7.94**	8.42*	-8.31**	-2.31	-5.82	-11.77**	-0.98	-2.80	-9.57**
NLO-17-9 × Pusa Sawani	14.59**	14.81**	-2.41	0.99	-4.51	-9.46*	3.78	3.78	-8.47*
NLO-17-9 × GAO-5	-0.35	4.36	-10.96**	-0.41	-2.61	-7.66*	-4.06	-8.40*	-11.18**
NLO-17-9 × GAO-6	-3.62	-3.19	-18.13**	6.40	5.77	0.28	11.70**	8.80*	1.22
VRO-22 × Pusa Sawani	5.77*	6.52	-9.46**	4.24	1.18	-9.18*	4.76	1.41	-10.56**
VRO-22 × GAO-5	10.64**	15.25*	-0.65	-10.17**	-10.60**	-18.98**	-2.22	-9.49*	-12.24**
VRO-22 × GAO-6	4.87	5.88	-10.46**	-4.65	-6.65	-12.54**	-0.28	-5.89	-12.45**
JOL-75-5 × Pusa Sawani	-5.51	-3.58*	-21.26**	17.91**	16.97**	0.42	-0.19	-3.37	-14.78**
JOL-75-5 × GAO-5	-0.32	6.83*	-12.76**	0.70	-1.96	-11.14**	1.58	-5.96	-8.82*
JOL-75-5 × GAO-6	6.67*	8.57	-11.34**	-0.36	-4.53	-10.56**	2.13	-3.61	-10.33**
JOL-16-06 × Pusa Sawani	3.52	3.60	-11.94**	-11.78**	-21.15**	-33.38**	-8.85*	-18.71**	-28.31**
JOL-16-06 × GAO-5	4.04	9.08	-7.13*	-11.72**	-23.45**	-30.62**	-10.05*	-22.96**	-25.30**
JOL-16-06 × GAO-6	-2.65	-2.33	-17.40**	-16.37**	-28.49**	-33.00**	-2.92	-15.40**	-21.29**
JDNOL-18-2 × Pusa Sawani	-3.40	2.42*	-22.32**	3.89	-2.88	-5.65	8.77**	4.16	0.37
JDNOL-18-2 × GAO-5	-6.96*	3.80**	-21.27**	-6.30	-9.45*	-12.03**	-5.92	-6.21	-9.06*
JDNOL-18-2 × GAO-6	-0.05	5.70	-19.83**	-7.91	-9.55*	-12.13**	-4.42	-6.07	-9.49**
Parbhani Kranti × Pusa Sawani	-7.72*	-1.79**	-26.02**	2.43	-3.39	-7.92*	-5.36	-11.58**	-10.22**
Parbhani Kranti × GAO-5	-12.24**	-1.72**	-25.97**	2.51	-0.01	-4.70	-4.70	-6.85	-5.41
Parbhani Kranti × GAO-6	-8.32**	-2.69**	-26.70**	15.81**	14.83**	9.44*	12.45**	7.74*	9.40**
Arka Anamika × Pusa Sawani	-0.50	0.73	-14.38**	8.96*	1.40	-14.33**	1.22	-0.86	-12.56**
Arka Anamika × GAO-5	5.99*	9.81	-4.36	6.94	-5.01	-13.91**	-12.66**	-18.24**	-20.72**
Arka Anamika × GAO-6	-1.65	-0.19	-15.58**	20.31**	6.89	0.13	12.77**	7.64*	0.14
Minimum	-12.24	-3.58	-26.70	-16.37	-28.49	-33.38	-12.66	-22.96	-28.31
Maximum	17.16	22.69	4.69	20.31	16.97	9.44	12.77	8.80	9.40
S.Em.±	2.07	2.39	2.39	9.73	11.24	11.24	0.72	0.83	0.83
No. of positive significant cross	7	7	0	4	2	1	4	3	1
No. of negative significant cross	4	4	20	4	6	18	3	7	19

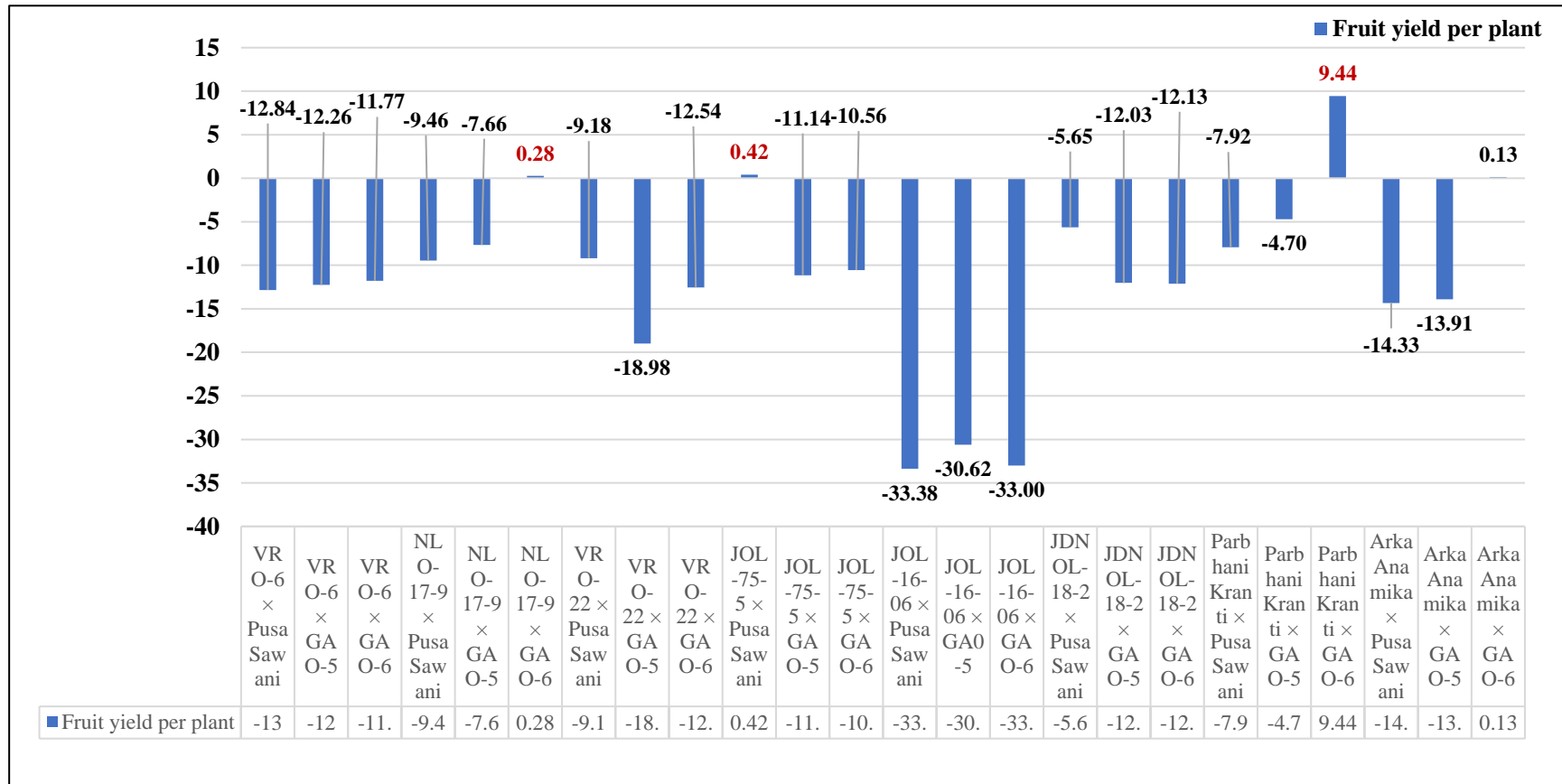


Fig.4.2. Graphical representation of Standard Heterosis (%) of hybrids for fruit yield per plant

Tripathi *et al.* (2004), Desai *et al.* (2007), Khanpara *et al.* (2009), Kumar and Sreeparvathy (2010), Raghuvanshi *et al.* (2011), Khatik *et al.* (2012), Paul (2013), Kishor *et al.* (2013), Kumar *et al.* (2013), Nagesh *et al.* (2014), Badiger *et al.* (2014) and Tiwari *et al.* (2015).

4.3.8 Fruit yield per plant

The relative heterosis range from -16.37 per cent (JOL-16-06 x GAO -6) to 20.31 per cent (Arka Anamika x GAO-6). Four crosses expressed the positive and significant relative heterosis while, in four crosses observed to significant and negative for number of fruit yield per plant.

Fruit yield is the attribute of economic importance. Hence, attempts of breeder are in the direction of breeding varieties with high fruit yield. The heterobeltiosis for fruit yield per plant ranged from -28.49% (JOL-16-06 x GAO-6) to 16.97% (JOL-75-5 x Pusa Sawani). Two crosses showed significant and positive heterobeltiosis for fruit yield per plant.

As, a regarded to standard heterosis, 18 hybrids showed significant and negative heterosis, with a ranged from -33.38% (JOL-16-06 x Pusa Sawani) to 9.44% (Parbhani Kranti x GAO-6). Only one cross showed significant and positive standard heterosis for fruit yield per plant. Positive heterosis for fruit yield per plant was observed by Pawar *et al.* (1999), Nichal *et al.* (2000), Saha and Kabir (2001), Singh *et al.* (2002), Rewale *et al.* (2003^a), Bhalekar *et al.* (2004), Tripathi *et al.* (2004), Vachhani *et al.* (2011), Khatik *et al.* (2012), Kumar *et al.* (2013), Paul (2013), Badiger *et al.* (2014), Gajera and Vaddoriya (2014), Katagi *et al.* (2015), Tiwari *et al.* (2015), Patel and Patel (2016), Gavint *et al.* (2017), Hadiya *et al.* (2018^a), Makdoomi *et al.* (2018) and Prakash *et al.* (2019).

4.3.9 Total number of fruits per plant

The relative heterosis range from -12.66 % (Arka Anamika x GAO-5) to 12.77 % (Arka Anamika x GAO-6). Four crosses expressed the positive and significant relative heterosis while, in three crosses observed to significant and negative for number of fruits per plant.

Out of 24 crosses, seven crosses showed significant and negative heterobeltiosis with range from -22.96% (JOL-16-06 x GAO-5) to 8.80% (NLO-17-9 x GAO-6). Three crosses showed significant and positive heterobeltiosis for number of fruits per plant.

