GENE ACTION STUDIES FOR FRUIT YELD AND HORTICULTURAL TRAITS IN OKRA (*Abelmoschus esculentus* (L.) Moench)

THESIS

By

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CERTIFICATE – I

This is to certify that the thesis entitled **"Gene action studies for fruit yield and horticultural traits in okra (*Abelmoschus esculentus* (L.) Moench)",** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the discipline of **Vegetable Science** of Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mr. Akhilesh Singh** son of Sh. Ravinder Singh and Late Smt. Urmila Devi under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

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Place: Palampur
Dated: July 22, 2019

CERTIFICATE- II

This is to certify that the thesis entitled **"Gene action studies for fruit yield and horticultural traits in okra (*Abelmoschus esculentus* (L.) Moench)",** submitted by **Mr. Akhilesh Singh (Admission No. A-2014-40-024)** son of Sh. Ravinder Singh and Late Smt. Urmila Devi to the Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Doctor of Philosophy (Agriculture)** in the discipline of **Vegetable Science** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Place: Palampur
Dated: July 22, 2019 ***(Akhilesh Singh)***

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LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1	et al.	et alii (and others)
2	i.e.	id est (that is)
3	*viz.,*	vi delicet (namely)
4	p	pages
5	pp	particular page
6	°C	degree Celsius
7	g	gram
8	Kg	kilogram
9	>	more than
10	<	less than
11	/	per
12	%	per cent
13	Fig.	figure
14	cm	centimeter
15	º	degree
16	t	tones
17	Max.	maximum
18	Min.	minimum
19	hrs	hours
20	RH	relative humidity
25	df	degree of freedom
26	SE (d) ±	standard error of difference
27	SE (m) ±	standard error of mean
28	*	significant
29	CD	critical difference
30	CV	coefficient of variation
31	CSK HPKV	Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya
32	YVMV	Yellow Vein Mosaic Virus
33	Cal.	calculated
34	@	at the rate
35	N	north
36	E	east
37	mm	millimeter
38	2n	diploid chromosome number
39	GCA	general combining ability
40	SCA	specific combining ability
41	vs	against
42	amsl	above mean sea level
43	ha	hectare

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ABSTRACT

The present investigation entitled "Gene action studies for fruit yield and horticultural traits in okra (*Abelmoschus esculentus* (L.) Moench)" was carried out at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK HPKV Palampur to gather information on genetic architecture for fruit yield and horticultural traits in okra. The experimental material comprised of 51 triple test cross progenies derived by mating 12 lines with three testers namely, 9801 (L_1), Hisar Unnat (L_2) and their single cross F_1 (L_3). This genetic material was evaluated in Randomized Complete Block Design with three replications during May to October, 2018. The observations were recorded on ten randomly selected plants in each entry over the replications on different quantitative traits [days to 50 per cent flowering, days to first picking, first fruit producing node, nodes per plant, internodal length (cm), fruit length (cm), fruit diameter (cm), average fruit weight (g), plant height (cm), harvest duration (days), fruits per plant and fruit yield per plant (g)], quality traits [immature fruit colour, fruit pubescence, ridges per fruit, dry matter (%) and mucilage (%)] and screening for yellow vein mosaic disease. Epistasis was found to be an integral part of genetic variation for majority of the traits including fruit yield per plant. Epistatic interaction for most of the traits was j+l type except first fruit producing node, nodes per plant, internodal length, fruit length, fruit diameter, average fruit weight, fruits per plant, ridges per fruit and dry matter whereas harvest duration, fruit yield per plant and mucilage carried both 'i' and 'j+l' type with predominance of 'i' type except fruit yield per plant. Additive component (D) was more pronounced than dominance component (H) for most of the traits except mucilage. Both additive and dominance components were of almost equal magnitude for mucilage indicating the importance of both additive and dominance type of gene action. Degree of dominance was in the range of partial dominance for most of the traits, while mucilage showed complete dominance. The kind of genetic variance revealed from triple test cross can be exploited by intermating selected individuals in early segregating generations with delayed selection in later generations, diallel selective mating/ biparental mating or recurrent selection followed by pedigree method to exploit both additive and non-additive components alongwith epistasis. Lines IC-169468, Parbhani Kranti, P-8, VRO-6 and Japan Round were found to be good general combiners for majority of the traits. The cross-combinations Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat and VRO-4 x Hisar Unnat exhibited high SCA, heterobeltiosis, economic heterosis and *per se* performance for fruit yield per plant and were rated as potential crosses. Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat and Parbhani Kranti x 9801 were the best cross-combinations for majority of the traits and were moderately resistant (Parbhani Kranti x 9801) to resistant (Parbhani Kranti x Hisar Unnat and P-8 x Hisar Unnat) to the YVMV disease. Due to ease in manual emasculation and pollination and resistance to yellow vein mosaic virus disease in the hybrids, it shall be a desirable proposition to exploit the parental lines of okra, in particular those revealing high SCA in the present study for the development of hybrids.

Akhilesh Singh **Student** **Date: July, 2019**		**Dr. Sonia Sood** **Major Advisor** **Date: July, 2019**
	Head of the Department	

1. INTRODUCTION

Okra [*Abelmoschus esculentus* (L.) Moench 2n=130], also known as bhindi in India and lady's finger in England, is one of the important warm season fruit vegetables grown extensively in tropics, subtropics and warmer parts of the temperate regions in the world. Accordingly, is native to northern Africa including the area of Ethiopia and is commercially cultivated in West Africa, India, South-East Asia, Southern United States, Brazil, Turkey and Northern Australia. The crop was earlier included in the genus *Hibiscus,* section *Abelmoschus* of *Malvaceae* family. The section *Abelmoschus* was subsequently raised to the rank of distinct genus by Medikus in 1787. The main difference between the genus *Abelmoschus* and *Hibiscus* was that of calyx, which was deciduous in the former, while it persisted in the latter. The crop is often cross-pollinated. Flowers are large sized and the monoadelphous stamens make emasculation and pollination processes easier. With the ease in fruit set and good number of seeds per pod, okra can potentially be exploited for hybrid vigour. It has a vast potential to earn foreign exchange and accounts for 60 % export of fresh vegetables excluding potato, onion and garlic, the destinations being the Middle East, the United Kingdom, Western Europe and the United States of America.

Okra assumes a nutritional and economic importance. It is valued for its tender and delicious fruits. Nutritionally, considerable amounts of minerals such as iron, calcium, manganese and magnesium as well as vitamins such as A, B, C and K and folate are present in okra (USDA national nutrient database 2016). Dietary consumption of tender pods of okra benefits patients suffering from certain gastro-intestinal and genito-urinary disorders (Singh et al. 2014). In addition, seeds of mature okra are high in oil and protein (Oyelade et al. 2003); the oil being rich in unsaturated fatty acids such as linoleic acid (Savello et al. 1980), which is considered as an essential component in human nutrition. From industrial perspective, mature fruits and stems of okra are used in paper industry, while roots and stems are also used for cleaning the cane juices (Singh 1989). Nano-cellulose synthesis from fibre of okra has also been reported, which potentially serves as a matrix and reinforcement agent thereby reducing the human dependence on many non-degradable products (Rahman et al. 2018).

Globally, okra is grown in an area of 24,02,039 hectares with an overall and average production of 96,41,284 metric tons and 4.01 tonnes/ha, respectively (Anonymous 2017). The nutritional benefits, acceptability of consumption, favourable climatic conditions and potential for foreign exchange renders okra to be widely cultivated and propagated in India, which ranks first in the world with an annual production of 60,95,000 metric tons produced from 5,09,000 hectares area, the average productivity being 11.97 tonnes/ha (Anonymous 2018). In Himachal Pradesh alone, okra is grown during summer and rainy season in low and mid hills and occupies an area of 2,950 hectares accounting for 3.30% of the total cultivable area under vegetables in the state, with an annual production of 39,360 metric tons (Anonymous 2017).

Of late, different varieties with high yield potential of okra have been developed. However, most of them are susceptible to various diseases, especially yellow vein mosaic virus, resulting in reduction of potential yield, quality and nutritive value of the green fruits thereby fetching lower returns to the growers. Although, yellow vein mosaic virus resistant varieties are available, further genetic improvement appears to be possible with identification and development of new improved disease resistant cultivars. Hence, there is a need to develop yellow vein mosaic virus resistant varieties with desirable horticultural traits (dwarf plants with short internodal length, more nodes, early maturity, smooth, green/ dark green/ coloured fruits). An appreciable quantum of information on inheritance pattern of different traits of okra is available, but still the aforementioned intent holds a future promise as the nature of gene action varies with the experimental material and the environment under study. The recombinant breeding is the most appropriate approach to combine various desirable horticultural traits with higher fruit yield. In such approach, the efficiency of breeding programme would mainly depend upon the genetic architecture of the traits under improvement (Cockerham 1961).

A number of biometrical approaches have been suggested to study the genetic architecture of polygenic traits. These approaches have their own advantages and limitations and a method suitable for a particular situation may not give valid genetic inferences under other situations. However, an appropriate biometrical procedure must have the least assumptions and should provide reliable genetic information about the materials under investigation. The assumption about the absence of epistasis, known to be of wide occurrence in almost all the crop plants, is the most disturbing one and must be included in the model for the unbiased estimation of genetic components (Mather and Jinks 1971).

Triple test cross analysis, devised by Kearsey and Jinks (1968), is one of the most efficient designs for investigating the genetic architecture of population. Since, this approach provides not only a precise test for epistasis, but also gives unbiased estimates of additive and dominance genetic components in the absence of epistasis. Furthermore, this method provides a comprehensive description of genetic architecture of the population, irrespective of its gene and genotypic frequencies, mating system and correlated gene distribution. Simultaneously, it gives a satisfactory estimate of additive genetic variance necessary for cross prediction. This estimate is uncorrelated with the dominance variance and has a lower bias even in the presence of epistasis. (Singh et al. 1987).

Besides, gathering information on various genetic components following triple test cross, knowledge of combining ability including precise estimates of general combining ability (gca) and specific combining ability (sca) can also be obtained through line x tester technique (Kempthorne 1957). These estimates are quite helpful in selecting the parents for hybridization programme.

Commercial production of hybrid varieties is one of the possibilities of enhancing the fruit yield of okra. Heterosis observed in okra and its commercial exploitation has become a reality due to its often-cross pollinating nature and setting of sufficient seeds per pod in each attempted cross. Therefore, identification of potential parents and specific parental combinations for producing desirable hybrids and transgressive segregants, respectively can presumably be of great value in this direction.

Therefore, keeping in view the above facts, the present investigation entitled "Gene action studies for fruit yield and horticultural traits in okra (*Abelmoschus esculentus* (L.) Moench)" was planned and executed with the following objectives:

i. To find out the contribution of different genetic components controlling the inheritance of various traits.

ii. To identify the potential parents and cross-combinations on the basis of combining ability and heterosis in okra.

2. REVIEW OF LITERATURE

Relevant literature pertaining to different aspects of the present study has been reviewed under the following sub-heads:

2.1 Genetic analysis

2.1.1 Triple test cross

2.1.2 Biometrical approaches other than triple test cross

2.2 Combining ability

2.3 Heterosis

2.1 Genetic analysis

The knowledge of gene action, the magnitude and relative importance of additive, dominance and epistatic genetic components of variance controlling various quantitative and qualitative characters is of paramount importance in determining the breeding methodology.

Several biometrical models have been developed to study the inheritance pattern of various quantitative traits. Most of these models ignore epistasis and thus may not be reliable for describing the nature of quantitative variation governing a particular character. To obtain more efficient estimates of additive, dominance and environmental components of variation for a trait, three difficulties inevitably arise from second-degree statistics.

Firstly, it is assumed in most of the analysis that non-allelic interactions are absent, although these analysis rarely provide a valid test of this assumption. Secondly, the estimates of dominance components invariably have much larger standard errors than that of corresponding additive components and lastly, the additive and dominance components are differentially affected by the linkages and correlated gene distribution in the parents. Comstock and Robinson (1952) developed North Carolina Design III to overcome the larger standard errors of dominance and epistasis. Kearsey and Jinks (1968) described an extension of North Carolina Design III called as ‘Triple test cross’.

2.1.1 Triple test cross

Triple test cross analysis provides unambiguous test for the presence of epistasis regardless of gene frequencies, degree of inbreeding and linkage relationships. The design has wide applicability as it can be used to investigate both segregating and non-segregating populations arising from different generations such as $F_{2,}$ backcross and homozygous lines. However, literature on triple test cross is quite meager in okra.

A triple test cross analysis with two testers and twenty parental lines was studied by Panda and Singh (2000) to detect the gene action in okra. They showed the evidence of epistasis for almost all the characters *viz.*, days to flowering, days to first picking, pod length, internodal length, plant height and fruit yield. All these characters were controlled predominantly by additive gene effect in both the seasons (summer and rainy seasons) except pod girth in summer season. However, over dominance was observed for girth of pod in summer season, suggesting greater contribution of dominance component in inheritance of the trait.

A triple test cross analysis comprising twenty families of two crosses of okra *viz.,* Pusa A-4 x KS-410 and AG-26 x Pb-8, was carried out by Tripathi and Arora (2001) and demonstrated the evidence of epistasis for almost all the characters *viz.*, days to first flowering, days to first picking, fruit weight, fruits per plant, length of pod, plant height, marketable yield and total fruit yield. Significant estimates of both additive (D) and dominance (H) components were observed for all the characters in both the crosses. However, partial dominance was observed in both the crosses except over dominance for fruit weight and plant height in Pusa A-4 x KS-410.

Vermani (2004) using triple test cross analysis revealed that epistasis was present for almost all the characters studied *viz.*, days to emergence, emergence of first floral bud, node at which 1^{st} flower appeared, fruit length, fruit diameter, internodal length, fruits per plant, fruit yield per plant, average fruit weight, nodes per plant and plant height. The i type of epistasis (additive x additive) was relatively more important for fruit yield per plant, average fruit weight, fruit diameter and internodal length, whereas j+l (additive x dominance and dominance x dominance) type of epistasis was more important for fruits per plant and plant height. The additive (D) and dominance (H) components based on the significance of sums and differences, respectively were significant for most of the characters studied and over-dominance was observed for fruit yield per plant, plant height, fruits per plant and internodal length suggesting the role of non-additive gene action in their inheritance.

Saravanan et al. (2005) using triple test cross analysis indicated the prevalence of significant epistasis in three crosses for plant height, internodal length, nodes per plant, fruits per plant, fruit length, fruit girth, fruit weight and fruit yield except days to first flowering, where significant additive x additive epistasis (i type) was recorded. Fruit yield showed significant j+l (additive x dominant and dominant x dominant) type of epistasis in the cross Arka Anamika x Parbhani Kranti. The additive and dominance components were significant for all the traits in the cross Arka Anamika x MDU-1 and the estimate of degree of dominance was less than unity for most of the characters.

Paragbhai (2006) by using triple test cross approach reported that total epistasis was significant for days to first flowering, days to first picking, nodes per plant, internodal length, plant height, days to last picking, fruit length, fruit girth, fruits per plant and fruit yield where both ‘i’ and ‘j+l’ type of epistasis was significant. Degree of dominance showed role of additive gene action for fruit yield over the environments.

Arora et al. (2007) revealed that epistasis was significant for fruit length, internodal length, fruit weight, fruits per plant, plant height, fruit yield per plant, mucilage and total minerals except days taken for first flowering in both the seasons for both crosses except for Hisar Unnat x Pant Bhindi in spring season. The ‘j+l’ type of gene effects were predominant for all the traits in both the season.

Patel et al. (2008) through triple test cross analysis construed that total epistasis was significant for internodal length, plant height, fruit length, fruit diameter and fruit yield. Only 'i' type epistasis was significant for plant height and fruit yield, while ‘j+l’ type epistasis was significant for internodal length, fruit length, fruit diameter and fruit yield. The additive (D) and dominance (H) component of genetic variance was significant for days to first flowering, internodal length, plant height, fruit length, fruit diameter, fruits per plant and fruit yield except dominance component for nodes per plant. Over dominance was observed for internodal length, plant height, fruit girth and fruit length, while partial dominance was observed for days to first flowering, nodes per plant, fruits per plant and fruit yield.

Mallikarjun et al. (2017) from triple test cross analysis revealed that epistasis was present for most of the characters *viz.,* days to 50 per cent flowering, fruit weight, number of ridges, fruit diameter, number of fruits, plant height, primary branches, number of nodes, internodal length and fruit yield in three crosses except primary branches in cross Pusa Sawani x Sel-1, days to flowering and number of ridges in cross DOV-1 x Sel-4, days to 50 per cent flowering and primary branches in cross DOV-1 x Arka Anamika. Significant additive x additive epistasis (i type) was recorded for fruits per plant, plant height and fruit yield while 'j'(additive x dominant) and 'l'(dominant x dominant) type epistasis was significant for fruit weight, fruit length, fruit diameter, fruits per plant, plant height, nodes per plant and fruit yield across the crosses. Degree of dominance revealed the predominance of additive genetic component for all the characters in all three crosses.

2.1.2 Biometrical approaches other than triple test cross

The approaches of genetic variance estimated for various traits in okra by following biometrical approaches other than triple test cross have been reviewed as follows:

From diallel analysis, Nichal et al. (2000) showed the importance of both additive and non-additive genetic components of variation in the inheritance of the quantitative traits. However, the mean squares due to GCA were greater, suggesting the predominant role of additive variance in the inheritance of all the characters. Pal and Hossain (2000) reported influence of both additive and non-additive gene effects in the inheritance of most of the traits studied in okra.

Sood and Kalia (2001) from diallel mating design found predominance of additive gene action for all the characters except fruit yield, fruits per plant and plant height, where non-additive gene action was important. Sood and Sharma (2001) reported non-additive gene effects were larger than additive effects for most of the characters studied. Both over dominance and epistasis contributed towards fruit yield.

Rani et al. (2002) from half-diallel mating design found over dominance for most of the traits *viz.*, plant height at first flowering, individual fruit weight, fruit length, fruit girth, plant height at final harvest, fruit yield and protein content in fruits. From an eight parental half-diallel analysis, Rani and Arora (2003) reported the predominance of non-additive gene action for all characters studied. Shekhawat et al. (2005) from eight parental diallel mating found both additive and non-additive gene effects for plant height, branches per plant, fruit length, fruits per plant and fruit yield.

Naphade et al. (2006) found the predominance of non-additive genetic variances for days to flower initiation, length of fruit, weight of fruit, primary branches on main stem, fruiting nodes on main stem and seeds per fruit, whereas additive genetic variance for fruit yield and fruits per plant from line x tester analysis. Mehta et al. (2007) reported that GCA and SCA were significant for all the characters and non-additive gene effects were found to play a major role in the inheritance of days to first flower, days to 50 percent flowering, fruit weight, fruit length, plant height, seeds per fruit and 100-seed weight, whereas additive genes were found to control inheritance of fruit yield.

From generation mean analysis, Arora et al. (2010) showed that most of the traits were under the control of non-additive gene action. Duplicate type of epistasis was observed for all the characters suggesting that recurrent selection in biparental progenies would help in development of high yielding cultivars of okra.

Dabhi et al. (2010) carried out combining ability analysis for fruit yield and its components in okra through line x tester technique and revealed that both additive and non-additive gene actions were involved in the genetic control of various characters i.e. days to first flower opening, nodes at first flowering, days to first picking, nodes per plant and fruit length, internodal length, plant height, 10-fruits weight, fruit girth, fruits per plant and fruit yield per plant. Kumar et al. (2010) carried out line x tester analysis by involving 16 lines and three testers and reported that variance due to SCA was higher than GCA for all the traits studied. However, dominance variance was much more pronounced than additive genetic variance for all the traits studied.

Patel et al. (2010b) studied gene action in okra and revealed that both additive and non-additive components of genetic variations were found important for the inheritance of fruit yield and its attributes. However, fixable components of genetic variation i.e. additive (d) and additive x additive (i) were observed for nodes per plant and internodal length, while all the three types of gene actions *viz.*, additive (d), dominance (h) and epistatic gene effects were observed for internodal length in the cross VRO-5 x GO-2.

Al-Kamal et al. (2011) carried out line x tester analysis using seven lines and three testers and found that analysis of variance revealed significant differences among genotypes for yield and associated traits, indicating the presence of sufficient genetic variability in the material studied. The additive as well as non-additive gene effects played significant role in the inheritance of yield and yield related traits with predominance of additive gene action in the inheritance of major yield contributing traits.

Kachhadia et al. (2011a) carried out combining ability study through line x tester mating method and revealed the preponderance of non-additive gene action in the expression of yield and its contributing characters except fruit girth which was governed by the additive gene action. Mistry and Vashi (2011) analyzed the nature and magnitude of gene action for pod yield and its contributing characters in six inter varietal crosses of okra and revealed that both additive and dominance gene effects were significant for majority of the traits but, the magnitude of dominance gene effect was higher.

Parmar et al. (2012) carried out 8 x 8 diallel analysis (excluding reciprocals) in okra for green fruit yield and its traits and revealed that significant GCA and SCA variances were observed for all the traits *viz.*, days to flowering, days to first picking, fruit length, fruit girth, number of nodes on the main stem, internodal length, plant height and fruit yield per plant and also reported that non-additive gene effects were predominant for all the traits studied. Reddy et al. (2012b) studied combining ability variances and effects of yield and its components in okra by involving 10 nearly homozygous germplasm lines and their 45 F_1 hybrids and 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 fruits and 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 branches per plant and fruit and shoot borer infestation on fruits and shoots.

Deo (2014) by using North Carolina Design III found that cross KS-410 x HRB-55 had importance of both additive and dominance components for all the traits except internodal length in summer and plant height in rainy season.

Jonah et al. (2015b) studied eight parents full-diallel set and reported that GCA variance was high for all the characters except for pod diameter and fruit yield reflecting the role of additive and additive x additive type of gene action.

Ayesha et al. (2017) from full-diallel mating found that both the additive and non-additive genetic components were involved in the inheritance of fruit yield and component traits with preponderance of non-additive gene action. Rameshkumar et al. (2017) from a six parent full-diallel analysis observed preponderance of non-additive gene action for days to first flowering, node at which first flower appear, fruit length, fruit girth, plant height and fruits per plant.

Srikanth et al. (2018) from joint scaling test found the presence of epistatic gene effect for days to 50% flowering, branches per plant, plant height, nodes per plant, fruit length, fruit weight, fruits per plant and fruit yield in crosses *viz.*, Hisar Naveen x Varsha Uphar, HB-25-2 x HB-32, HB-40 x HB-27 and HB-1157 x Pusa Sawani. Duplicate epistasis was found to be predominant for yield and yield attributing characters except fruits per plant, which showed complimentary epistasis. Both additive and non-additive components of genetic variance were found important for the inheritance of fruit yield and attributing traits.

Makdoomi et al. (2019) by using 10 x 10 diallel mating design reported higher magnitude of dominance component for days to first flowering, days to first picking, plant height, nodes per plant, internodal length, fruit length, fruit girth, average fruit weight, fruits per plant and fruit yield indicating the role of non-additive gene action in their inheritance.

2.2 Combining ability

Importance of combining ability of the inbred was first time realized by Richey and Mayer (1925), while working on maize. Davis (1927) suggested the use of inbred x variety cross to test the general combining ability (GCA) of inbreds. The concept of general combining ability (GCA) and specific combining ability (SCA) was given by Sprague and Tatum (1942). They further reported that GCA is dependent mainly on additive gene effects and additive x additive type of epistasis, whereas SCA includes both dominance and epistasis. According to them, the GCA is the average performance of line in a series of hybrid combinations, and the SCA refers to those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Griffing (1956) defined techniques for estimating the GCA and SCA effects under different situations.

Pawar et al. (1999) revealed that HRB-55, Pusa Sawani, DL-1-87-5 and Jo-5 were good general combiners for yield and many component traits and could be used in crossing programme to isolate superior segregants.

Dhankar and Dhankar (2001) concluded genotypes MR-15 (line) and BB-1 (tester) as good general combiners for fruit yield and its components. Cross-combination MR-10-1 x Varsha Uphar exhibited high SCA effect for fruit yield. Rajani et al. (2001) from 6 x 6 diallel analysis found that the line TCR 861 was the best general combiner for fruit weight and fruit length. Highest SCA effects were recorded in Cross TCR 893 x TCR 864 for yield, while TCR 865 x TCR 438 and TCR 893 x TCR 861 were notable for fruit length, diameter and fruit weight. Sood and Kalia (2001) reported good general combining ability in line IC-9856 for early flowering, maturity, dwarfness and shorter internodal length along with highest SCA effect for yield in P-7 x Arka Abhay and P-7 x Arka Anamika.

Adeniji and Kehinde (2003) evaluated West African okra and reported that specific combining ability variance was greater than the general combining ability variance indicating preponderance of non-additive gene action. The ratio $(H/D)^{1/2}$ indicated over dominance across loci for the mean degree of dominance for fruit yield. Mitra and Das (2003) from a 10 x 10 diallel analysis found predominance of non-additive gene action for days to 50 per cent flowering, branches per plant and fruits per plant.

Bendale et al. (2004) reported Gold finger as best general combiner and the cross Parbhani Kranti x Gold finger having the highest SCA values for fruit yield. Kumar et al. (2005) construed that lines AB-1 and AB-2 were best general combiners for yield. They found that cross-combinations AB-2 x BO-2, AB-1 (AG) x PK and AB-2 x AB-1 (AG) were good specific combiners for yield. Non-additive gene action was observed for days to flowering, height of plant, branches per plant, first fruiting node, nodes per plant, length of internode, length of fruit, width of fruit, fruits per plant and fruit yield.

Jindal and Ghai (2005) from 12 x 12 half-diallel analysis found high GCA effects for HRB-107-4, HU, S-2 for fruits number and yield. Highest SCA effects were recorded in VRO-4 x PP, PA-4 x NDO-10, NDO-10 x HRB-108-2 and PA-4 x PB-1. Kumar and Anandan (2006a) studied combining ability for days to first flowering, plant height, nodes per plant, branches per plant, fruits per plant, fruit length, fruit weight, fruit yield per plant, green matter production and harvest index by involving six parental cultivars and 30 crosses of okra and found that both additive and non-additive gene action were important in the inheritance of all traits.

Yadav et al. (2007b) using diallel mating design reported the major role of additive component in the expression of all the characters except fruit width which showed equal proportion of additive and non-additive gene action. Parents KS-410, Pusa Sawani, KS-305 and KS-312 were good general combiners, while crosses KS-410 x Pusa Sawani, KS-410 x KS-305, KS-410 x BO-2, Pusa Sawani x IIHR-4 and KS-410 x Arka Anamika were good specific combiners for yield and contributing traits. From a line x tester analysis, Weerasekara et al. (2008a) revealed that KAO-25 and KAO-61 (lines) and KAO-23 and KAO-AA (testers) were best general combiners. Cross-combinations, KAO-53 x KAO-18, KAO-35 x KAO-AA and KAO-17 x KAO-AA exhibited the highest SCA for yield.

Balakrishnan et al. (2009) form six parent diallel analysis obsereved that line Arka Anamika was good general combiner for fruit number, fruit weight and fruit length, while KL9 for days to first flowering, internode number and fruit weight. Non-additive gene action was observed for plant height, days to first flowering, number of internodes, fruit length and fruit yield. Khanpara et al. (2009) using line x tester method revealed predominantly additive gene action for days to 50% flowering, days to first picking, nodes per plant, plant height, branches per plant, fruit length and fruit yield, while predominance of non-additive gene action for internodal length and fruit girth. Parents, Pant Bhindi and D-1-87-5 were good general combiners for fruit yield, nodes per plant and fruits per plant.

Pal and Sabesan (2009) from diallel analysis found that parents Sat-dhari, Ratna-78, VRO 5 and Varsha Uphar were the best general combiners, while crosses Sat-dhari x Ratna-78, VRO 5 x Sagun, Ratna-78 x Punjab 8, Ankur–40 x Pankaj Dwarf, Sat-dhari x Varsha Uphar and Arka Anamika x Punjab-5 were best specific combiners for fruit yield and component traits. Preponderance of additive gene action was observed for primary branches per plant, ridges per fruit and fruit diameter, whereas non-additive gene action for plant height, nodes on main stem, days to first flowering, fruits per plant, fruit length, fruit weight and fruit yield.

Singh and Kumar (2010) through diallel method reported that cross-combination, KS-401 x Pusa Sawani exhibited high specific combining ability effects as well as *per se* performance. Parents KS-387, KS-404 and Pusa Sawani were good general combiners for fruit yield. Wammanda et al. (2010) in a study of nine parents and 36 hybrids reported that Mothol-AE2, Mothol-AE3, Gerio-AE1 and Mothol-AE1 were the best general combiners for most of the traits.

Malakannavar (2011) by using full-diallel mating design revealed that lines 4 (BH2 x 12-3-6-4-3-2-5-4-2), 5 (BH2 x BH13-2-4-6-5-2-4-5-4), 37 (BH2 x 13-2-1-3-2-1-4-3) and 22 (BH13 x 10-5-3-4-2-1-2-5-2) were good general combiners for yield. Both additive and non-additive gene effects were present for days to first flowering, 50 per cent flowering, plant height, branches, internodal length, fruit length, fruit diameter, fruits per plant, fruit weight and fruit yield. Rai et al. (2011) conducted a 5 x 5 diallel analysis for yield and component traits and reported that parents Selection 71-14 and KS-312 showed best general combining ability, whereas crosses, KS-312 x PBN-57 and PBN-57 x Selection 71-14 exhibited highest specific combining ability for fruit yield. Non-additive gene effects were observed for branches per plant, days to first flower and fruit yield.

