

**Heterosis and combining ability as a function of parental
divergence in okra [*Abelmoschus esculentus* (L.) Moench]**

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*Affectionately
dedicated to my
beloved parents*

**DEPARTMENT OF GENETICS AND PLANT BREEDING
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BANGALORE**

CERTIFICATE

This is to certify that the thesis entitled **Heterosis and combining ability as function of parental divergence in okra [*Abelmoschus esculentus (L.)* Mench]** submitted by **Mr. PRASANNA KUMAR, T.** in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE (AGRICULTURE) IN GENETICS AND PLANT BREEDING** to the University of Agricultural Sciences, Bangalore, is a record of bonafide research work carried out by him during the period of his study in this university under my guidance and supervision and that no part of the thesis has been submitted for the award of any other degree, diploma, associateship, fellowship or other similar titles.

Bangalore
July 2008

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ABSTRACT

An investigation was carried out involving ten okra (*Abelmoschus esculentus* (L.) Moench) lines selected based on mean and standard deviation of D^2 values. The lines belonging to high and low divergent clusters were involved in a 10×10 half diallel mating to synthesize 45 single cross hybrids to assess the status of parents and their crosses based on their gca and sca effects and to investigate the direction and magnitude of heterosis for fruit yield and its attributes. Further, the parents and hybrids were screened to identify the resistance against fruit borer. Observations were recorded on 11 yield and its attributing characters. The parent Punjab Padmini expressed highest mean values for important yield attributing characters. Among the crosses, Larma-1 \times Punjab Padmini, manifested highest mean values for primary branches, fruit weight and fruit yield per plant. It was interesting to note that, Punjab Padmini to nickwell with the other parents. The cross, Punjab Padmini \times HRB-9-2 was the best specific combination for fruit yield per plant. The hybrid, Larma-1 \times Punjab Padmini expressed significant standard heterosis for fruit yield per plant and the same cross was resistant to fruit borer infestation. The number of hybrids with high over all sca status was higher in H \times L category of crosses. It is worth while to start with H \times L type of crosses followed by L \times L for realizing hybrids with high heterosis and SCA effects. The parents which had moderate genetic divergence between them produced higher frequency of heterotic crosses than the parents which had extreme genetic divergence, indicating the existence of limits to parental divergence for optimum expression of heterosis.

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CONTENTS

CHAPTER	TITLE	PAGE NO.
I	INTRODUCTION	
II	REVIEW OF LITERATURE	
III	MATERIAL AND METHODS	
IV	EXPERIMENTAL RESULTS	
V	DISCUSSION	
VI	SUMMARY	
VII	REFERENCES	

List of Tables

Sl. No	Title of the Table	Page No.
1	List of okra varieties used for crossing programme in half diallel mating design	
2	Analysis of variance for fruit yield and its components in okra	
3	Mean performance of parents for fruit yield and its components in okra	
4	Mean performance of crosses for fruit yield and its components in okra	
5	Estimates of components of genetic variation for fruit yield and its components in okra	
6	Analysis of variance for combining ability for fruit yield and its components in okra	
7	Estimate of gca effects of parents for fruit yield and its components in okra	
8	Overall general combining ability status of parents in okra	
9	Estimates of sca effects of crosses for fruit yield and its components in okra	
10	Overall specific combining ability status of crosses in okra	
11	Estimate of variance due to gca and sca effects for yield and its components in okra	
12	Estimate of heterosis for yield and its components in okra	
13	Promising hybrids based on overall heterosis in okra	
14	Distribution of heterotic crosses in relation to gca status of parents and sca status of crosses in okra	
15	Mean (m), standard deviation(seeds) and range of divergence values	
16	Grouping of parental divergence into four divergence classes (DC)	
17	Distribution of heterotic crosses in different divergent classes (DC)	
18	Classification of okra genotypes with respect to their reaction to fruit borer damage	
19	Classification of okra hybrids with respect to their reaction to fruit borer damage	

LIST OF PLATES

Sl. No	Plates Title	Page No.
1	Plate-1: General view of experimental plot	
2	Plate-2: Borer resistant and susceptible hybrids	
3	Plate-3: Fruits of high yielding hybrid, larma-1 × Punjab Padmini	

INTRODUCTION

I. Introduction

Okra (*Abelmoschus esculentus* (L.) Moench) an annual, often cross-pollinated crop of the family Malvaceae is an important vegetable crop of the tropics and subtropics and also a warmer crop of the temperate regions. Africa is the centre of origin of okra. Okra also referred as gumbo, lady's finger and bhendi has found its place in India since time immemorial.

The genus *Abelmoschus* that has a diploid chromosome number ($2n = 130$) includes about 30 species in the old world, four in the new world and four in Australia. Joshi *et al.* (1956) reported allopolyploid nature of *A. esculentus*. They further observed that *A. esculentus* arose through hybridization of two unknown species, one species with $n = 29$ and another with $n = 36$ followed by doubling of the chromosome number. The progenitor of *A. esculentus* with $n = 29$ is reported to be *A. tuberculatus*.

In India it is cultivated in 0.34 M ha with a production of 3.34 M mt and productivity of 9.6 mt/ha (Anon, 2005). The major okra producing states are Uttar Pradesh, Orissa, West Bengal, Andhra Pradesh and Karnataka. It is one of the popular vegetable crops in the country. The okra leaves are used in medicine to soothe and reduce the inflammation (Mehta, 1959). The nutritional value of 100 g of edible okra is characterized as having 1.9 g protein, 0.2 g fat, 6.4 g carbohydrates, 0.7 g minerals and 1.2 g fibers. It is also used in paper industry as well as for the extraction of fiber. Okra has a good potential as a foreign exchange crop and accounts for 60 per cent of the export of fresh vegetables.