Standard heterosis ranged from -28.31% (JOL-16-06 x Pusa Sawani) to 9.40% (Parbhani Kranti x GAO-6). Total 19 crosses showed significant and negative heterosis, while only one cross showed significant and positive heterosis over check variety for number of fruits per plant. Numerous workers including Rewale *et al.* (2003^a), Bhalekar *et al.* (2004), Tripathi *et al.* (2004), Desai *et al.* (2007), Kumar and Sreeparvathy (2010), Vachhani *et al.* (2011), Khatik *et al.* (2012), Kumar *et al.* (2013), Paul (2013), Medagam *et al.* (2012), Badiger *et al.* (2014), Katagi *et al.* (2015), Patel and Patel (2016), Satish *et al.* (2017) and Makdoomi *et al.* (2018) observed positive heterosis for number of fruits per plant in okra.

4.3.10 Total number of seed per fruit

The relative heterosis range from -0.39 per cent (VRO-22 x GAO-5) to 27.53 per cent (NLO-17-9 x Pusa Sawani). Total 19 hybrids expressed the positive and significant relative heterosis while, in none of cross observed to significant and negative for number of seed per fruit.

The estimate of better parent heterosis was significant and positive direction in eight crosses. The cross NLO-17-9 x Pusa Sawani recorded the highest heterobeltiosis (22.48%) in positive direction. The two crosses had significant and negative better parent heterosis. The lowest heterobeltiosis was registered by the cross JOL-16-06 x GAO-6 (-6.1%) for number of seed per fruit. The present findings are in close association with results reported by Dhankhar *et al.* (1996), Nichal *et al.* (2000), Mehta *et al.* (2007), Singh *et al.* (2009), Khanpara *et al.* (2009), Dabhi *et al.* (2010), Paul (2013), Nagesh *et al.* (2014) and Badiger *et al.* (2014) for relative heterosis and heterobeltiosis.

The extent of heterosis over the standard check ranged from -31.66% (VRO-22 x GAO-6) to -2.06% (JOL-75-5 x Pusa Sawani). None of cross exhibited significant and positive standard heterosis and 23 crosses depicted significant and negative heterosis over standard check for number of seed per fruit.

4.3.11 Days to last picking

The relative heterosis range from -5.71 per cent (Parbhani Kranti x GAO-6) to 4.05 per cent (NLO-17-9 x GAO-6). Total 11 crosses expressed the negative and significant relative heterosis while, in five crosses observed to significant and positive for days to last picking.

Table 4.5: Estimation of relative heterosis (H_1), heterobeltiosis (H_2) and standard heterosis (H_3) in percentage for total numbers of seed per fruit and days to last picking

Hybrids	Total number of seed per fruit			Days to last picking		
	H_1	H_2	H_3	H_1	H_2	H_3
VRO-6 × Pusa Sawani	11.53**	3.51	-14.97**	-2.30*	-2.74 *	-1.54
VRO-6 × GAO-5	3.11	-3.01	-20.33**	-3.92**	-5.90**	-1.54
VRO-6 × GAO-6	8.17**	-4.85*	-21.84**	0.77	0.30	1.54
NLO-17-9 × Pusa Sawani	27.53**	22.48**	-6.46**	1.65	0.00	4.63**
NLO-17-9 × GAO-5	1.85	-0.81	-24.24**	2.95**	2.95**	7.72**
NLO-17-9 × GAO-6	14.65**	4.14	-20.47**	4.05**	2.36*	7.10**
VRO-22 × Pusa Sawani	6.91**	4.30	-26.65**	-2.13*	-2.42*	-0.62
VRO-22 × GAO-5	-0.39	-4.17	-30.63**	-2.54**	-3.83**	0.62
VRO-22 × GAO-6	5.74*	2.16	-31.66**	-3.65**	-3.94**	-2.16
JOL-75-5 × Pusa Sawani	27.15**	16.98**	-2.06	-5.58**	-6.57**	-3.40**
JOL-75-5 × GAO-5	15.44**	7.63**	-9.89**	-2.08*	-2.65*	1.85
JOL-75-5 × GAO-6	18.10**	3.04	-13.74**	3.77**	2.69*	6.17**
JOL-16-06 × Pusa Sawani	9.14**	7.04**	-21.70**	1.49	-0.87	5.25**
JOL-16-06 × GAO-5	1.37	0.85	-26.24**	-0.73	-1.45	4.63**
JOL-16-06 × GAO-6	1.37	-6.10*	-31.32**	-2.98**	-5.23**	0.62
JDNOL-18-2 × Pusa Sawani	12.53**	7.26**	-16.76**	-3.10**	-6.02**	1.23
JDNOL-18-2 × GAO-5	6.50**	2.92	-20.12**	0.58	-0.86	6.79**
JDNOL-18-2 × GAO-6	11.87**	0.88	-21.70**	3.40**	0.29	8.02**
Parbhani Kranti × Pusa Sawani	15.06**	7.46**	-12.91**	-4.20**	-5.62**	-1.54
Parbhani Kranti × GAO-5	6.80**	1.10	-18.06**	-0.74	-0.59	3.70**
Parbhani Kranti × GAO-6	9.58**	-3.05	-21.43**	-5.71**	-7.10**	-3.09**
Arka Anamika × Pusa Sawani	26.13**	17.06**	-3.85*	-1.52	-1.52	-0.31
Arka Anamika × GAO-5	17.69**	10.70**	-9.07**	-1.05	-2.65*	1.85
Arka Anamika × GAO-6	18.16**	3.93	-14.63**	3.05**	3.05**	4.32**
Minimum	-0.39	-6.10	-31.66	-5.71	-7.10	-3.40
Maximum	27.53	22.48	-2.06	4.05	3.05	8.02
S.Em.±	0.74	0.86	0.86	1.02	1.18	1.18
No. of positive significant cross	19	8	0	5	4	10
No. of negative significant cross	0	2	23	11	12	2

The estimate of better parent heterosis was significant and positive direction in four crosses. The cross Arka Anamika x GAO-6 recorded the highest heterobeltiosis (3.05%) in positive direction. Total 12 crosses had significant and negative better parent heterosis. The lowest heterobeltiosis was registered by the cross Parbhani Kranti x GAO-6 (-7.1%) for days to last picking.

As, a regarded to standard heterosis, 10 hybrids showed significant and positive heterosis, with a ranged from -3.40% (JOL-75-5 x Pusa Sawani) to 8.02% (JDNOL-18-2 x GAO-6). Only two crosses showed significant and negative standard heterosis for days to last picking. For days to last picking significant and positive heterosis was reported by Tiwari *et al.* (2015).

In present investigation, several crosses exhibited conspicuous heterotic response over better parents for different traits. However, apart from indicating genetic interaction, measure of heterosis over better parent is relatively less importance than standard heterosis. Hence, it is better to measure heterosis in terms of superiority over standard check variety, rather than over better parent. In the material studied, the degree of heterosis varied from cross to cross for all the character. Considerable high heterosis in certain crosses and low in the other crosses suggested that the nature of gene action varied with the genetic architecture of the parents.

❖ **Combining ability analysis**

Constant efforts are being made to improve fruit yield and yield contributing characters through hybridization in okra. Proper selection of parents is very crucial in any planned hybridization programme. Certain parents nick well, whereas other which appear equally good but produce poor progenies in combinations. Eventually, the lines, which produce good progenies on crossing, are of immense value to the plant breeder. In a crop improvement programme, much of the success depends upon isolation of valuable gene combinations as determined in the form of lines with high combining ability.

The concept of general and specific combining ability as a measure of gene action was proposed by Sprague and Tatum (1942). The resulting total genetic variance is partitioned into the variance due to general combining ability and specific combining ability. The general combining ability is an average performance of a line in hybrid combinations and can be recognized as a measure of

additive gene action, while the specific combining ability is the deviation from expectation on the basis of average performance of lines involved and can be regarded as a measure of non-additive gene action. The line x tester analysis as proposed by Kempthorne (1957) is a powerful tool to discriminate good as well as poor combiners and choose appropriate parental material in breeding programme. Therefore, combining ability analysis was carried-out in the present study with a view to obtain useful information for selection of better parents and crosses for their further use in breeding programme. The information regarding nature and magnitude of gene action could be obtained, which is useful in deciding breeding methodology aiming at exploitable fixable (additive) and non-fixable (non-additive) genetic variances.

4.4 Analysis of variance for combining ability

Analysis of variance for combining ability for all the characters was done according to line x tester analysis proposed by Kempthorne (1957). This technique has been extensively used to evaluate large number of inbreds/ pure lines in terms of general and specific combining ability variances and effects. The total variance of hybrids was further partitioned into the variance due to lines, testers and line x tester components, which were used to estimate the additive and non-additive gene components of variance. The mean squares due to lines, testers and lines x testers were first tested against the error mean squares. If lines x tester interaction was significant, the mean squares due to lines and testers were further tested against lines x tester interaction mean squares. The character-wise results in respect of analysis of variance for combining ability for eleven characters is presented in Table 4.6.

The results revealed that the lines were highly significant for all the traits except days to flowering and days to first picking and testers were significant for branches per plant, plant height, total number of seed per fruit and other traits were non-significant. Further, variance of lines and testers are tested against lines x testers variance. The results revealed that the variances of line and tester significant for plant height. This test indicated the line significant for internodal length. The magnitude of SCA variances was higher than the corresponding GCA variances for all the traits except number branches per plant and total number of seed per fruit. This indicated that non-additive effects were more pronounced than additive effects

for all the traits studied except number branches per plant and total number of seed per fruit. In case of fruit length, gca and sca variances were found non-significant therefore, there may be a role of environment in governing of this trait.

The importance of non-additive genetic variances for fruit yield per plant has been reported by several workers such as Sivakumar *et al.* (1995), Pal and Sabesan (2009), Wammanda *et al.* (2010), Singh (2011), Adiger *et al.* (2013), Reddy *et al.* (2013), Katagi *et al.* (2015), Jupiter *et al.* (2017), Tapas *et al.* (2017) and Hadiya *et al.* (2018).

Similar findings have been reported for days to flowering and days to first picking by Prakash *et al.* (2002), Pal and Sabesan (2009), Wammanda *et al.* (2010), Solankey and Singh (2010), Dabhi *et al.* (2010), Kumar *et al.* (2014), Katagi *et al.* (2015) and Hadiya *et al.* (2018).

Preponderance of non-additive gene action was reported for internodal length by several workers *viz.*; Patil *et al.* (1996^b), Wammanda *et al.* (2010), Singh *et al.* (2001), Singh (2011), Reddy *et al.* (2013) and Tapas *et al.* (2017).

The additive gene action was reported for total number of branches per plant by Khanpara *et al.*, (2009)

Preponderance of non-additive gene action for fruit girth was substantiated by several workers *viz.*; Sivakumar *et al.* (1995), Wammanda *et al.* (2010), Singh (2011), Prakash *et al.* (2012), Katagi *et al.* (2015), Jupiter *et al.* (2017) and Hadiya *et al.* (2018).