Aulakh and Dhall (2012) studied inheritance using joint scaling test and found that cross-combinations, Punjab-8 x Arya Dhanlaxhmi and Punjab-8 x Pusa Sawani showed over dominance for fruit yield, fruits per plant, average fruit weight and plant height along with evidence of epistasis. Dominance gene effects were higher in magnitude than additive gene effects indicating the role of non-additive gene action towards inheritance of all the traits except average fruit weight. Joshi and Murugan (2012) using line x tester analysis found that genotype IC 1543 was the best general combiner for days to first flowering, fruits per plant, fruit weight and fruit yield. Among males, Hisar Unnat and Parbhani Kranti were found best combiners, whereas among testers, Arka Anamika was the best combiner. SCA variance was higher in magnitude than GCA variance for days to first flowering, plant height at maturity, branches per plant, fruits per plant, fruit weight and fruit yield.

In an another study, Adiger et al. (2013a) revealed that Parbhani Kranti (tester) was best general combiner for fruit length, fruits per plant and fruit yield, while Arka Anamika (tester) for branches per plant, internodal length, test weight and fruit weight. Hazem et al. (2013) using half-diallel mating design found that GCA and SCA mean squares were significant for days to 50% flowering, plant height, branches per plant, fruits per plant, average fruit weight, fruit length, fruit diameter and yield. Pusa Sawani was the best general combiner for all the traits except average fruit weight.

Kumar et al. (2013) conducted line x tester studies and reported that three lines *viz.,* Arka Abhay, VRO-5 and VRO-6 had positive significant GCA effects for fruit yield. Cross Hisar Unnat x Punjab Padmini exhibited good specific combining ability for plant height, fruit yield, number of pickings, fruits per plant and fruit length. Kumar et al. (2013) from half-diallel analysis found that non-additive gene action was observed for days to 50% flowering, plant height, branches per plant, first fruiting node, length of internodes and length of fruit in both the generations except nodes per plant, width of fruit, fruits per plant and yield.

Lyngdoh et al. (2013) crossed 18 lines and four testers in line x tester design and revealed that cross, KO-2 x PK for plant height, KO-5 x V5 for internodal length and branches per plant and KO-4 x V6 for nodes on the main stem were good specific combiners, while parent KO-18 for plant height, KO-6 for internodal length and nodes on the main stem and KO-12 for branches per plant were found good general combiners. GCA and SCA variances revealed predominance of non-additive gene action. Reddy et al. (2013) reported that desirable GCA effects were exhibited by parents Arka Anamika and Arka Abhay, whereas SCA effects were shown by crosses, Arka Anamika x DBh- 43, DBh-47 x Arka Anamika and DBh-47 x DBh-30 for fruit yield.

Akotkar et al. (2014) using half-diallel design reported that genotypes IC-332453 and Parbhani Kranti were the best general combiners. Crosses, IC-33107 x IC-433665, IC-342075 x IC-332453, IC-43736 x Parbhani Kranti, IC-433672 x IC-332453 and IC-3307 x IC-4376 exhibited high SCA effects along with *per se* performance for fruit yield. Kumar et al. (2014) from half-diallel analysis construed that parents Hisar Unnat, IC-128891 and VRO-5 had GCA effects for yield, earliness and pod characters. Crosses, Larm-1 x IC-111527, IC-282280 x IC-111527 and IC-282280 x EC-329380 were most promising for earliness and fruit yield indicating the importance of both additive and non-additive genetic components.

Nagesh et al. (2014) crossed 18 lines with three testers using line x tester mating design and reported that line KON-5 for fruit length, fruit diameter, average fruit weight and fruit yield; KON-6 for fruits per plant were good general combiners. Cross, KON-8 x IC90174 was best specific combiner for fruit yield. SCA variances were higher than GCA for all the traits suggestive of non-additive gene action in their inheritance. Bhatt et al. (2015) using diallel method (without reciprocals) found that genotypes AOL-09-25 and GO-2 had good general combining ability for fruit yield. Cross-combinations, AOL-09-25 x AOL-09-26, GO-2 x AOL-09-28 and AOL-08-10 x AOL-08-2 showed positive significant SCA effects for fruit yield.

Kumar and Reddy (2016) from half-diallel analysis found that inbred line RNOYR-16 was the best general combiner, while cross-combinations, RNOYR-14 x RNOYR-17, RNOYR-16 x RNOYR-17 and RNOYR-17 x RNOYR-18 were the best specific combiners for marketable yield. Tiwari et al. (2016) using 5 x 5 full-diallel method revealed that line VRO-6 was good general combiner while crosses, GJO-3 x AA, AOL-12-52 x AA and GJO-3 x VRO-6 were the most promising specific combiners.

Jupiter and Kandasamy (2017) using line (7) x tester (3) method reported that SCA variance had higher magnitude for all the characters signifying preponderance of non-additive gene action. Line Sivagangai Local was the best general combiner for fruits per plant and fruit yield while testers Pudukottai Local and Arka Anamika were good general combiners for fruit yield. Satish et al. (2017) using line (10) x tester (5) analysis revealed that magnitude of SCA variance was higher for fruit yield and its contributing traits indicating the predominant non-additive gene effect. Among females, JOL-08-7 while, among males, Parbhani Kranti were good general combiners for fruit yield and component traits. Hybrid, JOL-08-7 x Parbhani Kranti exhibited high SCA effect for fruit yield.

Gavint et al. (2018) from line (8) x tester (4) analysis reported that GCA variance was higher than SCA variance for most traits except internodes per plant and fruit weight indicating preponderance of additive gene action for inheritance of these traits. Genotypes JOL-11-12, AOL-03-1, Arka Anamika and KS-404 among females, while GAO-5 among males, were good general combiners. Crosses, JF-55 x VRO-6, JF-108-02 x VRO-6 and JOL-11-12 x GAO-5 had desirable specific combining ability for fruit yield. Gowda et al. (2018) using 47 x 2 line x tester analysis found GCA effect in the Line-44 and Line-7 for fruit yield and average fruit weight, respectively. Crosses Line-24 x Arka Anamika and Line-23 x IC-550848 were good specific combiners for fruit yield.

Reddy and Sridevi (2018) found that Arka Anamika and Arka Abhay were best general combiners for fruit yield, while crosses Arka Anamika x DBh-43, DBh-47 x Arka Anamika and DBh-47 x DBh-30 were the best specific combiners. Shwetha et al. (2018) from half-diallel analysis found that parents KO1608 and KO1606 were good general combiners for fruits per plant and fruit yield, whereas crosses KO1601 x KO1605 and KO1603 x KO1606 were good specific combiners for average fruit weight and yield.

Punia and Garg (2019) using 6 x 10 line x tester analysis reported Kashi Kranti as best general combiner for days to 50% flowering, days to maturity, plant height, branches per plant, fruits per plant, fruit length and fruit weight. Cross-combination No. 315 x Hisar Unnat was best specific combiner for plant height, branches per plant, fruit length, fruit weight and fruit yield.

2.3 Heterosis

The term heterosis is now widely used, which refers to the phenomena in which the F_1 hybrids obtained by crossing the two genetically dissimilar homozygous individuals, showed increased or decreased vigour over the parental values. Shull (1908) referred this phenomenon as the stimulus of heterozygosis. 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 and maternal interactions. The degree of heterosis depends upon the number of heterozygous alleles. Higher the number of heterozygous alleles, more is the heterosis expected (East and Hayes 1912). The term heterobeltiosis was coined by Fonesca and Patterson (1968), which refers to the increased or decreased vigour of F_1 over its better parent. Hybrid vigour in okra has been first reported by Vijayaraghavan and Wariar (1946). Hybrids offer opportunities for improvement in productivity, earliness, uniformity, quality, wider adaptability and rapid deployment of dominant genes for resistance to diseases and pests. A considerable degree of heterosis has been documented in okra for various characters. The heterosis of some traits as reported by various workers is presented as follows.

Singh and Sood (1999) studied heterosis in okra in a set of 8 x 8 diallel crosses excluding reciprocals and revealed that four crosses *viz.*, P-7 x Arka Abhay, P-7 x Arka Anamika, P-7 x Prabhani Kranti and Prabhani Kranti x Arka Abhay exhibited maximum heterosis for fruit yield over standard check (Pusa Sawani).

Dhankar and Dhankar (2001) reported that out of 80 cross-combinations studied, the hybrid MR-10-1 x Varsha Uphar was the best for fruit yield followed by the hybrid MR-12 x Raj-12. Pathak et al. (2001) studied heterobeltiosis in 18 hybrids of okra and reported that the values for pod yield per plant ranged from -34.86 (Arka Abhay x EC 16511) to 62.66 per cent (7D-2 x EC16511). Nichal et al. (2001) reported heterobeltiosis to the extent of 87.90%, 22.32%, 23.28% and 129.22% for fruits per plant, average fruit weight and fruit length and yield per plant, respectively. Sood and Sharma (2001) while working in sub-temperate climatic region reported heterosis and gene action for fruit yield and associated traits in a diallel cross among five okra cultivars and two promising breeding lines and observed that P-7 x Arka Abhay exhibited highest heterobeltiosis of 68% and produced 80% more fruits than standard check Pusa Sawani.

Chauhan and Singh (2002) in a line x tester analysis involving 20 lines and four testers reported heterosis for yield and its contributing characters over the better parent and standard checks (Prabhani Kranti and Pusa Sawani). Cross-combination DC-97 x P-7 exhibited highest heterosis for yield over better parent and standard checks. Singh et al. (2002) reported heterosis as high as 141 per cent for fruit length (5709 x 6308) and 185 per cent for fruits per plant (6305 x 6901). They also obtained beneficial heterobeltiosis for fruit weight per plant in 6302 x 6308 (67.51%).

Rewale et al. (2003) reported significant heterobeltiosis in the cross DVR-3 x Green Gold for fruits per plant, yield per plant, nodes per plant, branches per plant and plant height and the crosses JNDO-5 x Prabhani Kranti and NOL-101 x Green Gold showed a higher magnitude of heterosis over better parent.

Bhalekar et al. (2004) studied heterosis in okra by using seven parents and their 21 crosses and revealed that four crosses *viz.*, A.A.D.F.1 x Arka Anamika, Arka Anamika x Lorm 1, Varsha Uphar x Lorm 1 and Arka Anamika x Prabhani Kranti exhibited maximum heterosis for yield over better parent. Neeta et al. (2004) reported that 45 F_1 progenies of okra exhibited heterosis over superior and economic parent for fruit yield and components.

Borgaonkar et al. (2005) in a study on heterosis in okra reported a high degree of heterosis for fruit length, internodal length, leaf area and yield per plant. Cross No. 129 x JNDO-5 exhibited the greatest heterobeltiosis (52.22%) for yield per plant followed by No. 74 x JNDO-5 (40.45%) and No. 114 x JNDO-5 (37.96%).

Mamidwar and Mehta (2006) studied heterosis using 14 lines and three testers in okra and results exhibited that out of 42 crosses the highest heterosis over better parent was recorded by VRO-6 x Parbhani Kranti followed by cross Daftari-1 x Arka Abhay for fruit yield. Naphade et al. (2006) reported that significant heterosis was measured over check variety Parbhani Kranti for primary branches on main stem in cross Arka Anamika x Tot 1502 (96.47%) and for fruits per plant in AKO 73 x Tot 1502 (37.79%). Similarly for fruiting nodes on main stem (31.28%) and plant height (25.15%) in cross Arka Anamika x Tot 1498 and for length of fruit (23.59%) and weight of fruit (23.57%) in cross Parbhani Kranti x Tot 1494, heterosis was found to be significant.

Nichal et al. (2006) conducted field experiment to study heterosis in seven promising lines and their crosses in okra and observed that the cross VRO-3 x Arka Abhay exhibited highest relative heterosis (132.84%) and heterobeltiosis (129.22%) for fruit yield. Singh and Syamal (2006) evaluated 12 x 12 diallel crosses in okra excluding reciprocals to determine the extent of heterosis in F_1 hybrid over three better parents. Heterobeltiosis was observed to the extent of 53.28% (IC-90177 x IC-90202) for pods per plant, 12.65% (Arka Abhay x BO-1) for pod weight and 54.54% (Arka Abhay x BO-1) for yield.

Dahake et al. (2007) studied heterosis for fruit yield and its components in okra and reported that Hissar Unnat x Duptari 45 exhibited the highest magnitude of heterosis for fruit yield to the extent of 24.36% and 13.93% over better parent and standard check, respectively. Mehta et al. (2007) produced 42 hybrids by crossing three testers with 14 lines using line x tester design and reported that most heterotic combinations for fruit yield were VRO-6 x Parbhani Kranti, VRO-4 x Parbhani Kranti, Daftari-1 x Arka Abhaya and Kaveri Selection x Ankur Abhaya.

Yadav et al. (2007a) carried out line x tester analysis in okra to determine heterosis over standard parent for yield and yield components. KS-440 x KS-404 and KS-440 x KS-410 exhibited the highest negative significant heterosis for number of first fruiting node and internodal length, respectively while KS-455 x Prabhani Kranti exhibited significant and positive heterosis for nodes per plant and fruits per plant. Significant and positive heterosis over the standard parent was observed in KS-455 x Prabhani Kranti and KS-445 x KS-404 for fruit length and fruit width, respectively.

Hosamani et al. (2008) conducted a study to exploit the heterosis for okra improvement by crossing three lines and eight testers in a line x tester fashion. The magnitude of heterosis over the standard control (Arka Anamika) was high for most of the characters studied. Out of twenty four hybrids, IC-90044 x Prabhani Kranti can be exploited commercially as it exhibited earliness, high number of fruits and high yield per plant. This cross recorded significantly higher yield i.e. 262.84%. Pandey et al. (2008) evaluated 28 F_1's developed through diallel mating design alongwith eight parental genotypes and reported heterosis for branches per plant, fruit length and fruits per plant over better parent in crosses Pusa Sawani x Azad Bhindi-2, Pusa Sawani x VRO-6 and P-7 x BO-2, respectively.

Singh et al. (2008) studied heterosis over better parent and mid parent in okra by using line x tester mating design and found high positive and significant heterosis over better parent and mid parent in crosses Arka Anamika x X-70 for green pod weight, X-71 x X-70 for plant height, Okra-2 x Okra-1 for branches per plant and X-2 x Pusa Makhmali for fruits per plant and fruit yield. Weerasekara et al. (2008b) in a line x tester study involving eight lines and three testers observed an appreciable amount of heterosis and heterobeltiosis for fruit yield. The cross IC-90273 x IC-90044 exhibited maximum heterosis (75.68% and 56.48 %) over mid parent and better parent, respectively.

Jindal et al. (2009) conducted heterosis studies in diallel fashion and found that hybrids PA-4 x NDO-10, PA-4 x PB-1, NDO-10 x HRB-108-2 and VRO-3 x S-2 were of commercial importance in respect of earliness and yield. Significant heterobeltiosis and economic heterosis was observed for all the traits and the magnitude of economic heterosis was higher than heterobeltiosis. Singh and Sharma (2009) evaluated 24 F_1 hybrids to assess the extent of heterosis for yield and its contributing traits. An appreciable heterosis was found over better and mid parent for all the characters studied. The crosses VRO-4 x Arka Anamika, VRO-4 x BS-14, VRO-4 x Hisar Unnat, VRO-5 x BS-12 and VRO-5 x BS-14 showed significant heterosis over better and mid parent.

Akhtar et al. (2010a) carried out line x tester analysis involving 10 lines and three testers and found that fruit yield per plant recorded maximum heterosis (55.20%) followed by branches per plant (47.21%), green fruit length (37.83%), plant height (35.22%), fruits per plant (30.32%), green fruit weight (19.87%), days to 50% flowering (-17.03%), days to first flowering (-22.86%) and fruit diameter (-15.49%). Among the crosses, Pusa Makhmali x Parbhani Kranti, VRO-6 x Parbhani Kranti, Pusa Makhmali x P-7, BO-2 x Pusa Sawani and Punjab Padmini x Parbhani Kranti were found potential hybrids for commercial exploitation. Dabhi et al. (2010) studied heterosis for fruit yield and its components using line x tester technique and recorded maximum heterosis in KS-404 x Arka Abhay (32.08%) and PB-266 x Arka Abhay (20.04%) for fruit yield. It was found maximum over better parent for number of nodes at first flowering in hybrid JOL-1 x Punjab-7 (66.67%), whereas maximum standard heterosis was exhibited by hybrid KS-404 x Punjab-7 (49.62%) for fruits per plant.

Kumar and Sreeparvarthy (2010) evaluated five parents and their 20 hybrids in 5 x 5 diallel fashion for estimating extent of heterosis and revealed that maximum standard heterosis for fruit yield was observed in hybrid MDU-1 x Hissar Unnat. Hybrid Varsha Uphar x Hissar Unnat had high mean, positive significant SCA and high standard heterosis for five traits including fruit yield. Murugan et al. (2010) studied heterosis in okra for some important biometrical traits by crossing eight genotypes in half-diallel fashion and reported that hybrids Varsha Uphar x Hissar Unnat had high mean, positive significant SCA and high standard heterosis for five traits including fruit yield per plant.

Patel et al. (2010a) while studying heterosis for fruit yield and attributing traits reported that positive and significant heterobeltiosis was observed in KS-404 x HRB-108-2 and VRO-5 x GO-2 for fruit length and fruit yield, respectively. Similarly, significant and positive relative heterosis was found in KS-404 x HRB-108-2 for nodes per plant, fruits per plant and fruit length and in VRO-5 x GO-2 for fruits per plant and fruit yield. Wammanda et al. (2010) reported significant heterosis over better parent for earliness, plant height and fruit number in diallel cross analysis of okra. Hybrid Mothol-AE2 x Mothol-AE3 was found to exhibit heterosis up to 23.3% for yield over the higher yielding parent.

Kachhadia et al. (2011b) studied heterosis for yield and yield components in okra through line x tester mating method involving 10 lines and four testers, over better parent and standard check (GO-2). The crosses *viz.*, JOL-06-5 x HRB-55 (47.05 and 78.43%), JOL-06-3 x Pusa Sawani (37.89 and 36.08%) and GO-2 x Prabhani Kranti (24.34 and 63.04%) manifested significant and desirable heterobeltiosis and standard heterosis, respectively for fruit yield. Kumar (2011) evaluated 7 x 7 diallel crosses in okra including reciprocals to assess the magnitude of heterosis over better parent and standard check for fruit yield and its component traits. The cross Pusa A-4 x Punjab Padmini exhibited the highest magnitude of heterosis to the extent of 43.23% over better parent and 55.96% over standard check for fruit yield per plant and 13.52% over better parent and 29.78% over standard check for fruits per plant. The crosses Pusa A-4 x Punjab Padmini, Punjab Padmini x Pusa A-4, Punjab Padmini x Varsha Uphar, Prabhani Kranti x Punjab Padmini, Pusa A-4 x EMS-8 and Varsha Uphar x Punjab Padmini were identified as promising hybrids.

Malakannavar (2011) reported maximum standard heterosis of 79.59% for fruit yield over Pusa Sawani. Standard heterosis was also observed for fruits per plant, fruit length and branches per plant. Rai et al. (2011) reported estimates of heterotic effects for 10 hybrids concluding that cross BO-I x KS-312 was the best combination with early fruiting followed by the crosses BO-I x Selection 71-14 and PBN-57 x Pusa Selection 7. Vachhani et al. (2011) studied 45 hybrids of okra derived from 10 x 10 diallel crosses excluding reciprocals for heterosis and inbreeding depression for fruit yield and yield components. The cross-combinations AOL-99-24 x Ajeet-121, JOL-1 x HRB-55, JOL-1 x VRO-6 and GO-2 x HRB-107-4 expressed the highest heterobeltiosis alongwith high magnitude of inbreeding depression for fruit yield per plant, which will be suitable for exploitation of hybrid vigour for commercial purpose.

Bassey et al. (2012) conducted a field experiment to evaluate heterosis and variability in 16 morphological characters in diallel crosses of seven okra varieties. The F_1 hybrids of Lady Finger x Agwu Early, Clemson Spineless x LD88, Agwu Early x Lady Finger and LD88 x Lady Finger, recorded highest better parent heterosis for length of pods, girth of pods, pods per plant and fresh pod yield, respectively. Joshi and Murugan (2012) reported that the hybrid IC-1543 x Arka Anamika exhibited high standard heterosis for fruit yield. This cross-combination also exhibited negative significant SCA effects for days to first flowering.

Medagam et al. (2012) evaluated 45 F_1's along with their 10 parents and standard control (Mahyco Hybrid No 10) for heterosis of yield and its components in okra and reported that 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. The F_1 hybrid IC-89976 x IC-111443 with high yield potential has the potential for commercial cultivation after further evaluation for early *kharif* season. Mistry (2012) analyzed heterosis and inbreeding depression by involving six intervarietal crosses of okra and revealed that all the three crosses exhibited significant heterosis over mid and better parents for yield and yield contributing characters followed by significant inbreeding depression. So, further improvement may be possible by exploiting the heterosis through heterosis breeding.

Reddy et al. (2012a) evaluated 45 hybrids alongwith 10 parents and one standard check (Mahyco Hybrid No. 10) for heterosis of yield and its components of okra and reported that overall mean heterosis over mid parent and standard check for total yield per plant was 6.92% and -15.44%, respectively, while for marketable yield per plant was 6.64% and -22.18%, respectively. Negatively heterotic crosses were C19 (IC-29119-B x IC-45732) for days to 50% flowering (-4.35%) and C4 (IC-282248 x IC-45732) for first flowering and fruiting nodes (-15.22%), respectively. Singh and Singh (2012) conducted a line x tester analysis by involving 15 lines and three testers to estimate heterosis for 10 characters including pod yield per plant over three different environments. The crosses Swati-10 x Prabhani Kranti, Punjab Padmini x Arka Abhay, Heritage Green x Arka Abhay, VRO-6 x Prabhani Kranti and Punjab Padmini x Prabhani Kranti were identified as potential combinations as they showed high heterobeltiosis across the environments.

Adiger et al. (2013b) studied heterosis for yield and yield components in double cross derived inbred lines of okra and recorded significant heterosis ranging from -63.68 to 78.58% over better parent for fruit yield. The gain over superior check US Agro ranged between -58.63 to 21.28%. Three hybrids namely, DBh383 (21.28%), DBh31 (19.23%) and DBh133 (10.93%) showed high heterosis for fruit yield over superior check US Agro and were most promising for commercial cultivation. Hazem et al. (2013) estimated heterosis using half-diallel design and revealed that majority of crosses were significantly better yielding than their mid parents and heterosis ranged from 2.35% to 21.80%.

Javia (2013) used line x tester mating design to study the heterosis and heterobeltiosis in okra and revealed that majority of the hybrids exhibited significant positive heterosis over mid and better parent for days to flowering, nodes per plant, internodal length, plant height, branches per plant, fruit length, fruit girth, fruits per plant and fruit yield. Parbhani Kranti x D-1-87-5 was the best heterotic combination (184.27%) for majority of traits except days to flowering and nodes per plant. Kumar et al. (2013) conducted a line x tester analysis by involving five testers and three lines to estimate heterosis. Three crosses *viz.*, VRO-5 x Arka Anamika (-8.59%), Hissar Unnat x Arka anamika (-4.95%) and Arka Abhay x Arka Anamika (-4.09%) displayed significant and negative heterosis over mid parent for plant height. Heterosis was negative and significant for days to first flowering over mid parent ranging from -4.88% (Hisar Unnat x Parbhani Kranti) to -26.67% (Arka Abhay x Arka Anamika). Standard heterosis varied from 4.49% (VRO-5 x Parbhani Kranti) to 36.18% (Hissar Unnat x Punjab Padmini) for plant height.

Lyngdoh et al. (2013) by using line x tester method reported that heterosis was observed for cross KO-2 x PK (48.20%) for plant height, KO-6 x PK (-43.05%) for internodal length over the better parent and KO-6 x PK (56.07%) for plant height over commercial check, while KO-6 x PK and KO-13 x V5 exhibited significant negative heterosis over the better parent (-10.42%) and the commercial check (-11.34%) for internodal length. Reddy et al. (2013) using 10 x 10 half-diallel mating design revealed that cross-combinations, C42 (P7 x P10), C31 (P5 x P6), C17 (P2 x P10), C35 (P5 x P10) and C25 (P4 x P5) exhibited non-significant standard heterosis for marketable fruit yield. Solankey et al. (2013) conducted a study to exploit the heterosis for okra improvement by crossing 17 lines and three testers in a line x tester fashion. The magnitude of heterosis over the standard control was high for most of the traits studied. Cross Arka Abhay x Arka Anamika was the best for high fruit yield potential and quality traits.

Nagesh et al. (2014) in a study on heterosis in okra reported that maximum positive heterosis was found in cross KON-8 x IC-90174 over better parent (107.90%) and the commercial check (92.42%) for total yield. Crosses KON-8 x IC-90174 (92.42%), KON-5 x AAN (45.83%), KON-16 x AAN (40.52%), KON-12 x AAN (35.07%) and KON-7 x IC-90174 (27.11%) showed significant heterosis over the commercial check for total yield.

Goswami et al. (2015) studied heterosis in 20 parents and their 51 F_1 hybrids developed in line x tester analysis and revealed that heterosis for yield ranged from -17.14% (VRO 1668 x Azad Krishna) to 26.09% (IC-69302 x Azad Bhindi1) over better parent and from -17.19% (IC-11527 x Azad Krishna) to 21.85% (IC-69302 x Azad Bhindi1) over mid parent. Patel (2015) reported that cross-combinations Local Red x Parbhani Kranti (65.44%) and Sel.2 x HRB-55 (57.05%) exhibited highest heterosis for fruit yield over better parent and commercial check, respectively.

Tiwari et al. (2015) evaluated diallel crosses in okra excluding reciprocals to assess the magnitude of heterobeltiosis. The cross VRO-6 x GJO-3 displayed significant and economic heterosis for fruit yield. VRO-6 x Arka Anamika, Arka Anamika x GJO-3, GJO-3 x PK, GJO-3 x Arka Anamika and Arka Anamika x AOL-12-52 were the top ranking combinations exhibiting significant heterosis over better parent for internodal length, fruits per plant, plant height, fruit diameter and average fruit weight, respectively. Verma and Sood (2015b) conducted a study on 28 okra hybrids developed in 8 x 8 diallel fashion involving inbred lines and reported that maximum heterosis for fruit yield was recorded for VRO-4 x Hisar Unnat followed by Tulsi-I x SKBS-11, P- 20 x Tulsi-I, 9801 x SKBS-11 and VRO-4 x Parbhani Kranti.

Bhatt et al. (2016) evaluated hybrids of okra and found that maximum positive heterosis for fruit yield over better parent and standard check (JOH 2) was observed to be 62.12% and 44.11%, respectively. The best hybrid, AOL 09-25 x AOL 09-26 recorded 44.11% heterosis for yield over standard check thus can be exploited for commercial cultivation.

Kumar et al. (2017) revealed that hybrid IC-282280 x EC-329380 manifested high heterosis over better parent and standard check for pod yield (82.42% and 35.66%) and pods per plant (62.82% and 48.54%), respectively. Paul et al. (2017b) conducted a study to exploit the heterosis for okra improvement and found that crosses HRB-55 x AOL-09-17 (71.08%), JOL-09-8 x AOL-09-17 (49.37%), AOL-09-17 x JOL-09-7 (41.78%) and JOL-55-3 x HRB-55 (26.99%) were found superior for standard heterosis, whereas crosses JOL-09-8 x JOL-09-7 (53.93%), JOL-09-8 x AOL-09-17 (37.99%) and JOL-09-12 x AOL-09-2 (37.76%) recorded highest heterobeltiosis for fruit yield. The cross HRB-55 x AOL-09-17 exhibited maximum heterosis (53.88%) over standard check for fruit yield.

Eswaran and Anbanandan (2018) in their study revealed highest heterosis for fruit yield in Parbkani Kranti x EC-305626 and Arka Anamika x Parbkani Kranti, while for earliness significant negative heterosis was recorded in Arka Anamika x EC-305626. Most of the yield related traits exhibited heterosis over its mid parent ranging from 83.36% to 35.35% for primary branches per plant, 93.10% to 14.65%

for first fruiting node and 32.56% to 10.87% for fruit weight. Kerure and Pitchaimuthu (2018) from 10 parental half-diallel crosses observed significant standard heterosis for fruit yield except for IIHR-604 x IIHR-107 (-0.13%). Maximum significant heterosis was observed in cross IIHR-875 x IIHR-478 over better parent (83.78%) and over standard parent (168.55%) (Nunhems hybrid Shakti) suggesting its suitability for commercial cultivation. Makdoomi et al. (2018) revealed that cross-combinations IC-117018 x Pusa Sawani, SKBS-11 x IC-117018, SKBS-11 x Parbhani Kranti and Pant Bhindi x Azad Ganga exhibited significant heterosis for fruit yield which ranged from 55.00% to -0.38%.

Sapavadiya et al. (2019) conducted line (8) x tester (4) analysis and found that cross-combinations JOL-11-12 x AOL-03-02, KS-404 x JOL-2K-19, Pusa Sawani x AOL-03-01 and Pusa Sawani x AOL-08-05 had significant heterosis over standard check (GJOH-3) for fruit yield.