Apart from fruit yield, the major bottlenecks in okra cultivation are the yellow vein mosaic virus disease and fruit borer. Although okra is subjected to attack by many insect pests, the fruit borer, *Earias spp.*, (Lepidopterae-noctuidae)

is the major pest causing damage to the extent of 3.5-90% (Krishnaiah *et al*, 1976). The fruit borer causes severe damage to the crop leading to a considerable yield loss in okra. The larvae bore into the growing shoot, buds and tender fruits resulting in their shedding and consequently affecting the fruit quality and yield to a large extent. Most of the present day cultivars are susceptible to this pest (Gupta and Yadav, 1978). There are two major species of fruit borer viz, *Earias insulana* and *Earias vitella* of which *E. vitella* is the dominant one and *E. insulana* is not that important.

Yield of okra varies considerably depending on the growing conditions and varieties. The average yield of okra in India (3.34 M mt) is low (Anon, 2005). There is a considerable gap in productivity between farmer's field and research farms. One of the ways to augment the productivity is by exploiting heterosis, which is still not a completely tapped resource for okra improvement in terms of yield. Moreover, it is a quick and convenient way of combining desirable traits from different parents. Heterosis breeding requires availability of suitable parents that are normally desired from large number of crosses. Early elimination of poor crosses helps in efficient utilization of resources and allows handling of reasonably large segregating populations of a few promising crosses. In this regard heterosis may be a key parameter for selection of promising crosses for deriving superior inbred lines for use in development of heterotic hybrids.

Studies (Pumble, 1983) showed that frequency of productive derivatives in F_5 and later generations is higher from heterotic F_1 's than from non-heterotic F_1 's. However, in order to take up the programme of hybrid okra successfully, choice of suitable parents through careful and critical evaluation of current material is of paramount importance. This is because *per se* performance of a parent is not always a true indicator of its potential in hybrid combination. There are several criteria by which a breeder can choose suitable parents for successful

hybridization, of which the two important ones are: 1) Genetic diversity between the parents and 2) Combining ability of the parents. The attraction of combining ability is that, it provides an empirical summary of complex observations which form a reasonable basis for forecasting the performance of yet untested crosses without making any genetical assumptions. Being based on first-degree statistics, they are statistically robust and being genetically neutral, they are equally applicable to inbreeders and outbreeders. In essence, it is essentially an important predictive procedure free of genetical assumptions.

It is being increasingly realized that crosses between divergent parents usually produce greater heterosis than those between closely related ones as was pointed out long time ago by Hayes and Johnson (1939) and East and Hayes (1912). Cress (1966) has established a strong theoretical foundation for the requirement of parental divergence for the occurrence of hybrid heterosis. It is essential therefore to explore the possible limits, if any, to parental divergence within which there are reasonably high chances for the occurrence of heterosis.

Keeping these points in mind, the present study was conducted to accomplish the following objectives.

1. To assess parental divergence based on D^2 statistics.
2. To assess the gca status of parents and sca status of their crosses.
3. To assess the direction and magnitude of F_1 hybrid heterosis for fruit yield and its attributes.
4. To explore the relationship of parental diversity and general combining ability status with hybrid specific combining ability and heterosis.
5. To identify hybrids resistant to fruit borer.

REVIEW OF LITERATURE

II. REVIEWS OF LITERATURE

A review of some important reports pertaining to the present investigation is presented under the following subheadings.

2.1 Parental divergence

2.2 Combining ability

2.3 Heterosis

2.4 Fruit borer infestation.

2.1 Parental Divergence

Mahalanobis (1936) introduced the concept of D^2 statistic for measuring the divergence between the two populations, which gives a result based on the magnitude of divergence and is independent of the size of the samples. Rao (1948) suggested a more flexible method, which would replace the measurements on a large number of characters, all of which contribute in some degree or other towards discrimination by relatively few measurements.

Allard (1961) described the relationship between genetic diversity and consistency of performance in different environments by using the distinct environments. The three distinct levels of genetic diversity and productivity were completely related and further stated that many factors determined the productivity of mixed population, while genetic diversity and stability appeared more simply related irrespective of number of characteristics of the components involved.

Factor, principle component and canonical analysis of data on 25 field, morphological and agronomical characters were used to study the extent of genetic diversity among 30 accessions of West African okra (Ariyo, 1993). The first three

canonical variables accounted for 100 percent of the total variance, while the number of pods per plant and pod weight primarily accounted for the first canonical variable. Second canonical variable had number of seeds per pod and fruit colour. The third canonical variable was comprised of weight of 100 seeds and number of epicalyx segments.

Singh *et al.* (1993) classified thirty okra hybrids using multivariate cluster analysis, of these, ten clusters had distinguished variability within clusters and were positively related to the degree of heterozygosity

Vahab *et al.* (1994) evaluated 18 genotypes of okra for genetic divergence for 16 yield components. Analysis of variance showed significant differences for 13 out of 16 characters studied and the genotypes were grouped into five clusters. Cluster I with seven genotypes was the largest followed by cluster III with six genotypes. Cluster II and IV had two genotypes each, while cluster V had only one genotype. Geographical distribution of cluster was not necessarily related to the diversity. Fruit characters and plant height contributed the most to the total genetic diversity, but the greatest contribution was from average fruit weight.

Dash and Mishra (1997) studied 17 developmental characters in 27 cultivars of okra subjecting them to D^2 statistic. The results indicated the formation of six clusters, with second cluster being the largest consisting of 16 cultivars followed by cluster III and I with four cultivar each. The widest genetic distance was found between cluster IV and VI suggesting extensive diversity between these groups. Four characters *viz.*, plant height; days to first flowering, nodes per plant and seeds per fruit were the highest contributors to D^2 value.

Ghai *et al.* (2005) estimated the genetic diversity among thirty genotypes of okra collected from various ecological regions of India. Mahalanobis D^2 analysis was applied to evaluate the genetic divergence and Tocher's method was used to form the clusters. The genotypes were classified into 13 discrete clusters and the entire collections were allocated to different clusters. From the results, it could be observed that, the clustering pattern revealed that there was no parallelism between genetic and geographic divergence as the types chosen from same eco-geographic region were found scattered in different clusters. There was sustained variation in cluster means for all the characters studied

2.2 Combining ability

A critical survey of relative magnitude of gca and sca effects of parents and their crosses, respectively, will provide valuable guidelines for choice of parents and for planning suitable breeding strategy. Moreover, the close relationship between the *per se* performance could be used as a criterion to select parents involved in breeding programme. Thus, combining ability is useful in the testing and choosing the desirable hybrid combination and in the choice of desirable parent. It is also possible to know the magnitude of additive and dominance variance in the material.