Above mentioned results in the regards of days to last picking and number of fruits per plant corroborated with those of Pal and Sabesan (2009), Wammanda *et al.* (2010), Singh *et al.* (2001), Singh (2011), Prakash *et al.* (2002), Katagi *et al.* (2015), Jupiter *et al.* (2017) and Hadiya *et al.* (2018).

Preponderance of non-additive gene action for plant height was reported by several workers *viz.*, Dhankhar and Dhankhar (2001), Singh *et al.* (2006), Mehta *et al.* (2007), Weerasekara *et al.* (2008), Wammanda *et al.* (2010), Singh (2011).

From the present results, it was evident that the non-additive gene action had greater role in the expression of all fruit yield and majority of yield contributing traits under study, hence, merely selection will result in no or slow genetic improvement. Successful breeding methods are those that accumulate the genes to form superior gene constellations interacting in a favorable manner. The importance

of non-additive gene action for all yield components in the present study indicated that heterosis breeding is the best possible option for improving these traits in okra.

For the improvement of the material under investigation, it was suggested that

1. characters having predominance of additive genetic variance could be improved by simple selection following pedigree method of selection.
2. characters having predominance of non-additive genetic variance could be improved by exploitation of hybrids vigour for commercial utilization.

4.5 General and specific combining ability and effects

Selection of parents for hybridization programme is an important aspect in all crop improvement programmes and the performance of varieties in a trial may give an idea of their relative superiority. Therefore, in any sound breeding programme, the proper choice of parents based on their combining ability is a pre-requisite. As such, studies intended to determine the combining ability not only provide necessary information regarding the choice of parents but they also simultaneously illustrate the nature and magnitude of gene action involved. Accordingly, the present investigation was undertaken to have an idea of the combining ability for yield and its components in okra with a view to identify good combiners which may be used to build up a population with favorable genes for effective yield improvement in okra.

The estimated gca effect (g_i) of the parents and sca effects (S_{ij}) of the crosses for various characters are presented in Table 4.7 and Table 4.9, respectively.

4.5.1 Days to flowering

This character is considered to be important for earliness or lateness in okra. Plant having lesser days to flowering generally produced early fruits. The data revealed that gca effects varied from -2.32 (JOL-75-5) to 2.56 (JDNOL-18-2). Estimation of gca effects indicated that parents VRO-22, JOL-75-5, Parbhani Kranti and Pusa Sawani had significant and negative gca effects and were found to be good general combiners for earliness. On the other hand, JDNOL-18-2, NLO-17-9 and JOL-16-06 exhibited significant and positive effects. Hence, they were good general combiners towards lateness. Estimates of sca effects revealed that 8 crosses expressed significant sca effects. Out of these, significant crosses, three and five crosses had negative and positive sca effects, respectively. The range of sca effects was from -3.03 (JOL-16-06 x GAO-6) to 3.19 (VRO-6 x GAO-6).

Table 4.6: Analysis of variance for combining ability for eleven characters in okra

Source of variation	d.f.	Days to flowering	Days to first picking	Fruit length	Fruit girth	Number of branches per plant	Internodal length	Plant height	Fruit yield per plant	Total number of fruits per plant	Total number of seed per fruit	Days to last picking
Replication	2	2.68	8.03	0.19	0.59	0.00	0.11	13.56	482.24	2.21	2.97	6.56
Hybrid	23	20.46**	15.68**	0.79	1.28**	0.09**	1.09**	146.81**	2880.84**	11.29**	48.28**	44.75**
Line	7	30.84	19.36	1.67**	2.54**	0.16**	2.14**	308.57**	7346.71**	22.59**	114.16**	78.89**
Tester	2	9.29	12.72	0.16	1.18	0.33**	1.42	196.68*	1492.86	13.89	121.70**	61.54
Line × Tester	14	16.86**	14.26**	0.44	0.67**	0.01*	0.52**	58.81**	846.20**	5.27**	4.85**	25.29**
Error	46	2.82	2.90	0.57	0.28	0.01	0.04	6.02	132.80	1.12	1.22	2.04
Estimates of genetic component of variance												
σ^2_{gca}		0.19	0.11	0.03	0.07*	0.01 **	0.08*	11.75**	216.58**	0.79**	6.85**	2.72*
σ^2_{sca}		4.74**	3.90**	-0.05(#)	0.15**	0.002	0.16**	16.83**	220.46**	1.42**	1.26**	7.69**
$\sigma^2_{gca} / \sigma^2_{sca}$		0.04	0.03	-0.60(#)	0.48	5.00	0.48	0.70	0.98	0.55	5.45	0.35

Estimate negative value

*, ** Significant at P=0.05 and P=0.01, respectively.

4.5.2 Days to first picking

Six out of eleven parents showed significant gca effect for days to first picking. Of these line JOL-75-5 (-1.69) exhibited significant and negative gca effect. In case of tester, Pusa Sawani (-0.80) was found good general combiner for days to first picking

The estimates of sca effects, seven cross combinations showed significant effects for days to first picking. Out of these significant crosses, four and three showed negative and positive sca effect, respectively. The range of estimate sca effect for days to first picking was -3.19 (Parbhani Kranti x GAO-6) to 3.39 (Parbhani Kranti x GAO-5). In cross combination, Parbhani Kranti x GAO-6 (-3.19), JOL-16-06 x GAO-6 (-2.64) and JOL-75-5 x GAO-5 (-2.06) showed significant and negative sca effects for days to first picking.

4.5.3 Fruit length

Out of eleven parents, two parents showed significant gca effects, of only one parent *viz.*, JDNOL-18-2 exhibited significant and positive gca effect, thereby indicated good general combiner for fruit length.

Among all crosses, one cross showed significant and positive sca effects. The significant and positive sca effect was recorded by the hybrid JDNOL-18-2 × Pusa Sawani (0.91).

4.5.4 Fruit girth

Only three parents showed significant gca effects. However, parent Parbhani Kranti and GAO-6 exhibited significant and positive; parent JOL-16-06 exhibited significant and negative gca effects. So, Parbhani Kranti and GAO-6 considered as good general combiner. The range of gca effects was observed from -0.66 (JOL-16-06) to 1.16 (Parbhani Kranti) for fruit girth.

Only four crosses found significant sca effect for fruit girth. Three crosses were exhibited significant with negative sca effect while, only one cross was exhibited significant and positive sca effect. The corresponding range was -0.65 (JDNOL-18-2 × Pusa Sawani) & (NLO-17-9 × GAO-5) to 0.82 (NLO-17-9 x GAO-6).

4.5.5 Number of branches per plant

The estimates of gca effects revealed that ten parents expressed significant gca effects. The range of gca effect of parents was observed -0.17 (NLO-17-9) to 0.22 (Arka Anamika). The significant and positive gca effect recorded three lines JOL-75-5, Parbhani Kranti, Arka Anamika. While, one tester GAO-6 had significant and

positive values for number of branches per plant. Thereby indicating good general combiner for number of branches per plant.

Out of 24 crosses, two crosses exhibited significantly for sca effects which were significant with positive values. The range of sca effects was observed from -0.09 (JOL-16-06 x Pusa Sawani) to 0.1 (VRO-6 x Pusa Sawani) & (JOL-16-06 x GAO-5) for number of branches per plant.

4.5.6 Internodal length

Considering short internodal length as desired direction (negative), four parents were found significant and negative for gca effects. The lines JDNOL-18-2(-0.70) and Parbhani Kranti (-0.67) were the best general combiners followed by tester GAO-6 (-0.28). Whereas, VRO-6, NLO-17-9, Arka Anamika, Pusa Sawani and GAO-5 expressed significant and positive gca effects.

A perusal of sca effects revealed that four crosses combinations expressed significant sca effects for internodal length of which, four crosses had significant and negative sca effects. The range of sca effects was observed from -0.79 (NLO-17-9 x GAO-6) to 0.74 (NLO-17-9 x Pusa Sawani) for internodal length.

4.5.7 Plant height

Nine parents showed significant gca effects. The range of gca effect was observed from -10.59 (Parbhani Kranti) to 6.39 (VRO-6). The parents VRO-6, NLO-17-9, VRO-22, Arka Anamika and GAO-5 significant and positive gca effects for plant height indicating that they were good combiners for tall plant.

The results on sca effects indicated that eight crosses showed significant sca effects. The corresponding range was -5.93 (VRO-6 x Pusa Sawani) to 8.20 (NLO-17-9 x Pusa Sawani) for this trait. The five crosses showed significant and negative sca effect for plant height.

4.5.8 Fruit yield per plant (g)

The gca effects of the parents indicated that parents NLO-17-9 (17.75), Parbhani Kranti (31.69), JOL-75-5(13.22) and GAO-6 (8.09) were found good general combiners for fruit yield per plant. Whereas, three lines JOL-16-6 (-64.10), VRO-22 (-6.62) and VRO-6 (-2.70) and two testers Pusa Sawani (-0.41) and GAO-5 (-7.67) were found poor general combiners for fruit yield per plant.

Table 4.7: Estimation of general combining ability effects for eleven characters in okra

Parents	Days to flowering	Days To first picking	Fruit length	Fruit girth	Number of branches per plant	Internodal length	Plant height	Fruit yield per plant	Total number of fruits per plant	Total number of seed per fruit	Days to last picking
LINES											
VRO-6	-0.99	-1.03	0.14	-0.02	-0.10**	0.42**	6.39**	-2.70	0.33	-0.33	-2.89**
NLO-17-9	2.13**	2.19**	-0.35	0.23	-0.17**	0.58**	2.70**	17.75**	0.96**	0.63	4.67**
VRO-22	-1.65**	-1.25*	0.33	-0.29	0.04	0.09	5.78**	-6.62	-0.34	-5.48**	-3.11**
JOL-75-5	-2.32**	-1.69**	0.33	-0.12	0.07*	-0.15*	-1.20	13.22**	0.24	4.76**	-0.67
JOL-16-06	1.24*	0.97	-0.12	-0.66**	-0.06*	0.03	1.30	-64.10**	-3.42**	-3.91**	1.44**
JDNOL-18-2	2.56**	1.53**	0.63*	-0.08	-0.10**	-0.70**	-6.29**	4.51	0.98**	-0.57	3.44**
Parbhani Kranti	-1.43*	-1.14*	-0.68**	1.16**	0.11**	-0.67**	-10.59**	31.69**	1.91**	0.43	-2.67**
Arka Anamika	0.46	0.42	-0.27	-0.22	0.22**	0.41**	1.91*	6.24	-0.18**	4.46**	-0.22
TESTERS											
Pusa Sawani	-0.71*	-0.81*	0.09	-0.11	-0.05**	0.18**	-1.37**	-0.41	-0.32	2.52**	-1.83**
GAO-5	0.46	0.61	-0.03	-0.15	-0.08**	0.09*	3.29**	-7.67**	-0.55*	-0.71**	1.13**
GAO-6	0.25	0.19	-0.06	0.26*	0.13**	-0.28**	-1.92**	8.09**	0.87**	-1.81**	0.71*
Range	-2.32 to 2.56	-1.69 to 2.19	-0.35 to 0.63	-0.66 to 1.16	-0.17 to 0.22	-0.70 to 0.58	-10.59 to 6.39	-64.10 to 31.69	-3.42 to 1.91	-5.48 to 4.76	-3.11 to 4.67