3. MATERIALS AND METHODS

The present investigation was carried out at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (H.P.) from May-September, 2016 to 2018. The details of material used and methods employed in the present investigation are presented below:

3.1 EXPERIMENTAL SITE

3.1.1 Location

The experimental farm is situated at 32°6' N latitude, 76°3' E longitude and 1290.8 m altitude.

3.1.2 Climate

The location represents the mid hill zone (Zone-II) of Himachal Pradesh characterized by humid sub-temperate climate with high rainfall of 2,500 mm per annum of which 80 per cent is received during June to September. The soil is acidic in nature with pH ranging from 5.0 to 5.6 with silty clay loam texture. The mean weekly meteorological data recorded at Agro-meteorological Observatory of the Department of Agronomy, CSK HPKV, Palampur during the crop growing period of the location is given in Appendix-I and depicted in Figure 3.1 (Anonymous 2018).

Table 3.1 Genotypes used for developing triple test cross hybrids

S. No.	Lines	S. No.	Lines
1.	P-20	9.	P-23
2.	VRO-4	10.	Japan Red
3.	Parbhani Kranti	11.	Japan 5 Ridged
4.	P-8	12.	Japan Round
5.	Tulsi-1		**Testers**
6.	SKBS-11	1.	9801 (L_1)
7.	VRO-6	2.	Hisar Unnat (L_2)
8.	IC-169468	3.	F_1 (L_3)

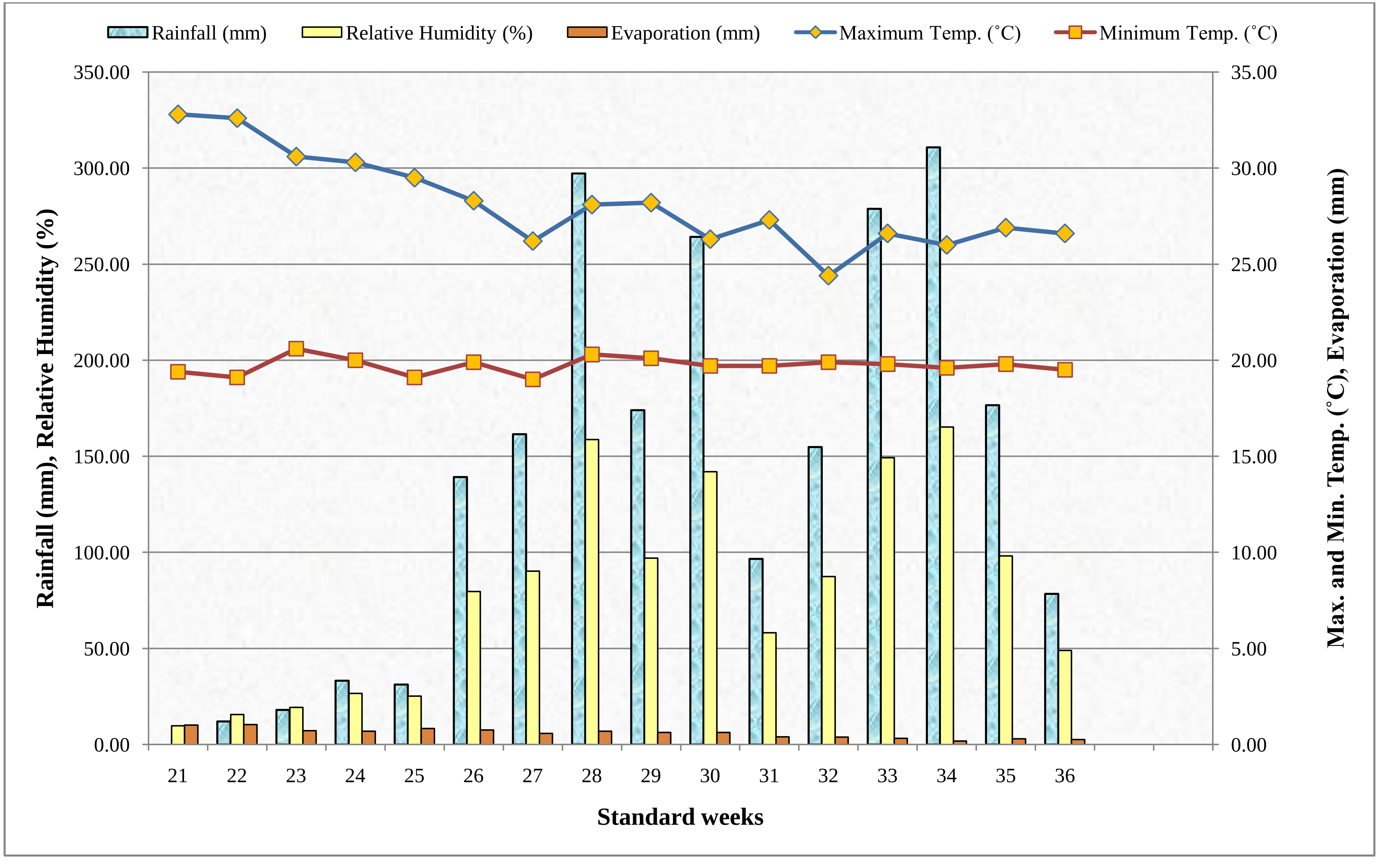

Figure 3.1 Mean weekly weather conditions during the cropping season at Palampur

3.2 EXPERIMENTAL MATERIALS

The experimental material included 12 fixed lines (Plate 3.1), three testers (Plate 3.2) and their 36 triple test cross families. Diverse genotypes 9801 and Hisar Unnat (P_1 and P_2) and their F_1, were used as testers 'L_1', 'L_2' and 'L_3', respectively. The detail of these genotypes is given in Table 3.1. 'Palam Komal' was included as standard check for line x tester analysis.

3.3 METHODS

3.3.1 Crossing Plan

The crosses were attempted as per triple test cross (TTC) design proposed by Kearsey and Jinks (1968). During summer-rainy season 2016, 9801 was crossed with Hisar Unnat and ample F_1 seeds were produced. During summer-rainy season of 2017, these three testers were used as male parents for crossing with 12 lines (females) to develop 36 triple test cross hybrids.

3.3.2 Experimental Design and Layout

The 36 F_1 hybrids, 12 lines and three testers were grown in a Completely Randomized Block Design with three replications during summer-rainy season 2018 (Plate 3.3). The experimental material was sown in single row. Row to row and plant to plant distances were maintained at 45 cm x 15 cm, respectively.

3.3.3 Cultural Practices

Farm Yard Manure @ 10 tonnes/ha and chemical fertilizers (75 Kg N, 50 Kg P_2O_5, 50 Kg K_2O /ha) were applied as per the recommended package of practices. Half dose of N and full doses of P_2O_5 and K_2O were applied at the time of field preparation. The remaining half dose of N was top dressed in two equal amounts, first at earthing up and second after one month.

3.3.4 Observations Recorded

The observations *viz.*, days to 50 per cent flowering, days to first picking, first fruit producing node, nodes per plant, internodal length (cm), average fruit weight (g), plant height (cm), harvest duration (days), fruits per plant and fruit yield per plant (g) were recorded on 10 competitive plants in each entry. For the parameters *viz.*, immature fruit colour, fruit pubescence, ridges per fruit, fruit length (cm) and fruit diameter (cm), a random sample of 5 fruits per entry was drawn from 4^{th} and 8^{th} pickings. Laboratory analysis was done to estimate dry matter (%) and mucilage (%) in fresh marketable pods.

Line 1

Line 2

Line 3

Line 4

Line 5

Line 6

Plate 3.1 Parental lines used in the study

Plate 3.1 Contd….

Line 7

Line 8

Line 9

Line 10

Line 11

Line 12

Plate 3.1 Parental lines used in the study

L_1: 9801

L_2: Hisar Unnat

L_3: F_1 (9801 x Hisar Unnat)

Plate 3.2 Three testers used in the study

i) Quantitative traits

1. Days to 50 per cent flowering

Days to 50 per cent flowering were recorded from sowing to the date when 50 per cent of plants in each entry had flowered.

2. Days to first picking

Number of days from date of sowing to the first harvest in each entry were counted.

3. First fruit producing node

The node at which first fruit set from the base took place was counted for each entry.

4. Nodes per plant

Total number of nodes per plant from base to tip in each entry was counted at the time of final picking.

5. Internodal length (cm)

Internodal length was calculated in centimeters, by dividing plant height with total number of nodes in each entry and replication.

6. Fruit length (cm)

Five fruits were taken at random and measured for their length in centimeters in 4^{th} and 8^{th} picking from the proximal to the distal end of the fruit and average was worked out.

7. Fruit diameter (cm)

The fruits used for measuring fruit length were also used for measuring the diameter in centimeters with the help of vernier calliper from the mid portion of the fruit and average values were worked out.

8. Average fruit weight (g)

The total weight of fruits was divided by the total number of fruits harvested over all the pickings to get the average fruit weight in each entry.

9. Plant height (cm)

The plant height was measured in centimeters in each entry from ground level to the top of the main shoot after the last picking.

Crop after 25 days of sowing **Crop after 60 days of sowing**

Crop after 75 days of sowing

Plate 3.3 General view of the experiment

10. Harvest duration (days)

Total number of days from first picking to the final picking of marketable fruits were counted in each entry to estimate the harvest duration.

11. Fruits per plant

Total number of marketable fruits per plant over all the pickings in each entry were recorded.

12. Fruit yield per plant (g)

The weight of marketable fruits harvested from each plant in all the pickings was recorded in grams and totaled to have fruit yield per plant.

ii) Quality traits

1. Immature fruit colour

Five fruits were taken at random from each entry per replication and through visual observation they were classified into six different categories namely yellowish green (1), green (2), dark green (3), red (4), dark red (5) and others (99) according to Minimal Descriptors for Agri-Horticultural Crops (Srivastava et al. 2001).

2. Fruit pubescence

The fruits used same as above were classified as downy (3), slightly rough (5), prickly (7) and others (99) according to Minimal Descriptors for Agri-Horticultural Crops (Srivastava et al. 2001).

3. Ridges per fruit

The fruits used same as above were classified into none (1), from 5 to 7 (2), from 8 to 10 (3), more than 10 (4) and others (9) according to Minimal Descriptors for Agri-Horticultural Crops (Srivastava et al. 2001).

4. Dry matter (%)

Procedure:

It was estimated as per procedure of Arora et al. (2008). 50 g of fresh immature fruit samples of each replication/entry was cut and added in pre-weighed empty Petri-dishes separately. It was kept in oven at a temperature of 60˚C for duration of 48 hours. Thereafter, the samples were taken out and Petri dishes were again weighed.

Calculations:

$$\text{Dry matter (\%)} = \frac{W_2 - W_1}{W} \times 100$$

where,

W_2 = Weight of dried sample + Weight of empty Petri dish (g)

W_1 = Weight of empty Petri dish (g)

W = Weight of sample taken (g)

5. Mucilage (%)

Reagents used: Ethanol, acetone.

Procedure:

It was estimated as per the procedure of Woolfe et al. (1977). 25 g of fresh immature fruit sample was ground in 125 ml of distilled water. It was then centrifuged at 4000 g (~6500 rpm) for 15 minutes and the clear viscous solution decanted. The solution was then heated at 70 °C temperature for 5 minutes to inactivate enzymes. The mucilage was precipitated with 3 volumes of ethanol (75 ml) and washed with more ethanol followed by acetone. The cream coloured solid collected on pre-weighed Whatman's No. 1 filter paper was dried under vacuum at 25 °C for 12 hours.

Calculations (Rao and Sulladamath 1977):

$$\text{Mucilage (\%)} = \frac{W_2 - W_1}{W} \times 100$$

where,

W_2 = Weight of filter paper + mucilage solid after drying (g)

W_1 = Weight of filter paper (g)

W = Weight of fruit sample taken (g)

iii) Disease reaction of yellow vein mosaic virus:

For the screening of yellow vein mosaic virus, a separate experiment was conducted at KVK Kangra during summer-rainy season, 2018. Disease scoring was done by disease scale suggested by Mayee and Datar (1986). The description of scale is given as under (Table 3.2):

Table 3.2 Description of disease scale for Yellow Vein Mosaic Virus

Scale	Reaction category	Type of Infection
0	No disease	No plants infected
1	Highly resistant (HR)	<1% plants showing symptoms
3	Resistant (R)	1-10% plants showing mottling of leaves
5	Moderately Resistant (MR)	11-20% plants showing mottling and yellow discoloration of leaves
7	Susceptible (S)	21-50% plants showing mottling and yellow discoloration of leaves and stunting of plants
9	Highly Susceptible (HS)	> 50% plants affected, stunting of plants pronounced, flower and fruit set reduced and yellow mottling severe

Growth stages: At seedling stage, flowering, fruit setting and fruit maturity

3.4 STATISTICAL ANALYSIS

The statistical analysis for various characters recorded were carried out as prescribed under:

3.4.1 Analysis of variance for randomized block design

For working out the analysis of variance, the data was analyzed by using the following model as suggested by Panse and Sukhatme (1984).

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

where,

Y_{ij} = phenotypic observation of i^{th} entry in the j^{th} replication

μ = general mean

g_i = effect of i^{th} entry

r_j = effect of j^{th} replication, and

e_{ij} = error component

Analysis of variance

Source of variation	df	Mean squares	Expected mean squares
Replication	r – 1	Mr	$\sigma_e^2 + g\,\sigma_r^2$
Treatment	g – 1	Mg	$\sigma_e^2 + r\sigma_g^2$
Error	(r – 1) (g – 1)	Me	σ_e^2

where,

r = number of replication

g = number of entries

σ_r^2 = replication variance

σ_g^2 = entries variance

σ_e^2 = error variance

The replication and treatment mean squares were tested against error mean squares by 'F' test, at P=0.05.

From this analysis, the following standard errors were calculated where the 'F' test was significant:-

i) Standard error for the treatment mean:

$$SE(m) = \pm \sqrt{\frac{Me}{r}}$$

ii) Standard error for the difference of treatment mean:

$$SE(d) = \pm \sqrt{\frac{2Me}{r}}$$

3.4.2 Triple test cross analysis

The information on the genetic architecture of the material under investigation was gathered through triple test cross design. The analysis of this design is divided into two parts.

i) Test for the detection of epistasis, and

ii) Estimation of additive and dominance components of variation

3.4.2.1 Test for the detection of epistasis

The presence of non-allelic interaction can be determined by using the model proposed by Kearsey and Jinks (1968). This test is based on the following comparison:

Test	Comparison	Reference
$\bar{L}_{1i} + \bar{L}_{2i} - 2\bar{L}_{3i}$	1 1 -2	Kearsey and Jinks (1968)

The test $\bar{L}_{1i} + \bar{L}_{2i} - 2\bar{L}_{3i}$ is unambiguous and always tests the presence of epistasis for non-common loci between the L_1 and L_2 testers. $\bar{L}_{1i}$, $\bar{L}_{2i}$ and $\bar{L}_{3i}$ are mean of the i^{th} family with respect to the tester concerned.

The analysis of variance to detect the presence/absence of epistasis has been performed with the following partitioning.

Analysis of variance to detect the presence of epistasis and its further portioning

Source of variation	df
Epistasis	n
i type	1
(j+l) type	(n–1)
Epistasis x replication	(r–1)n
i type x replication	(r–1)
(j+l) type x replication	(n–1) (r–1)
Error (within family)	3nr (m–1)

where,

n = number of lines/males/TTC families

m = average number of plants, and

r = number of replications

The epistasis sum of squares for 'n' degrees of freedom was further partitioned into 'i' type (homozygote x homozygote) of epistatic interaction having '1' degree of freedom and 'j+l' type of epistatic interaction, i.e. the homozygote x heterozygote and heterozygote x heterozygote interactions, having (n–1) (r–1) degrees of freedom. Similarly, the sum of squares due to replication x epistasis for (r–1)n degree of freedom was divided into replication x epistasis (i-type) and replication x epistasis (j and l type) with (r–1) and (r–1) (n–1) degrees of freedom, respectively. Each of the three types of epistasis was tested against their respective interaction with replications using 'F' test at 5 per cent level of significance.

3.4.2.2 Estimation of additive and dominance components of variation

The genetic components are to be estimated only if epistasis is absent. In the present study, the additive (sums) and dominance (difference) components of variation have been computed irrespective of the presence or absence of epistasis for the characters under study in order to determine their relative magnitude for various interactions.

The additive (D) and dominance (H) components of genetic variation were estimated from the following orthogonal comparisons (Kearsey and Jinks 1968)

Comparison	$\bar{L}_{1i}$	$\bar{L}_{2i}$	$\bar{L}_{3i}$	Component
Sums	1	1	1	Additive
Differences	1	-1	0	Dominance

When all the three crosses are made, an alternative analysis is possible in which all comparisons among the three kinds of family means i.e. $\bar{L}_{1i}$, $\bar{L}_{2i}$ and $\bar{L}_{3i}$ are orthogonal to one another (Jinks and Perkins 1970).

Comparison	$\bar{L}_{1i}$	$\bar{L}_{2i}$	$\bar{L}_{3i}$	Component
1	1	1	1	Additive
2	1	-1	0	Dominance
3	1	1	-2	Epistasis

For testing the significance, the analysis of variance will take the following form:

ii) **Analysis of variance for sums and differences**

Analysis of sums

Source	df	MS	Expectations of mean squares
Replication	R–1		
Sum	N–1	MS_3	$\frac{1}{m}\ \sigma_e^2+\sigma_{sar}^2+3r\sigma_s^2$
Sum x replication	(n–1) (r–1)	MS_2	$\frac{1}{m}\ \sigma_e^2+\sigma_{sr}^2$
Error (within family)	3nr (m–1)	MS_1	$\frac{1}{m}\ \sigma_e^2$

Analysis of difference

Source	df	MS	Expectation
Replication	r–1		
Difference	n–1	MS_3	$\frac{1}{m}\ \sigma_e^2+\sigma_{dr}^2+3r\sigma_d^2$
Difference x replication	(n–1) (r–1)	MS_2	$\frac{1}{m}\ \sigma_e^2+\sigma_{dr}^2$
Error (within family)	2nr (m–1)	MS_1	$\frac{1}{m}\ \sigma_e^2$

where,

n = number of males

m = average number of plants per progeny

σ_e^2 = variance due to error

σ_s^2 = variance due to sums and

σ_d^2 = variance due to differences

3.4.2.3 Average degree of dominance

On a simple additive-dominance model, the additive and dominance components of variation were estimated as:

$$\sigma_s^2 = \frac{MS_3 - MS_2}{2r}$$

$$D = 8\sum_{i=1}^{n} uvdi^2 = 8\sigma_s^2$$

$$\sigma_d^2 = \frac{MS_3 - MS_2}{2r}$$

$$H = 8\sum_{i=1}^{n} uvhi^2 = 8\sigma_d^2$$

The average degree of dominance was computed from the estimated components of D and H as:

Average degree of dominance = $(H/D)^{1/2}$

where,

H = Dominance genetic variances

D = Additive genetic variance

3.4.2.4 Covariance (sums/differences)

In the absence of epistasis and correlated gene distribution, this covariance has the expectation

$$\text{Cov sums/differences} = \sum_{i=1}^{n} uvd_i h_i = ¼\ F$$

F, therefore, has the same coefficient as D and H, but measures the sum of products of the d and h terms. Both the magnitude and the sign of covariance provide information about the magnitude and direction of dominance, which supplements that obtained from σ_d^2.

3.4.2.5 Estimation of correlation coefficient

To determine whether the covariance is significant, it can be converted into a correlation coefficient with (n–3) degree of freedom.

$$R\ (\text{sums/differences}) = \frac{\text{Cov (sums/differences)}}{\sqrt{V\ (\text{sum}) \times V\ (\text{differences})}}$$

A number of situations can occur in practice each of which has its own interpretation. These are:

(a) σ_d^2 is significant and $r_{(sums/differences)}$ is also significant

This means that there is a dominant contribution to the variation and the dominance is predominantly in one direction. By examining the sign of 'F' (which is the opposite of the sign of co-variance), the predominant direction of the dominance effects can be determined. If F is positive, then the increasing alleles are dominant more often than the decreasing alleles, if F is negative, the decreasing alleles are predominant more often than the increasing alleles.

(b) σ_d^2 is significant and $r_{(sums/differences)}$ is non-significant

This emphasizes that there is a dominance contribution to the variation but the dominance is ambi-directional, increasing and decreasing alleles being dominant and recessive to the same extent.

(c) σ_d^2 is non-significant and $r_{(sums/differences)}$ is also non-significant

This means that there is no evidence of dominance contribution to the variation.

(d) σ_d^2 is non-significant and $r_{(sums/differences)}$ is significant

This is trivial and could arise as a result of sampling error.

3.4.3 Line x tester analysis

The line x tester analysis was carried out as per the method given by Kempthorne (1957) after excluding the L_{3i} families and the F_1 tester.

3.4.3.1 Analysis of variance

Analysis of variance was carried out following model given by Panse and Sukhatme (1984):

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

(i=1, ……………, g)

(j=1, ……………, r)

where,

Y_{ij} = phenotypic observation of i^{th} entry in j^{th} replication

μ = general mean

g_i = effect of i^{th} entry

r_j = effect of j^{th} replication and

e_{ij} = the error component

The effects of the above model are assumed to be fixed unknown parameters, except e_{ij}'s which are assumed to be normally and independently distributed with mean zero and common variance σ^2. The analysis of variance based on the above model takes the following form:-

Analysis of variance

Source of variation	df	Sum of squares	Expected mean squares
Replication	(r-1)	$1/g \sum_{j=1}^{r} y_1^2 - (\sum_{j=1}^{r} y_1)^2 / gr$	-
Progeny	(g-1)	$1/r \sum_{j=1}^{g} y_1^2 - (\sum_{j=1}^{g} y_1)^2 / gr$	$M_g = \sigma_e^2 + rr_g^2$
Parent	(p-1)	$1/r \sum_{j=1}^{p} y_1^2 - (\sum_{j=1}^{p} y_1)^2 / pr$	$M_p = \sigma_e^2 + rr_p^2$
Line/Female	(f-1)	$1/r \sum_{j=1}^{t} y_1^2 - (\sum_{j=1}^{t} y_1)^2 / mr$	$M_f = \sigma_e^2 + rr_f^2$
Tester/Male	(m-1)	$1/r \sum_{j=1}^{m} y_1^2 - (\sum_{j=1}^{m} y_1)^2 / \mathrm{fr}$	$M_m = \sigma_e^2 + rr_m^2$
Line vs Testers	1	Parents SS-Lines SS-Testers SS	
Hybrid	(h-1)	$1/g \sum_{j=1}^{h} y_1^2 - (\sum_{j=1}^{h} y_1)^2 / hr$	$M_h = \sigma_e^2 + rr_h^2$
Parent vs. Hybrid	1	Progenies SS-Parents SS-Hybrid SS	
Error	(g-1) (r-1)	Total SS-Progenies SS-Replication SS	$Me = \sigma_e^2$

where,

g = tm + t + m; p = t + m ; h = tm

m = number of testers

f = number of lines

p = number of parents

h = number of hybrids

r = number of replications

g = number of genotypes

The different sums of squares were divided by their respective degree of freedom to obtain mean squares, which were tested against error mean squares using F-test at 5 per cent level of significance.

3.4.3.2 Combining ability analysis

3.4.3.2.1 Analysis of variance

The combining ability analysis was carried out as per the method of Kempthorne (1957).

Analysis of variance for combining ability

Source	df	SS	MS	Expectations of MS
Replication	r–1	SS_R	-	-
Hybrid	h–1	SS_H	-	-
Tester/Male	m–1	SS_M	M_1	$\sigma_e^2 + \frac{fr}{m-1}\sum_i^f g_i^2$
Line/Female	f–1	SS_F	M_2	$\sigma_e^2 + \frac{mr}{f-1}\sum_i^m g_i^2$
Female x Male	(f-1) (m-1)	SS_{MP}	M_3	$\sigma_e^2 + \frac{fr}{m-1}\sum_i^f \sum_i^m s_{ij}^2$
Error	(mf-1) (r-1)		M_5	σ_e^2

where, r, m and f are number of replications, testers (males) and lines (females), respectively.

$$SS_R = \sum_{k=1}^{r} Y..k/fm–(Y...)^2/mfr$$

$$SS_H = \sum_{k=1}^{m}\sum_{j=1}^{f} Y_{ij}./r–((Y...)^2/mfr$$

$$SS_M = \sum_{i=1}^{m} Y_i../fr–(...)^2/mfr$$

$$SS_F = \sum_{j=1}^{f} Y.j./mr – (Y\ldots)^2/mfr$$

$$SS_{MF} = \sum_{i}^{m}\sum_{j}^{f}(Y_{ij}.)^2/r – \sum_{1}^{m} Y_i../fr – \sum_{j}^{f} Y.j./mr + (Y\ldots)^2/mfr$$

The different sum of squares, thus obtained were divided by their respective degrees of freedom to obtain mean squares, which were tested against respective error mean squares by F test at 5 per cent level of significance.

3.4.3.2.2 Estimation of general and specific combining ability effects

The model of Kempthorne (1957) was used for estimating the GCA and SCA effects in combining ability analysis as under:

$$Y_{ijk} = \mu + g_i + g_j + S_{ij} + e_{ijk}$$

where,

μ = general mean

Y_{ijk} = mean value of a character measured on i×j in kth replication

g_i = general combining ability (GCA) effect of ith line (female)

g_j = general combining ability (GCA) effect of jth tester (male)

S_{ij} = specific combining ability (SCA) of the cross involving ith line and jth tester

e_{ijk} = error associated with ijkth observation

i = ith line (1, 2,….. And 12)

j = jth tester (1 and 2)

k = kth replication (1,2 and 3)

3.4.3.2.2.1 Individual effects were estimated as follows

(i) Estimation of general mean

$$\mu = \frac{Y\ldots}{mfr}$$

where,

Y... = total of all the cross-combinations

m = number of testers (male)

f = number of lines (female)

r = number of replications

(ii) GCA effect of i^th line (female)

$$g_i = \frac{Yi..}{mr} - \frac{Y...}{mfr}$$

where,

Yi.. = total of i^th female (line) parent over all males and replications

(iii) GCA effect of j^th tester (male)

$$g_j = \frac{Y.j.}{fr} - \frac{Y...}{mfr}$$

where,

Y.j. = total of j^th male (tester) parent over all females and replications

(iv) SCA effect of ij^th hybrid

$$S_{ij} = \frac{Yij.}{r} - \frac{Yi..}{mr} - \frac{Y.j.}{fr} + \frac{Y...}{mfr}$$

where,

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

(v) Standard error for combining ability effects

(a) SE ± (g_i) lines = $\pm\sqrt{Me/mr}$

(b) SE ± (g_j) testers = $\pm\sqrt{Me/fr}$

(c) SE ± (S_{ij}) crosses = $\pm\sqrt{Me/r}$

(d) SE ± (g_i-g_j) lines = $\pm\sqrt{2Me/mr}$

(e) SE ± (g_i-g_j) testers = $\pm\sqrt{2Me/fr}$

(f) SE ± (S_{ij}-S_{kj}) crosses = $\pm\sqrt{2Me/r}$

where,

Me = mean squares due to error

r = number of replications

(vi) Test of significance for GCA and SCA: There are two methods:

Method I :

GCA and SCA effects $\geq[(SE_{gi}/SE_{gj}/SE_{sij})$ x 't' tabulated at error degree of freedom (74) and P=0.05 were marked significantly (*).

Method II:

(a) t_i (cal) for GCA of lines (females) = $(g_i\text{-}0)/SE(g_i)$

(b) t_j (cal) for GCA of testers (males) = $(g_j\text{-}0)/SE(g_j)$

(c) t_{ij} (cal) for SCA of crosses = $(s_{ij}\text{-}0)/SE(s_{ij})$

where,

t_i (cal), t_j (cal) and t_{ij} (cal) are the calculated 't' values,

g_i = GCA effect of i^{th} line

g_j = GCA effect of j^{th} tester and

s_{ij} = SCA effect of ij^{th} cross

The GCA effects of line and testers and SCA effects of crosses were marked (*) when the values (t_i (cal), t_j (cal) and t_{ij} (cal)) ≥ t tabulated value at error degree of freedom (74) and P=0.05.

3.4.4 Estimation of heterosis

The estimates of heterosis were calculated as the deviation of F_1 mean from the better parent (BP) and standard check (SC)

1. Heterosis over better parent (BP) % = $\dfrac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$

2. Heterosis over the standard check (SC) % = $\dfrac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$

3.4.4.1 Calculation of standard error

SE for testing heterosis over BP i.e. SE (H_1) = $\pm\sqrt{2Me/r}$

SE for testing heterosis over SC i.e. SE (H_2) = $\pm\sqrt{2Me}/r$

3.4.4.2 Test of significance for heterosis

1. Heterosis over BP = $\frac{\overline{F_1} - \overline{BP}}{SE\ (H_1)}$ = ‘t_1’ calculated
2. Heterosis over SC = $\frac{\overline{F_1} - \overline{SC}}{SE\ (H_2)}$ = ‘t_2’ calculated

The ‘t’ calculated values (t_1 and t_2) for heterosis over better parent (BP) and standard check (SC) were compared with ‘t’ tabulated values at error degree of freedom (74) and P=0.05. The ‘t’ calculated value ≥ ‘t’ tabulated values were marked significant and an asterisk (*) was put on per cent values only (Dabholkar 1992).