A brief review of combining ability in okra for different characters is given below.

The analysis of variance for combining ability estimated by Rajendra Kumar Yadav *et al.* (1990) indicated highly significant general combining ability and specific combining ability variances for all the characters emphasizing the importance of both additive and non additive gene action. The general combining ability effect with high estimates observed for different attributes of economic

importance was reported to be useful for sorting out outstanding parents with favorable alleles for the different components of yield.

Veeraragavathatham and Irulappan (1991) estimated gca of seven parents and sca of 21 direct and 21 reciprocal crosses through combining ability analysis for yield and other related traits using 7×7 diallel analysis. The GCA variance was found to be significant for most of the traits when compared to SCA variance indicating the preponderance of additive gene action. *Per se* performance of the hybrids *v/s* sca of hybrids revealed that parental array mean is better indexing than parental *per se* for the selection of good general combiners. They stressed that parents with good gca did not always produce hybrids with good sca and hence the estimation of sca of the hybrids based on the gca of the parents was necessary.

Sundari *et al.* (1992) studied ten plants in parents and ten plants in hybrids. They noticed that parents with significant and negative gca produced hybrids with positive significant sca due to complementation of favorable genes. Variations in the hybridity were attributed to the cytoplasmic genes including the mitochondrial genes.

Vasline and Ganesan (1995) used 12 lines, three testers and 36 hybrids to estimate the combining ability and reported the absence of relationship between parental *per se* performance and gca and sca effect. The parent AE 110 and AE158 were found to be good general combiners for fruit yield and other yield attributing characters. The best hybrids for high heterotic expression were Pusa Sawani \times CO2 and Parbani Kranti \times CO2

Shinde *et al.* (1995) gave information on combining ability studies derived from data on seven yield components in eight okra varieties and their 28 F_1 hybrids. Hybrids revealed that Japan \times Parbhani Tillu, Japan \times 168 and Parbhani

Tillu×168 were found to be the most promising hybrids and suggested that they could be exploited for green pod yield per plant.

Singh *et al.* (1996(a)) conducted combining ability analysis in okra from data on nine yield components in eight lines and their F₁ hybrids. Non additive gene action was predominant for all the characters investigated. The best specific combinations were found to be Punjab Padmini×Punjab-7, Punjab-7×P5 for total yield and other yield attributing characters.

Das *et al.* (1996) conducted 10×10 diallel analysis in okra for 11 biometric characters and reported the presence of additive and non-additive gene action for six traits. Dominant gene action with asymmetrical distribution of genes and overdominance was found to be predominant for almost all the characters. They further, suggested that recurrent selection and heterosis breeding could prove effective for okra improvement.

Patil *et al.* (1996) conducted a diallel mating design experiment by using three Indian okra varieties, along with seven exotic lines. The parents and their 45 F₁ progeny were evaluated for weight of good pods (without borer infestation) per plant. PI 489782 registered the highest GCA for pod yield and was also the best general combiner based on pooled score analysis of GCA for nine other qualitative traits.

Ahmed *et al.* (1997) carried out combining ability analysis in okra with 8×8 diallel cross excluding reciprocals, to isolate desirable parents and F₁ cross combinations. The results indicated that, variances due to general combining ability (gca) and specific combining ability (sca) were found to be highly significant for all the characters. However, higher due to sca than gca indicated predominance of non-additive gene actions for all the characters except fruit girth.

Ahmed *et al.* (1999) studied a set of F₁ hybrid developed following diallel mating design with eight divergent parents. The results indicated manifestation of heterosis over better parent in both the directions for all the characters but the degree and direction of heterosis varied greatly for different traits and crosses. The maximum heterosis observed in the hybrids was not expressed by the best performing parents, but, at least one poor or average performing parent was involved in these significantly high heterotic F₁ hybrids.

Combining ability in okra was studied in set of 10×10 diallel cross by Pawar *et al.* (1999). Analysis of variance indicated highly significant differences for all the characters, suggesting the presence of considerable genetic diversity among the materials studied. The magnitude of heterosis reportedly varied from cross to cross for all the characters. Degree of heterosis was found to be higher for number of branches per plant, moderate for first fruiting node; while days to 50% flowering and days to first picking exhibited low heterosis.

Pal and Hossain (2000) worked out combining ability analysis by using 7×7 diallel cross of okra for seed yield and some of its components and some quality traits of seed. The results indicated that both additive and non-additive gene effects were important in the inheritance of most of the traits and might be utilized for further selection of superior progenies in respect of seed yield and seed quality.

Vermani and vidyasagar (1999) analyzed the performance of 28 cross combinations of okra derived from Line×Tester crossing. Crop yield was found to be highest in the crosses Dhira ×P-8, Pusa Makhmali×Arka Anamika and Pusa Makhmali×Arka Anamika as evident by high heterobeltiosis, standard heterosis and specific combining ability for fruit yield.

Nichal *et al.* (2001) estimated combining ability in 21 okra F₁ hybrids and seven parental cultivars. The mean squares due to general (gca) and specific combining ability were found to be highly significant for all the characters except average fruit weight, indicating the importance of additive and non-additive genetic components of variation. However, the mean squares due to gca were greater, suggesting the greater role of additive variance in the inheritance of all the characters.

Singh *et al.* (2001) conducted an experiment by crossing 15 diverse genotypes of okra in a diallel fashion excluding reciprocals. The results on yield characters were subjected to analysis of variance which revealed the predominance of non-additive gene action for most of the characters. No parent was noticed to be a good general combiner for all the traits.