*,** Significant at P=0.05 and P=0.01, respectively

Table 4.8: Summary of general combining ability effects of parents for eleven characters in okra

Parents	Days to flowering	Days To first picking	Fruit length	Fruit girth	Number of branches per plant	Internodal length	Plant height	Fruit yield per plant	Total number of fruits per plant	Total number of seed per fruit	Days to last picking
Lines											
VRO-6	A	A	A	A	P	P	P	A	A	A	P
NLO-17-9	P	P	A	A	P	P	P	G	G	A	G
VRO-22	G	G	A	A	A	A	P	A	A	P	P
JOL-75-5	G	G	A	A	G	G	A	G	A	G	A
JOL-16-06	P	A	A	P	P	A	A	P	P	P	G
JDNOL-18-2	P	P	G	A	P	G	G	A	G	A	G
Parbhani Kranti	G	G	P	G	G	G	G	G	G	A	P
Arka Anamika	A	A	A	A	G	P	P	A	A	G	A
Testers											
Pusa Sawani	G	G	A	A	P	P	G	A	A	G	P
GAO-5	A	A	A	A	P	P	P	P	P	P	G
GAO-6	A	A	A	G	G	G	G	G	G	P	G

G: Parent having significant GCA effects in desired direction (Good general combiner)

A: Parent having non-significant GCA effects (Average general combiner)

P: Parent having significant GCA effects in undesired direction (Poor general combiner)

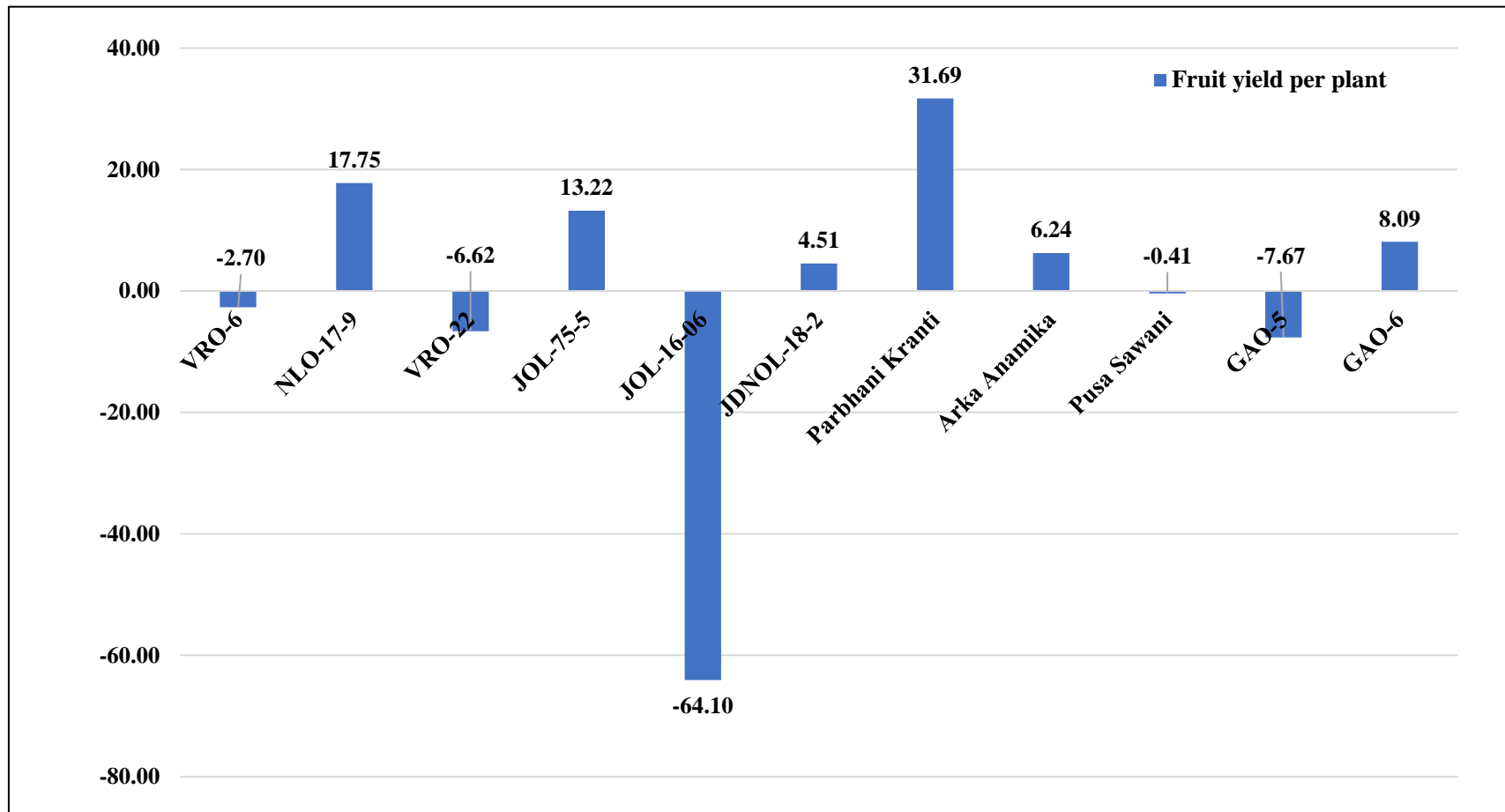


Fig. 4.3. Graphical representation of gca effect for fruit yield per plant

Table 4.9: Estimation of specific combining ability effects for days to flowering, days to first picking, fruit length, fruit girth and number of branches per plant in okra

Hybrids	Days to flowering	Days to first picking	Fruit length	Fruit girth	Number of branches per plant
VRO-6 × Pusa Sawani	-1.85	-0.97	-0.08	0.21	0.10 *
VRO-6 × GAO-5	-1.35	-1.06	0.24	0.36	-0.07
VRO-6 × GAO-6	3.19 **	2.03 *	-0.15	-0.57 *	-0.03
NLO-17-9 × Pusa Sawani	1.04	0.81	0.03	-0.17	-0.05
NLO-17-9 × GAO-5	-0.79	-0.94	-0.11	-0.65 *	-0.02
NLO-17-9 × GAO-6	-0.25	0.14	0.08	0.82 **	0.07
VRO-22 × Pusa Sawani	2.82 **	1.92 *	-0.40	0.40	0.03
VRO-22 × GAO-5	-1.01	-1.17	0.27	0.03	-0.02
VRO-22 × GAO-6	-1.81	-0.75	0.12	-0.43	-0.01
JOL-75-5 × Pusa Sawani	-2.51 **	-0.97	-0.01	-0.13	0.02
JOL-75-5 × GAO-5	-0.68	-2.06 *	-0.12	0.24	0.07
JOL-75-5 × GAO-6	3.19 **	3.03 **	0.13	-0.12	-0.08
JOL-16-06 × Pusa Sawani	1.93 *	1.69	-0.10	-0.22	-0.09
JOL-16-06 × GAO-5	1.10	0.94	0.18	0.17	0.10 *
JOL-16-06 × GAO-6	-3.03 **	-2.64 **	-0.08	0.06	-0.02
JDNOL-18-2 × Pusa Sawani	-1.07	-0.86	0.91 *	-0.65 *	-0.01

*,** Significant at P=0.05 and P=0.01, respectively

Table 4.9. Cont...

Hybrids	Days to flowering	Days to first picking	Fruit length	Fruit girth	Number of branches per plant
JDNOL-18-2 × GAO-5	1.43	1.06	-0.35	0.39	-0.04
JDNOL-18-2 × GAO-6	-0.36	-0.19	-0.56	0.26	0.06
Parabhani Kranti × Pusa Sawani	-0.07	-0.19	0.02	0.35	0.04
Parabhani Kranti × GAO-5	2.43 *	3.39 **	-0.04	-0.38	0.01
Parbhani Kranti × GAO-6	-2.36 *	-3.19 **	0.02	0.04	-0.05
Arka Anamika × Pusa Sawani	-0.29	-1.42	-0.37	0.20	-0.03
Arka Anamika × GAO-5	-1.13	-0.17	-0.07	-0.16	-0.02
Arka Anamika × GAO-6	1.42	1.58	0.44	-0.05	0.05
S.E.(Sij) ±	0.97	0.98	0.44	0.30	0.04
Range	-3.03 to 3.19	-3.19 to 3.39	-0.56 to 0.91	-0.65 to 0.82	-0.09 to 0.1
Number of positive significant cross	5	4	1	1	2
Number of negative significant cross	3	3	0	3	0

*,** Significant at P=0.05 and P=0.01, respectively

With regard to sca effects, five crosses showed significant effects. Three crosses showed significant and positive sca effects. The sca effects ranged from -20.61 (Parbhani Kranti x Pusa Sawani) to 25.06 (Parbhani Kranti x GAO-6).

4.5.9 Number of fruits per plant

The estimates of gca effects indicated that of eleven parents studied, six parents showed significant gca effects. The gca effects ranged from -3.42 (JOL-16-06) to 1.91 (Parbhani Kranti). Four parents, NLO-17-9(0.96), JDNOL-18-2 (0.98), Parbhani Kranti (1.91) and GAO-6 (0.87) identified as good general combiners as they exhibited significant and positive gca effect for this character.

Estimates of sca effects showed that six crosses noticed significant sca effects of which, three crosses JDNOL-18-2 × Pusa Sawani (1.82), Parbhani Kranti × GAO-6 (1.80) and Arka Anamika × GAO-6 (1.74) had significant and positive sca effects. The corresponding range was observed -1.71 (Arka Anamika x Pusa Sawani) to 1.82 (JDNOL-18-2 x Pusa Sawani) for number of fruits per plant.

4.5.10 Total number of seed per fruit

The results on gca effect showed that three and four parents showed significantly positive and negative gca effects for number of seed per fruit, respectively. The line, JOL-75-5 (4.76) and Arka Anamika (4.46) were significant and positive gca effect while, only one tester Pusa Sawani (2.52) observed significant and positive gca effect for number of seed per fruit. So, two line and one tester consider as good general combiner for number of seed per fruit.