4. RESULTS AND DISCUSSION

The objectives of the present study entitled "Gene action studies for fruit yield and horticultural traits in okra (*Abelmoschus esculentus* (L.) Moench)" were to get information on the nature and magnitude of gene action (additive, dominance and epistasis) in okra using triple test cross (TTC) and line x tester analysis. The efforts were made to identify potential parents and cross-combinations for the genetic improvement on the basis of combining ability and magnitude of exploitable heterosis. The results obtained on the above aspects have been presented and discussed under the following heads.

4.1 Analysis of variance for the experimental design

4.2 Triple test cross analysis

4.3 Line x tester analysis

4.4 Nature and magnitude of heterosis

4.5 Yellow Vein Mosaic Virus (YVMV) incidence

4.1 Analysis of variance for the experimental design

A combined analysis of variance for parents (12 lines and three testers) and their 36 triple test cross hybrids (Table 4.1) revealed significant differences among genotypes for all the traits, namely, days to 50 per cent flowering, days to first picking, first fruit producing node, nodes per plant, internodal length, fruit length, average fruit weight, plant height, harvest duration, fruits per plant, fruit yield per plant, ridges per fruit, dry matter and mucilage except fruit diameter. It highlighted the presence of sufficient genetic variability in the existing genetic material.

4.2 Triple test cross analysis

Genetic architecture of any crop species has a great bearing on success of breeding procedures. Since, it is already established that estimates of genetic parameters get biased in the presence of epistasis, it is imperative to get a clearer picture by getting unbiased estimates of such parameters. In this context, triple test cross is a useful procedure to detect epistatic bias and equally applicable to

Table 4.1 Analysis of variance for the Randomized Complete Block Design for fruit yield and horticultural traits in okra

Source of variation		Mean squares due to		
		Replication	**Treatment**	**Error**
Traits	**df**	**2**	**50**	**100**
Days to 50 per cent flowering		1.48	57.53*	1.84
Days to first picking		3.26	31.67*	2.80
First fruit producing node		0.001	2.85*	0.27
Nodes per plant		0.18	32.61*	8.90
Internodal length (cm)		0.20	11.53*	1.72
Fruit length (cm)		0.03	1.61*	0.46
Fruit diameter (cm)		0.02	0.09	0.14
Average fruit weight (g)		0.53	10.81*	6.26
Plant height (cm)		9.35	5182.32*	51.00
Harvest duration (days)		0.48	16.37*	2.57
Fruits per plant		0.34	28.18*	9.06
Fruit yield per plant (g)		2.70	9289.83*	15.86
Ridges per fruit		0.15*	2.44*	0.04
Dry matter (%)		0.02	2.07*	0.40
Mucilage (%)		0.001	0.47*	0.001

***Significant at $P \leq 0.05$**

segregating and non-segregating generations such as F_2, backcross and homozygous lines (Kearsey and Jinks 1968; Chahal and Jinks 1978). The data obtained from 36 triple test cross families were subjected to triple test cross analysis to estimate different components of genetic variance. A perusal of the analysis of variance for the triple test cross (Table 4.2) indicated that mean squares due to crosses were significant for all the traits except fruit diameter and average fruit weight which suggested the

Table 4.2 Analysis of variance for triple test cross hybrids for fruit yield and horticultural traits in okra

Source of variation		Mean squares due to		
		Replication	**Hybrid**	**Error**
Traits	**df**	**2**	**35**	**70**
Days to 50 per cent flowering		0.81	19.44*	1.95
Days to first picking		2.11	12.31*	2.97
First fruit producing node		0.03	2.84*	0.31
Nodes per plant		0.13	18.16*	10.43
Internodal length (cm)		0.03	10.39*	1.97
Fruit length (cm)		0.09	1.15*	0.50
Fruit diameter (cm)		0.02	0.04	0.16
Average fruit weight (g)		0.32	10.68	7.03
Plant height (cm)		0.19	3768.28*	52.92
Harvest duration (days)		0.94	14.61*	2.73
Fruits per plant		0.08	16.75*	10.35
Fruit yield per plant (g)		5.60	6471.53*	20.62
Ridges per fruit		0.16*	0.53*	0.05
Dry matter (%)		0.01	1.61*	0.45
Mucilage (%)		0.001	0.53*	0.001

***Significant at $P \leq 0.05$**

presence of sufficient variability in the triple test cross progenies for use in recombination breeding.

4.2.1 Test for the detection of epistasis

It has been reported by many workers that epistasis is an integral component of genetic variation and ignorance of the presence of epistasis would lead to the biased estimates of additive and dominance components of variation. As a consequence one may choose wrong breeding procedures. The significance of mean squares due to epistasis (Table 4.3) revealed the presence of epistasis for the traits, *viz.*, days to 50 per cent flowering, plant height, harvest duration, fruit yield per plant

Table 4.3 Analysis of variance for the detection of epistasis for fruit yield and horticultural traits in okra

Source of variation		**Epistasis**	**i-type interaction**	**(j+l) type interaction**	**Epistasis x replication**	**i-type x replication**	**(j+l) type x replication**
Traits	**df**	**12**	**1**	**11**	**24**	**2**	**22**
Days to 50 per cent flowering		73.74*	71.97	73.90*	12.10	24.65	10.96
Days to first picking		35.25	30.25	35.71*	17.17	33.58	15.67
First fruit producing node		3.19	3.15	3.20	2.49	0.88	2.64
Nodes per plant		67.92	249.64	51.40	87.32	22.91	93.18
Internodal length (cm)		23.80	37.29	22.57	15.55	8.31	16.21
Fruit length (cm)		2.97	20.04*	1.42	3.19	0.55	3.42
Fruit diameter (cm)		0.03	0.17	0.02	1.20	0.10	1.30
Average fruit weight (g)		70.23	208.90	57.62	66.98	27.18	70.60
Plant height (cm)		3604.25*	1059.72	3835.57*	396.28	141.30	419.46
Harvest duration (days)		56.43*	61.18*	56.00*	17.69	1.00	19.21
Fruits per plant		58.80	291.04	37.69	91.11	37.47	95.98
Fruit yield per plant (g)		18854.81*	990.88*	20478.81*	159.20	33.18	170.66
Ridges per fruit		0.45	1.09*	0.39	0.28	0.03	0.30
Dry matter (%)		0.69	0.01	0.75	4.02	0.66	4.32
Mucilage (%)		4.11*	18.75*	2.78*	0.001	0.001	0.001

***Significant at P ≤ 0.05**

and mucilage. The significant estimates of epistasis may be the result of the involvement of different alleles due to heterozygous state of the lines.

Further partitioning of mean squares due to epistasis into 'i' and 'j+l' showed the absence of additive x additive 'i' type of interaction for majority of the traits except fruit length, harvest duration, fruit yield per plant, ridges per fruit and mucilage. On the other hand, the presence of additive x dominance and dominance x dominance (j+l type) components were noticed for almost all the traits except first fruit producing node, nodes per plant, internodal length, fruit length, fruit diameter, average fruit weight, fruits per plant, ridges per fruit and dry matter. Therefore, it is clear from the results that epistasis is an integral component of the genetic variation and should not be ignored while formulating breeding programme to improve commercially important traits. If the presence of epistasis is ignored, information of interallelic interactions may be lost and one may get biased estimates of additive and dominance components leading to wrong conclusions. Similar results were also observed by Patel et al. (2008), Akhtar et al. (2010b), Aulakh and Dhall (2013), Akotkar and De (2014), Mallikarjun et al. (2017), Srikanth et al. (2018) and other workers.

4.2.2 Estimation of additive and dominance components

4.2.2.1 Analysis of variance

The analysis of variance for sums ($L_{1i} + L_{2i} + L_{3i}$) and differences ($L_{1i} – L_{2i}$) which provide a direct test for the detection of additive and dominance genetic components has been presented in Table 4.4 revealed that the mean squares due to sums ($L_{1i} + L_{2i} + L_{3i}$) were significant for all the traits except nodes per plant, fruit diameter and fruits per plant whereas, mean squares due to differences ($L_{1i} – L_{2i}$) were significant for all the traits except days to first picking, nodes per plant, internodal length, fruit length, fruit diameter, average fruit weight, fruits per plant and dry matter. The significance of mean squares due to the sums and differences provide a direct test of significance of additive (D) and dominance (H) components of variation.

4.2.2.2 Estimation of genetic components of variance

The genetic components additive (D), dominance (H) and related parameters were worked out for all the traits which exhibited significant mean squares due to sums and differences. Estimates of additive (D), dominance (H) and average degree of dominance $(H/D)^{1/2}$ for different traits are given in Table 4.4.

The estimates of mean squares due to sums (measuring D component) and differences (measuring H component) showed that additive genetic components were significant for all the traits except nodes per plant, fruit diameter and fruits per plant whereas, dominance genetic components were significant for all the traits except days to first picking, nodes per plant, internodal length, fruit length, fruit diameter, average fruit weight, fruits per plant and dry matter which indicated the importance of both components in controlling these traits. The preponderance of additive variance for most of the traits indicated the relative importance of fixable type of gene action in their inheritance. However, non-fixable type of gene action was important for mucilage due to high magnitude of dominance component (Aulakh and Dhall 2013; Verma and Sood 2015a).

The relative magnitude of D and H components revealed that additive genetic component was predominant for days to 50 per cent flowering, days to first picking, first fruit producing node, nodes per plant, internodal length, fruit length, average fruit weight, plant height, harvest duration, fruits per plant, fruit yield per plant, ridges per fruit and dry matter, whereas dominance was predominant for mucilage. Use of recurrent selection has been suggested to improve the characters when both additive and non-additive gene effects are involved in expression of the traits. The preponderance of additive gene action for fruit yield and most of its component traits is in contrary to the reports of earlier workers who have reported the preponderance of non-additive gene action for fruit yield and most of its component by following line x tester and diallel mating designs (Kumar and Anandan 2006b; Arora et al. 2007; Vachhani and Shekhat 2008; Aulakh and Dhall 2012; Patil et al. 2016; RameshKumar et al. 2017; Ayesha et al. 2017; More et al. 2017; Lokeswari et al. 2018). However, in contradiction to non-additive gene action for fruit yield and most of its component through line x tester and diallel mating design by forementioned workers, the limited reports (Panda and Singh 2000; Tripathi and Arora 2001; Saravanan et al. 2005; Patel et al. 2008; Mallikarjun et al. 2017) of additive gene action through triple test cross for these traits supports the results of present study. This, in addition, also signifies the reliability of triple test cross mating design in precisely determining the gene action of biometrical traits.

The average degree of dominance $(H/D)^{1/2}$ was in the range of partial dominance for most of the traits namely, days to 50 per cent flowering, days to first picking, first fruit producing node, internodal length, fruit length, average fruit weight, plant height, harvest duration, fruit yield per plant and ridges per fruit supporting the relative importance of additive gene action for these traits. The greater magnitude of additive gene action in okra has also been reported by Panda and Singh (2000) and Mallikarjun et al. (2017) for days to 50 per cent flowering and first fruit producing node; Tripathi and Arora (2001) for days to first picking, Panda and Singh (2000), Saravanan et al. (2005), Patel et al. (2008) and Mallikarjun et al. (2017) for nodes per plant; Saravanan et al. (2005) for internodal length, Tripathi and Arora (2001) and Mallikarjun et al. (2017) for fruit length; Saravanan et al. (2005) and Mallikarjun et al. (2017) for average fruit weight; Panda and Singh (2000), Tripathi and Arora (2001), Saravanan et al. (2005) and Mallikarjun et al. (2017) for plant height; Panda and Singh (2000), Tripathi and Arora (2001), Saravanan et al. (2005), Patel et al. (2008) and Mallikarjun et al. (2017) for fruits per plant and fruit yield per plant and Mallikarjun et al. (2017) for ridges per fruit by following triple test cross. In addition, El-Gendy and El-Aziz (2013) and Ram et al. (2016) for days to 50 per cent flowering; Verma and Sood (2015a) and Ram et al. (2016) for days to first picking and first fruit producing node; Akotkar et al. (2014) for nodes per plant; Verma and Sood (2015a) for internodal length and harvest duration; Verma and Sood (2015a), El-Gendy and El-Aziz (2013) and Ayesha et al. (2017) for fruit length; El-Gendy and El-Aziz (2013) for fruit diameter; Ram et al. (2016) and Ayesha et al. (2017) for average fruit weight; Akotkar et al. (2014), El-Gendy and El-Aziz (2013) and Ram et al. (2016) for plant height; El-Gendy and El-Aziz (2013) and Ram et al. (2016) for fruits per plant; Vani et al. (2017) for fruit yield per plant and Ayesha et al. (2017) for ridges per fruit reported additive gene action by following biometrical approaches other than triple test cross. Also, complete dominance was recorded for mucilage indicating the importance of both additive and dominance type of gene action. The importance of both additive and non-additive gene action was also reported by Aulakh and Dhall (2013) for mucilage.

Table 4.4 Analysis of variance for sums ($L_{1i} + L_{2i} + L_{3i}$) and differences ($L_{1i} - L_{2i}$) and the estimates of genetic parameters for fruit yield and horticultural traits in okra

		Mean squares due to				Estimates of genetic parameters			
Source of variation		**Sums**	**Sums x Rep.**	**Differences**	**Diff. x Rep.**	**D**	**H**	**$(H/D)^{1/2}$**	**r**
Traits	**df**	**11**	**22**	**11**	**22**				
Days to 50 per cent flowering		73.21*	3.39	14.21*	4.60	93.10*	12.81*	0.37	-0.04
Days to first picking		44.43*	5.80	12.80	6.08	51.52*	8.95	0.42	-0.27
First fruit producing node		7.97*	0.59	2.65*	0.60	9.83*	2.73*	0.53	-0.70
Nodes per plant		41.80	20.88	14.19	18.75	27.89	-	-	-0.23
Internodal length (cm)		33.70*	3.41	7.93	4.19	40.40*	4.98	0.35	0.04
Fruit length (cm)		2.81*	1.10	0.90	0.84	2.28*	0.08	0.19	0.64*
Fruit diameter (cm)		0.06	0.30	0.02	0.29	-	-	-	0.15
Average fruit weight (g)		33.72*	10.29	15.88	11.25	31.23*	6.16	0.44	0.04
Plant height (cm)		6391.82*	110.98	1443.71*	97.04	8374.46*	1795.57*	0.46	0.35
Harvest duration (days)		31.59*	7.95	15.30*	5.26	31.52*	13.38*	0.65	0.68*
Fruits per plant		37.69	18.84	12.17	17.05	25.13	-	-	0.29
Fruit yield per plant (g)		22497.73*	56.96	5438.12*	27.28	29921.03*	7214.46*	0.49	0.00
Ridges per fruit		1.98*	0.11	0.42*	0.09	2.50*	0.44*	0.42	0.43
Dry matter (%)		5.85*	0.66	0.27	1.02	6.92*	-	-	-0.63
Mucilage (%)		0.76*	0.001	0.91*	0.001	1.01*	1.21*	1.10	-0.09

***Significant at $P \leq 0.05$**

$(H/D)^{1/2}$ = Degree of dominance
D = Additive component, r = Correlation
H = Dominance component, - = Not calculated (because of negative value)

It is evident from the analysis of variance studies that ample genetic variability was generated in the material under investigation. The presence of epistasis emphasized that this component should not be ignored as this would lead to either under or over estimation of additive and dominance components of variation. However, as of now, there is no conclusive evidence about the extent of bias and the effect of epistasis on the expression of the quantitative traits (Sofi et al. 2006). Since, additive gene action has been observed for majority of the traits studied, selection in the early generations may be useful for the improvement of these traits. The results also revealed the importance of additive x dominance (j) and dominance x dominance (l) type of epistasis in the inheritance of fruit yield and related traits. Besides, mucilage showed the importance of both D and H components. Due to their non-fixable nature, the dominance component and 'j' and 'l' types of epistasis can be exploited through heterosis breeding by developing high yielding hybrids. The other alternative approaches for utilizing such non-fixable component may be intermating of selected individuals in early segregating generations with delayed selection in the later generations, diallel selective mating/ biparental mating or recurrent selection followed by pedigree method of selection which might give fruitful results by exploiting both additive and non-additive components of variation along with epistasis (Sood et al. 2007). Moreover, the interest in okra breeding is to improve disease resistance alongwith yield involving multiple parents, the random intermating in segregating generations could be effective in pooling up the useful genes of interest in advanced progenies.

Overall, the triple test cross analysis revealed the importance of additive, dominance and epistasis gene actions in the inheritance of different characters. Under these situations, biparental mating and mating of selected individual plants in early segregating generation could be done for developing potential populations having optimum levels of homozygosity and heterozygosity. Further, where all three types of gene effects are present, transgressive segregants can be exploited by alternative intermating and subsequent handling of segregating generations in order to isolate high yielding stable lines in okra. Such a strategy will help to increase frequency of favourable alleles while maintaining genetic variation in breeding population (Doerksen et al. 2003).

4.3 Line x tester analysis

4.3.1 Analysis of variance

It is also possible to gather genetic information by following line x tester analysis after excluding the $\bar{L}_{3i}$ progeny families and F_1 tester used for triple test cross. The analysis of variance for line x tester design showed significant differences among parents for all the traits (Table 4.5) except fruit diameter and average fruit weight which indicated the presence of substantial amount of genetic variability for exploitation through recombinant breeding. Further partitioning of the variances of the parents into testers, lines and lines vs testers indicated significant differences among lines for most traits and among testers for days to 50 per cent flowering, first fruit producing node, internodal length, fruit length, plant height, fruit yield per plant, ridges per fruit, dry matter and mucilage. The testers differed from lines for majority of the traits except first fruit producing node, fruit length, fruit diameter and average fruit weight. The lines expressed greater magnitude of mean squares as compared to testers for all the traits except internodal length, fruit length, fruit diameter and plant height indicating wider genetic diversity of lines as compared to testers for these traits. The significant differences between first and second parent indicated that L_1 and L_2 testers possess the extreme high vs low relation with the population and would provide an estimate of additive and dominance variation with equal precision (Ram et al. 2007).

Hybrids showed significant differences for all the traits studied except fruit diameter which revealed sufficient differences among the crosses for these traits and hence, selection is possible to identify most desirable segregants within the crosses. Similarly, the crosses also differed from the parents for almost all the traits except first fruit producing node, internodal length, fruit length, fruit diameter and harvest duration implying that parental lines as a group differed from the crosses which may be due to heterosis resulting from dominant and complementary gene interaction (Gravois and McNew 1993). Similar results were also reported by Singh et al. (2006), Mehta et al. (2007), Weerasekara et al. (2008a), Khanpara et al. (2009), Pal et al. (2010), Adiger et al. (2013a), Gavint et al. (2018) and Gowda et al. (2018) for fruit yield and other attributes.

Table 4.5 Analysis of variance for parents and hybrids (line x tester) for fruit yield and horticultural traits in okra

Source of variation	Replication	Parent	Line	Tester	Line vs Tester	Hybrid	Parent vs Hybrid	Error
Traits **df**	**2**	**13**	**11**	**1**	**1**	**23**	**1**	**74**
Days to 50 per cent flowering	0.10	139.37*	147.56*	48.22*	140.49*	23.77*	263.86*	1.86
Days to first picking	0.59	67.89*	75.06*	0.67	56.19*	15.65*	194.57*	2.81
First fruit producing node	0.04	3.18*	3.61*	1.50*	0.16	2.57*	1.01	0.26
Nodes per plant	2.12	50.23*	21.72*	2.94	411.19*	16.90*	95.69*	8.51
Internodal length (cm)	0.98	16.23*	14.94*	38.15*	8.53*	12.63*	0.09	1.62
Fruit length (cm)	0.15	3.01*	3.19*	3.75*	0.39	1.17*	0.00	0.50
Fruit diameter (cm)	0.03	0.19	0.17	0.33	0.21	0.06	0.41	0.14
Average fruit weight (g)	2.90	8.28	9.06	0.03	7.90	12.63*	25.80*	5.25
Plant height (cm)	23.68	7104.46*	3864.61*	31363.74*	18483.44*	4251.65*	10680.66*	52.09
Harvest duration (days)	0.02	19.08*	17.07*	0.05	60.15*	12.24*	3.98	2.88
Fruits per plant	2.85	42.39*	17.98*	0.45	352.87*	14.11*	100.24*	8.38
Fruit yield per plant (g)	0.07	10183.51*	2586.46*	86.64*	103847.89*	6698.83*	46849.43*	15.27
Ridges per fruit	0.11	7.35*	8.54*	0.17*	1.42*	0.58*	7.60*	0.04
Dry matter (%)	0.03	3.14*	2.67*	2.38*	9.07*	1.51*	2.41*	0.40
Mucilage (%)	0.001	0.19*	0.21*	0.03*	0.17*	0.40*	0.71*	0.001

***Significant at $P \leq 0.05$**

4.3.2 Combining ability analysis

The success of a breeding programme depends upon the choice of suitable parents and their utilization by adopting an appropriate breeding method. The combining ability analysis has been extensively used to identify potential parents and cross-combinations on the basis of their combining ability effects to obtain maximum genetic gain in advance generations for desirable economic traits to obtain elite purelines. This analysis facilitates the partitioning of genotypic variation of crosses into variation due to general combining ability (GCA) and specific combining ability (SCA). GCA effects are the measure of additive gene action which represent the fixable components of genetic variance and are used to classify the parents for the breeding behavior in cross-combinations.

On the other hand, SCA effects are the measure of non-additive gene action and are related to non-fixable component of genetic variance (Sprague 1966) which ultimately reflects hybrid vigour. It is not necessary that performance, adaptation and genetic variability are the basis of selection of parents to obtain useful results. This is due to the differential ability of the parents which otherwise depends upon the complex interaction among the genes and hence, cannot be judged by *per se* performance alone (Allard 1960). The combining ability not only provides necessary information regarding the choice of parents but also simultaneously illustrate the nature and magnitude of gene action involved in the expression of desirable traits. In the present study, line x tester method (Kempthorne 1957) which is a useful tool for preliminary evaluation of genetic stock with a view to identify good combiners may be used to build up a population with favourable fixable genes for effective yield improvement.

4.3.2.1 Analysis of variance

The analysis of variance for combining ability indicated significant differences among hybrids for all the traits studied except nodes per plant, fruit diameter and fruits per plant (Table 4.6). The mean squares due to crosses were partitioned into three components, *viz.,* lines, testers and lines x testers interaction. Mean squares due to lines were significant for all the traits except fruit diameter whereas due to testers were significant for all the traits except first fruit producing node, average fruit weight, ridges per fruit and dry matter. Mean squares due to line x tester interactions were significant for all the traits except nodes per plant, fruit length, fruit diameter, average fruit weight, fruits per plant and dry matter suggesting that the experimental material possessed considerable variability and that both GCA and SCA were involved in the genetic expression of these factors and highlighted the suitability of parents and crosses for combining ability studies. The significant difference between line x tester interactions indicated that specific combining ability contributed heavily in the expression of these traits and showed the importance of non-additive variance for all the traits (Sanghera and Hussain 2012). The estimates of additive and dominance variances (Table 4.6) revealed the importance of both additive and dominant gene action with pre dominance of dominance gene action for first fruit producing node, fruit yield per plant, ridges per fruit and mucilage. However, the additive gene action pre dominated for days to 50 per cent flowering, days to first picking, nodes per plant, internodal length, fruit length, fruit diameter, average fruit weight, plant height, fruits per plant and dry matter. The average degree of dominance revealed over dominance for first fruit producing node, fruit yield per plant, ridges per fruit and mucilage while complete dominance was observed for harvest duration. Average degree of dominance revealed preponderance of additive gene action for days to 50 per cent flowering, days to first picking, internodal length, average fruit weight and plant height. The role of non-additive gene action in inheritance of different traits following line x tester design has also been reported by Singh and Sanwal (2010), Kumar and Pathania (2011) and More et al. (2017) for first fruit producing node; Satish et al. (2017) for harvest duration; Singh et al. (2006), Singh and Sanwal (2010), Kumar and Pathania (2011), Singh et al. (2012), Solankey et al. (2012), Adiger et al. (2013a), Lyngdoh et al. (2017) and More et al. (2017) for fruit yield per plant and Solankey et al. (2012) and Lyngdoh et al. (2017) for ridges per fruit. In this situation, where non-additive component was important for the expression of characters, heterosis breeding is required to be followed for exploitation of these traits. Whereas, the role of additive gene action in the inheritance of different traits has also been reported by El-Gendy and El-Aziz (2013) and Ram et al. (2016) for days to 50 per cent flowering; Verma and Sood (2015a) and Ram et al. (2016) for days to first picking; Akotkar et al. (2014) for nodes per plant; Verma and

Table 4.6 Analysis of variance for combining ability and estimates of genetic parameters for fruit yield and horticultural traits in okra

Source of variation	**Replication**	**Crosses**	**Lines**	**Testers**	**Lines x Testers**	**Error**	**Estimates of genetic parameters**			
Traits df	**2**	**23**	**11**	**1**	**11**	**46**	**σ^2A**	**σ^2D**	**$(H/D)^{1/2}$**	**h^2 ns**
Days to 50 per cent flowering	0.24	23.77*	36.60*	65.82*	7.10*	1.99	4.70	1.75	0.61	66.50
Days to first picking	0.13	15.65*	22.22*	45.13*	6.40*	3.04	2.94	1.19	0.64	57.95
First fruit producing node	0.03	2.57*	3.98*	0.61	1.33*	0.32	0.19	0.35	1.35	30.51
Nodes per plant	0.73	16.90	20.90*	80.77*	7.09	10.28	4.03	-	-	63.03
Internodal length (cm)	0.52	12.63*	16.85*	61.57*	3.96*	1.87	3.58	0.78	0.47	73.04
Fruit length (cm)	0.05	1.17*	1.40*	6.55*	0.45	0.58	0.33	-	-	68.78
Fruit diameter (cm)	0.03	0.06	0.03	0.91*	0.01	0.17	0.03	-	-	89.95
Average fruit weight (g)	2.11	12.63*	16.86*	17.76	7.94	5.55	1.15	0.90	0.88	30.27
Plant height (cm)	9.09	4251.65*	3195.94*	54692.27*	721.86*	57.12	2751.62	223.26	0.28	91.96
Harvest duration (days)	0.38	12.24*	15.79*	23.61*	7.65*	3.41	1.60	1.59	1.00	38.59
Fruits per plant	1.68	14.11	18.84*	50.40*	6.08	9.58	2.50	-	-	55.21
Fruit yield per plant (g)	0.97	6698.83*	11248.96*	424.81*	2719.06*	22.15	554.44	901.26	1.27	37.96
Ridges per fruit	0.11	0.58*	0.99*	0.11	0.21*	0.05	0.05	0.06	1.09	40.70
Dry matter (%)	0.05	1.51*	2.93*	1.16	0.13	0.45	0.16	-	-	77.79
Mucilage (%)	0.001	0.40*	0.38*	0.11*	0.46*	0.001	0.02	0.15	2.56	13.21

***Significant at $P \leq 0.05$**

σ^2A = Additive variance **$(H/D)^{1/2}$ = Degree of dominance**
σ^2D = Dominance variance **GA (5%) = Genetic advance at 5%**
h^2 ns = Narrow sense heritability **- = Not calculated (as H was negative and non-significant)**

Sood (2015a) for internodal length; Kumar and Pathania (2011), Verma and Sood (2015a), El-Gendy and El-Aziz (2013) and Ayesha et al. (2017) for fruit length; Kumar and Pathania (2011) and Ram et al. (2016) for average fruit weight; Kumar and Pathania (2011), Akotkar et al. (2014), El-Gendy and El-Aziz (2013) and Ram et al. (2016) for plant height and Kumar and Pathania (2011), El-Gendy and El-Aziz (2013) and Ram et al. (2016) for fruits per plant. In this situation, where additive component was important for the expression of the characters, hybridization followed by selection would be effective for its improvement.

Furthermore, narrow sense heritability estimates are more useful in breeding than broad sense heritability which are influenced by dominance heterosis and epistasis (Scossiroli et al. 1971). Narrow sense heritability (h^2 ns) estimates are classified here as high (>50 per cent), medium (30-50 per cent) and low (<30 per cent). On the basis of present study heritability (in narrow sense) was high for days to 50 per cent flowering, days to first picking, nodes per plant, internodal length, fruit length, fruit diameter, plant height, fruits per plant and dry matter. It was medium for first fruit producing node, average fruit weight, harvest duration, fruit yield per plant and ridges per fruit and was low for mucilage. Medium heritability for yield and pre dominance of non-additive gene effect suggested straight forward selection and utilization of heterosis to improve yield (Thakur 1987). Medium heritability for fruit yield was recorded by Ram et al. (2016) whereas Akotkar et al. (2014) observed high heritability for fruit yield. Abdelmageed (2010) and Akotkar et al. (2014) for days to 50 per cent flowering; Adeniji and Kehinde (2003), Vachhani and Shekhat (2008) and Ram et al. (2016) for fruit length; Adeniji and Kehinde (2003) for fruit diameter; Abdelmageed (2010) and Akotkar et al. (2014) for plant height and Abdelmageed (2010) and Akotkar et al. (2014) for fruits per plant observed high heritability. In the presence of additive gene action, it is suggested that selection in early generations may be fruitful either following mass selection or progeny selection or hybridization and selection with pedigree breeding.

4.3.2.2 Estimates of combining ability effects

GCA and SCA effects were estimated for all the traits exhibiting significant values for the respective variances. These estimates for individual traits are presented in Table 4.7 to Table 4.12 and are described below:

4.3.2.2.1 Estimates of GCA effects

The choice of parents is the secret to success in developing high yielding varieties/hybrids. The broad principles governing the choice of parents are their *per se* performance and GCA effects in desired magnitude and direction. The parent with high mean values may not necessarily be able to transmit the superior trait into their progenies (Simmonds 1979).