Sood and Kalia (2001) carried out combining ability test for ten characters in eight diverse and widely adapted parental lines of okra in a diallel cross (excluding reciprocals). The variances due to general combining ability (gca) and specific combining ability (sca) indicated that the gene action was additive for all the characters, except fruit yield, fruits per plant and plant height for which non-additive gene action was found to be important.

Dhankhar and Dhankar (2001) conducted a field experiment to estimate the combining ability in okra through a Line×Tester analysis involving 20 lines (female) and 4 testers (male). The combining ability analysis revealed significant variances due to treatments, crosses, lines, testers, and parents *v/s* crosses for fruit yield, number of fruits per plant, days to 50% flowering, number of branches per plant, plant height, and number of effective nodes on stem but not for internodal

length of stem for tester. The dominant components (δD^2) was noticed to be higher than the additive (δA^2), indicated the role of non-additive gene action.

Rajani *et al.* (2001) estimated the combining ability of six genetically divergent parental strains of okra by using diallel-mating design. The combining ability analysis by using the Method I of Griffing's approach revealed that the parent NBPGR/TCR 861 was found to be the best general combiner for single fruit weight and length, and NBPGR/TCR 864 for yellow vein mosaic (YVM) resistance. Among the hybrids, NBPGR/TCR 893×NBPGR/TCR 864 registered outstanding specific combining ability effect for yield. While, the hybrid NBPGR/TCR 854×NBPGR/TCR 865 was found to show maximum tolerance to YVM.

Prakash *et al.* (2002) through the estimation of general and specific combining ability and their ratio indicated the predominance of non-additive gene action for all traits. Pusa Makhmali, Arka Anamika, Punjab Padmini and Dharmapuri local were noticed to be the best general combiners for fruit yield per plant. The crosses, Punjab Padmini×Pusa Makhmali and Dharmapuri local×Parbhani Kranti exhibited favorable SCA effects for the majority of the characters and suggested that they could be exploited in breeding for improved yield.

Liou-MinLi *et al.* (2002) studied combining ability and heterosis by using 6×6 diallel cross of okra. The characters, days to flowering, number of fruits per plant, yield, fruit diameter and fruit weight were found to be controlled by additive and non-additive genes. The reciprocal effects were noticed to be significant for days to flowering, number of fruits per plant, fruit length and fruit weight.

Duzyaman and Vunel (2002) performed an 8×8 half-diallel analysis by using okra genotypes of Indian, West African, USA and Turkish origins. Promising crosses were statistically significant for general or specific combining abilities, particularly in combinations among genotypes of different ecogeographic origin. The possibilities of selecting the parental material for further breeding work and a combination breeding based on additive gene effects have been discussed.

Singh and Singh (2003) estimated the combining ability for yield and its components in 15 okra inbred lines. The general and specific combining abilities were reported to be significant for most of the characters, indicating that both the additive and non-additive gene effects were involved in the inheritance of these traits. The cross 67308×7312 showed significant positive SCA effects on fruit yield per plant.

Jindal and Grai (2005) studied combining ability for yield and related traits of okra from an experiment consisting of 12 parents and 66 F₁ hybrids produced in a diallel mating excluding reciprocals. Analysis of variance for combining ability reportedly exhibited the significance of both GCA and SCA effects for all the characters. It was also concluded that improvement of these traits could be accomplished both through pure line breeding as well as through heterosis breeding.

Kumar and Anandan (2006) conducted a Line×Tester analysis in okra with six lines and three testers to estimate the combining ability and variance effects. The combining ability and variances indicated the preponderance of non-additive gene action for all the characters. The study further emphasized the scope for heterosis breeding in improvement in okra.

Kumar *et al.* (2006) estimated combining ability and heterosis for yield and yield components in okra. The additive and non-additive gene action was reported to be important in the inheritance of all traits. The estimates of general combining ability variances were higher than the corresponding specific combining ability variances. In the presence of additive and non-additive gene actions coupled with reciprocal differences, reciprocal recurrent selection could be used for the genetic improvement of okra.

Combining ability effects were estimated by Singh and Pal (2006) for different characters following Line×Tester crossing programme comprising of 60 crosses of okra produced by crossing of 15 lines and four testers. The results indicated that the parents and hybrids/crosses differed significantly for general and specific combining ability effects, respectively. High average degree of dominance revealed predominance of non-additive gene effects for all the traits. This indicated that parent showing high general combining ability for fruit yield/plant was due to high gca for fruit weight, fruit length, fruit diameter, internodal length and number of fruits per plant.

Borgaonkar *et al.* (2006) carried out an experiment with eight okra genotypes and their 28 crosses to estimate the general and specific combining ability effects. The combining ability analysis revealed that mean squares due to gca and sca were highly significant for all the characters. High general combining ability effects are related to additive genetic effects and additive×additive part of epistatic gene action. SCA represented dominance and epistatic components of variation, which contributed in the identification of promising cross combinations. Most of the cross combinations with high and significant sca effects were also found to have high heterotic effects

Combining ability with respect to dry seed yield and component characters was estimated by Kanchan *et al.* (2007) from a 10×10 full diallel cross in okra. The mean sum of squares due to GCA and SCA were reported to be significant for all characters indicating the presence of variability in combining ability of parents. The magnitude of GCA variance was greater than SCA variance and ratio of GCA:SCA was more than one, indicating the predominance of additive gene action. The general combining ability (GCA) effects were more important in genetic control of dry seed yield, while both GCA and SCA effects were important for number of seeds per fruit, 100-seed weight and seed oil content. It was also found that there was non-significant association between dry seed yield and oil content.

Adeniji *et al.* (2007) studied combining ability and genetic components for the length and width of pods in seven parents and 21 F₁ generations of *Abelmoschus caillei*. The results indicated that the mean squares due to general combining ability (GCA) and specific combining ability (SCA) for length and width of pods were significant. The estimated variance due to SCA was greater than GCA variance for length and width of pods at edible stage and vice versa for length and width of pods at maturity. The obtained results indicated an empirical superiority of the possibilities of evolving pure lines and hybrid okra with improved length and width into the cropping system.