Estimates of sca effects revealed that only one cross NLO-17-9 x Pusa Sawani (2.62) expressed significant and positive sca effects.

4.5.11 Days to last picking

Nine out of eleven parents showed significant gca effect for days to last picking. Of these, three lines JOL-16-06 (1.44), NLO-17-9 (4.67) and JDNOL-18-2 (3.44) exhibited significant and positive gca effect. In case of tester, GAO-5 (1.13) and GAO-6 (0.71) was found good general combiner for days to last picking.

The estimates of sca effects, 12 cross combinations showed significant effects for days to last picking. Out of these significant crosses, six and six showed negative and positive sca effect, respectively for this trait. The range of estimate sca effect for days to last picking was -3.82 (JOL-16-06 x GAO-6) to 4.29 (JOL-75-5 x GAO-6). In cross combination, six crosses showed significant and positive sca effects for days to last picking.

Table 4.10: Estimation of specific combining ability effects for internodal length, plant height, fruit yield per plant, total number of fruits per plant, total number of seed per fruit and days to last picking in okra

Hybrids	Internodal length	Plant height	Fruit yield per plant	Total number of fruits per plant	Total number of seed per fruit	Days to last picking
VRO-6 × Pusa Sawani	-0.33 **	-5.93 **	-1.27	0.36	-0.54	0.72
VRO-6 × GAO-5	0.08	5.85 **	7.75	0.68	0.09	-2.24 **
VRO-6 × GAO-6	0.25 *	0.08	-6.49	-1.04	0.46	1.51
NLO-17-9 × Pusa Sawani	0.74 **	8.20 **	-11.38	-0.22	2.62 **	-0.17
NLO-17-9 × GAO-5	0.05	-3.68 **	1.40	-0.62	-2.78 **	0.21
NLO-17-9 × GAO-6	-0.79 **	-4.52 **	9.97	0.85	0.16	-0.04
VRO-22 × Pusa Sawani	-0.19	-0.83	13.84	0.60	-1.07	1.94 *
VRO-22 × GAO-5	0.18	1.95	-8.90	0.43	0.23	0.32
VRO-22 × GAO-6	0.02	-1.12	-4.95	-1.03	0.83	-2.26 **
JOL-75-5 × Pusa Sawani	0.13	-3.82 *	23.44 **	-0.49	0.63	-3.50 **
JOL-75-5 × GAO-5	-0.57 **	-1.30	-4.73	1.13	0.06	-0.79
JOL-75-5 × GAO-6	0.43 **	5.11 **	-18.71 *	-0.64	-0.70	4.29 **
JOL-16-06 × Pusa Sawani	-0.09	1.56	-2.79	-0.46	-0.23	3.72 **
JOL-16-06 × GAO-5	-0.10	0.95	12.92	0.47	0.80	0.10
JOL-16-06 × GAO-6	0.19	-2.51	-10.13	-0.01	-0.57	-3.82 **
JDNOL-18-2 × Pusa Sawani	-0.16	0.38	13.55	1.82 **	-1.18	-2.61 **
JDNOL-18-2 × GAO-5	-0.06	-3.40 *	1.26	-0.15	0.42	0.43
JDNOL-18-2 × GAO-6	0.22	3.03	-14.81	-1.67 **	0.76	2.18 *

*,** Significant at P=0.05 and P=0.01, respectively

Table 4.10. Cont...

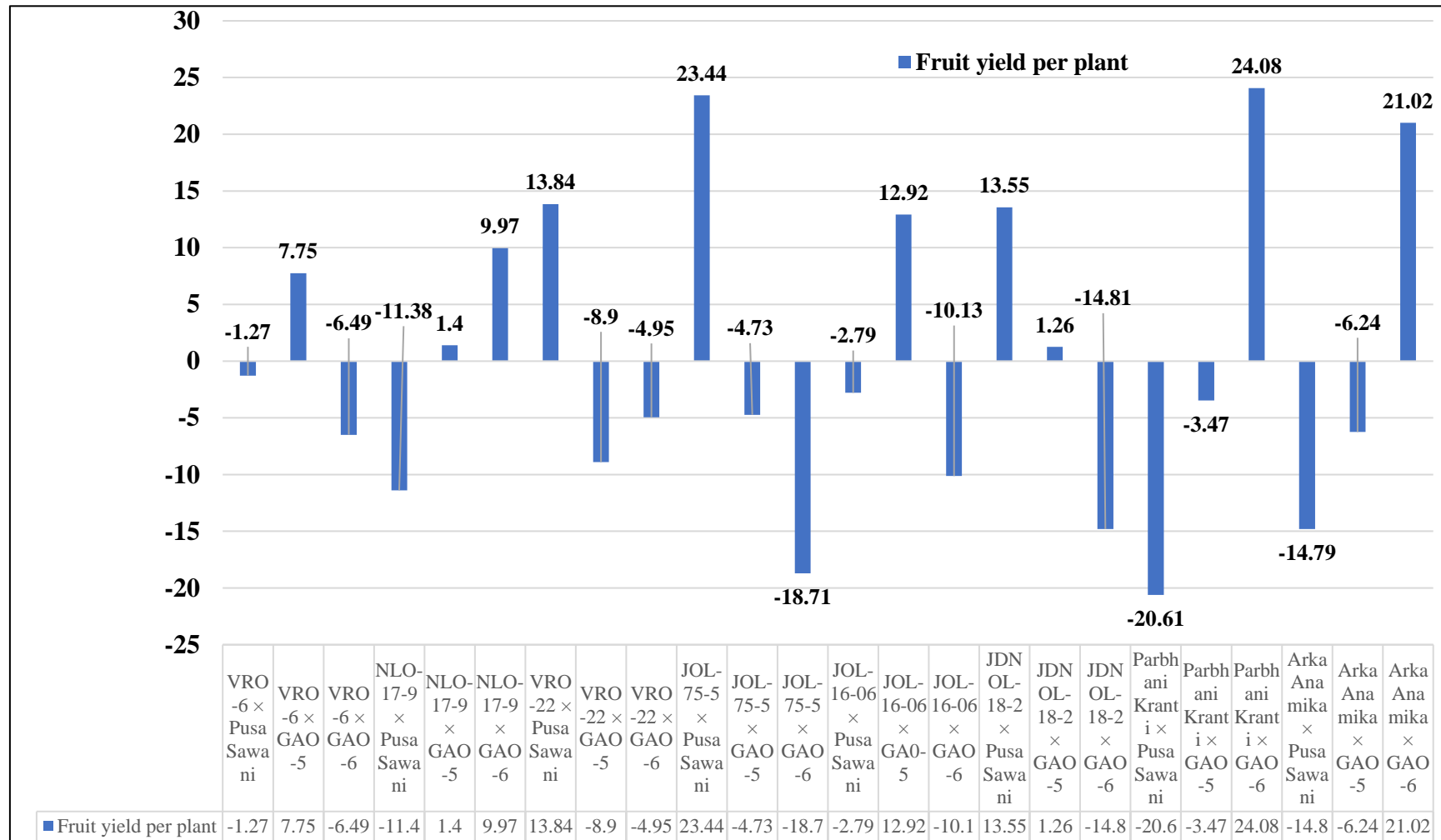


Fig.4.4. Graphical representation of sca effect of hybrids for fruit yield per plant

Table 4.10. Cont...

Hybrids	Internodal length	Plant height	Fruit yield per plant	Total number of fruits per plant	Total number of seed per fruit	Days to last picking
Parabhani Kranti × Pusa Sawani	-0.03	1.55	-20.61 *	-1.58 **	-0.31	0.50
Parabhani Kranti × GAO-5	-0.02	-3.07	-3.47	-0.23	0.42	3.21 **
Parbhani Kranti × GAO-6	0.05	1.52	24.08 **	1.80 **	-0.11	-3.71 **
Arka Anamika × Pusa Sawani	-0.07	-1.11	-14.79	-0.03	0.07	-0.61
Arka Anamika × GAO-5	0.43 **	2.69	-6.24	-1.71 **	0.76	-1.24
Arka Anamika × GAO-6	-0.37 **	-1.58	21.02 **	1.74 **	-0.83	1.85 *
S.E.(Sij) ±	0.12	1.42	6.65	0.61	0.64	0.83
Range	-0.79 to 0.74	-5.93 to 8.20	-20.61 to 24.08	-1.71 to 1.82	-2.78 to 2.62	-3.82 to 4.29
Number of positive significant cross	4	3	3	3	1	6
Number of negative significant cross	4	5	2	3	1	6

*,** Significant at P=0.05 and P=0.01, respectively

In the present study, highly significant general combining ability effects were observed for all the characters studied. An overall appraisal of gca effects for the material used in the present study indicated that none of the parents was good general combiner for all the characters studied.

A comparison of crosses for fruit yield was made for other yield related characters along with fruit yield per plant (g). It was observed positive standard heterosis for fruit yield in the crosses Parbhani Kranti x GAO-6, JOL-75-5 x Pusa Sawani, NLO-17-9 x GAO-6, Arka Anamika x GAO-6.

When cross Parbhani Kranti x GAO-6 had high positive standard heterosis in fruit yield per plant (g) with accompanied by positive standard heterosis for fruit girth and total number of fruit per plant and negative standard heterosis for days to first picking, internodal length and plant height.

When cross JOL-75-5 x Pusa Sawani had positive standard heterosis in fruit yield per plant (kg) with accompanied by negative standard heterosis for days to flowering, days to first picking, internodal length and plant height.

When cross NLO-17-9 x GAO-6 had positive standard heterosis in fruit yield per plant (g) with accompanied by by positive standard heterosis for fruit girth, total number of fruit per plant and days to last picking and negative standard heterosis for internodal length and plant height.

When cross Arka Anamika x GAO-6 had positive standard heterosis in fruit yield per plant (g) with accompanied by by positive standard heterosis for number of branches per plant, total number of fruit per plant and days to last picking and negative standard heterosis for internodal length and plant height.

A comparison of best performing four crosses, each in case for plant height, internodal length and number of fruit per plant were common in comparison. This indicate that the selection of crosses on the basis of either *per se* performance or heterotic response would be equally important, but the forming being more desirable.

Among all four combinations, one common parent (GAO-6) found good for fruit yield and yield attributing traits.