The estimates of GCA effects were determined for all the traits and are presented in Table 4.7. Earliness is a highly desirable trait in okra as market prices are invariably high early in the season. The days to 50 per cent flowering and days to first picking are the indicators of earliness. The significant negative GCA effects were observed for four lines for days to 50 per cent flowering and five lines for days to first picking and the magnitude ranged from 6.73 to -2.50 and 5.04 to -1.96 for these traits, respectively. In case of days to 50 per cent flowering, genotype Japan 5 Ridged was recorded to be the best general combiner as it showed the highest significant negative GCA effect. The line P-23 was also a good general combiner for earliness followed by IC-169468 and VRO-4. Japan Red was found to be the poorest general combiner exhibiting maximum positive GCA effect for the trait. In case of days to first picking, genotype P-23 was the best general combiner as it showed the highest negative GCA effects followed by VRO-4, Parbhani Kranti, VRO-6 and IC-169468.

In case of first fruit producing node, the highest negative GCA estimates were observed for IC-169468 followed by VRO-4, Parbhani Kranti and SKBS-11. The genotype Japan Round exhibited the highest positive effect and was observed the poorest general combiner. For nodes per plant which is an important yield contributing trait, the best combiner was VRO-6. Internodal length determines the height and nodes per plant. Besides having minimum internodal length, it is important to have more number of fruits bearing nodes per plant. The desirable negative GCA effects for this trait were recorded for genotype Japan Round followed by VRO-6, P-20 and Tulsi-1. For fruit length, best general combiner was Parbhani Kranti. For average fruit weight, the best general combiner was P-8 followed by Parbhani Kranti. Japan 5 Ridged was poorest general combiner.

Table 4.7 Estimates of general combining ability effects of lines (females) and testers (males) for fruit yield and horticultural traits in okra

Lines/Testers	Days to 50 per cent flowering	Days to first picking	First fruit producing node	Nodes per plant	Internodal length	Fruit length	Fruit diameter	Average fruit weight	Plant height	Harvest duration	Fruits per plant	Fruit yield per plant	Ridges per fruit	Dry matter	Mucilage
Lines															
P-20	0.40	0.04	0.70*	0.77	-1.19*	-0.47	-0.10	-1.05	-14.70*	-3.30*	-0.17	-20.02*	0.07	-0.66*	-0.09*
VRO-4	-1.49*	-1.46*	-0.56*	0.17	0.22	0.43	-0.05	0.27	5.13	-1.05	0.46	12.30*	-0.10	-0.32	0.03
Parbhani Kranti	0.09	-1.46*	-0.53*	1.87	0.36	0.95*	0.11	2.75*	28.67*	-0.04	1.75	75.56*	-0.04	-0.92*	-0.31*
P-8	0.84	0.54	0.15	0.54	-0.72	-0.10	0.00	2.99*	-6.93*	1.52*	0.87	66.88*	-0.19*	-0.79*	0.16*
Tulsi-1	1.56*	1.54*	-0.21	1.27	-1.19*	-0.50	0.04	-0.40	-11.36*	0.58	1.29	7.29*	-0.28*	-0.04	0.03*
SKBS-11	-0.76	0.54	-0.46*	-1.64	3.66*	0.40	-0.01	1.48	54.32*	0.54	-0.69	13.18*	-0.04	-0.16	0.16*
VRO-6	-0.50	-1.46*	-0.16	2.79*	-1.58*	0.13	-0.05	-1.59	-7.06*	-2.22*	2.33	2.50	-0.14	0.37	0.41*
IC-169468	-2.07*	-1.46*	-0.91*	-0.34	0.03	0.13	-0.01	0.72	-5.33	2.03*	1.21	24.71*	-0.19*	0.35	0.18*
P-23	-2.22*	-1.96*	-0.06	-2.74*	-0.43	-0.45	-0.12	-1.47	-29.49*	1.11	-2.44*	-56.73*	-0.26*	-0.54*	0.06*
Japan Red	6.73*	5.04*	0.05	-3.64*	2.83*	0.30	0.05	-0.63	13.52	-1.19	-3.64*	-61.23*	1.25*	0.45	-0.40*
Japan 5 Ridged	-2.50*	0.04	-0.28	-0.09	-0.16	-0.72*	0.09	-2.08*	-3.96	0.61	0.44	-30.77*	-0.05	0.96*	-0.39*
Japan Round	-0.09	0.04	2.25*	1.04	1.82*	-0.11	0.05	-0.99	-22.83*	1.40*	-1.44	-33.67*	-0.02	1.29*	0.15*
SE (gi) ±	0.56	0.69	0.21	1.19	0.52	0.29	0.15	0.94	2.95	0.69	1.18	1.60	0.08	0.26	0.02
SE (gi-gj) ±	0.79	0.97	0.30	1.68	0.74	0.41	0.21	1.32	4.17	0.28	1.67	2.26	0.11	0.36	0.02
Testers															
9801	-0.96*	-0.79*	-0.09	-1.06*	-0.93*	0.30*	-0.11*	0.50	-27.56*	-0.57*	-0.84*	-2.43*	0.04	0.13	-0.04*
Hisar Unnat	0.96*	0.79*	0.09	1.06*	0.93*	-0.30*	0.11*	-0.50	27.56*	0.57*	0.84*	2.43*	- 0.04	-0.13	0.04*
SE (gi) ±	0.23	0.28	0.09	0.49	0.21	0.12	0.06	0.38	1.20	0.98	0.48	0.65	0.03	0.11	0.01
SE (gi-gk) ±	0.32	0.40	0.12	0.69	0.30	0.17	0.09	0.54	1.70	0.40	0.68	0.92	0.05	0.15	0.01

***Significant at P ≤ 0.05**

Less plant height is desirable so as to ease in harvesting. In this context, lines with negative general combining ability would be desirable for plant height. Highest negative estimates for GCA was recorded for P-23 which was followed by Japan Round, P-20, Tulsi-1, VRO-6 and P-8 while SKBS-11 had maximum positive effect making it a poor general combiner for this trait. Increase in harvest duration contributes towards highest marketable yield in okra. It is desirable to take advantage of off-season marketing for a longer period. Maximum positive estimates of GCA were exhibited by IC-169468 followed by P-8 and Japan Round. P-20 proved to be poorest general combiner with maximum negative GCA effect.

Number of fruits per plant has a direct bearing on the total productivity of okra. Keeping this in view, VRO-6, Parbhani Kranti, Tulsi-1, IC-169468, P-8, VRO-4 and Japan 5 Ridged showed positive but non-significant GCA effects. For fruit yield per plant, which is the most important trait, six lines *viz.*, Parbhani Kranti, P-8, IC-169468, SKBS-11, VRO-4 and Tulsi-1 were found to be the best general combiners having positive significant values while Japan Red was the poorest general combiner for this trait. For ridges per fruit, only Japan Red had significant positive GCA effect while non-significant effect was displayed by P-20. Maximum significant negative GCA effects for this trait were exhibited by Tulsi-1, P-23, IC-169468 and P-8 making them poor general combiners.

Drying is the most common method of preservation for fruits and vegetables. The removal of moisture suppresses the growth of microorganisms responsible for deterioration of quality of food products (Kumar et al. 2011). Therefore, for drying purpose okra fruits with high dry matter content are preferred. Okra mucilage is suitable for medicinal and industrial applications. It has medically found application as a plasma replacement or blood volume expander. The mucilage, or gelatinous outside coating, and the fibre content found in okra are excellent for maintaining blood sugar levels. The mucilage, traps toxins and releases them through stool. Industrially, okra mucilage is usually used in for glazing papers and also useful in confectionery (Markose and Peter 1990). Amongst the quality traits, two lines *viz.,* Japan Round followed by Japan 5 Ridged for dry matter showed significant positive GCA effects whereas seven lines *viz.,* VRO-6, IC-169468, SKBS-11, P-8, Japan Round, P-23 and Tulsi-1 exhibited significant positive GCA effects for mucilage (Tables 4.7 and 4.8).

Table 4.8 List of good general combiners for different horticultural traits in okra

Traits	Lines	Testers
Days to 50 per cent flowering	Japan 5 Ridged, P-23, IC-169468 and VRO-4	9801
Days to first picking	P-23, VRO-4, Parbhani Kranti, VRO-6 and IC-169468	9801
First fruit producing node	IC-169468, VRO-4, Parbhani Kranti and SKBS-11	None
Nodes per plant	VRO-6	Hisar Unnat
Internodal length (cm)	Japan Round, VRO-6, P-20 and Tulsi-1	9801
Fruit length (cm)	Parbhani Kranti	9801
Fruit diameter (cm)	None	9801
Average fruit weight (g)	P-8 and Parbhani Kranti	None
Plant height (cm)	P-23, Japan Round, P-20, Tulsi-1, VRO-6 and P-8	9801
Harvest duration (days)	IC-169468, P-8 and Japan Round	Hisar Unnat
Fruits per plant	None	Hisar Unnat
Fruit yield per plant (g)	Parbhani Kranti, P-8, IC-168468, SKBS-11, VRO-4 and Tulsi-1	Hisar Unnat
Ridges per fruit	Japan Red	None
Dry matter (%)	Japan Round and Japan 5 Ridged	None
Mucilage (%)	VRO-6, IC-169468, P-8, SKBS-11, Japan Round, P-23 and Tulsi-1	Hisar Unnat

Table 4.9 List of lines exhibiting desirable general combining effects for fruit yield and horticultural traits in okra

Lines	**Traits**
Japan 5 Ridged	Days to 50 per cent flowering and dry matter
P-23	Days to 50 per cent flowering, days to first picking, plant height and mucilage
IC-169468	Days to 50 per cent flowering, days to first picking, first fruit producing node, harvest duration, fruit yield per plant and mucilage
VRO-4	Days to 50 per cent flowering, days to first picking, first fruit producing node, fruit yield per plant
Parbhani Kranti	Days to first picking, first fruit producing node, fruit length, average fruit weight and fruit yield per plant
VRO-6	Days to first picking, nodes per plant, internodal length, plant height and mucilage
SKBS-11	First fruit producing node, fruit yield per plant and mucilage
Japan Round	Internodal length, plant height, harvest duration, dry matter and mucilage
P-20	Internodal length and plant height
Tulsi-1	Internodal length, plant height, fruit yield per plant and mucilage
P-8	Average fruit weight, plant height, harvest duration, fruit yield per plant and mucilage
Japan Red	Ridges per fruit
Testers	
9801	Days to 50 per cent flowering, days to first picking, internodal length, fruit length, fruit diameter and plant height
Hisar Unnat	Nodes per plant, harvest duration, fruits per plant, fruit yield per plant and mucilage

The good general combiners with respect to different traits indicated that no single parent proved to be a good general combiner for all the traits studied (Table 4.8). Line 'Parbhani Kranti' was found to be a good general combiner for most of the traits *viz.*, days to first picking, first fruit producing node, fruit length, average fruit weight and fruit yield per plant (Table 4.9). Likewise line P-8 was found to be good general combiner for average fruit weight, plant height, harvest duration, fruit yield per plant and mucilage. Tulsi-1 was found to be good general combiner for internodal length, plant height, fruit yield per plant and mucilage. On the basis of the parents with good GCA to horticultural traits, it can be concluded that line IC-169468 was found to be best general combiner for six traits out of fifteen followed by Parbhani Kranti, P-8, VRO-6 and Japan Round for five traits; VRO-4, Tulsi-1 and P-23 for four traits; SKBS-11 for three traits and P-20 and Japan 5 Ridged for two traits (Table 4.9). Lines 'VRO-4', 'Parbhani Kranti' and 'IC-169468' were found to be good general combiners for earliness and fruit yield per plant. Similarly, various workers recorded good general combiners for various traits in okra with their different genetic materials (Kumar and Pathania 2011; Nagesh et al. 2014; Bhatt et al. 2015; Jonah et al. 2015a; Kumar et al. 2015; Singh and Goswami 2015; Kumar and Reddy 2016; Patil et al. 2016; Tiwari et al. 2016; Verma et al. 2016; Wakode et al. 2016; Paul et al. 2017a; Satish et al. 2017; Eswaran and Anbanandan 2018; Gavint et al. 2018; Reddy and Sridevi 2018 and Shwetha et al. 2018).

4.3.2.2.2 Estimates of SCA effects

SCA is the deviation in performance of a cross-combination which is estimated on the basis of GCA of the parents involved in cross-combination. These effects represent dominance and epistasis components of variation which are non-fixable in nature and relates to hybrid vigour. This indicates that SCA effects could contribute more towards improvement of self pollinated crops where commercial exploitation of hybrids is feasible. Okra being an often cross pollinated crop, SCA estimates have importance. However, the interest of the breeders in the production of homozygous lines usually rests upon the transgressive segregants which can be obtained from the segregating population of cross-combinations. The choice of the cross-combinations is done based on the *per se* performance, heterosis and SCA of the cross-combinations and also the GCA effects of parents involved.

The estimates of SCA effects (Table 4.10) revealed that all the cross-combinations were average combiners for different traits. In case of days to 50 per cent flowering, cross-combination, Japan 5 Ridged x Hisar Unnat showed the highest significantly negative SCA effects followed by SKBS-11 x 9801. For days to first picking, cross-combination P-8 x Hisar Unnat exhibited highest significant negative SCA effect followed by P-20 x 9801. For first fruit producing node, the highest significant negative SCA effects was obtained from the cross Japan Round x 9801 followed by Japan Red x Hisar Unnat and were the best combinations for fruit setting at the lowest node. Rest of the cross-combinations were either having positive or negative non-significant SCA effects. For nodes per plant, none of the cross-combination exhibited significant value but the highest positive non-significant SCA effects were obtained for IC-169468 x 9801. For internodal length, only one cross-combination Japan 5 Ridged x 9801 showed significant negative SCA effects.

For plant height, five cross-combinations showed significant negative SCA effects, highest being Japan 5 Ridged x Hisar Unnat followed by Japan Round x Hisar Unnat, SKBS-11 x 9801, VRO-6 x 9801 and VRO-4 x Hisar Unnat. For harvest duration, the highest positive SCA effect was obtained for the cross-combination VRO-6 x Hisar Unnat. In case of fruit yield per plant, the highest positive SCA effect was observed for the cross-combination VRO-4 x Hisar Unnat followed by Tulsi-1 x 9801, SKBS-11 x 9801, Japan Red x Hisar Unnat, IC-169468 x 9801, P-8 x Hisar Unnat, Parbhani Kranti x Hisar Unnat, Japan 5 Ridged x 9801 and P-20 x 9801.

For ridges per fruit, three cross-combinations *viz.*, P-20 x Hisar Unnat, Japan Red x 9801 and Parbhani Kranti x 9801 revealed positive significant SCA effects. For dry matter, no cross-combination exhibited significant value whereas for mucilage, nine crosses showed significant positive SCA effects, SKBS-11 x Hisar Unnat being best specific combiner followed by P-23 x Hisar Unnat, Japan Round x 9801, Japan 5 Ridged x 9801, Parbhani Kranti x 9801, Japan Red x Hisar Unnat, P-8 x 9801, VRO-4 x Hisar Unnat and VRO-6 x 9801.

The trait wise good cross-combinations have been summarized in Table 4.11. It was observed that no single cross could reveal significant SCA effects for all the traits. Earlier workers have also reported significant SCA effects in their respective

Table 4.10 Estimates of SCA effects of different cross-combinations for fruit yield and horticultural traits in okra

Crosses	Days to 50 per cent flowering	Days to first picking	First fruit producing node	Internodal length	Plant height	Harvest duration	Fruit yield per plant	Ridges per fruit	Mucilage
P-20 x 9801	- 0.26	- 1.71*	0.04	0.39	8.08	- 0.26	4.83*	-0.35*	0.02
P-20 x Hisar Unnat	0.26	1.71*	- 0.04	- 0.39	- 8.08	0.26	- 4.83*	0.35*	- 0.02
VRO-4 x 9801	0.29	0.79	0.19	- 0.52	- 13.53*	- 1.12	- 52.45*	0.11	- 0.13*
VRO-4 x Hisar Unnat	- 0.29	- 0.79	- 0.19	0.52	13.53*	1.12	52.45*	- 0.11	0.13*
Parbhani Kranti x 9801	- 0.62	- 0.21	0.16	0.81	0.61	- 0.85	- 5.85*	0.25*	0.25*
Parbhani Kranti x Hisar Unnat	0.62	0.21	- 0.16	- 0.81	- 0.61	0.85	5.85*	- 0.25*	- 0.25*
P-8 x 9801	1.29	1.79*	- 0.31	0.37	5.62	0.81	- 6.27*	0.10	0.24*
P-8 x Hisar Unnat	- 1.29	- 1.79*	0.31	-0.37	- 5.62	- 0.81	6.27*	- 0.10	- 0.24*
Tulsi-1 x 9801	1.01	- 0.21	0.24	0.38	1.64	0.29	32.44*	0.04	0.01
Tulsi-1 x Hisar Unnat	- 1.01	0.21	- 0.24	- 0.38	- 1.64	- 0.29	- 32.44*	- 0.04	- 0.01
SKBS-11 x 9801	- 1.78*	- 1.21	- 0.11	0.46	14.86*	0.72	23.03*	0.10	- 0.48*
SKBS-11 x Hisar Unnat	1.78*	1.21	0.11	- 0.46	- 14.86*	- 0.72	- 23.03*	- 0.10	0.48*
VRO-6 x 9801	- 0.38	- 0.21	- 0.01	0.84	14.74*	- 2.68*	- 2.47	- 0.15	0.11*
VRO-6 x Hisar Unnat	0.38	0.21	0.01	- 0.84	- 14.74*	2.68*	2.47	0.15	- 0.11*
IC-169468 x 9801	- 0.13	0.79	- 0.01	- 1.29	- 2.39	0.12	15.02*	0.01	- 0.02
IC-169468 x Hisar Unnat	0.13	- 0.79	0.01	1.29	2.39	- 0.12	- 15.02*	0.01	0.02
P-23 x 9801	- 0.77	0.29	- 0.11	0.39	- 0.33	1.00	1.73	- 0.13	- 0.42*
P-23 x Hisar Unnat	0.77	- 0.29	0.11	- 0.39	0.33	- 1.00	- 1.73	0.13	0.42*
Japan Red x 9801	- 0.15	- 0.71	0.79*	0.21	4.46	- 0.15	-16.97*	0.30*	- 0.24*
Japan Red x Hisar Unnat	0.15	0.71	- 0.79*	- 0.21	- 4.46	0.15	16.97*	- 0.30*	0.24*
Japan 5 Ridged x 9801	2.29*	1.29	0.32	- 1.74*	- 18.76*	0.70	5.49*	- 0.20	0.29*
Japan 5 Ridged x Hisar Unnat	- 2.29*	- 1.29	- 0.32	1.74*	18.76*	- 0.70	- 5.49*	0.20	- 0.29*
Japan Round x 9801	- 0.77	- 0.71	- 1.21*	- 0.32	- 14.99*	1.43	1.47	- 0.04	0.36*
Japan Round x Hisar Unnat	0.77	0.71	1.21*	0.32	14.99*	- 1.43	- 1.47	0.04	- 0.36*
SE (Sij) ±	0.79	0.97	0.30	0.74	4.17	0.28	2.26	0.11	0.02
SE (Sij-Skl) ±	1.11	1.37	0.42	1.04	5.89	1.39	3.19	0.16	0.03

***Significant at $P \leq 0.05$**

studies under different environmental conditions for different traits, *viz.*, days to 50 per cent flowering and first fruit producing node by Patel et al. (2015b); internodal length and plant height by Reddy and Sridevi (2018) and fruit yield per plant and ridges per fruit by Shwetha et al. (2018).

Table 4.11 List of cross-combinations showing good specific combining ability (SCA) effects for horticultural traits in okra

Traits	Cross combination(s)
Days to 50 per cent flowering	Japan 5 Ridged x Hisar Unnat (G x P) and SKBS-11 x 9801 (A x G)
Days to first picking	P-8 x Hisar Unnat (P x P) and P-20 x 9801(P x G)
First fruit producing node	Japan Round x 9801 (P x A) and Japan Red x Hisar Unnat (P x A)
Internodal length (cm)	Japan 5 Ridged x 9801 (A x G)
Plant height (cm)	Japan 5 Ridged x 9801 (A x G), Japan Round x 9801 (G x G), SKBS-11 x Hisar Unnat (P x P), VRO-6 x Hisar Unnat (G x P) and VRO-4 x 9801 (P x G)
Harvest duration (days)	VRO-6 x Hisar Unnat (P x G)
Fruit yield per plant (g)	VRO-4 x Hisar Unnat (G x G), Tulsi-1 x 9801 (G x P), SKBS-11 x 9801 (G x P), Japan Red x Hisar Unnat (P x G), IC-169468 x 9801 (G x P), P-8 x Hisar Unnat (G x G), Parbhani Kranti x Hisar Unnat (G x G), Japan 5 Ridged x 9801 (P x P) and P-20 x 9801 (P x P)
Ridges per fruit	P-20 x Hisar Unnat (A x P), Japan Red x 9801 (G x A) and Parbhani Kranti x 9801 (P x A)
Mucilage (%)	SKBS-11 x Hisar Unnat (G x G), P-23 x Hisar Unnat (G x G), Japan Round x 9801 (G x P), Japan 5 Ridged x 9801 (P x P), Parbhani Kranti x 9801 (P x P), P-8 x 9801 (G x P), Japan Red x Hisar Unnat (P x G), VRO-4 x Hisar Unnat (A x G) and VRO-6 x 9801 (G x P)

(G) Good, (A) Average, (P) Poor

On the basis of SCA effects, it can be concluded that desirable SCA effects were not revealed by any of cross-combinations for all the traits (Table 4.10). The hybrid Japan 5 Ridged x 9801 was exceptionally good with desirable sca effects for fruit yield per plant, internodal length, plant height and mucilage. The parents involved in this hybrid are poor performers (except average x good for internodal length and plant height) suggesting that poor x poor parental combinations could also be of use in the production of hybrids, due to the complementation of favourable genes (Table 4.11). A few instances in this regard have been reported earlier by Khanpara et al. (2009), Tiwari et al. (2016) and Pandey (2017) in okra. The other promising hybrid exhibiting significant desirable sca effect was Japan Red x Hisar Unnat involving poor x good general combiners for fruit yield per plant and mucilage and poor x average for first fruit producing node. Good specific combinations for other yield attributes were Japan Round x 9801 (good x good), SKBS-11 x Hisar Unnat (poor x poor) and VRO-4 x 9801 (poor x good) for plant height and VRO-6 x Hisar Unnat for plant height and harvest duration involving good x poor and poor x good combiners, respectively. Earlier researchers *viz.,* Singh et al. (2006), Khanpara et al. (2009), Obiadalla-Ali et al. (2013), Bhatt et al. (2015), Patil et al. (2016), Tiwari et al. (2016) and Pandey (2017) using different parental lines have also reported the involvement of good x good, good x poor, poor x good, poor x average and poor x poor combiners in the hybrids revealing significant sca effects.

The cross-combinations involving one good and other poor or average combiner may give desirable transgressive segregants if the additive effect of one parent and complementary epistatic effect (if present in the cross) act in the same direction and maximize desirable plant character. But in the present study, high sca effects were also shown by some cross-combinations involving poor x poor general combiners which might be due to diverse genetic background of the parental lines involved in the crosses. The specific interaction effects of poor x poor crosses may perform better than good x good and good x poor combinations because of the prevalence of high magnitude of non-additive component for the superiority of the pertinent cross-combination. The combinations exhibiting high SCA effects derived from good or average general combiners will be of main interest as they certainly perform better for particular character. However, Singh et al. (1985) were of the view that the best crosses involving at least one parent with good combining ability may produce transgressive segregants which are also possible in many of the crosses of the present study.

Table 4.12 Specific cross-combinations with desirable SCA effects and *per se* performance for fruit yield and horticultural traits in okra

Cross-combinations	*Per se* performance	Traits
VRO-4 x Hisar Unnat	310.00	Fruit yield per plant and mucilage
Tulsi-1 x 9801	280.12	Fruit yield per plant
SKBS-11 x 9801	276.60	Fruit yield per plant and days to 50 per cent flowering
Japan Red x Hisar Unnat	201.00	Fruit yield per plant, first fruit producing node and mucilage
IC-169468 x 9801	280.12	Fruit yield per plant
P-8 x Hisar Unnat	318.40	Fruit yield per plant and days to first picking
Parbhani Kranti x Hisar Unnat	326.66	Fruit yield per plant
Japan 5 Ridged x 9801	215.12	Fruit yield per plant, internodal length, plant height and mucilage
P-20 x 9801	225.21	Fruit yield per plant and days to first picking

4.3.2.3 Proportionate contribution of lines, testers and their interactions to genetic variance

The relative contribution of lines, testers and lines x testers interaction towards the total sum of squares of the hybrids are presented in Table 4.13.

The proportional contribution of lines ranged from 25.26 (fruit diameter) to 92.41 (dry matter) and it was 80.31 per cent for fruit yield per plant. The proportional per cent contribution of testers ranged from 0.28 (fruit yield per plant) to 66.19 per cent (fruit diameter). The proportional contribution of line x tester interactions ranged from 4.25 (dry matter) to 54.00 per cent (mucilage) while its contribution for fruit yield per plant was 19.41 per cent.

Table 4.13 Estimates of proportional contribution of lines, testers and their interactions

Traits	Contribution (%) due to		
	Lines	Testers	Line x Tester
Days to 50 per cent flowering	73.66	12.04	14.30
Days to first picking	67.90	12.54	19.56
First fruit producing node	74.26	1.04	24.70
Nodes per plant	59.15	20.78	20.07
Internodal length (cm)	63.80	21.19	15.01
Fruit length (cm)	57.27	24.30	18.43
Fruit diameter (cm)	25.26	66.19	8.55
Average fruit weight (g)	63.83	6.11	30.06
Plant height (cm)	35.95	55.93	8.12
Harvest duration (days)	61.72	8.39	29.89
Fruits per plant	63.86	15.52	20.62
Fruit yield per plant (g)	80.31	0.28	19.41
Ridges per fruit	81.72	0.78	17.50
Dry matter (%)	92.41	3.34	4.25
Mucilage (%)	44.81	1.19	54.00

Further, it was noticed that the per cent contribution of lines was higher than the corresponding testers and their interaction for most of the traits except for fruit diameter and plant height where contribution of testers was higher than the value of corresponding line. Therefore, it can be concluded that lines played a significant role in the expression of different characters in various cross-combinations.

Table 4.14 Estimates of additive (D) and dominance (H) components of line x tester analysis expressed as per cent deviation over those of TTC analysis

Traits	Additive variance due to		Estimates of D(%)	Dominance variance due to		Estimates of H(%)
	TTC	L x T		TTC	L x T	
Days to 50 per cent flowering	93.10	4.70	-94.95	12.81	1.75	-86.34
Days to first picking	51.52	2.94	-94.29	8.95	1.19	-86.70
First fruit producing node	9.83	0.19	-98.07	2.73	0.35	-87.18
Nodes per plant	27.89	4.03	-85.55	-	-	-
Internodal length (cm)	40.40	3.58	-91.14	4.98	0.78	-84.34
Fruit length (cm)	2.28	0.33	-85.53	0.08	-	-
Fruit diameter (cm)	-	0.03	-	-	-	-
Average fruit weight (g)	31.23	1.15	-96.32	6.16	0.90	-85.39
Plant height (cm)	8374.46	2751.62	-67.14	1795.57	223.26	-87.57
Harvest duration (days)	31.52	1.60	-94.92	13.38	1.59	-88.12
Fruits per plant	25.13	2.50	-90.05	-	-	-
Fruit yield per plant (g)	29921.03	554.44	-98.15	7214.46	901.26	-87.51
Ridges per fruit	2.50	0.05	-98.00	0.44	0.06	-86.36
Dry matter (%)	6.92	0.16	-97.69	-	-	-
Mucilage (%)	1.01	0.02	-98.02	1.21	0.15	-87.60

Per cent deviation was calculated as:

$$\frac{(\text{LxT variance} - \text{TTC variance})}{\text{TTC variance}} \text{ x } 100$$

4.3.2.4 Comparison of TTC and line x tester analysis in the estimation of additive and dominance genetic component

Comparison of the two approaches used in the experiment for the analysis of genetic architecture of the population for quantitative traits (Table 4.14) revealed that, in general, both additive and dominance genetic components have been underestimated in the line x tester mating design. With respect to the estimates of TTC analysis the underestimation for additive genetic component was to the extent of -67.14 to -98.15% and dominant genetic component was underestimated in the range of -84.34 to -88.12% than the line x tester analysis.

In general, the underestimation has been comparatively more with respect to additive genetic variance in relation to dominance variance except for plant height, as described above. Pooni and Jinks (1976) have also reported that for getting the precise information on the additive genetic variance even in the presence of epistasis, the TTC is most powerful. The present results also confirm this view.