2.3 Heterosis

Heterosis is the superiority of the F₁ hybrid over mid parent (mid parent heterosis) or better parent (heterobeltiosis) or a check variety/hybrid (standard or economic or useful or true heterosis). Various hypotheses have been put forward to explain the phenomenon of heterosis. The most accepted hypothesis states that dominance, over dominance and epistasis, all action appear to produce heterotic

effect. Plant breeders have extensively used and exploited heterosis to improve yield in many crops.

A brief review on heterosis in okra for different characters is given below.

Korla and Sharma (1988) studied six populations (P_1 , P_2 , F_1 , F_2 , BC_1 and BC_2) of okra for three seed characters. Heterosis over the better parent was not observed in any of the crosses for seeds per fruit. In one cross, better parent heterosis was observed for seed weight per fruit and in two crosses for 100-seed weight. In heterotic crosses the magnitude of dominance gene effects was high.

Shukla *et al.* (1990) reported hybrid vigor for most of the characters and the hybrid combinations which showed higher heterosis in general also indicated high inbreeding depression. The close relationship between the heterosis response and inbreeding depression suggested the importance of non additive genes. Little inbreeding suggested that increased vigour of F_1 's was mainly due to accumulation of favorable additive genes.

Poshiya and Shukla (1995) demonstrated that highest heterosis of 27.32% for fruit yield was observed over better parent. The hybrids exhibiting significant heterosis for fruit yield were also found to exhibit heterosis for most of the other characters studied. The best heterotic hybrids were not the cross combinations that exhibited maximum SCA effects. However, mean performance of the hybrids showed close association with SCA effects, indicating that selection of the hybrids based on *per se* response is equally effective.

Singh *et al.* (1996(b)) estimated the heterobeltiosis by using eight varieties of okra and their F_1 hybrids. The best performing hybrids were noticed to be Pusa

Makhmali×Parbhani Kranti and Pusa Sawani×Parbhani Kranti with better yield than the best parent Punjab Padmini.

More and Patil (1997) carried out an experiment to study the extent of heterosis, inbreeding depression for seven quantitative characters in okra from the F₁ and F₂ generation of 8×8 diallel crosses. They reported average values for inbreeding depression for fruit yield per plant and other characters. A close relationship between heterosis and inbreeding depression was observed suggesting preponderance of non-additive gene action.

Pathak and Syamal (1997) conducted an experiment by using crosses of six female lines and three testers of okra. The results indicated that, 13 out of the 18 crosses manifested high heterosis of pod yields per plant and also to six to ten other parameters, depending on the genotype. They concluded that, heterosis of pod yield resulted from heterosis of other important yield components.

Wankhade *et al.* (1997) carried out diallel mating design by using 12 parental lines. The results revealed appreciable and significant heterobeltiosis for all the characters including yield and its attributing characters. Among the F₁ hybrids, Vaishali Vadhu× Local Aloka was found to be outstanding for fruits per plant yield per plant and seven other characters.

Sood (1999) studied heterosis in okra in a set of 8×8 diallel crosses excluding reciprocals. Analysis of variance indicated significant differences for all characters suggesting the presence of genetic variability among the material studied. Many crosses exhibited heterosis for different characters; four crosses exhibited the maximum heterosis for fruit yield over the standard check, showing the importance of non-additive genes and these promising crosses for their exploitation in hybrid production.

Singh and Sood (1999) studied heterosis in okra in a set of 8×8 diallel crosses excluding reciprocals. Analysis of variance indicated significant differences for all the characters, indicating the presence of genetic variability among the material studied. Heterosis was reported in many crosses for different characters, which had the potential to throw desirable transgressive segregants in the latter generations, which may lead to a high-yielding variety.

Panda and Singh (1999) studied six characters for heterosis. Considerable amount of inbreeding depression was noticed for most of the traits studied. It was found that selection in advanced generation would be beneficial for improving yield in the crosses like; HRB-9-2×Arka Anamika showed high heterosis for yield and its components and noticed to be comparatively low inbreeding depression in the F₂ generation.

Indurani *et al.* (2000) reported that improvement of yield coupled with good amount of resistance could be achieved through the development of F₁ hybrids in okra.

Sood and Sharma (2001) carried out an experiment in a sub-temperate climatic region on heterosis and gene action for fruit yield and associated traits in a diallel cross. The results indicated that, among cultivars P-7, Parbhani Kranti, Pusa Sawani, Arka Abhay and Arka Anamika were found to be promising lines of okra. Non-additive gene effects were reported to be larger than additive effects in both F₁ and F₂ generations. Both over dominance and epistasis contributed to fruit yield. They have further discussed the breeding of improved parents by pedigree and recurrent selection methods are discussed.

Mehta *et al.* (2001) crossed three testers with fourteen lines and evaluated F₁'s along with parents to study heterosis and gene action for yield and its attributing characters. The gca variance was found to be greater than sca variances for fruit yield per plant indicating preponderance of additive gene action for this trait. Overall, the results indicated the fact that hybrid okra has great potentialities of maximizing fruit yield.

Shoba and Marippan (2002) carried out a study on hybrids developed with five lines and two testers to determine the extent of heterosis. The results revealed highly significant differences for all the characters between the parents and genotypes studied indicating wider range of variability.

Chauhan and Singh (2002) studied the extent of heterosis for yield and its attributing characters in okra. The cross, Punjab Padmini × Varsha Uphar exhibited higher heterosis over the better parent and standard check 1, while Arka Anamika × Arka Abhay also found to exhibit heterosis over standard check 2, revealing the importance of non-additive genes.

Heterobeltiosis in okra ranged from 141 per cent for length of fruits to 185 per cent for number of fruits per plant. Maximum beneficial heterobeltiosis for weight of fruits per plant (yield per plant) was observed. In general, hybrids showed a wide range of heterotic effects for each character. It was further revealed that, most of the high heterotic cross combinations for different characters showed high inbreeding depression in F₂ generation which could be due to the fact that, the most part of heterobeltiosis was accounted for dominance and dominance × dominance type of epistatic interactions and less of additive × dominance type of gene effect (Singh *et al.*, 2002).