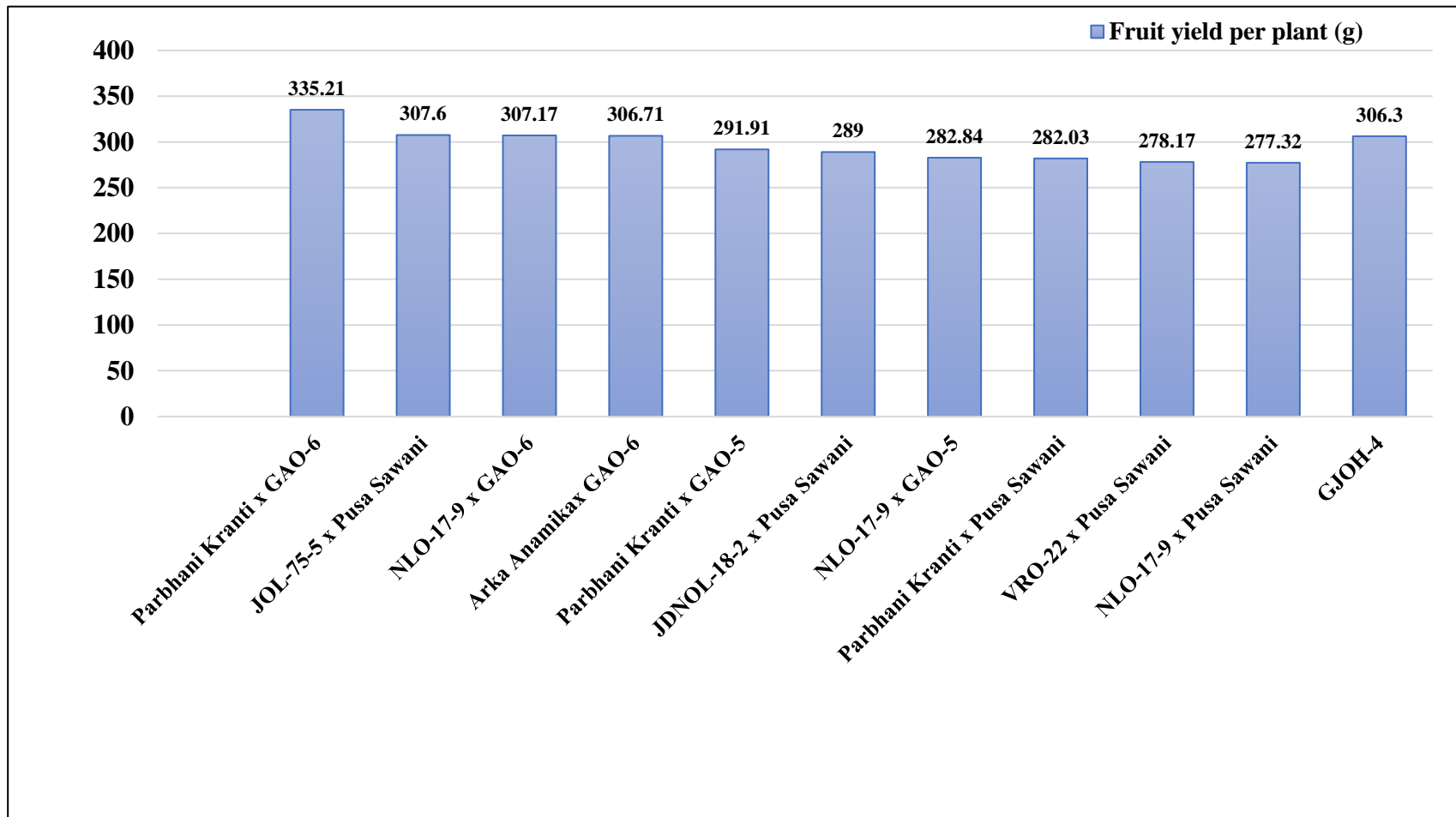


Fig.4.5. Graphical representation of top ten crosses based on *per se* performance with check for fruit yield per plant(g)

Table 4.11: Promising hybrids for fruit yield per plant based on *per se* performance with standard heterosis, gca effects, sca effects and component traits showing significant desired heterosis

Sr. No.	Hybrid	Fruit yield per plant (g)	Standard heterosis (%)	Combination	sca effects	Useful and significant for component traits
						Standard heterosis (%)
1.	Parbhani Kranti x GAO-6	335.21	9.44	G X G	24.08**	DFP, FG, IL, PH, TNFP
2.	JOL-75-5 x Pusa Sawani	307.60	0.42	G X A	23.44**	DF, DFP, IL, PH
3	NLO-17-9 x GAO-6	307.17	0.28	G X G	9.97	FG, IL, PH, TNFP, DLP
4	Arka Anamika x GAO-6	306.71	0.13	A X G	21.02**	IL, PH, NBP, TNFP, DLP

DF Days to Flowering
 DFP Days to first picking
 FG Fruit girth (cm)
 NBP Number of branches per plant
 IL Internodal length
 PH Plant height
 TNFP Total number of fruits per plant
 DLP Days to last picking

Table 4.12: Three best parents selected on the basis of *per se* performance and GCA effects and three best crosses selected on the basis of *per se* performance, heterosis over mid parent, better parent and standard check and SCA effects for eleven characters in okra

Characters	Per se performance		Combining ability effects		Magnitude of heterosis over		
	Parents	F ₁ s	GCA	SCA	Mid parent	Better Parent	Standard Check
Days to flowering	VRO-22 JOL-16-06 JOL-75-5	JOL-75-5×Pusa Sawani Parbhani Kranti×GAO-6 VRO-6×Pusa Sawani	JOL-75-5 VRO-22 Parbhani Kranti	JOL-16-06×GAO-6 JOL-75-5×Pusa Sawani Parbhani Kranti×GAO-6	JOL-75-5×Pusa Sawani Parbhani Kranti×GAO-6	JOL-75-5×Pusa Sawani Parbhani Kranti×GAO-6	JOL-75-5×Pusa Sawani
Days to first picking	VRO-22 Parbhani- Kranti JOL-16-06	Parbhani Kranti×GAO-6 JOL-75-5×Pusa Sawani JOL-75-5×GAO-5	JOL-75-5 VRO-22 Parbhani Kranti	Parbhani Kranti×GAO-6 JOL-16-06×GAO-6 JOL-75-5×GAO-5	JOL-75-5×GAO-5 JOL-75-5×Pusa Sawani Parbhani Kranti×GAO-6	JOL-75-5×Pusa Sawani JOL-75-5×GAO-5	-
Fruit length(cm)	GAO-6 Pusa Sawani GAO-5	JDNOL-18-2×Pusa Sawani VRO-22×GAO-5 JOL-75-5×Pusa Sawani	JDNOL-18-2	JDNOL-18-2×Pusa Sawani	JDNOL-18-2×Pusa Sawani VRO-6×GAO-5	JDNOL-18-2×Pusa Sawani	-
Fruit girth(cm)	Parbhani Kranti GAO-6 GAO-5	Parbhani Kranti×GAO-6 Parbhani Kranti×Pusa Sawani NLO-17-9×GAO-6	Parbhani Kranti GAO-6	NLO-17-9×GAO-6	NLO-17-9×GAO-6 Parbhani Kranti×Pusa Sawani Parbhani Kranti×GAO-6	-	-
Number of branches per plant	Arka Anamika Parbhani Kranti GAO-6	Arka Anamika×GAO-6 Parbhani Kranti×GAO-6 VRO-22×GAO-6	Arka Anamika Parbhani Kranti GAO-6	VRO-6×Pusa Sawani JOL-16-06×GAO-5	Arka Anamika×GAO-6	-	Arka Anamika×GAO- 6
Internodal length (cm)	JOL-75-5 JDNOL-18-2 Parbhani- Kranti	NLO-17-9×Pusa Sawani Arka Anamika×GAO-5 NLO-17-9×GAO-5	JDNOL-18-2 Parbhani Kranti GAO-6	NLO-17-9×GAO-6 JOL-75-5×GAO-5 Arka Anamika×GAO- 6	NLO-17-9×GAO-6 JDNOL-18-2×Pusa Sawani Parbhani Kranti×GAO-6	Parbhani Kranti×GAO-6 NLO-17-9×GAO-6 JDNOL-18-2×GAO-6	Parbhani Kranti×GAO-6 NLO-17-9×GAO-6 JDNOL-18-2×Pusa Sawani

Table 4.12 Cont....

Table 4.12 Cont....

Plant height (cm)	Parbhani Kranti JDNOL-18-2 JOL-75-5	Parbhani Kranti×GAO -6 Parbhani Kranti×Pusa Sawani Parbhani Kranti×GAO-5	Parbhani Kranti JDNOL-18-2 GAO-6	VRO-6×Pusa Sawani NLO-17-9×GAO-6 JOL-75-5×Pusa Sawani	Parbhani Kranti×GAO-5 Parbhani Kranti×GAO-6 Parbhani Kranti×Pusa Sawani	JOL-75-5×Pusa Sawani Parbhani Kranti×GAO-6 Parbhani Kranti×Pusa Sawani	Parbhani Kranti×GAO-6 Parbhani Kranti×Pusa Sawani Parbhani Kranti×GAO-5
Fruit yield per plant(g)	JDNOL-18-2 Parbhani Kranti JOL-75-5	Parbhani Kranti×GAO-6 JOL-75-5×Pusa Sawani NLO-17-9×GAO-6	Parbhani Kranti NLO-17-9 JOL-75-5	Parbhani Kranti×GAO-6 JOL-75-5×Pusa Sawani Arka Anamika×GAO-6	Arka Anamika×GAO-6 JOL-75-5×Pusa Sawani Parbhani Kranti×GAO-6	JOL-75-5×Pusa Sawani Parbhani Kranti×GAO-6	Parbhani Kranti×GAO-6
Total number of fruit per plant	Parbhani Kranti GAO-5 JDNOL-18-2	Parbhani Kranti×GAO-6 NLO-17-9×GAO-6 JDNOL-18-2×Pusa Sawani	Parbhani Kranti JDNOL-18-2 NLO-17-9	JDNOL-18-2×Pusa Sawani Parbhani Kranti×GAO-6 Arka Anamika×GAO-6	Arka Anamika×GAO-6 Parbhani Kranti×GAO-6 NLO-17-9×GAO-6	NLO-17-9×GAO-6 Parbhani Kranti×GAO-6 Arka Anamika×GAO-6	Parbhani Kranti×GAO-6
Total number of seed per fruit	JOL-75-5 VRO-6 Arka Anamika	JOL-75-5×Pusa Sawani Arka Anamika×Pusa Sawani NLO-17-9×Pusa Sawani	JOL-75-5 Arka Anamika Pusa Sawani	NLO-17-9×Pusa Sawani	NLO-17-9×Pusa Sawani JOL-75-5×Pusa Sawani	NLO-17-9×Pusa Sawani Arka Anamika×Pusa Sawani JOL-75-5×Pusa Sawani	-
Days to last picking	JDNOL-18-2 JOL-16-06 Arka Anamika	JDNOL-18-2×GAO-6 NLO-17-9×GAO-5 NLO-17-9×GAO-6	NLO-17-9 JDNOL-18-2 JOL-16-06	JOL-75-5×GAO-6 JOL-16-06×Pusa Sawani Parbhani Kranti×GAO-6	NLO-17-9×GAO-6 JOL-75-5×GAO-6 JDNOL-18-2×GAO-6	Arka Anamika×GAO-6 NLO-17-9×GAO-5 JOL-75-5×GAO-6	JDNOL-18-2×GAO-6 NLO-17-9×GAO-5 NLO-17-9×GAO-6

A list of three best parents selected on the basis of *per se* performance and gca effects and three best F₁ crosses on the basis of *per se* performance, heterosis over standard check and sca effects of various characters studied is given in Table 4.12. A perusal of this table revealed that most of cases, linearity found between standard heterosis and sca effects. This means that a cross showing the highest standard heterosis may show the highest sca effects. With respect to specific combining ability effects, following conclusion could be drawn from the present study;

1. No cross combination exhibited consistently high specific combining ability effects for all the characters studied.
2. The crosses exhibiting high sca effects did not always involve parents with high gca effects suggesting that interallelic interaction were important for the characters.
3. Crosses having high sca effects for fruit yield may or may not have high sca effects for yield contributing characters.