4.4 Nature and magnitude of heterosis

Discovery of hybrid vigour by Shull (1908) gave birth to heterosis breeding. The phenomenon of heterosis has been proved to be the most important genetic tool in improving yield of self as well as cross pollinated species. Genetically diverse varieties are the main necessity to observe heterosis in F_1 hybrids (Mole et al. 1962). It is an effective tool in improving the yield and component traits of different crop species. Commercial exploitation of heterosis in self (Rick 1945; Bishop 1954) and cross pollinated species (Hutchins 1939) suggests that irrespective of the breeding system, these crops are essentially similar in their heterotic response and therefore, use of heterosis should carefully be considered in all the crop plants. Heterosis for increased fruit size, fruit weight and fruits per plant in okra was first reported by Vijayaraghvan and Warriar (1946). The identification of potential cross-combinations on the basis of heterosis with respect to various horticultural traits in okra is of paramount importance for future breeding strategies. In the present study, an attempt has been made to gather information on nature and magnitude of heterosis for yield and other traits in twenty four cross-combinations over better parent (BP) and standard check (SC) 'Palam Komal'. In general, heterosis over BP and SC was observed for majority of the traits and is discussed trait wise as under (Table 4.15):

Days to 50 per cent flowering

For this trait, negative heterosis is of main interest to the breeder because it is desirable to incorporate earliness, hence more attention was given towards negative heterosis. The parent IC-169468 and 9801 were the earliest (44.33 days) and the parent Japan Red was significantly late (70.00 days) for days to 50 per cent flowering (Appendix-II). Among crosses, the cross P-23 x 9801 (44.54 days) was the earliest in flowering followed by Japan 5 Ridged x Hisar Unnat (44.66 days) (Table 4.15).

The range of heterosis over better parent and standard check varied from -7.27 per cent (Japan 5 Ridged x Hisar Unnat) to 22.06 per cent (Japan Red x 9801) and -5.23 per cent (P-23 x 9801) to 19.85 per cent (Japan Red x Hisar Unnat), respectively. Out of twenty four crosses, only one cross displayed significant negative heterosis over better parent. The results are in broad conformity to the findings of Adiger et al. (2013b), Kumar et al. (2017) and Kerure and Pitchaimuthu (2018).

Days to first picking

As already mentioned in case of days to 50 per cent flowering, one is always interested to have early maturing strains; hence for this trait also negative heterosis is of interest. Among the parents, IC-169468 was the earliest for days to first picking (49.00 days) while Japan Red (69.00 days) took significantly longer days to first picking in comparison to other parental lines. Among the cross-combinations, least mean days to first picking were taken by P-20 x 9801, Parbhani Kranti x 9801, VRO-6 x 9801 and P-23 x 9801 (50.00 days).

The magnitude of heterosis ranged from -3.85 per cent (P-20 x 9801, Parbhani Kranti x 9801, VRO-6 x 9801 and P-23 x 9801) to 12.03 per cent (Japan Red x Hisar Unnat) over better parent and over standard check it ranged from -1.96 per cent (P-20 x 9801, Parbhani Kranti x 9801, VRO-6 x 9801 and P-23 x 9801) to 15.69 per cent (Japan Red x Hisar Unnat). None of the cross-combination was significantly earlier to better parent and standard check. Heterosis with variable magnitude has also been observed earlier by Akhtar et al. (2010a), Eswaran and Anbanandan (2018) and Makdoomi et al. (2018) for days to first picking.

First fruit producing node

First fruit producing node in parents ranged from 1.60 (VRO-4 and Japan 5 Ridged) to 5.80 (Japan Red). Among crosses, it ranged from IC-169468 x 9801 (1.25) to Japan Round x Hisar Unnat (5.80). The range of heterosis varied from -42.86 per cent (Japan Red x Hisar Unnat) to 123.08 per cent (Japan Round x Hisar Unnat) and 0.00 per cent (IC-169468 x 9801) to 364.00 per cent (Japan Round x Hisar Unnat) over better parent and standard check, respectively.

Out of twenty four crosses, cross Japan Red x Hisar Unnat showed significant negative heterosis over better parent, while crosses P-20 x 9801, Japan Red x 9801, Japan Round x 9801 and Japan Round x Hisar Unnat over better parent and P-20 x 9801, P-20 x Hisar Unnat, P-8 x Hisar Unnat, Tulsi-1 x 9801, VRO-6 x Hisar Unnat, P-23 x Hisar Unnat, Japan Red x 9801, Japan 5 Ridged x 9801, Japan Round x 9801 and Japan Round x Hisar Unnat over standard check showed significant positive heterosis. Similar observations have also been reported by Reddy et al. (2012a), Eswaran and Anbanandan (2018) and Kerure and Pitchaimuthu (2018).

Nodes per plant

The lowest node per plant was observed in the parent Tulsi-1 (13.12) while it was highest for Hisar Unnat (27.00) as depicted in Appendix-II. Among crosses, it ranged from 15.80 (P-23 x 9801) while it was highest 24.70 for Parbhani Kranti x Hisar Unnat.

Perusal of the data revealed that the heterosis for this trait varied from -38.28 per cent (P-23 x 9801) to -8.52 per cent (Parbhani Kranti x Hisar Unnat) over better parent and -6.95 per cent (P-23 x 9801) to 45.47 per cent (Parbhani Kranti x Hisar Unnat) over standard check. Out of twenty four crosses, eight crosses showed significant positive heterosis over standard check. None of the crosses showed significant positive heterosis while 14 crosses showed significant negative heterosis over better parent. More et al. (2015), Kumar et al. (2017) and Kerure and Pitchaimuthu (2018) reported positive heterosis for this trait.

Internodal length (cm)

For this trait, negative heterosis is of main interest as it is always desirable to incorporate stronger stem and more number of nodes, hence more attention is given towards negative heterosis for shorter internodal length. Internodal length of parents ranged between 6.03 cm (9801) to 13.84 cm (SKBS-11) and of crosses ranged between 6.65 cm (Japan Round x 9801) to 13.83 cm (SKBS-11 x Hisar Unnat). The heterosis over better parent ranged from -15.73 per cent (Tulsi-1 x Hisar Unnat) to 114.10 per cent (SKBS-11 x 9801) and over standard check ranged from -35.12 per cent (Japan Round x 9801) to 34.96 per cent (SKBS-11 x Hisar Unnat). None of the crosses showed significantly negative heterobeltiosis. In comparison to standard check, six crosses showed significantly negative heterosis. These results are in agreement with the findings of Reddy et al. (2013), Harne et al. (2015), Bhatt et al. (2016) and Chavan et al. (2018).

Fruit length (cm)

Among the parents, Japan 5 Ridged had the shortest (11.96 cm) while Parbhani Kranti had the longest fruit (14.88 cm). Among the crosses, the fruit length ranged between 12.21 cm (P-23 x Hisar Unnat) to 14.82 cm (Parbhani Kranti x 9801). The heterosis for this trait ranged from -10.53 per cent (SKBS-11 x Hisar Unnat) to 2.05 per cent (Tulsi-1 x Hisar Unnat) over better parent and from -13.40 per cent (P-23 x Hisar Unnat) to 5.11 per cent (Parbhani Kranti x 9801) over standard check. Out of twenty four crosses, none of the crosses exhibited significant positive heterosis both over better parent and standard check. The cross-combinations Tulsi-1 x Hisar Unnat and Parbhani Kranti x 9801 recorded highest magnitude of positive heterosis over better parent and standard check, respectively. The results are in line with those of Harne et al. (2015), Bhatt et al. (2016), Chavan et al. (2018) and Makdoomi et al. (2018).

Fruit diameter (cm)

Among parents, Japan Red had minimum fruit diameter (1.11 cm) and Hisar Unnat had the broadest fruit (2.10 cm) as depicted in the Appendix-II. Among crosses, P-23 x 9801 had the shortest fruit diameter (1.56 cm) and Japan 5 Ridged x Hisar Unnat had the broadest fruit (2.04 cm).

The heterosis over better parent and standard check ranged from -4.29 per cent (P-23 x 9801) to 81.98 per cent (Japan Red x Hisar Unnat) and 5.41 per cent (P-23 x 9801) to 37.84 per cent (Japan 5 Ridged x Hisar Unnat), respectively. Two crosses showed significant positive heterosis over better parent while none of the cross-combination exhibited desirable significant negative heterosis over better parent and standard check. The results are in broad conformity with those of Adiger et al. (2013b), Harne et al. (2015), Chavan et al. (2018) and Kerure and Pitchaimuthu (2018).

Average fruit weight (g)

Average fruit weight among parents varied from 10.72 g (SKBS-11) to 16.25 g (Japan 5 Ridged). Among crosses, it ranged from 10.95 g (P-23 x Hisar Unnat) to 18.30 g (Parbhani Kranti x 9801).

Heterosis over better parent and over standard check for average fruit weight varied from -26.13 per cent (Japan 5 Ridged x 9801) to 21.38 per cent (SKBS-11 x 9801) and -28.77 per cent (P-23 x Hisar Unnat) to 18.99 per cent (Parbhani Kranti x 9801), respectively. None of the crosses exhibited significant positive heterosis over better parent as well as standard check. Two cross-combinations over better parent and standard check showed significant negative heterosis, respectively. Reddy et al. (2013), Harne et al. (2015), Bhatt et al. (2016) and Kumar et al. (2017) also observed significant negative heterosis for this trait in their respective studies.

Plant height (cm)

Lowest plant height among parents was observed in Japan 5 Ridged (113.60 cm), while it was highest in Hisar Unnat (299.00 cm). Among F_1's, the plant height was lowest in Japan Round x 9801 (130.00 cm) and highest in SKBS-11 x Hisar Unnat (262.40 cm).

Significant and positive heterosis was observed in 15 crosses over standard check, while three cross-combinations showed significant negative heterosis over standard check. The cross-combination (SKBS-11 x Hisar Unnat) recorded maximum economic heterosis of 55.50 per cent. The range of heterosis varied from -10.62 per cent (P-23 x 9801) to 109.29 per cent (Japan 5 Ridged x Hisar Unnat) over better parent and -22.96 per cent (Japan Round x 9801) to 55.50 per cent (SKBS-11 x Hisar Unnat) over standard check. Cross P-23 x 9801 exhibited desirable negative significant heterosis over better parent for plant height. These findings are in agreement with those of Patel et al. (2015a), Bhatt et al. (2016), Kumar et al. (2017) and Makdoomi et al. (2018).

Harvest duration (days)

Longer harvest duration results in the higher fruit yield in okra. Harvest duration ranged from 50.11 days in Japan Red to 58.10 days in 9801 among parents.

Table 4.15 Estimation of heterosis (%) over better parent and standard check and mean of crosses for fruit yield and horticultural traits in okra

S. No.	Hybrids	Quantitative traits								
		Days to 50 per cent flowering			Days to first picking			First fruit producing node		
		Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
1.	P-20 x 9801	47.67	7.53*	1.43	50.00	-3.85	-1.96	2.90	61.11*	132.00*
2.	P-20 x Hisar Unnat	50.11	0.22	6.62*	55.00	4.43	7.84*	3.00	25.00	140.00*
3.	VRO-4 x 9801	46.33	4.51	-1.43	51.00	-1.92	0.00	1.80	12.50	44.00
4.	VRO-4 x Hisar Unnat	47.67	-0.91	1.43	51.00	-1.92	0.00	1.60	0.00	28.00
5.	Parbhani Kranti x 9801	47.00	6.02*	0.00	50.00	-3.85	-1.96	1.80	0.00	44.00
6.	Parbhani Kranti x Hisar Unnat	50.16	0.32	6.72*	52.00	-1.27	1.96	1.66	-30.83	32.80
7.	P-8 x 9801	49.67	12.05*	5.68*	54.00	3.85	5.88*	2.00	11.11	60.00
8.	P-8 x Hisar Unnat	49.00	-2.00	4.26	52.00	-1.27	1.96	2.80	12.00	124.00*
9.	Tulsi-1 x 9801	50.11	13.04*	6.62*	53.00	1.92	3.92	2.20	22.22	76.00*
10.	Tulsi-1 x Hisar Unnat	50.00	0.00	6.38*	55.00	4.43	7.84*	1.90	-5.00	52.00
11.	SKBS-11 x 9801	45.00	1.51	-4.26	51.00	-1.92	0.00	1.60	-11.11	28.00
12.	SKBS-11 x Hisar Unnat	50.47	0.94	7.38*	55.00	4.43	7.84*	2.00	-9.09	60.00
13.	VRO-6 x 9801	46.66	5.26*	-0.72	50.00	-3.85	-1.96	2.00	11.11	60.00
14.	VRO-6 x Hisar Unnat	49.33	-1.34	4.96*	52.00	-1.27	1.96	2.20	10.00	76.00*
15.	IC-169468 x 9801	45.33	2.26	-3.55	51.00	4.08	0.00	1.25	-30.56	0.00
16.	IC-169468 x Hisar Unnat	47.51	7.17*	1.09	51.00	4.08	0.00	1.45	-34.09	16.00
17.	P-23 x 9801	44.54	0.47	-5.23*	50.00	-3.85	-1.96	2.00	11.11	60.00
18.	P-23 x Hisar Unnat	48.00	4.10	2.13	51.00	-1.92	0.00	2.40	0.00	92.00*
19.	Japan Red x 9801	54.11	22.06*	15.13*	56.00	7.69*	9.80*	3.00	66.67*	140.00*
20.	Japan Red x Hisar Unnat	56.33	12.66*	19.85*	59.00	12.03*	15.69*	1.60	-42.86*	28.00
21.	Japan 5 Ridged x 9801	47.33	6.77*	0.70	53.00	1.92	3.92	2.20	37.50	76.00*
22.	Japan 5 Ridged x Hisar Unnat	44.66	-7.27*	-4.98*	52.00	-1.27	1.96	1.75	9.37	40.00
23.	Japan Round x 9801	46.67	5.28*	-0.70	51.00	-1.92	0.00	3.20	77.78*	156.00*
24.	Japan Round x Hisar Unnat	50.13	0.25	6.65*	54.00	2.53	5.88*	5.80	123.08*	364.00*
	SE(d)		1.11	1.11		1.37	1.37		0.42	0.42

***Significant at 5% level**

Contd….

S. No.	Hybrids	Quantitative traits								
		Nodes per plant			Internodal length			Fruit length		
		Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
1.	P-20 x 9801	20.20	-21.09*	18.96	7.99	32.56	-22.02*	12.40	-10.01*	-12.06*
2.	P-20 x Hisar Unnat	22.40	-17.04	31.92*	9.06	2.57	-11.64	13.10	1.87	-7.09
3.	VRO-4 x 9801	19.00	-25.78*	11.90	8.48	40.68*	-17.24	14.20	-1.11	0.71
4.	VRO-4 x Hisar Unnat	22.40	-17.04	31.92*	11.38	29.02*	11.02	13.10	-8.77*	-7.09
5.	Parbhani Kranti x 9801	20.11	-21.45*	18.43	9.96	65.17*	-2.83	14.82	-0.40	5.11
6.	Parbhani Kranti x Hisar Unnat	24.70	-8.52	45.47*	10.18	-8.07	-0.68	13.52	-9.14*	-4.11
7.	P-8 x 9801	19.75	-22.85*	16.31	8.45	40.08*	-17.59	13.24	-3.92	-6.10
8.	P-8 x Hisar Unnat	22.40	-17.04	31.92*	9.55	-13.73	-6.80	13.01	2.04	-7.73
9.	Tulsi-1 x 9801	20.10	-21.48*	18.37	7.98	32.34	-22.15*	12.99	-5.73	-7.87
10.	Tulsi-1 x Hisar Unnat	23.50	-12.96	38.40*	9.07	-15.73	-11.48	12.45	2.05	-11.70*
11.	SKBS-11 x 9801	18.60	-27.34*	9.54	12.91	114.10*	25.95*	14.07	-4.42	-0.21
12.	SKBS-11 x Hisar Unnat	19.20	-28.89*	13.07	13.83	24.92*	34.96*	13.17	-10.53*	-6.60
13.	VRO-6 x 9801	22.00	-14.06	29.56*	8.05	33.55	-21.43*	13.66	-0.87	-3.12
14.	VRO-6 x Hisar Unnat	24.64	-8.74	45.11*	8.22	-8.36	-19.80	13.05	-0.08	-7.45
15.	IC-169468 x 9801	21.40	-16.41	26.03	7.54	24.99	-26.47*	13.74	-0.29	-2.55
16.	IC-169468 x Hisar Unnat	19.00	-29.63*	11.90	11.96	66.27*	16.68	12.97	-4.21	-8.01*
17.	P-23 x 9801	15.80	-38.28*	-6.95	8.75	45.11*	-14.63	13.34	-3.19	-5.39
18.	P-23 x Hisar Unnat	19.80	-26.67*	16.61	9.82	0.61	-4.23	12.21	0.08	-13.40*
19.	Japan Red x 9801	16.00	-37.50*	-5.77	11.83	96.13*	15.38	13.96	-0.43	-0.99
20.	Japan Red x Hisar Unnat	17.80	-34.07*	4.83	13.25	29.22*	29.30*	13.08	-6.70	-7.23
21.	Japan 5 Ridged x 9801	21.15	-17.38	24.56	6.89	14.26	-32.78*	12.60	-8.56*	-10.64*
22.	Japan 5 Ridged x Hisar Unnat	19.75	-26.85*	16.31	12.21	62.34*	19.15	12.41	1.72	-11.99*
23.	Japan Round x 9801	19.60	-23.44*	15.43	6.65	10.28	-35.12*	13.26	-3.77	-5.96
24.	Japan Round x Hisar Unnat	23.54	-12.81	38.63*	9.13	28.70*	-10.89	12.97	1.17	-8.01*
	SE(d)		2.38	2.38		1.04	1.04		0.57	0.57

***Significant at 5% level** **Contd….**

S. No.	Hybrids	Quantitative traits								
		Fruit diameter			Average fruit weight			Plant height		
		Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
1.	P-20 x 9801	1.59	22.31	7.43	13.80	-2.17	-10.23	161.20	11.63*	-4.47
2.	P-20 x Hisar Unnat	1.84	41.54	24.32	12.29	-13.67	-20.05	200.16	38.61*	18.61*
3.	VRO-4 x 9801	1.71	4.91	15.54	12.60	-10.73	-18.08	159.42	13.87*	-5.53
4.	VRO-4 x Hisar Unnat	1.82	4.00	22.97	16.13	13.27	4.90	241.60	72.57*	43.17*
5.	Parbhani Kranti x 9801	1.88	15.34	27.03	18.30	17.51	18.99	197.10	27.66*	16.80*
6.	Parbhani Kranti x Hisar Unnat	1.98	4.76	33.78	15.39	-1.13	0.11	251.00	37.76*	48.74*
7.	P-8 x 9801	1.68	3.07	13.51	17.12	21.36	11.36	166.51	7.84*	-1.33
8.	P-8 x Hisar Unnat	1.96	14.62	32.43	17.05	19.71	10.86	210.40	19.55*	24.68*
9.	Tulsi-1 x 9801	1.70	4.29	14.86	16.17	14.60	5.16	158.10	8.88*	-6.31
10.	Tulsi-1 x Hisar Unnat	2.01	19.64	35.81	11.24	-21.09	-26.92*	209.95	44.59*	24.41*
11.	SKBS-11 x 9801	1.70	4.29	14.86	17.13	21.38	11.38	237.00	53.50*	40.44*
12.	SKBS-11 x Hisar Unnat	1.92	10.34	29.73	14.04	-1.43	-8.71	262.40	69.95*	55.50*
13.	VRO-6 x 9801	1.61	1.90	8.78	12.68	-10.16	-17.56	175.50	13.67*	4.00
14.	VRO-6 x Hisar Unnat	1.92	21.52	29.73	12.34	-13.37	-19.77	201.15	26.03*	19.20*
15.	IC-169468 x 9801	1.76	7.98	18.92	14.23	0.83	-7.48	160.10	4.10	-5.13
16.	IC-169468 x Hisar Unnat	1.85	3.93	25.00	15.42	8.26	0.26	220.00	43.04*	30.37*
17.	P-23 x 9801	1.56	-4.29	5.41	14.31	1.39	-6.96	138.00	-10.62*	-18.22*
18.	P-23 x Hisar Unnat	1.83	10.91	23.65	10.95	-23.08	-28.77*	193.79	-4.16	14.84*
19.	Japan Red x 9801	1.71	54.05*	15.54	13.69	-3.00	-10.99	185.80	20.34*	10.10*
20.	Japan Red x Hisar Unnat	2.02	81.98*	36.49	13.25	-6.95	-13.83	232.00	16.23*	37.48*
21.	Japan 5 Ridged x 9801	1.77	8.59	19.59	12.00	-26.13*	-21.94	145.10	27.73*	-14.01*
22.	Japan 5 Ridged x Hisar Unnat	2.04	4.62	37.84	12.03	-25.97*	-21.76	237.75	109.29*	40.89*
23.	Japan Round x 9801	1.78	9.20	20.27	13.13	-6.97	-14.63	130.00	-7.01	-22.96*
24.	Japan Round x Hisar Unnat	1.96	7.69	32.43	13.10	-8.01	-14.81	215.10	53.86*	27.47*
	SE(d)		0.30	0.30		1.87	1.87		5.89	5.89

***Significant at 5% level** **Contd….**

S. No.	Hybrids	Quantitative traits								
		Harvest duration			Fruits per plant			Fruit yield per plant		
		Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
1.	P-20 x 9801	51.33	-11.65*	-9.55*	16.34	-28.85*	9.08	225.21	-31.00*	2.29
2.	P-20 x Hisar Unnat	53.00	-8.49*	-6.61*	18.39	-17.96	22.76	220.40	-30.87*	0.11
3.	VRO-4 x 9801	52.73	-9.24*	-7.08*	16.20	-29.48*	8.12	200.25	-38.65*	-9.04*
4.	VRO-4 x Hisar Unnat	56.11	-3.12	-1.13	19.80	-11.67	32.18*	310.00	-2.76*	40.81*
5.	Parbhani Kranti x 9801	54.00	-7.06*	-4.85*	17.23	-24.96*	15.04	310.11	-4.99*	40.86*
6.	Parbhani Kranti x Hisar Unnat	56.85	-1.85	0.18	21.34	-4.79	42.48*	326.66	2.47*	48.37*
7.	P-8 x 9801	57.22	-1.51	0.83	17.61	-23.34*	17.53	301.00	-7.78*	36.72*
8.	P-8 x Hisar Unnat	56.75	-2.02	0.00	19.21	-14.29	28.26	318.40	-0.13	44.62*
9.	Tulsi-1 x 9801	55.77	-4.02	-1.73	17.83	-22.35*	19.05	280.12	-14.18*	27.23*
10.	Tulsi-1 x Hisar Unnat	56.33	-2.75	-0.74	19.81	-11.63	32.24*	220.10	-30.96*	-0.03
11.	SKBS-11 x 9801	56.15	-3.36	-1.06	16.51	-28.13*	10.19	276.60	-15.26*	25.64*
12.	SKBS-11 x Hisar Unnat	55.86	-3.56	-1.57	17.18	-23.36*	14.69	235.40	-26.16*	6.92*
13.	VRO-6 x 9801	50.00	-13.94*	-11.89*	19.26	-16.14	28.57	240.42	-26.34*	9.20*
14.	VRO-6 x Hisar Unnat	56.50	-2.45	-0.44	20.48	-8.64	36.72*	250.22	-21.51*	13.65*
15.	IC-169468 x 9801	57.05	-1.81	0.53	20.00	-12.92	33.51*	280.12	-14.18*	27.23*
16.	IC-169468 x Hisar Unnat	57.95	0.05	2.11	17.50	-21.93*	16.82	254.95	-20.03*	15.80*
17.	P-23 x 9801	57.00	-1.89	0.44	13.00	-43.40*	-13.22	185.40	-43.20*	-15.79*
18.	P-23 x Hisar Unnat	56.15	-3.06	-1.06	17.20	-23.27*	14.82	186.80	-41.41*	-15.15*
19.	Japan Red x 9801	53.55	-7.83*	-5.64*	12.20	-46.88*	-18.56	162.20	-50.31*	-26.33*
20.	Japan Red x Hisar Unnat	55.00	-5.04*	-3.08	15.60	-30.41*	4.14	201.00	-36.95*	-8.70*
21.	Japan 5 Ridged x 9801	56.20	-3.27	-0.97	18.21	-20.71	21.56	215.12	-34.09*	-2.29
22.	Japan 5 Ridged x Hisar Unnat	55.95	-3.40	-1.41	17.75	-20.82	18.49	209.00	-34.44*	-5.07*
23.	Japan Round x 9801	57.72	-0.65	1.71	16.00	-30.33*	6.81	208.20	-36.21*	-5.43*
24.	Japan Round x Hisar Unnat	56.01	-3.30	-1.30	16.20	-27.73*	8.14	210.12	-34.09*	-4.56*
	SE(d)		1.38	1.38		2.36	2.36		3.19	3.19

***Significant at 5% level**

Contd….

S. No.	Hybrids	Quality traits								
		Ridges per fruit			Dry matter			Mucilage		
		Mean	Better parent	Standard check	Mean	Better parent	Standard check	Mean	Better parent	Standard check
1.	P-20 x 9801	5.17	0.00	-10.92*	6.11	-8.12	0.99	0.98	-2.00	6.52
2.	P-20 x Hisar Unnat	5.80	5.45	0.00	6.07	-8.72	0.33	1.01	-12.17*	9.78*
3.	VRO-4 x 9801	5.47	5.81	-5.75*	6.75	-1.89	11.57	0.94	-6.00	2.17
4.	VRO-4 x Hisar Unnat	5.17	-6.06*	-10.92*	6.10	-11.34	0.83	1.28	11.30*	39.13*
5.	Parbhani Kranti x 9801	5.67	9.68*	-2.30	6.25	-4.43	3.31	0.98	-2.00	6.52
6.	Parbhani Kranti x Hisar Unnat	5.10	-7.27*	-12.07*	5.41	-7.04	-10.58	0.56	-51.30*	-39.13*
7.	P-8 x 9801	5.37	3.87	-7.47*	6.21	-5.05	2.64	1.44	33.33*	56.52*
8.	P-8 x Hisar Unnat	5.10	-7.27*	-12.07*	5.71	-5.46	-5.62	1.04	-9.57*	13.04*
9.	Tulsi-1 x 9801	5.22	0.97	-10.06*	6.83	-9.30	12.89	1.09	-2.68	18.48*
10.	Tulsi-1 x Hisar Unnat	5.07	-7.88*	-12.64*	6.59	-12.48	8.93	1.14	-0.87	23.91*
11.	SKBS-11 x 9801	5.52	6.77*	-4.89	6.65	-0.45	9.92	0.72	-28.00*	-21.74*
12.	SKBS-11 x Hisar Unnat	5.23	-4.85	-9.77*	6.52	-2.40	7.77	1.76	53.04*	91.30*
13.	VRO-6 x 9801	5.17	0.00	-10.92*	7.11	-9.54	17.52*	1.56	56.00*	69.57*
14.	VRO-6 x Hisar Unnat	5.38	-2.12	-7.18*	7.12	-9.41	17.69*	1.42	23.48*	54.35*
15.	IC-169468 x 9801	5.25	1.61	-9.48*	7.18	-7.12	18.68*	1.20	-11.76*	30.43*
16.	IC-169468 x Hisar Unnat	5.20	-5.45	-10.34*	7.01	-9.31	15.87	1.32	-2.94	43.48*
17.	P-23 x 9801	5.07	-1.94	-12.64*	6.44	-1.83	6.45	0.68	-32.00*	-26.09*
18.	P-23 x Hisar Unnat	5.25	-4.55	-9.48*	5.98	-8.84	-1.16	1.60	39.13*	73.91*
19.	Japan Red x 9801	7.00	-7.89*	20.69*	7.10	-8.97	17.36*	0.40	-64.29*	-56.52*
20.	Japan Red x Hisar Unnat	6.33	-16.67*	9.20*	7.30	-6.41	20.66*	0.96	-16.52*	4.35
21.	Japan 5 Ridged x 9801	5.20	0.65	-10.34*	7.76	-8.35	28.26*	0.95	-5.00	3.26
22.	Japan 5 Ridged x Hisar Unnat	5.53	0.61	-4.60	7.65	-9.65	26.45*	0.44	-61.74*	-52.17*
23.	Japan Round x 9801	5.40	4.52	-6.90*	8.10	-8.37	33.88*	1.56	56.00*	69.57*
24.	Japan Round x Hisar Unnat	5.40	-1.82	-6.90*	7.98	-9.73	31.90*	0.91	-20.87*	-1.09
	SE(d)		0.16	0.16		0.51	0.51		0.03	0.03

***Significant at 5% level**

Among crosses, it ranged from 50.00 days in case of VRO-6 x 9801 to 57.95 days in IC-169468 x Hisar Unnat.

The respective range of heterosis for this trait varied from -13.94 (VRO-6 x 9801) to 0.05 per cent (IC-169468 x Hisar Unnat) and from -11.89 (VRO-6 x 9801) to 2.11 per cent (IC-169468 x Hisar Unnat) over better parent and standard check, respectively. None of the crosses exhibited desirable positive significant heterosis over better parent as well as over standard check for this trait. Seven crosses over better parent while six crosses over standard check showed significant negative heterosis.

Fruits per plant

Fruits per plant in parents ranged from 11.20 (Tulsi-1) to 22.97 (9801). Among crosses, it ranged from 12.20 (Japan Red x 9801) to 21.34 (Parbhani Kranti x Hisar Unnat). The heterosis for this trait varied from -46.88 per cent (Japan Red x 9801) to -4.79 per cent (Parbhani Kranti x Hisar Unnat) over better parent and -18.56 per cent (Japan Red x 9801) to 42.48 per cent (Parbhani Kranti x Hisar Unnat) over standard check. For this trait, none of the crosses over better parent recorded positive heterosis while five cross-combinations over standard check showed positive significant heterosis. Parbhani Kranti x Hisar Unnat exhibited highest positive heterosis over standard check (42.48 per cent) followed by VRO-6 x Hisar Unnat (36.72 per cent). The results are in line with those Kumar et al. (2015), Patel et al. (2015a), Kumar et al. (2017) and Makdoomi et al. (2018).