The heterosis and combining ability studies were conducted by Bendale *et al.* (2004) with eight parents of okra and their 28 crosses developed in half diallel fashion. They have reported that the average fruit yield per plant of hybrids was higher than parental mean. Among the parents, Gold Finger was found to be good general combiner and among hybrids; the cross Parbani Kranti×Gold Finger showed the highest positive significant specific combining ability value for fruit yield plant.

Bhalekar *et al.* (2004) studied the extent of heterosis for fruit yield and its attributes in okra by growing seven diverse pure lines of okra and their 21 crosses. The results indicated heterosis in desirable direction for fruit yield and its component characters, except for average fruit weight. The magnitude of the heterosis was higher for incidence of yellow vein mosaic virus and yield per plant.

Pankaj *et al.* (2004) estimated heterosis over standard parent (Azad Ganga) and inbreeding depression for 19 characters using a diallel mating design involving four parents. A significant useful heterosis was noticed for all the characters studied except for yield per plant. Significant and desirable heterosis along with significant inbreeding depression was reported for all the characters, which indicated that most part of heterosis was due to dominance×dominance type of interaction.

Borgaonkar *et al.* (2005) studied heterosis in eight parents and 28 hybrids of okra obtained through an 8×8 diallel mating design. Analysis of variance showed highly significant differences for yield and its component characters indicating the presence of considerable genetic diversity among the genotypes. The magnitude of heterosis varied between the crosses. The degree of heterosis was higher for fruit length, internode length, leaf area and yield per plant; moderate for number of nodes on the main stem and plant height; and low for

number of days to 50 per cent flowering, number of days to first picking and fruit girth.

Yadav *et al.* (2005) conducted an experiment to estimate the heterosis in 10 parental lines of okra and their 45 F₁'s and F₂'s. In general, considerable heterosis over superior and economic parent was observed for all the characters. The cross 7103×LG was reported to be a good cross for exploiting hybrid vigour.

Borgaonkar *et al.* (2006) conducted an experiment to assess the extent of heterosis over mid and better parents for yield and its related attributes in okra. Out of 28 hybrids, 17 showed significant positive heterosis over mid and better parents. Heterosis for yield was manifested through component heterosis and hybrid vigor of even a small magnitude for individual traits may have additive effects on yield per plant.

Mamidwar and Mehta (2006) stressed the importance of heterobeltiosis for yield and yield components in 14 lines (females), three testers (males) and 42 hybrids of okra. Heterobeltiosis in the positive direction was observed in hybrids 13, 26, 37, 32, 27, 19, 25 and 37 for number of days to first flowering, number of days to 50% flowering, fruit weight, fruit length, plant height, number of seeds per fruit, 100-seed weight and fruit yield per plant, respectively.

Desai *et al.* (2007) reported that among the 28 okra hybrids tested, the hybrid, Parbhani Kranti×Gold Finger recorded superior performance for plant height, nodes plant⁻¹, fruit weight, fruits plant⁻¹ and yield plant⁻¹. While the hybrid, Smooth Finger× Green Gold also showed superior performance for these characters except fruit weight. Yield per plant exhibited the highest heterosis of 558% over mid parent and 447% over better parent. Considering the high

magnitude of heterosis and *per se* performance these hybrids were identified as promising hybrids in okra

Mehta (2007) conducted an experiment by using 42 hybrids generated by crossing three testers with fourteen lines along with parents for studying heterosis and gene action. The sca variance for days to fruit flower, number of seeds per fruit and 100 seed weight were higher than gca variance. The gca variances was greater than sca variances for fruit yield per plant indicating preponderance of additive gene action for this trait.

2.4 Fruit borer infestation

Bhalla *et al.* (1990) evaluated 1000 okra germplasm lines for their resistance to *Earias. spp.* In the field in Delhi and Maharashtra and reported that most of the lines were susceptible and only 50 were moderately resistant; none was completely resistant to this pest.

Mahal and Lal (1993) conducted the studies on the ovipositional preference of adults of *Amrasca biguttula* on different plant ages of varieties of okra in India. The results revealed that fewer nymphs emerged from the leaves of the resistant variety IC 7194 (9.83) compared with 13.23 nymphs for the susceptible variety Pusa Sawani. An inverse relationship was noticed between the emergence of nymphs with the density of trichomes on the mid vein of leaves of different ages in susceptible and resistant varieties, suggesting that all four-plant ages were suitable for screening, one-week-old plants being preferred for achieving rapid results.

Brar, *et al.* (1994) noticed that the percentage of fruit infestation in okras caused by *Earias spp.* was lowest in cv. EMS 8 in crops sown on 15 May. The greatest fruit yield was obtained in cv. EMS 8 from a crop sown on 15 June, whereas crops sown on 30 July had the lowest yield. The losses in fruit yield were lowest on crops sown on 30 July (22.79%) and greatest on crops sown on 30 May (50.58%).

Shukla *et al.* (1997) released the adult pairs of males and females of *Earias vittella*, a pest of cotton and okra, in breeding chambers in different sets, containing the odors of leaves of neem, bulbs of garlic and one control set with no odor to find out the effect of different plant odors on fecundity and hatching of *Earias spp.* Adult longevity did not differ significantly among the treatments. All the treatments significantly reduced the egg output as compared to the control and also revealed that, all the odors significantly reduced egg hatching compared to the control. The lowest number of eggs and hatching were recorded with Azadirachta leaves odor.

Twenty okra germplasm lines were evaluated against *E. vitella*, by Singh *et al.* (2005). The results revealed that none was found free from infestation. However, damage levels varied from 21.33 to 43.99% in case of shoots and 21.0 to 51.3% in case of fruits. Based on overall assessment, the germplasm lines namely KS-410, A-4 and NDO-10 showed lower damage against *E. vittella* for both shoot and fruit damage.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The data on material used and the techniques followed for collection, analysis and interpretation of data are described in this chapter.