The cross exhibiting high specific combining ability effects for various characters suggested the possibilities of improvement of such character by selection and hybridization. The cross exhibiting high positive or negative specific combining ability effects involved either average x good, average x poor, poor x good and poor x poor parents. Therefore, information on combining ability alone may not be sufficient to predict the extent of heterosis. Hence, information on combining ability effects needs to be supplemented by that of *per se* performance.

High sca denotes undoubtedly a high heterotic response, but this may be due to very poor performance of the parents in comparison with their hybrids. With the same amount of heterotic effects, the sca may be less, where the mean performance of the parents was higher but this estimate may also be biased (Ziauddin *et al.*, 1979). This suggested that the selection of cross combination based on heterotic response would be more realistic rather than on the basis of sca effects.

The marked undesirable effect in crosses between good x good and good x average combiners could be attributed to the lack of co-adaption between favourable alleles of the parents involved, whereas marked desirable specific combining ability effects in crosses between poor x poor, poor x average, or average x average could be due to better complementation between favourable alleles of parents involved. The present investigation suggested non-additive

genetic variances were important for most of the characters. So, suggested to attempt heterosis breeding for enhancing the fruit yield potential of okra.

4.6. Proportional contribution of lines, testers and their interactions (%)

Proportional contribution of lines, testers and their interactions has been presented in the Table 4.13. Contribution of lines for different traits ranged from 35.68 to 77.61 per cent.

The contribution of lines was found higher than the individual contribution of testers and lines \times testers interactions for all the traits exclude days to flowering and days to first picking. The range of the proportional contribution of testers varied from 1.76 to 33.21 per cent. The proportional contribution of lines \times testers interactions ranged from 6.12 to 53.43 per cent.

Table 4.13: Proportional contribution of lines, testers and their interactions to sum of squares of the hybrids for eleven characters in okra

Character	% contribution of		
	Lines	Testers	Lines \times Testers
Days to flowering	45.88	3.95	50.17
Days to first picking	35.68	10.89	53.43
Fruit length	64.40	1.76	33.84
Fruit girth	60.28	8.04	31.68
Plant height	63.97	11.65	24.38
Total seed per fruit	71.97	21.92	6.12
Number of branches per plant	56.22	33.21	10.58
Internodal length	59.72	11.35	28.93
Number of fruits per plant	60.88	10.70	28.43
Fruit yield per plant	77.61	4.51	17.88
Days to last picking	53.65	11.96	34.39

SUMMARY AND CONCLUSIONS

V. SUMMARY AND CONCLUSIONS

The present investigation on “Heterosis and combining ability in okra [*Abelmoschus esculentus* (L.) Moench]” was undertaken with a view to study the heterosis, nature of gene action and combining ability for different characters of okra parents and hybrids. The investigation was undertaken at the Seed & Spices Research Station, Sardarkrushinagar Dantiwada Agricultural University, Jagudan during summer 2021. The experimental material comprised of eleven parents (8 lines and 3 testers) and their twenty-four resultant hybrids derived from line x tester mating and one check variety (GJOH-4). These 36 genotypes were sown in a Randomized Block Design with three replications at the Agronomy Instructional Farm, C.P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar during *kharif* 2021. The observations on five randomly selected plants were recorded for eleven characters (except days to flowering, days to first picking and days to last picking) *viz.*, plant height, number of branches per plant, fruit girth, fruit length, internodal length, number of fruits per plant, number of seed per fruit and fruit yield per plant. The salient findings of the present study are summarized below:

1. The analysis of variance for the experimental design revealed highly significant mean squares among the genotype, parents and hybrids except fruit length indicating enormous genetic variation among the genotypes. The mean squares due to parents *vs.* hybrids were also found for fruit length, number of branches per plant, days to last picking and total number of seed per fruit which indicated that the performance of parents as a group was different than that of crosses as a group, thereby supporting the presence of mean heterosis for all the traits studied. Mean squares due to check *vs.* hybrids was also significant for all the characters except fruit length. Fruit length is non-significant for parents, hybrids and check *vs.* hybrids which indicated that considerable amount of genetic variability was not present in particular character. Significant mean square for various traits indicating the presence of considerable genetic diversity in the material studied.
2. The data on mean performance revealed that as usual the performance of crosses was better than parental lines. Among the females, JDNOL-18-2

exhibited the highest fruit yield per plant followed by Parbhani Kranti. Both these females were also superior for most of the yield contributing traits. Among the males, GAO-6 exhibited higher *per se* performance for fruit yield per plant and its contributing traits followed by GAO-5 and Pusa Sawani. Considering *per se* performance of hybrids, the superior cross combinations for fruit yield per plant were Parbhani Kranti x GAO-6, JOL-75-5 x Pusa Sawani and NLO-17-9 x GAO-6. These cross combinations also had high *per se* performance for one or more yield contributing traits.

3. The crosses expressed desirable relative heterosis and heterobeltiosis, respectively for different characters *viz.*, JOL-75-5 x Pusa Sawani and Parbhani Kranti x GAO-6 for days to flowering; JOL-75-5 x GAO-5 and JOL-75-5 x Pusa Sawani for days to first picking; JDNOL-18-2 x Pusa Sawani for fruit length; NLO-17-9 x GAO-6 and JDNOL-18-2 x Pusa Sawani for internodal length; Parbhani Kranti x GAO-5 and Parbhani Kranti x GAO-6 for plant height; JOL-75-5 x Pusa Sawani and Parbhani Kranti x GAO-6 for fruit yield per plant; Arka Anamika x GAO-6 and Parbhani Kranti x GAO-6 for total number of fruits per plant; NLO-17-9 x Pusa Sawani and JOL-75-5 x Pusa Sawani for total number of seed per fruit; NLO-17-9 x GAO-6 and JOL-75-5 x GAO-6 for days to last picking. Such crosses could be exploited further for yield advancement in okra.
4. Significant standard heterosis in desirable direction was reported for all traits except days to first picking, fruit length, fruit girth, total number of seed per fruit. Standard heterosis for fruit yield per plant (g) ranged from -33.38 per cent (JOL-16-06 x Pusa Sawani) to 9.44 per cent (Parbhani Kranti x GAO-6). Out of 24 hybrids; top three hybrids *viz.*, Parbhani Kranti x GAO-6 (9.44 per cent), JOL-75-5 x Pusa Sawani (0.42 per cent) and NLO-17-9 x GAO-6 (0.28 per cent) recorded higher positive standard heterosis for fruit yield per plant (g).
5. The analysis of variance for combining ability revealed that mean squares due to lines \times testers were found highly significant for all the traits under study except fruit length. These findings indicated more importance of non-additive gene action as compared to additive gene action in the expression of fruit yield and its component traits.

6. The magnitude of σ^2_{sca} was higher than σ^2_{gca} for all the traits except number of branches per plant and total number of seed per fruit indicated preponderance of non-additive gene action in the expression of yield and yield attributing traits. In case of fruit length, gca and sca variances were found non-significant therefore, there may be a role of environment in governing of this trait.
7. The results on gca effects of the parents indicated that none of the parent was found to be good general combiner simultaneously for all the characters. The estimates of gca effects of parents revealed that were VRO-22, JOL-75-5, Parbhani Kranti and Pusa Sawani for days to flowering and days to first picking, JDNOL-18-2 for fruit length, Parbhani Kranti, GAO-6 for fruit girth, JOL-75-5, Parbhani Kranti, Arka Anamika and GAO-6 for number of branches per plant, JOL-75-5, Parbhani Kranti, JDNOL-18-2 and GAO-6 for internodal length, Parbhani Kranti, JDNOL-18-2, Pusa Sawani and GAO-6 for plant height, NLO-17-9, JOL-75-5, Parbhani Kranti and GAO-6 for fruit yield per plant, NLO-17-9, JDNOL-18-2, Parbhani Kranti and GAO-6 for total number of fruit per plant, JOL-75-5, Arka Anamika and Pusa Sawani for total number of seed per fruit, JOL-75-5, NLO-17-9, JDNOL-18-2, GAO-5 and GAO-6 for days to last picking.
8. As regards to specific combining ability effects, the best cross combinations were JOL-16-06 \times GAO-6 for days to flowering; Parbhani Kranti \times GAO-6 days to first picking; JDNOL-18-2 \times Pusa Sawani for fruit length; NLO-17-9 \times GAO-6 for fruit girth; VRO-6 \times Pusa Sawani & JOL-16-06 \times GAO-5 for number of branches per plant; NLO-17-9 \times GAO-6 for internodal length; VRO-6 \times Pusa Sawani for plant height; Parbhani Kranti \times GAO-6 for fruit yield per plant; JDNOL-18-2 \times Pusa Sawani for total number of fruits per plant; NLO-17-9 \times Pusa Sawani for total number of seed per fruit and JOL-75-5 \times GAO-6 for days to last picking.
9. Parents exhibiting high mean performance also evinced good general combining ability effects for most of the characters. This showed consonance between per se performance and gca effects of parents that could be used as reliable and efficient selection criterion for good combiners for different characters on the basis of per se performance of parents.
10. From the present findings, it can be concluded that sufficient variability was present in the materials studied for yield and its components. The non-additive

gene action was observed in the inheritance of fruit yield and other yield associated traits. This suggested that heterosis breeding would be more suitable for the improvement of these traits in okra.