Fruit yield per plant (g)

The ultimate goal of plant breeding programme is to achieve high yield. Fruit yield per plant of parents ranged between 144.40 g (Japan Red) to 326.40 g (9801). Among crosses, it was highest for Parbhani Kranti x Hisar Unnat (326.66 g). The lowest fruit yield per plant was observed in case of Japan Red x 9801 (162.20 g).

The heterosis ranged from -50.31 per cent (Japan Red x 9801) to 2.47 per cent (Parbhani Kranti x Hisar Unnat) over better parent and -26.33 per cent (Japan Red x 9801) to 48.37 per cent (Parbhani Kranti x Hisar Unnat) over standard check. For this trait, one cross over better parent while 12 cross-combinations over standard check exhibited significant positive heterosis. The earlier workers (Adiger et al. 2013b; Reddy et al. 2013; Kumar et al. 2015; Patel et al. 2015a; Paul et al. 2017b; Kerure and

Pitchaimuthu 2018 and Makdoomi et al. 2018) have also noticed cross-combinations with positive heterosis for fruit yield per plant.

Ridges per fruit

Lowest ridges per fruit among parents were observed in Japan Round (0.00) while highest in Japan Red (7.60). Among F_1's, ridges per fruit were lowest in Tulsi-1 x Hisar Unnat and P-23 x 9801 (5.07) and highest in Japan Red x 9801 (7.00).

The range of heterosis for this trait varied from -16.67 per cent (Japan Red x Hisar Unnat) to 9.68 per cent (Parbhani Kranti x 9801) over better parent and -12.64 per cent (Tulsi-1 x Hisar Unnat and P-23 x 9801) to 20.69 per cent (Japan Red x 9801) over standard check. Out of twenty four crosses, two cross-combinations showed significant positive heterosis over better parent and standard check, respectively. Positive significant heterosis for this trait has also been reported by Kerure et al. (2019).

Dry matter (%)

Among the parents, Japan Round (8.84%) had maximum dry matter content while Hisar Unnat (5.28%) had minimum dry matter content. The dry matter content ranged between 5.41% in Parbhani Kranti x Hisar Unnat to 8.10% in Japan Round x 9801 among crosses. Over the better parent, magnitude of heterosis ranged from -12.48 per cent (Tulsi-1 x Hisar Unnat) to -0.45 per cent (SKBS-11 x 9801), while it was -10.58 per cent (Parbhani Kranti x Hisar Unnat) to 33.88 per cent (Japan Round x 9801) over standard check. Significant positive heterosis was observed in nine crosses over standard check.

Mucilage (%)

The lowest mucilage content among parents was observed in P-23 (0.40%), while it was highest in IC-169468 (1.36%). Among F_1's, mucilage content was lowest in Japan Red x 9801 (0.40%) and highest in SKBS-11 x Hisar Unnat (1.76%). The range of heterosis for this trait varied from -64.29 per cent (Japan Red x 9801) to 56.00 per cent (VRO-6 x 9801 and Japan Round x 9801) over better parent and -56.52 per cent (Japan Red x 9801) to 91.30 per cent (SKBS-11 x Hisar Unnat) over standard check. Out of twenty four crosses, seven cross-combinations showed significant positive heterosis over better parent while 13 cross-combinations showed significant positive heterosis over standard check.

Heterosis studies provide information about per cent increase/decrease of F_1 over mid and better parents and thus, helps in spotting out the best crosses but, do not indicate the possible causes for superiority of crosses. In general, crosses which exhibited a high magnitude of heterosis for yield and other related traits are though superior but when such F_1 hybrids are compared with the better parent, very few combinations stand out to be significantly superior to these in performance and very often that lack in combination of economic traits.

The study revealed significant differences among the treatments (Table 4.1) for all the traits, indicating thereby the presence of significant genetic diversity in the material studied. Cross-combinations exhibiting heterosis over better parent and standard check for all the traits are presented in Table 4.16.

The analysis of variance for parents vs hybrids are significant for all the traits, except for first fruit producing node, internodal length, fruit length, fruit diameter and harvest duration in F_1's (Table 4.5). Earliness is highly desirable attribute in vegetables. The genotypes which flower early are desirable because they result in early fruit development and consequently fetching higher returns to the farmers. For days to 50 per cent flowering, hybrid Japan 5 Ridged x Hisar Unnat showed its superiority over better parent whereas two cross-combinations (P-23 x 9801 and Japan 5 Ridged x Hisar Unnat) were superior over standard check (Palam Komal). Cross Japan 5 Ridged x Hisar Unnat expressed significant negative heterosis over better parent and standard check for days to 50 per cent flowering. For days to first picking, no hybrid revealed significant negative heterosis over better parent and standard check as compared to days to 50 per cent flowering. This implies that there exist genotypic differences in the plant processes after flowering till fruit maturity. Variable magnitude of both flowering and early maturity has also been reported by Eswaran and Anbanandan (2018) and Makdoomi et al. (2018). Cross-combination Japan Red x Hisar Unnat expressed desirable negative heterosis for first fruit producing node over better parent whereas none of the cross-combination was superior over standard check.

Table 4.16 Cross-combination(s) exhibiting heterosis over respective better parent and standard check in okra

S.No.	Traits	Better parent	Standard check (Palam Komal)
1.	**Days to 50% flowering**	Japan 5 Ridged x Hisar Unnat	P-23 x 9801, Japan 5 Ridged x Hisar Unnat
2.	**First fruit producing node**	Japan Red x Hisar Unnat	---------------------------
3.	**Nodes per plant**	---------------------------	Parbhani Kranti x Hisar Unnat, VRO-6 x Hisar Unnat, Japan Round x Hisar Unnat, Tulsi-1 x Hisar Unnat, P-20 x Hisar Unnat, VRO-4 x Hisar Unnat, P-8 x Hisar Unnat, VRO-6 x 9801
4.	**Internodal length**	---------------------------	Japan Round x 9801, Japan 5 Ridged x 9801, IC-169468 x 9801, Tulsi-1 x 9801, P-20 x 9801, VRO-6 x 9801
5.	**Plant height**	P-23 x 9801	Japan Round x 9801, P-23 x 9801, Japan 5 Ridged x 9801
6.	**Fruits per plant**	---------------------------	Parbhani Kranti x Hisar Unnat, VRO-6 x Hisar Unnat, IC-169468 x 9801, Tulsi-1 x Hisar Unnat, VRO-4 x Hisar Unnat
7.	**Fruit yield per plant**	Parbhani Kranti x Hisar Unnat	Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat, Parbhani Kranti x 9801, VRO-4 x Hisar Unnat, P-8 x 9801, Tulsi-1 x 9801, IC-169468 x 9801, SKBS-11 x 9801, IC-169468 x Hisar Unnat, VRO-6 x Hisar Unnat, VRO-6 x 9801, SKBS-11 x Hisar Unnat
8.	**Ridges per fruit**	Parbhani Kranti x 9801, SKBS-11 x 9801	Japan Red x 9801, Japan Red x Hisar Unnat
9.	**Dry matter**	---------------------------	Japan Round x 9801, Japan Round x Hisar Unnat, Japan 5 Ridged x 9801, Japan 5 Ridged x Hisar Unnat, Japan Red x Hisar Unnat, IC-169468 x 9801, VRO-6 x Hisar Unnat, VRO-6 x 9801, Japan Red x 9801
10.	**Mucilage**	VRO-6 x 9801, Japan Round x 9801, SKBS-11 x Hisar Unnat, P-23 x Hisar Unnat, P-8 x 9801, VRO-6 x Hisar Unnat, VRO-4 x Hisar Unnat	SKBS-11 x Hisar Unnat, P-23 x Hisar Unnat, VRO-6 x 9801, Japan Round x 9801, P-8 x 9801, VRO-6 x Hisar Unnat, IC-169468 x Hisar Unnat, VRO-4 x Hisar Unnat, IC-169468 x 9801, Tulsi-1 x Hisar Unnat, Tulsi-1 x 9801, P-8 x Hisar Unnat, P-20 x Hisar Unnat

The number of nodes per plant is a direct component for the production of fruits, which ultimately leads to higher fruit yield in okra. Eight of the hybrids (Parbhani Kranti x Hisar Unnat, VRO-6 x Hisar Unnat, Japan Round x Hisar Unnat, Tulsi-1 x Hisar Unnat, P-20 x Hisar Unnat, VRO-4 x Hisar Unnat, P-8 x Hisar Unnat and VRO-6 x 9801) revealed hybrid vigour over standard check for nodes per plant. However, all the cross-combinations showed negative heterosis over better parent. The strains having short internodal length are of immense value to the breeders, hence, for this trait the interest of breeder lies in search of combinations having negative heterosis. No cross-combination over better parent while six of the cross-combinations (Japan Round x 9801, Japan 5 Ridged x 9801, IC-169468 x 9801, Tulsi-1 x 9801, P-20 x 9801 and VRO-6 x 9801) over standard check exhibited significant negative heterosis for internodal length.

Fruit length is one of the most important traits which contribute towards yield and heterosis in positive direction is desirable for this trait. In case of fruit length, none of the hybrids exhibited heterobeltiosis and heterosis over standard check. The consumer prefers slender fruits with lower fruit girth. As far as fruit diameter is concerned, none of the cross-combinations exhibited desirable negative heterosis over better parent as well as standard check. Harne et al. (2015) also reported negative heterosis for fruit length and positive heterosis for fruit diameter in their respective studies.

Average fruit weight is also one of the most important component trait which contributes for yield. No hybrid was found superior over better parent as well as standard check. Dwarf plants with shorter internodal length is a desirable trait to realize higher yield provided the environmental conditions are otherwise conducive for growth and fruiting over a longer period. The experimental material used in the present investigation is quite variable as is evident from significant differences among parents for plant height. Three hybrids expressed heterosis over standard check whereas one hybrid was superior over better parent. The hybrids *viz.*, Japan Round x 9801, P-23 x 9801 and Japan 5 Ridged x 9801 expressed significant negative heterosis over standard check. This may be due to the hybrids developed through crossing between dwarf and tall parents. These findings are in consonance with Bhatt et al.

(2016), Kumar et al. (2017) and Kerure et al. (2019) who have also reported positive heterosis for average fruit weight and negative for plant height.

Increase in harvest duration contributes towards highest marketable yield in okra. Out of twenty four, none of the cross-combination expressed hybrid vigour over better parent and standard check.

Fruits per plant are also a direct component towards fruit yield. None of the cross-combinations over better parent and five hybrids over standard check exhibited hybrid vigour for fruits per plant. Cross Parbhani Kranti x Hisar Unnat revealed the highest positive heterosis over standard check. The cross-combinations VRO-6 x Hisar Unnat, IC-169468 x 9801, Tulsi-1 x Hisar Unnat and VRO-4 x Hisar Unnat were also found heterotic over standard check.

High fruit yield is the basic objective of all the crop improvement programmes and is of relevance to the farmers from economic view point. Unless a new hybrid has a potential equal to or exceeding that of current cultivars, it will achieve little or no success even if it has excellent quality and resistance to diseases. Cross Parbhani Kranti x Hisar Unnat revealed hybrid vigour for fruit yield per plant over better parent. 12 cross-combinations *viz*., Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat, Parbhani Kranti x 9801, VRO-4 x Hisar Unnat, P-8 x 9801, Tulsi-1 x 9801, IC-169468 x 9801, SKBS-11 x 9801, IC-169468 x Hisar Unnat, VRO-6 x Hisar Unnat, VRO-6 x 9801 and SKBS-11 x Hisar Unnat showed hybrid vigour over standard check. The higher fruit yield in the hybrids may be attributed to increase in fruits per plant, nodes per plant, harvest duration, average fruit weight and shorter internodal length. But, the average fruit weight, shorter internodal length and fruits per plant are three direct components which contribute towards yield. Hybrid vigour for fruits per plant and fruit yield per plant have also been reported by Kumar et al. (2015), Patel et al. (2015a) and Makdoomi et al. (2018).

For ridges per fruit, cross-combinations Parbhani Kranti x 9801 and SKBS-11 x 9801 over better parent whereas cross-combinations Japan Red x 9801 and Japan Red x Hisar Unnat over standard check expressed significant positive heterosis.

Table 4.17 Hybrids exhibiting desirable economic heterosis for different horticultural traits in addition to fruit yield in okra

Hybrid	Trait(s)
Parbhani Kranti x Hisar Unnat	Nodes per plant and fruits per plant
P-8 x Hisar Unnat	Nodes per plant and mucilage
Parbhani Kranti x 9801	-
VRO-4 x Hisar Unnat	Nodes per plant, fruits per plant and mucilage
P-8 x 9801	Mucilage
Tulsi-1 x 9801	Internodal length and mucilage
IC-169468 x 9801	Internodal length, fruits per plant, dry matter and mucilage
SKBS-11 x 9801	-
IC-169468 x Hisar Unnat	Mucilage
VRO-6 x Hisar Unnat	Nodes per plant, fruits per plant, dry matter and mucilage
VRO-6 x 9801	Nodes per plant, internodal length, dry matter and mucilage
SKBS-11 x Hisar Unnat	Mucilage

As far as dry matter is concerned, nine cross-combinations *viz*., Japan Round x 9801, Japan Round x Hisar Unnat, Japan 5 Ridged x 9801, Japan 5 Ridged x Hisar Unnat, Japan Red x Hisar Unnat, IC-169468 x 9801, VRO-6 x Hisar Unnat, VRO-6 x 9801 and Japan Red x 9801 expressed desirable positive heterosis over standard check whereas none of the cross-combination was superior over better parent. In case of mucilage, seven hybrids *viz.*, VRO-6 x 9801, Japan Round x 9801, SKBS-11 x Hisar

Unnat, P-23 x Hisar Unnat, P-8 x 9801, VRO-6 x Hisar Unnat and VRO-4 x Hisar Unnat showed significant positive heterosis over better parent while cross-combinations SKBS-11 x Hisar Unnat followed by P-23 x Hisar Unnat, VRO-6 x 9801, Japan Round x 9801, P-8 x 9801, VRO-6 x Hisar Unnat, IC-169468 x Hisar Unnat, VRO-4 x Hisar Unnat, IC-169468 x 9801, Tulsi-1 x Hisar Unnat, Tulsi-1 x 9801, P-8 x Hisar Unnat and P-20 x Hisar Unnat showed significant positive heterosis over standard check for this trait. Cross-combinations exhibiting desirable economic heterosis for different horticultural traits in addition to fruit yield are given in Table 4.17.

Comparison of top ranking cross-combinations based on *per se* performance, sca effects and heterosis

The study of heterosis provides only the per cent increase or decrease of F_1 over the better parent or the standard check, thereby identifying the best crosses but fails to identify the possible causes of the superiority of the hybrids. The genetic basis of the superiority of the best crosses is assessed on the basis of combining ability effects. Thus, the comparison of the top ranking hybrid combinations based on *per se* performance, sca effects and heterosis revealed that in general, the top ranking hybrids based on *per se/* mean performance also figured among the best combinations on the basis of sca effects and /or heterobeltiosis / standard heterosis for most of the traits (Appendix-III). The cross, Parbhani Kranti x Hisar Unnat followed by P-8 x Hisar Unnat and VRO-4 x Hisar Unnat figured quite often for component traits. A close relationship of *per se* performance with sca effects and / or heterosis for yield and yield attributing characters as in the present study have also been reported by More et al. (2015) and Kerure et al. (2019).

Variability among genotypes for visually observed traits

Traits *viz*., immature fruit colour, fruit pubescence and ridges per fruit were observed visually and categorized according to Minimal Descriptors for Agri-Horticultural crops (Table 4.18). Variation for these traits is discussed below:

Table 4.18 Variation in visually observed traits among parents and hybrids of okra

S. No.	Parents/F_1 hybrids and standard check	Immature fruit colour	Fruit pubescence	Ridges per fruit
1.	P-20	2	3	2
2.	VRO-4	4	3	2
3.	Parbhani Kranti	2	3	2
4.	P-8	2	3	2
5.	Tulsi-1	2	3	2
6.	SKBS-11	4	7	2
7.	VRO-6	2	5	2
8.	IC-169468	1	7	2
9.	P-23	4	5	2
10.	Japan Red	5	3	2
11.	Japan 5 Ridged	4	5	2
12.	Japan Round	4	3	1
13.	9801	2	3	2
14.	Hisar Unnat	2	3	2
15.	P-20 x 9801	2	3	2
16.	P-20 x Hisar Unnat	2	3	2
17.	VRO-4 x 9801	2	3	2
18.	VRO-4 x Hisar Unnat	2	3	2
19.	Parbhani Kranti x 9801	2	3	2
20.	Parbhani Kranti x Hisar Unnat	2	3	2
21.	P-8 x 9801	2	3	2
22.	P-8 x Hisar Unnat	2	3	2
23.	Tulsi-1 x 9801	2	3	2
24.	Tulsi-1 x Hisar Unnat	2	3	2
25.	SKBS-11 x 9801	2	5	2
26.	SKBS-11 x Hisar Unnat	2	5	2
27.	VRO-6 x 9801	2	5	2
28.	VRO-6 x Hisar Unnat	2	5	2
29.	IC-169468 x 9801	2	3	2
30.	IC-169468 x Hisar Unnat	2	3	2
31.	P-23 x 9801	2	3	2
32.	P-23 x Hisar Unnat	2	3	2
33.	Japan Red x 9801	3	3	2
34.	Japan Red x Hisar Unnat	3	3	2
35.	Japan 5 Ridged x 9801	2	3	2
36.	Japan 5 Ridged x Hisar Unnat	2	5	2
37.	Japan Round x 9801	2	3	2
38.	Japan Round x Hisar Unnat	2	3	2
39.	Palam Komal	4	3	2

Immature fruit colour : 1= yellowish green, 2= green, 3= green with red patches, 4= dark green, 5= dark red
Fruit pubescence : 3= downy, 5= slightly rough, 7= prickly
Ridges per fruit : 1= no ridges, 2= 5-7 ridges per fruit

i) Immature fruit colour

Immature fruits of five colour intensities were observed. These were grouped as yellowish green, green, dark green, green with red patches and dark red. The parents P-20, Parbhani Kranti, P-8, Tulsi-1, VRO-6, 9801 and Hisar Unnat produced green fruits, whereas parents VRO-4, SKBS-11, P-23, Japan 5 Ridged and Japan Round produced dark green fruits. Parent IC-169468 produced yellowish green fruits while Japan Red produced dark red fruits. Among crosses, Japan Red x 9801 and Japan Red x Hisar Unnat produced green fruits with red patches. The remaining crosses produced green colour fruits.

ii) Fruit pubescence

Three fruit pubescences *viz*., downy, slightly rough and prickly were recorded. Among parents, SKBS-11 and IC-169468 produced fruits with prickly pubescence whereas parents VRO-6, P-23 and Japan 5 Ridged produced fruits with slightly rough pubescence. Rest of the parents produced fruits with downy pubescence. Among crosses, SKBS-11 x 9801, SKBS-11 x Hisar Unnat, VRO-6 x 9801, VRO-6 x Hisar Unnat and Japan 5 Ridged x Hisar Unnat produced fruits with slightly rough pubescence. Rest of the hybrids produced fruits with downy pubescence.

iii) Ridges per fruit

Five to seven ridges per fruit were recorded for all the parents and cross-combinations except parent Japan Round having no ridges.

Attractive fruit colour, smooth fruit texture and disease free fruits are the desirable horticultural attributes from consumer's point of view. Fruit colour and fruit texture are the most important quality characters on the basis of which the consumers prefer green to dark green and smooth textured fruits, and these observations often provide preconceived idea about other quality attributes. The colour of immature fruit varied between yellowish green, dark green, green, green with red patches and dark red. Fruits of all the parents and crosses showed downy to prickly pubescence.

All the parents and cross-combinations except parent Japan Round had five to seven ridges per fruit, which is a desirable quality character. The variation in fruit colour, pubescence and ridges per fruit is a varietal character. Dark green colour of fruits coupled with smooth texture is the most desirable trait in okra. Among the highest yielding crosses, Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat and Parbhani Kranti x 9801 possessed good quality attributes with green fruit colour, downy pubescence and five ridges per fruit. Kumar et al. (2006), Manivannan et al. (2007), Oppong-Sekyere et al. (2011) and Ogwu et al. (2018) reported variability for ridges per fruit in okra.

4.5 Yellow Vein Mosaic Virus (YVMV) incidence

The understanding of inheritance of disease is very essential for formulating a systematic breeding programme for developing a resistant variety with desirable horticultural traits. Disease resistance is the most desirable trait in any breeding programme. A genotype is of a little or no importance unless it is resistant to disease even if it is best for all other traits.

In literature, most of the research work on heterosis refers to average heterosis and heterobeltiosis only. However, it is the standard heterosis which is of practical interest to the breeders as well as growers. In India, the first hybrid for commercial cultivation was made available in 1973. As on today, new policy on seed development (w.e.f. October 1988) and bulk import of vegetable seeds under Open General License (OGL) have led to the availability of numerous hybrids which are being marketed by the private sector seed companies. Yellow Vein Mosaic Virus (YVMV) transmitted by white fly (*Bemisia tabaci* Gen.) is the most serious disease of okra affecting both yield and fruit quality. Infection of 100% plants in a field is very usual and yield losses range from 50% to 94% depending on the stage of crop growth at which infection occurs (Sastry and Singh 1974). Symptoms of Yellow Vein Mosaic Virus disease in okra are shown in Plate 4.1. Fruit yield is also greatly reduced by as much as 96% if the crop is infected at early stage (Pun and Doraiswamy 1999). The disease cannot be controlled adequately by chemical means. Uprooting of infected plants is not practical and economical because of heavy infection rates in the field. So, the only practical solution of this problem is to develop tolerant/resistant varieties. The essential prerequisite for improving disease resistance is the availability of a suitable source of resistance within a cultivated species itself or in related wild species,

Plate 4.1: Symptoms of Yellow Vein Mosaic Virus (YVMV) disease in okra

however, the resistance occurring within cultivated species is more desirable as this can be more easily transferred to an otherwise superior but, susceptible variety.

Parent SKBS-11 and the cross-combinations *viz*., VRO-4 x Hisar Unnat, Parbhani Kranti x 9801, Tulsi-1 x Hisar Unnat, SKBS-11 x 9801, VRO-6 x Hisar Unnat, P-23 x Hisar Unnat, Japan Red x Hisar Unnat, Japan Round x 9801 and Japan Round x Hisar Unnat were found to be moderately resistant to YVMV while P-20 x 9801 showed no disease incidence and the check Pusa Sawani was highly susceptible to the disease (Table 4.19). The line Pusa Sawani has been reported as susceptible by Solankey et al. (2014), Kumar and Raju (2017) and Sree et al. (2018). The remaining parents and crosses were resistant to the disease. Disease resistance for YVMV has also been reported in okra by many researchers *viz.,* Singh et al. (2012), Tiwari et al. (2012), Kumar and Raju (2017) and Patra et al. (2018).

The cross-combinations, Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat and Parbhani Kranti x 9801 were the best for majority of the traits and were moderately resistant (Parbhani Kranti x 9801) to resistant (Parbhani Kranti x Hisar Unnat and P-8 x Hisar Unnat) to the YVMV disease.

The results of present investigation revealed that sufficient genetic variability has been generated by hybridization for yield and component traits. There were significant differences among the parents and crosses for all the traits studied.

Line x tester analysis for combining ability effects revealed that the parents *viz*., Japan 5 Ridged, P-23, IC-169468, VRO-4 and 9801 were good general combiners for earliness. They may be included in making crosses for exploiting hybrid vigour or development of pure lines.

The cross-combinations, *viz*., Japan 5 Ridged x Hisar Unnat and SKBS-11 x 9801 were the most promising for earliness. Best cross-combinations for earliness are shown in Plate 4.2.

The hybrid Parbhani Kranti x Hisar Unnat recorded the significant SCA as well as hybrid vigour and mean performance for fruit yield and related traits, hence it

Table 4.19 Incidence of Yellow Vein Mosaic Virus (%) disease in okra at Kangra

S.No.	Parents/F_1 hybrids	At seedling stage	At flowering stage	At fruit setting stage	At fruit maturity	Reaction category
1.	P-20	-	0 (1.0)	1 (1.4)	1 (1.4)	R
2.	VRO-4	-	2 (1.7)	4 (2.2)	5 (2.4)	R
3.	Parbhani Kranti	-	3 (2.0)	6 (2.6)	9 (3.2)	R
4.	P-8	-	0 (1.0)	1 (1.4)	2 (1.7)	R
5.	Tulsi-1	-	0 (1.0)	1 (1.4)	2 (1.7)	R
6.	SKBS-11	-	5 (2.4)	9 (3.2)	11 (3.5)	MR
7.	VRO-6	-	3 (2.0)	5 (2.4)	6 (2.6)	R
8.	IC-169468	-	4 (2.2)	4 (2.2)	5 (2.4)	R
9.	P-23	-	5 (2.4)	6 (2.6)	8 (3.0)	R
10.	Japan Red	-	4 (2.2)	5 (2.4)	7 (2.8)	R
11.	Japan 5 Ridged	-	3 (2.0)	5 (2.4)	6 (2.6)	R
12.	Japan Round	-	4 (2.2)	6 (2.6)	9 (3.2)	R
13.	9801	-	3 (2.0)	4 (2.2)	5.5 (2.5)	R
14.	Hisar Unnat	-	3 (2.0)	5 (2.4)	8 (3.0)	R
15.	P-20 x 9801	-	0 (1.0)	0 (1.0)	0 (1.0)	No disease
16.	P-20 x Hisar Unnat	-	3 (2.0)	5 (2.4)	7 (2.8)	R
17.	VRO-4 x 9801	-	2 (1.7)	3.5 (2.1)	5 (2.4)	R
18.	VRO-4 x Hisar Unnat	-	7 (2.8)	9.5 (3.2)	11.5 (3.5)	MR
19.	Parbhani Kranti x 9801	-	8 (3.0)	10 (3.3)	11.5 (3.5)	MR
20.	Parbhani Kranti x Hisar Unnat	-	7 (2.8)	8.5 (3.1)	9.5 (3.2)	R
21.	P-8 x 9801	-	5 (2.4)	7 (2.8)	8.5 (3.1)	R
22.	P-8 x Hisar Unnat	-	8.5 (3.1)	9.5 (3.2)	10 (3.3)	R
23.	Tulsi-1 x 9801	-	2 (1.7)	3 (2.0)	5 (2.4)	R
24.	Tulsi-1 x Hisar Unnat	-	5 (2.4)	6.5 (2.7)	8 (3.0)	MR
25.	SKBS-11 x 9801	-	9 (3.2)	11.5 (3.5)	14 (3.9)	MR
26.	SKBS-11 x Hisar Unnat	-	4 (2.2)	6.5 (2.7)	9.5 (3.2)	R
27.	VRO-6 x 9801	-	6 (2.6)	8.5 (3.1)	10 (3.3)	R
28.	VRO-6 x Hisar Unnat	-	6 (2.6)	9.5 (3.2)	11 (3.5)	MR
29.	IC-169468 x 9801	-	4.5 (2.3)	6 (2.6)	7 (2.8)	R
30.	IC-169468 x Hisar Unnat	-	5 (2.4)	7 (2.8)	8.5 (3.1)	R
31.	P-23 x 9801	-	6.5 (2.7)	8 (3.0)	9.5 (3.2)	R
32.	P-23 x Hisar Unnat	-	6 (2.6)	8.5 (3.1)	11.5 (3.5)	MR
33.	Japan Red x 9801	-	3 (2.0)	4.5 (2.3)	7 (2.8)	R
34.	Japan Red x Hisar Unnat	-	7 (2.8)	9 (3.2)	12 (3.6)	MR
35.	Japan 5 Ridged x 9801	-	2 (1.7)	5.5 (2.5)	7 (2.8)	R
36.	Japan 5 Ridged x Hisar Unnat	-	5.5 (2.5)	7 (2.8)	9.5 (3.2)	R
37.	Japan Round x 9801	-	7 (2.8)	10 (3.3)	12.5 (3.7)	MR
38.	Japan Round x Hisar Unnat	-	6.5 (2.7)	8.5 (3.1)	12.5 (3.7)	MR
39.	Palam Komal	-	4 (2.2)	5.5 (2.5)	7 (2.8)	R
40.	Pusa Sawani	-	32 (5.7)	41 (6.5)	54 (7.4)	HS
	CD (5%)	-	0.40	0.33	0.33	

The figures in parentheses are square root transformation

R = Resistant, MR = Moderately Resistant, HS = Highly Susceptible

Plate 4.2: Best cross-combinations for earliness

Plate 4.3: Best cross-combinations for fruit yield

is the best cross-combination followed by P-8 x Hisar Unnat and VRO-4 x Hisar Unnat. Best cross-combinations for fruit yield per plant and related traits are shown in Plate 4.3. Crosses showing high *per se* performance, high heterosis and high SCA effects are presented in Table 4.20 and Appendix-III.