3.1 Material

The material for the study comprised of ten diverse parents collected from different sources. (Table-1)

3.2 Selection of parents and crossing

The ten parental lines were grouped into different clusters using Tocher's method based on D^2 statistic between pairs of lines. Based on mean and standard deviation of D^2 values, high and low divergent clusters were formulated. Five lines belonging to highly divergent (H) and five lines belonging to low divergent (L) groups were crossed in a 10×10 half diallel mating design in the experimental plots of the Department of Genetics and Plant Breeding, UAS, G.K.V.K, Bangalore during 2007 to synthesize 45 single cross hybrids.

3.3 Crossing technique

In the evening of the day prior to flower opening, flower buds with proper size were selected and emasculated. The emasculated flower buds were covered with butter papers and were hand pollinated on the next day between 0900 and 1200 hrs with the pollen collected from the male parent.

3.4 Experimental design and layout

The 45 hybrids along with their ten parents (55 entries) were evaluated during 2008 summer following Randomized Complete Block Design with three replications.

Table-1 list of okra lines used for crossing programme in half diallel mating design

Sl. No	Name of the variety	Source	Salient features
1	KA-006	Raichur	Medium height, small fruits, moderately susceptible to fruit borer
2	Pusa Sawani	Indian Agriculture Research Institute	Medium height, small fruits, moderately susceptible to fruit borer
3	HRB-55	Hissar	Medium height, small fruits, moderately susceptible to fruit borer
4	PB-266	(ACRP(VC))	Tall, long fruits, susceptible to fruit borer
5	101	Hyderabad Local	Medium height, long fruits, susceptible to fruit borer
6	114	Dharwad local	Medium height, medium fruit length, moderately susceptible to fruit borer
7	Larma-1	Raichur	Tall, medium fruit length, moderately susceptible to fruit borer
8	Punjab Padmini	Punjab Agriculture University	Tall, medium fruit length, susceptible to fruit borer
9	Arka Abhay	Indian Institute of Horticulture Research	Tall, long fruits moderately susceptible to fruit borer
10	HRB-9-2	Hissar	Tall, long fruits, susceptible to fruit borer

3.5 Cultural practices

The field was prepared to fine tilth by ploughing, harrowing and clod crushing followed by leveling. Ridges were opened at 0.6 m apart with 0.15 m height for taking up sowing. Each entry was sown in a single row of 3 m length with spacing of 0.6 m × 0.3 m. Two to three seeds were dibbled at each hill and after germination and plant establishment, thinning was carried out to maintain a single healthy plant per hill. Basal dose of fertilizer at the rate of 33:50:25 kg NPK per hectare was applied to the crop at the time of sowing and 33 kg of N per hectare was given as top –dressing in two splits *i.e.*, 30 days and 60 days after sowing, respectively. The fresh tender green pods were harvested at an interval of two to three days. Further, all the recommended package of practices was followed to raise a good crop.

3.6 Recording of observations

Five competent plants per cross and parent in each replication were selected randomly and were tagged. Observations were recorded on these tagged plants on the following characters.

3.6.1 Days to 50 per cent flowering (DFF)

Number of days taken by fifty per cent of plants in each entry in all the replications to complete flowering was recorded from the date of sowing.

3.6.2 Plant height (PH) (cm)

Height of the plant was measured using a meter scale from the ground level to the tip of the plant at first harvest and was recorded in centimeters.

3.6.3 Primary branches per plant (PB)

Number of branches arising from the main stem above the ground was recorded at harvest.

3.6.4 Number of internodes per plant (NOI)

The number of nodes per plant present on main stem at harvest was counted and recorded as the number of nodes per plant.

3.6.5 Internodal length (INL) (cm)

The internodal length was computed by dividing the height of plant by number of nodes in that plant and was expressed in centimeters

3.6.6 Green fruits per plant (GPP)

Green fruits per plant were counted as the total number of fruits from first to last harvest

3.6.7 Fruit length (FL) (cm)

The length of the green pods harvested per plant was measured in centimeters from the base to the tip of the fruit and expressed in centimeters.

3.6.8 Number of ridges per fruit (NOR)

The number of ridges per fruit was counted on five randomly selected plants in each entry of all the replications, and the average of that was recorded.

3.6.9 Average fruit weight (FW) (g)

The average of total fruit weight of five randomly selected plants in each entry of each replication was considered as average fruit weight.

3.6.10 Green fruit yield per plant (NFP) (g)

The green fruit weight per plant of all pickings was recorded and the same is expressed in grams.

3.6.11 Per cent fruit borer damage

Per cent fruit borer damage was computed as follows

$$\% \text{ Infestation} = \frac{\text{Number of fruits infested}}{\text{Total number of fruits harvested}} \times 100$$

Further, the borer infestation was recorded on a 1-5 scale based on per cent fruit infested (Nath, 1966). Based on the infestation, the entries were classified into different groups.

Where,

- 1 = Immune (no damage)
- 2 = Resistant (1-5 % infestation)
- 3 = Moderately resistant (6-15 % infestation)
- 4 = Moderately susceptible (16-30 % infestation)
- 5 = Susceptible (more than 30% infestation)

3.7 Statistical Analysis

The method of diallel cross analysis has been extensively used for estimation of second degree genetic parameters. There is a range of alternative methods of partitioning the total variation (Jinks and Hayman 1953; Jinks 1954; Hayman 1954) where parental lines are inbred lines.

The mean of five randomly selected plants recorded for 11 quantitative traits in each entry and replication were subjected to statistical analysis.

3.7.1 Estimation of components of variance

Before estimating the components of variance, analysis of variance (ANOVA) was carried out according to Panse and Sukhatme (1985). If the variance due to genotypes (F_1 's and Parents) was significant, then the genetic components of variance were estimated. The structure of ANOVA is as follows.