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APPENDICES

Appendix –A

Weekly meteorological data recorded during the crop season (July-2021 to October-2021) at Agronomy Instructional Farm, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar.

Month and year	Std. Weeks	Temperature (°C)		Relative Humidity (%)		Rain fall (mm)	Bright sunshine (hrs./day)	Wind velocity (km/hr)	Pan Evaporation (mm/day)
		Max.	Min.	Morn.	Even.				
July 2021	26	37.2	25.6	79	65	9.0	6.0	7.9	6.0
	27	38.0	26.8	76	65	0.0	8.4	11.1	7.3
	28	39.1	26.0	81	63	47.0	5.7	6.7	7.1
	29	36.1	26.2	82	75	8.0	3.8	7.4	7.0
	30	31.6	24.8	85	90	65.5	0.7	10.2	4.6
	31	29.0	24.3	84	85	17.5	0.0	8.6	3.5
August 2021	32	33.5	25.9	80	74	0.0	6.8	5.4	6.1
	33	36.5	25.7	73	68	0.0	9.5	5.9	7.5
	34	36.9	26.0	76	67	2.0	7.6	4.9	7.3
	35	35.6	24.7	82	66	36.5	6.6	5.3	6.0
September 2021	36	34.4	24.9	88	83	41.0	4.1	5.7	5.5
	37	32.9	24.2	85	83	109.5	3.6	3.3	4.4
	38	33.5	23.6	80	77	6.0	5.2	4.7	5.6
	39	33.1	24.9	81	77	87.5	4.4	5.1	5.8
October 2021	40	34.7	25.0	78	70	0.0	7.7	3.9	7.0
	41	37.4	25.8	77	62	0.0	9.8	2.1	7.9
	42	36.9	21.1	69	62	0.0	9.7	2.2	7.3
	43	36.2	18.0	66	59	0.0	9.9	4.7	6.8
	44	33.3	15.9	69	50	0.0	9.7	2.3	5.8

Source: Agricultural Meteorology Department, C. P. College of Agriculture, Sardarkrushinagar

Appendix-B

Mean performance of the parents and their F₁ hybrids for eleven traits in okra

Sr. No.	Genotypes	Days to flowering	Days to first picking	Fruit length (cm)	Fruit girth (cm)	Number of branches per plant	Internodal length (cm)
Lines							
1	VRO-6	47.00	50.33	10.33	4.80	1.90	4.47
2	NLO-17-9	49.00	52.67	11.75	5.09	1.75	5.04
3	VRO-22	44.33	48.33	11.61	4.55	2.09	3.92
4	JOL-75-5	46.00	50.00	11.49	5.59	2.07	3.41
5	JOL-16-06	45.00	49.67	11.29	4.76	1.83	4.25
6	JDNOL-18-2	49.67	53.67	11.68	6.18	2.06	3.77
7	Parbhani Kranti	47.00	48.67	10.96	6.68	2.18	3.83
8	Arka Anamika	48.67	52.33	11.52	4.93	2.35	4.82
Testers							
9	Pusa Sawani	46.33	51.33	12.15	5.83	2.09	4.64
10	GAO-5	47.67	52.33	11.99	6.22	2.07	4.23
11	GAO-6	47.00	50.67	12.35	6.31	2.13	4.07
Hybrids							
12	VRO-6 × Pusa Sawani	43.33	48.67	12.07	5.82	1.94	4.53
13	VRO-6 × GAO-5	45.00	50.00	12.27	5.93	1.73	4.86
14	VRO-6 × GAO-6	49.33	52.67	11.85	5.40	2.00	4.65
15	NLO-17-9 × Pusa Sawani	49.33	53.67	11.70	5.68	1.71	5.76
16	NLO-17-9 × GAO-5	48.67	53.33	11.44	5.17	1.71	4.99
17	NLO-17-9 × GAO-6	49.00	54.00	11.59	7.03	2.02	3.77

Cont....

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Sr. No.	Genotypes	Days to flowering	Days to first picking	Fruit length (cm)	Fruit girth (cm)	Number of branches per plant	Internodal length (cm)
18	VRO-22 × Pusa Sawani	47.33	49.67	11.95	5.74	2.01	4.33
19	VRO-22 × GAO-5	44.67	49.67	12.49	5.33	1.93	4.62
20	VRO-22 × GAO-6	43.67	49.67	12.31	5.27	2.16	4.08
21	JOL-75-5 × Pusa Sawani	41.33	48.00	12.33	5.39	2.02	4.42
22	JOL-75-5 × GAO-5	44.33	48.33	12.10	5.72	2.04	3.63
23	JOL-75-5 × GAO-6	48.00	53.00	12.32	5.76	2.11	4.26
24	JOL-16-06 × Pusa Sawani	49.33	53.33	11.79	4.75	1.79	4.37
25	JOL-16-06 × GAO-5	49.67	54.00	11.94	5.10	1.95	4.28
26	JOL-16-06 × GAO-6	45.33	50.00	11.66	5.39	2.04	4.20
27	JDNOL-18-2 × Pusa Sawani	47.67	49.67	13.55	4.90	1.82	3.58
28	JDNOL-18-2 × GAO-5	51.33	54.67	12.17	5.90	1.76	3.58
29	JDNOL-18-2 × GAO-6	49.33	53.00	11.92	6.18	2.08	3.50
30	Parbhani Kranti × Pusa	44.67	49.33	11.35	7.13	2.09	3.73
31	Parbhani Kranti × GAO-5	48.33	54.33	11.17	6.36	2.03	3.66
32	Parbhani Kranti × GAO-6	43.33	46.67	11.20	7.18	2.19	3.36
33	Arka Anamika × Pusa Sawani	46.33	49.67	11.37	5.61	2.13	4.78
34	Arka Anamika × GAO-5	46.67	52.33	11.55	5.21	2.11	5.19

Cont....

Cont....

Sr. No.	Genotypes	Days to flowering	Days to first picking	Fruit length (cm)	Fruit girth (cm)	Number of branches per plant	Internodal length (cm)
35	Arka Anamika × GAO-6	49.00	53.67	12.03	5.72	2.40	4.02
Check							
36	GJOH-4	44.67	48.67	12.62	7.02	2.19	5.37
	Parental mean	47.06	50.91	11.56	5.54	2.05	4.22
	Hybrid mean	46.88	51.47	11.92	5.74	1.99	4.26
	S. Em. ±	0.92	0.92	0.45	0.27	0.04	0.12
	CD (5%)	2.68	2.58	1.25	0.76	0.13	0.34
	GM	46.93	51.30	11.81	5.67	2.01	4.25

Cont....

Abbreviations: CD- Critical Difference; GM- General Mean; CV- Coefficient of Variation

Cont....

Sr. No.	Genotypes	Plant height (cm)	Fruit yield per plant (g)	Total number of fruits per plant	Total number of seed per fruit	Days to last picking
Lines						
1	VRO-6	72.09	266.32	20.87	39.87	108.33
2	NLO-17-9	72.09	290.42	20.54	37.07	113.00
3	VRO-22	72.83	274.92	19.23	32.47	110.00
4	JOL-75-5	68.99	262.96	19.23	40.63	111.67
5	JOL-16-06	71.93	203.8	16.10	35.50	114.67
6	JDNOL-18-2	64.08	297.56	22.45	37.67	116.33
7	Parbhani Kranti	63.64	291.93	23.65	39.33	112.67
8	Arka Anamika	73.59	222.89	19.70	39.87	109.33
Testers						
9	Pusa Sawani	71.81	258.78	20.54	34.13	109.33
10	GAO-5	78.90	277.60	22.59	35.13	113.00
11	GAO-6	71.45	286.95	21.67	30.27	109.33
Hybrids						
12	VRO-6 × Pusa Sawani	72.00	266.98	21.27	41.27	106.33
13	VRO-6 × GAO-5	88.45	268.74	21.36	38.67	106.33
14	VRO-6 × GAO-6	77.47	270.25	21.06	37.93	109.67
15	NLO-17-9 × Pusa Sawani	82.45	277.32	21.32	45.40	113.00
16	NLO-17-9 × GAO-5	75.23	282.84	20.69	36.77	116.33
17	NLO-17-9 × GAO-6	69.17	307.17	23.58	38.60	115.67

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Sr. No.	Genotypes	Plant height (cm)	Fruit yield per plant (g)	Total number of fruits per plant	Total number of seed per fruit	Days to last picking
18	VRO-22 × Pusa Sawani	76.49	278.17	20.83	35.60	107.33
19	VRO-22 × GAO-5	83.93	248.17	20.44	33.67	108.67
20	VRO-22 × GAO-6	75.65	267.88	20.39	33.17	105.67
21	JOL-75-5 × Pusa Sawani	66.53	307.60	19.85	47.53	104.33
22	JOL-75-5 × GAO-5	73.71	272.17	21.24	43.73	110.00
23	JOL-75-5 × GAO-6	74.91	273.95	20.89	41.87	114.67
24	JOL-16-06 × Pusa Sawani	74.40	204.05	16.70	38.00	113.67
25	JOL-16-06 × GAO-5	78.46	212.50	17.40	35.80	113.00
26	JOL-16-06 × GAO-6	69.79	205.21	18.33	33.33	108.67
27	JDNOL-18-2 × Pusa Sawani	65.63	289.00	23.38	40.40	109.33
28	JDNOL-18-2 × GAO-5	66.51	269.46	21.18	38.77	115.33
29	JDNOL-18-2 × GAO-6	67.73	269.15	21.08	38.00	116.67
30	Parbhani Kranti × Pusa Sawani	62.50	282.03	20.91	42.27	106.33
31	Parbhani Kranti × GAO-5	62.55	291.91	22.03	39.77	112.00
32	Parbhani Kranti × GAO-6	61.93	335.21	25.48	38.13	104.67
33	Arka Anamika × Pusa Sawani	72.34	262.40	20.37	46.67	107.67
34	Arka Anamika × GAO-5	80.81	263.69	18.47	44.13	110.00

Cont....

Cont....

Sr. No.	Genotypes	Plant height (cm)	Fruit yield per plant (g)	Total number of fruits per plant	Total number of seed per fruit	Days to last picking
35	Arka Anamika × GAO-6	71.32	306.71	23.33	41.43	112.67
Hybrids						
36	GJOH-4	84.49	306.30	23.29	48.53	108.00
	Parental mean	71.04	266.74	20.60	36.54	111.61
	Hybrid mean	72.91	271.36	20.90	39.62	110.33
	S. Em. ±	1.69	7.95	0.58	0.60	0.84
	CD (5%)	4.73	22.25	1.64	1.69	2.34
	GM	72.32	269.91	20.80	38.65	110.73

Abbreviations: CD- Critical Difference; GM- General Mean;

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