The estimates of additive and dominant components of variance indicated that for the traits *viz.,* first fruit producing node, average fruit weight, harvest duration, fruit yield per plant, ridges per fruit and mucilage, non-additive gene action was in preponderance or in appreciable magnitude, therefore, heterosis breeding could be a better option compared to other breeding approaches. For the traits *viz.,* days to 50 per cent flowering, days to first picking, internodal length and plant height, additive gene action was in preponderance, hence selection could prove effective method for their improvement.

Table 4.20 Crosses showing high *per se* performance, heterosis and high SCA effects in okra

<table>
<tr><th rowspan="2">Cross-combinations</th><th rowspan="2">Per se performance (fruit yield per plant)</th><th colspan="2">Common traits for heterosis and SCA</th></tr>
<tr><th>For economic heterosis</th><th>For SCA</th></tr>
<tr><td rowspan="2">Parbhani Kranti x Hisar Unnat</td><td rowspan="2">326.66g</td><td colspan="2">Fruit yield per plant</td></tr>
<tr><td>Nodes per plant and fruits per plant</td><td>Nil</td></tr>
<tr><td rowspan="2">P-8 x Hisar Unnat</td><td rowspan="2">318.40g</td><td colspan="2">Fruit yield per plant</td></tr>
<tr><td>Nodes per plant and mucilage</td><td>Days to first picking</td></tr>
<tr><td rowspan="3">VRO-4 x Hisar Unnat</td><td rowspan="3">310.00g</td><td colspan="2">Fruit yield per plant and mucilage</td></tr>
<tr><td>Nodes per plant and fruits per plant</td><td>Nil</td></tr>
<tr><td>Ridges per fruit</td><td>Days to 50 per cent flowering</td></tr>
</table>

Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat and VRO-4 x Hisar Unnat were the most promising cross-combinations for fruit yield per plant and other traits important from consumer’s view point. On the basis of morphological descriptors also, these hybrids had immature green fruit colour, downy pubescence and five ridges per fruit preferred for Indian markets, beside higher yield. However, these hybrids were resistant to moderately resistant to the Yellow Vein Mosaic Virus (YVMV) disease. These three cross-combinations are superior over standard check Palam Komal with respect to fruit yield per plant and are promising cross-combinations from consumer's view point.

The estimates of additive (σ^2A) and dominant components (σ^2D) of variance and per cent contribution of lines, testers and line x tester interaction indicated that for fruit yield per plant, non-additive gene action was in preponderance or in appreciable magnitude lending credence to the already well established practice of exploitation of hybrid vigour in okra.

5. SUMMARY AND CONCLUSIONS

The present investigation entitled "Gene action studies for fruit yield and horticultural traits in okra (*Abelmoschus esculentus* (L.) Moench)" was carried out to gather information on genetic architecture, combining ability and heterosis. The experimental material comprised of 36 triple test cross progenies derived by mating 12 lines with three testers namely 9801 (L_1), Hisar Unnat (L_2) and their single cross F_1 (L_3). This material was raised in Randomized Complete Block Design with three replications during May to September, 2018 at Experimental Farm of Department of Vegetable Science and Floriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The observations were recorded on ten plants marked at random in each entry over the replications on different quantitative traits [days to 50 per cent flowering, days to first picking, first fruit producing node, nodes per plant, internodal length (cm), fruit length (cm), fruit diameter (cm), average fruit weight (g), plant height (cm), harvest duration (days), fruits per plant and fruit yield per plant (g)], quality traits [immature fruit colour, fruit pubescence, ridges per fruit, dry matter (%) and mucilage (%)] and screening for yellow vein mosaic disease. The data were subjected to the biometrical analysis by following triple test cross method of Kearsey and Jinks (1968) to detect epistasis and estimates of additive and dominance components of genetic variance. The data were also subjected to line x tester analysis (Kempthorne 1957) to estimate the general and specific combining ability effects alongwith heterosis by excluding the triple test cross progenies and F_1 tester (L_3) thus, comprising of 24 cross-combinations derived from two testers and 12 lines.

Analysis of variance in RBD and triple test cross hybrids were significant for all the traits except fruit diameter and average fruit weight which highlighted the presence of sufficient genetic variability in the existing genetic material. Triple test cross analysis revealed significant epistasis for the traits *viz.*, days to 50 per cent flowering, plant height, harvest duration, fruit yield per plant and mucilage. Further partitioning of epistasis revealed the importance of 'j+l' type (additive x dominance and dominance x dominance) of epistasis for the traits *viz.*, days to 50 per cent flowering, days to first picking, plant height, harvest duration, fruit yield per plant and mucilage. However, the relative magnitude of 'i' type (additive x additive) was higher than 'j+l' type for nodes per plant, internodal length, fruit length, fruit diameter, average fruit weight, harvest duration, fruits per plant, ridges per fruit and mucilage. The significance of mean squares due to sums (additive) and differences (dominance) for the traits *viz.*, days to 50 per cent flowering, first fruit producing node, plant height, harvest duration, fruit yield per plant, ridges per fruit and mucilage indicated the importance of both additive and dominance components of genetic variation in their inheritance. Therefore hybridization breeding and selection in segregating generations are recommended for their improvement. However, the relative magnitude of additive component (D) was predominant over dominance component (H) for most of the traits except mucilage indicating the relative importance of fixable type of gene action in their inheritance. However, these estimates may be biased to an unknown extent due to the presence of epistasis for days to 50 per cent flowering, plant height, harvest duration, fruit yield per plant and mucilage. The average degree of dominance was in the range of partial dominance for most of the traits except mucilage where complete degree of dominance was observed.

The gene action studies based on triple test cross revealed that epistasis should not be overlooked as it may otherwise lead to biased estimates of additive and dominance components. The triple test cross analysis indicated the importance of additive, dominant and epistatic gene action in the inheritance of different traits which can be exploited by following alternative intermating in the early segregating generations, biparental mating or diallel selective mating to isolate transgressive segregants or recurrent selection followed by pedigree method of selection.

The line x tester analysis revealed significant differences for lines, testers and line x tester for majority of the traits studied. The additive variances (σ^2A) were higher for days to 50 per cent flowering, days to first picking, nodes per plant, internodal length, fruit length, fruit diameter, average fruit weight, plant height, fruits per plant and dry matter indicating the importance of additive gene action and hence selection could be effective method for their improvement whereas, dominance variances (σ^2D) were of higher magnitude for first fruit producing node, fruit yield per plant, ridges per fruit and mucilage, reflecting the role of non-additive gene action and thus hybrid vigour could be better exploited for these traits.

The estimates of GCA effects revealed the line IC-169468 as good general combiner for six traits out of fifteen traits studied followed by Parbhani Kranti, P-8, VRO-6 and Japan Round for five, VRO-4, Tulsi-1 and P-23 for four and SKBS-11 for three traits. Japan 5 Ridged, P-23 and IC-169468 were good general combiners for earliness. For fruit yield per plant, Parbhani Kranti, P-8, IC-169468, SKBS-11 and VRO-4 were the top ranking general combiners. VRO-4, Parbhani Kranti and IC-169468 were also found to be good general combiners for earliness and fruit yield per plant. For quality traits, Japan Red, Japan Round and VRO-6 were top ranking good general combiners for ridges per fruit, dry matter and mucilage, respectively.

On the basis of SCA effects, it was observed that none of the crosses could reveal significant specific combining ability effects for all the traits. For fruit yield per plant, VRO-4 x Hisar Unnat (good x good), Tulsi-1 x 9801 (good x poor), SKBS-11 x 9801 (good x poor), Japan Red x Hisar Unnat (poor x good) and IC-169468 x 9801 (good x poor) were the best five specific combiners involving both good or one good and other poor general combiner. Since, fixable as well as non-fixable components of genetic variation were present in the material under study. Therefore, breeding plans like biparental mating as well as selective intermating in early segregating generations which account for exploiting both types of gene effects simultaneously would prove more effective for enhancing the fruit yield. Cross-combination SKBS-11 x 9801 was also found to have good SCA effect for days to 50 per cent flowering while Japan Red x Hisar Unnat for first fruit producing node and mucilage.

Heterosis was observed for most of the characters including fruit yield, fruits per plant, nodes per plant, shorter internodal length and plant height. On the basis of mean performance and the magnitude of positive heterosis, the hybrid Parbhani Kranti x Hisar Unnat (326.66 g/plant) produced the highest fruit yield followed by P-8 x Hisar Unnat (318.40 g/plant), Parbhani Kranti x 9801 (310.11 g/plant) and VRO-4 x Hisar Unnat (310.00 g/plant). The cross-combination P-23 x 9801 showed maximum desirable heterosis for days to 50 per cent flowering. Overall, the cross-combinations Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat and VRO-4 x Hisar Unnat exhibited high SCA, heterosis and *per se* performance for fruit yield per plant and therefore, rated as potential crosses for further evaluation. These cross-combinations were resistant/moderately resistant to the YVMV disease along with downy pubescence, five ridges and green fruits offering high scope for the exploitation as hybrids. Due to ease in manual emasculation and pollination and resistance to YVMV disease in the hybrids, it shall be a desirable proposition to exploit the parental lines of okra used in the present study for development of hybrids.

Conclusions

- Epistasis was found to be an integral part of genetic variation for majority of the traits and should not be ignored otherwise, may lead to wrong conclusions of additive and dominance variance.
- Epistasis has been found to be invariably present for days to 50 per cent flowering, plant height, harvest duration, fruit yield per plant and mucilage. Both i type and (j+l) type of interactions were significant for harvest duration, fruit yield per plant and mucilage which implied that epistatic component could not be overlooked as this would lead to biased estimates (over- and under- estimates) of the additive and dominance components of variation.
- Additive component (D) was more pronounced than dominance component (H) for most of the traits except mucilage. However, these estimates may be biased to an unknown extent due to the presence of epistasis.
- Degree of dominance was in the range of partial dominance for most of the traits while mucilage showed complete dominance.
- Genetic variance revealed from triple test cross progenies can be exploited by intermating selected individuals in early segregating generations with delayed selection in later generations, diallel selective mating/ biparental mating or recurrent selection followed by pedigree method to exploit both additive and non-additive components alongwith epistasis.
- Line x tester analysis revealed the preponderance of non-additive gene effects for first fruit producing node, fruit yield per plant, ridges per fruit and mucilage while additive gene effects for the remaining traits with degree of

dominance in the range of partial dominance except harvest duration exhibiting complete dominance.

- Line IC-169468 was found to be good general combiner for six of the traits.
- On the basis of SCA effects, the top ranking cross-combinations for fruit yield namely, VRO-4 x Hisar Unnat (good x good), Tulsi-1 x 9801 (good x poor), SKBS-11 x 9801 (good x poor), Japan Red x Hisar Unnat (poor x good), IC-169468 x 9801 (good x poor), P-8 x Hisar Unnat (good x good), Parbhani Kranti x Hisar Unnat (good x good), Japan 5 Ridged x 9801 (poor x poor) and P-20 x 9801 (poor x poor) were the best specific combiners involving both good or one good and other poor general combiner. Since, fixable as well as non-fixable components of genetic variation were present in the material under study. Therefore, breeding plans like biparental mating as well as selective intermating in early segregating generations which account for exploiting both types of gene effects simultaneously would prove more effective for increasing fruit yield.
- Considerable heterosis was observed for most of the traits studied over better parent and the standard check Palam Komal.
- Parbhani Kranti x Hisar Unnat, P-8 x Hisar Unnat and Parbhani Kranti x 9801 were the most promising cross-combinations for fruit yield and related traits. Fruits of these cross-combinations were green coloured with downy pubescence and five ridged which are desirable traits for fresh market. Parbhani Kranti x 9801 was moderately resistant to YVMV disease while Parbhani Kranti x Hisar Unnat and P-8 x Hisar Unnat were resistant. Due to ease in manual emasculation and pollination and resistance to YVMV disease in the hybrids, it shall be a desirable proposition to exploit the parental lines of okra used in the present study for development of hybrids.

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APPENDICES

APPENDIX-I

Mean weekly meteorological data (May to September, 2018) at Palampur

Standard week	Periods	Temperature (°C)		Rainfall (mm)	Relative Humidity (%)	Evaporation (mm)
		Max.	Min.			
21	21-27 May	32.80	19.40	0.00	9.70	10.10
22	28-03 June	32.60	19.10	12.00	15.55	10.30
23	04-10	30.60	20.60	18.00	19.30	7.10
24	11-17	30.30	20.00	33.20	26.60	6.90
25	18-24	29.50	19.10	31.20	25.15	8.30
26	25-01 July	28.30	19.90	139.20	79.55	7.60
27	02-08	26.20	19.00	161.50	90.25	5.80
28	09-15	28.10	20.30	297.20	158.75	6.90
29	16-22	28.20	20.10	174.00	97.05	6.20
30	23-29	26.30	19.70	264.20	141.95	6.20
31	30-05 Aug	27.30	19.70	96.60	58.15	4.00
32	06-12	24.40	19.90	154.80	87.35	3.80
33	13-19	26.60	19.80	278.80	149.30	3.20
34	20-26	26.00	19.60	310.80	165.20	1.80
35	27-02 Sep	26.90	19.80	176.60	98.20	2.90
36	03-09	26.60	19.50	78.40	48.95	2.50

APPENDIX-II

Mean performance of parents and their hybrids for different traits in okra

Traits	Days to 50 per cent flowering	Days to first picking	First fruit producing node	Nodes per plant	Internodal length (cm)	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Plant height (cm)	Harvest duration	Fruits per plant	Fruit yield per plant (g)	Ridges per fruit	Dry matter %	Mucilage %
Lines															
P-20	50.00	53.00	2.40	16.40	8.83	12.86	1.30	13.27	144.40	56.00	13.80	180.60	5.07	6.65	0.95
VRO-4	48.11	52.00	1.60	16.00	8.82	14.36	1.75	12.80	140.00	57.25	14.00	175.65	5.03	6.88	0.80
Parbhani Kranti	50.33	55.00	2.40	14.00	13.12	14.88	1.89	15.57	182.20	54.56	11.85	180.90	5.00	5.82	0.96
P-8	52.00	54.67	2.50	15.10	11.90	12.75	1.71	13.68	176.00	53.00	12.40	161.00	5.00	6.04	1.08
Tulsi-1	56.33	58.00	2.00	13.60	10.77	12.20	1.68	13.62	145.20	56.73	11.20	150.19	5.00	7.53	1.12
SKBS-11	53.00	55.00	2.20	18.00	13.84	14.72	1.74	10.72	244.60	54.15	15.30	159.40	5.00	6.68	0.60
VRO-6	50.22	55.00	2.00	18.20	8.97	13.06	1.58	11.44	159.60	57.55	15.80	174.40	5.00	7.86	0.76
IC-169468	44.33	49.00	2.20	21.40	7.19	13.54	1.78	13.44	153.80	56.00	18.95	252.80	5.00	7.73	1.36
P-23	46.11	52.00	2.40	21.00	9.76	12.00	1.65	11.02	202.20	55.00	18.20	194.40	5.00	6.56	0.40
Japan Red	70.00	69.00	5.80	19.60	10.26	14.02	1.11	11.84	199.60	50.11	12.50	144.40	7.60	7.80	1.12
Japan 5 Ridged	48.16	56.00	1.60	15.20	7.52	11.96	1.95	16.25	113.60	50.73	13.20	211.40	5.00	8.47	0.82
Japan Round	60.11	59.00	2.60	19.80	7.10	12.82	1.82	11.58	139.80	54.00	15.70	180.85	0.00	8.84	0.72
Testers															
9801	44.33	52.00	1.80	25.60	6.03	13.78	1.63	14.11	154.40	58.10	22.97	326.40	5.17	6.54	1.00
9801 x Hisar Unnat	45.66	50.33	3.00	29.40	9.49	13.82	1.94	14.64	279.00	59.55	25.03	366.42	5.07	5.77	1.36
Hisar Unnat	50.00	52.67	2.80	27.00	11.07	12.20	2.10	14.24	299.00	57.92	22.42	318.80	5.50	5.28	1.15

Traits	Days to 50 per cent flowering	Days to first picking	First fruit producing node	Nodes per plant	Internodal length (cm)	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Plant height (cm)	Harvest duration	Fruits per plant	Fruit yield per plant (g)	Ridges per fruit	Dry matter %	Mucilage %
Hybrids															
P-20 x 9801	47.67	50.00	2.90	20.20	7.99	12.40	1.59	13.80	161.20	51.33	16.34	225.21	5.17	6.11	0.98
P-20 x (9801 x Hisar Unnat)	48.00	52.00	3.00	18.33	10.32	13.12	1.77	15.34	187.66	52.55	15.25	228.66	5.50	6.62	1.32
P-20 x Hisar Unnat	50.11	55.00	3.00	22.40	9.06	13.10	1.84	12.29	200.16	53.00	18.39	220.40	5.80	6.07	1.01
VRO-4 x 9801	46.33	51.00	1.80	19.00	8.48	14.20	1.71	12.60	159.42	52.73	16.20	200.25	5.47	6.75	0.94
VRO-4 x (9801 x Hisar Unnat)	49.66	53.00	2.00	19.75	8.84	14.25	1.85	14.56	173.75	49.56	14.48	210.00	5.20	6.25	1.60
VRO-4 x Hisar Unnat	47.67	51.00	1.60	22.40	11.38	13.10	1.82	16.13	241.60	56.11	19.80	310.00	5.17	6.10	1.28
Parbhani Kranti x 9801	47.00	50.00	1.80	20.11	9.96	14.82	1.88	18.30	197.10	54.00	17.23	**310.11**[3]	5.67	6.25	0.98
Parbhani Kranti x (9801 x Hisar Unnat)	47.33	51.00	1.80	23.80	9.94	13.97	1.91	15.49	232.80	56.51	20.59	314.00	5.20	5.72	1.96
Parbhani Kranti x Hisar Unnat	50.16	52.00	1.66	24.70	10.18	13.52	1.98	15.39	251.00	56.85	21.34	**326.66**[1]	5.10	5.41	0.56
P-8 x 9801	49.67	54.00	2.00	19.75	8.45	13.24	1.68	17.12	166.51	57.22	17.61	301.00	5.37	6.21	1.44
P-8 x (9801 x Hisar Unnat)	45.33	50.00	1.40	17.60	10.69	13.28	1.84	14.94	185.60	58.00	15.39	226.40	5.32	5.90	1.52
P-8 x Hisar Unnat	49.00	52.00	2.80	22.40	9.55	13.01	1.96	17.05	210.40	56.75	19.21	**318.40**[2]	5.10	5.71	1.04
Tulsi-1 x 9801	50.11	53.00	2.20	20.10	7.98	12.99	1.70	16.17	158.10	55.77	17.83	280.12	5.22	6.83	1.09
Tulsi-1 x (9801 x Hisar Unnat)	51.33	54.00	2.40	18.40	10.27	12.82	1.90	12.83	182.70	57.81	15.75	188.80	5.14	6.70	1.17
Tulsi-1 x Hisar Unnat	50.00	55.00	1.90	23.50	9.07	12.45	2.01	11.24	209.95	56.33	19.81	220.10	5.07	6.59	1.14
SKBS-11 x 9801	45.00	51.00	1.60	18.60	12.91	14.07	1.70	17.13	237.00	56.15	16.51	276.60	5.52	6.65	0.72
SKBS-11 x (9801 x Hisar Unnat)	48.88	53.00	2.40	20.80	13.42	14.44	1.83	16.21	276.60	57.42	18.10	288.60	5.20	6.21	2.08
SKBS-11 x Hisar Unnat	50.47	55.00	2.00	19.20	13.83	13.17	1.92	14.04	262.40	55.86	17.18	235.40	5.23	6.52	1.76

Traits	Days to 50 per cent flowering	Days to first picking	First fruit producing node	Nodes per plant	Internodal length (cm)	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Plant height (cm)	Harvest duration	Fruits per plant	Fruit yield per plant (g)	Ridges per fruit	Dry matter %	Mucilage %
VRO-6 x 9801	46.66	50.00	2.00	22.00	8.05	13.66	1.61	12.68	175.50	50.00	19.26	240.42	5.17	7.11	1.56
VRO-6 x (9801 x Hisar Unnat)	45.22	51.00	1.80	19.60	9.79	13.90	1.79	16.67	188.10	57.33	17.40	281.21	5.27	6.95	0.89
VRO-6 x Hisar Unnat	49.33	52.00	2.20	24.64	8.22	13.05	1.92	12.34	201.15	56.50	20.48	250.22	5.38	7.12	1.42
IC-169468 x 9801	45.33	51.00	1.25	21.40	7.54	13.74	1.76	14.23	160.10	57.05	20.00	280.12	5.25	7.18	1.20
IC-169468 x (9801 x Hisar Unnat)	46.44	50.00	1.33	22.05	7.98	13.65	1.81	14.97	175.00	56.88	20.10	296.75	5.25	7.15	2.04
IC-169468 x Hisar Unnat	47.51	51.00	1.45	19.00	11.96	12.97	1.85	15.42	220.00	57.95	17.50	254.95	5.20	7.01	1.32
P-23 x 9801	44.54	50.00	2.00	15.80	8.75	13.34	1.56	14.31	138.00	57.00	13.00	185.40	5.07	6.44	0.68
P-23 x (9801 x Hisar Unnat)	48.11	53.00	2.00	15.20	11.14	13.77	1.79	15.78	161.00	55.51	12.90	197.00	5.40	6.10	1.44
P-23 x Hisar Unnat	48.00	51.00	2.40	19.80	9.82	12.21	1.83	10.95	193.79	56.15	17.20	186.80	5.25	5.98	1.60
Japan Red x 9801	54.11	56.00	3.00	16.00	11.83	13.96	1.71	13.69	185.80	53.55	12.20	162.20	7.00	7.10	0.40
Japan Red x (9801 x Hisar Unnat)	50.00	54.00	2.60	15.40	11.63	14.00	1.96	14.08	186.00	56.00	12.40	169.40	6.48	7.15	0.72
Japan Red x Hisar Unnat	56.33	59.00	1.60	17.80	13.25	13.08	2.02	13.25	232.00	55.00	15.60	201.00	6.33	7.30	0.96
Japan 5 Ridged x 9801	47.33	53.00	2.20	21.15	6.89	12.60	1.77	12.00	145.10	56.20	18.21	215.12	5.20	7.76	0.95
Japan 5 Ridged x (9801 x Hisar Unnat)	47.11	51.00	2.60	19.18	9.02	12.85	1.90	15.24	165.80	57.51	16.00	222.60	5.00	7.91	1.40
Japan 5 Ridged x Hisar Unnat	44.66	52.00	1.75	19.75	12.21	12.41	2.04	12.03	237.75	55.95	17.75	209.00	5.53	7.65	0.44
Japan Round x 9801	46.67	51.00	3.20	19.60	6.65	13.26	1.78	13.13	130.00	57.72	16.00	208.20	5.40	8.10	1.56
Japan Round x (9801 x Hisar Unnat)	46.00	52.00	5.50	20.51	9.64	13.09	1.86	17.51	197.00	58.33	15.00	259.00	5.03	8.41	1.16
Japan Round x Hisar Unnat	50.13	54.00	5.80	23.54	9.13	12.97	1.96	13.10	215.10	56.01	16.20	210.12	5.40	7.98	0.91
C.D. 5%	2.20	2.71	0.84	4.83	2.13	1.10	0.60	4.05	11.57	2.60	4.88	6.45	0.31	1.03	0.06
C.V. %	2.76	3.15	19.52	15.01	13.37	5.11	19.06	17.72	3.74	2.88	17.90	1.71	3.69	9.33	3.40

APPENDIX-III

List of top ranking hybrid combinations based on *per se* performance, specific combining ability, heterobeltiosis and standard heterosis for horticultural traits in okra

Trait	*per se* performance	sca effects	Heterobeltiosis	Standard heterosis
Days to 50 per cent flowering	i. P-23 x 9801 ii. Japan 5 Ridged x HU iii. SKBS-11 x 9801 iv. IC-169468 x 9801 v. VRO-4 x 9801	i. Japan 5 Ridged x HU ii. SKBS-11 x 9801	i. Japan 5 Ridged x HU	i. P-23 x 9801 ii. Japan 5 Ridged x HU
Days to first picking	i. P-20 x 9801, Parbhani Kranti x 9801, VRO-6 x 9801, P-23 x 9801 ii. VRO-4 x 9801, VRO-4 x HU, SKBS-11 x 9801, IC169468 x 9801, IC-169468 x HU, P-23 x HU, Japan Round x 9801 iii. Parbhani Kranti x HU, P-8 x HU, VRO-6 x HU, Japan 5 Ridged x HU iv. Tulsi-1 x 9801, Japan 5 Ridged x 9801 v. P-8 x 9801, Japan Round x HU	i. P-8 x HU ii. P-20 x 9801	-	-
First fruit producing node	i. IC-169468 x 9801 ii. IC-169468 x HU iii. VRO-4 x HU, SKBS-11 x 9801, Japan Red x HU iv. Parbhani Kranti x HU v. Japan 5 Ridged x HU	i. Japan Round x 9801 ii. Japan Red x HU	i. Japan Red x HU	-
Nodes per plant	i. Parbhani Kranti x HU i. VRO-6 x HU i. Japan Round x HU v. Tulsi-1 x HU v. P-20 x HU, VRO-4 x HU and P-8 x HU	-	-	i. Parbhani Kranti x HU ii. VRO-6 x HU iii. Japan Round x HU iv. Tulsi-1 x HU v. P-20 x HU, VRO-4 x HU and P-8 x HU
Internodal length	i. Japan Round x 9801 ii. Japan 5 Ridged x 9801 iii. IC-169468 x 9801 iv. Tulsi-1 x 9801 v. P-20 x 9801	i. Japan 5 Ridged x 9801	-	i. Japan Round x 9801 ii. Japan 5 Ridged x 9801 iii. IC-169468 x 9801 iv. Tulsi-1 x 9801 v. P-20 x 9801

Trait	*per se* performance	sca effects	Heterobeltiosis	Standard heterosis
Fruit length	i. Parbhani Kranti x 9801 ii. VRO-4 x 9801 iii. SKBS-11 x 9801 iv. Japan Red x 9801 v. IC-169468 x 9801	-	-	-
Fruit diameter	i. P-23 x 9801 ii. P-20 x 9801 iii. VRO-6 x 9801 iv. P-8 x 9801 v. Tulsi-1 x 9801, SKBS-11 x 9801	-	-	-
Average fruit weight	i. Parbhani Kranti x 9801 ii. SKBS-11 x 9801 iii. P-8 x 9801 iv. P-8 x HU v. Tulsi-1 x 9801	-	-	-
Plant height	i. Japan Round x 9801 ii. P-23 x 9801 iii. Japan 5 Ridged x 9801 iv. Tulsi-1 x 9801 v. VRO-4 x 9801	i. Japan 5 Ridged x 9801 ii. Japan Round x 9801 iii. SKBS-11 x HU iv. VRO-6 x HU v. VRO-4 x 9801	i. P-23 x 9801	i. Japan Round x 9801 ii. P-23 x 9801 iii. Japan 5 Ridged x 9801
Harvest duration	i. IC-169468 x HU ii. Japan Round x 9801 iii. P-8 x 9801 iv. IC-169468 x 9801 v. P-23 x 9801	i. VRO-6 x HU	-	-

Trait	*per se* performance	sca effects	Heterobeltiosis	Standard heterosis
Fruits per plant	i. Parbhani Kranti x HU ii. VRO-6 x HU iii. IC-169468 x 9801 iv. Tulsi-1 x HU v. VRO-4 x HU	-	-	i. Parbhani Kranti x HU ii. VRO-6 x HU iii. IC-169468 x 9801 iv. Tulsi-1 x HU v. VRO-4 x HU
Fruit yield per plant	i. Parbhani Kranti x HU ii. P-8 x HU iii. Parbhani Kranti x 9801 iv. VRO-4 x HU v. P-8 x 9801	i. VRO-4 x HU ii. Tulsi-1 x 9801 iii. SKBS-11 x 9801 iv. Japan Red x HU v. IC-169468 x 9801	i. Parbhani Kranti x HU	i. Parbhani Kranti x HU ii. P-8 x HU iii. Parbhani Kranti x 9801 iv. VRO-4 x HU v. P-8 x 9801
Ridges per fruit	i. Japan Red x 9801 ii. Japan Red x HU iii. P-20 x HU iv. Parbhani Kranti x 9801 v. Japan 5 Ridged x HU	i. P-20 x HU ii. Japan Red x 9801 iii. Parbhani Kranti x 9801	i. Parbhani Kranti x 9801 ii. SKBS-11 x 9801	i. Japan Red x 9801 ii. Japan Red x HU
Dry matter	i. Japan Round x 9801 ii. Japan Round x HU iii. Japan 5 Ridged x 9801 iv. Japan 5 Ridged x HU v. Japan Red x HU	-	-	i. Japan Round x 9801 ii. Japan Round x HU iii. Japan 5 Ridged x 9801 iv. Japan 5 Ridged x HU v. Japan Red x HU
Mucilage	i. SKBS-11 x HU ii. P-23 x HU iii. VRO-6 x 9801, Japan Round x 9801 iv. P-8 x 9801 v. VRO-6 x HU	i. SKBS-11 x HU ii. P-23 x HU iii. Japan Round x 9801 iv. Japan 5 Ridged x 9801 v. Parbhani Kranti x 9801	i. VRO-6 x 9801 , Japan Round x 9801 ii. SKBS-11 x HU iii. P-23 x HU iv. P-8 x 9801 v. VRO-6 x HU	i. SKBS-11 x HU ii. P-23 x HU iii. VRO-6 x 9801, Japan Round x 9801 iv. P-8 x 9801 v. VRO-6 x HU

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