Source	d.f.	Mean sum of squares
Replication	(r-1)	MSS_r
Genotypes (Parents+Hybrids)	(g-1)	MSS_g
Error	(r-1)(g-1)	MSS_e

Where, r = number of replications

g = number of parents (n) + number of crosses (p)

After ascertaining the significance of the mean squares due to genotypes, adequacy of additive-dominance model was tested using t^2 test. By this, the validity of assumptions of diallel analysis such as diploid segregation, absence of reciprocal differences, and absence of multiple allelism and independent distribution of genes among the parents were also tested. Significance of t^2 value at (n-2) df indicate the fulfillment of assumptions. The value of t^2 was obtained by the following formula (Panse and Sukhatme, 1985).

$$t^2 = \frac{n-2}{4} \frac{(\text{var } V_r - \text{var } W_r)^2}{\text{var } V_r \times \text{var } W_r - \text{cov}^2(V_r, W_r)}$$

Which follows 'F' distribution with 4 and (n-2) df.

The validity of assumptions was also tested using the significance of regression (b) of W_r on V_r from unity and zero.

If the additive dominance model was satisfactory, components of variance were then estimated using the following perfect fit solutions provided by Hayman (1954).

$$E = \hat{E}$$

$$D = V_p - \hat{E}$$

$$H_1 = 4\bar{V}_r + V_p - 4\bar{W}_r - \left[\frac{(3n-2)}{n} \right] \hat{E}$$

$$H_2 = 4\bar{V}_r - 4V_r - 2\hat{E}$$

$$F = 2V_p - 4W_r - \left[\frac{2(n-2)}{n} \right] \hat{E}$$

$$h^2 = 4(M_{L1} - M_{L0})^2 - \left[\frac{4(n-1)}{n^2} \right] \hat{E}$$

Where,

E	=	Error mean square
-		
V _p	=	Variance of parental means
-	=	Mean variances of progeny family means
V _r		around the array mean
-	=	Mean covariance of progeny family means on
W _r		the means of non-common parent
V _r	=	Difference between the mean of n parents
		(M _{L0}) and the mean of their n ² progeny
		families (M _{L1})
(M _{L1} -M _{L0})	=	Difference between the mean of n parents
		(M _{L0}) and the mean of their n ² progeny
		families (M _{L1})

Standard error to test the significance of these components of variance was obtained using the following formulae

$$SE_D = \left[\left(\frac{n^5 + n^4}{n^5} \right) S^2 \right]^{1/2}$$

$$SE_{H_1} = \left[\left(\frac{n^5 + 41n^4 - 12n^3 + 4n^2}{n^5} \right) S^2 \right]^{1/2}$$

$$SE_{H_2} = \left[\left(\frac{36n^4}{n^5} \right) S^2 \right]^{1/2}$$

$$SE_{h^2} = \left[\left(\frac{16n^4 + 16n^2 - 32n + 16}{n^5} \right) S^2 \right]^{1/2}$$

$$SE_F = \left[\left(\frac{4n^5 + 20n^4 - 16n^3 + 16n^2}{n^5} \right) S^2 \right]^{1/2}$$

$$SE_E = \left[\left(\frac{n^4}{n^5} \right) S^2 \right]^{1/2}$$

Where, n = Number of parents

S^2 = Estimate of error variance of these estimated components of variance.

The co-efficients of S^2 in each parameter are the diagonal elements of a covariance matrix given by Hayman (1954).

Significance of the components of variance was tested by 't' test.

$$t_D = \frac{(D - 0)}{SE_D}$$

$$t_{H_1} = \frac{H_1 - 0}{SE(H_1)}$$

$$t_{h^2} = \frac{h^2 - 0}{SE(h^2)}$$

$$t_F = \frac{F - 0}{SE(F)}$$

$$t_D = \frac{D - 0}{SE(D)}$$

$$t_{H_2} = \frac{H_2 - 0}{SE(H_2)}$$

If the estimates of D, H₁, H₂, F and h² were significant, following ratios were then computed

$(H_1/D)^{1/2}$ = Provides information regarding average degree of dominance involved in the action of genes

$H_2/4H_1$ = Provides information on symmetry/asymmetry of the distribution of genes with positive and negative effects among the parents

$\frac{(4DH_1)^{1/2} + F}{(4DH_1)^{1/2} - F}$ = Provides relative distribution of dominant and recessive genes among the parental lines.

Following Mather and Jinks (1982), narrow sense heritability (ns) was obtained as

$$\left[\frac{\frac{1}{2}D + \frac{1}{2}H_1 - \frac{1}{2}H_2 - \frac{1}{2}F}{\frac{1}{2}D + \frac{1}{2}H_1 - \frac{1}{4}H_2 + E} \right] \times 100$$

3.7.2 Combining ability analysis

Griffing's (1956) method 2, model 1 was followed to estimate general and specific combining ability effects and their variances.

The following linear mathematical model was followed for an observation made on

i^{th} genotype:

$$Y_{ij} = \mu + g_i + g_j + s_{ij} + \frac{1}{bc} \sum_k \sum_l e_{ijkl}$$

Where,

μ = Population mean

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

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

s_{ij} = Specific combining ability effect of ij^{th} cross

e_{ijkl} = Environmental effect associated with $ijkl^{\text{th}}$ observation

i, j = 1, 2,, n

k = 1, 2,, b

l = 1, 2,, c

n = Number of parents

b = Number of blocks (replications)

c = Number of individuals per cross in each replication

In this model, it is assumed that e_{ijkl} are normally and independently distributed with the mean zero and variance σ_e^2

The structure of ANOVA for combining ability analysis is as follows:

Source	df	Observed MSS	Expected MSS
gca	(n-1)	MSS_{gca}	$\sigma_e^2 (n+2) \left(\frac{1}{n-1} \right) \sum i g_i^2$
sca	$\frac{n(n-1)}{2}$	MSS_{sca}	$\sigma_e^2 + \frac{2}{n(n-1)} \sum i \sum j S_{ij}^2$
Error	m	MSS_e	σ_e^2

where,

MSS_{gca} = Observed mean sum of squares due to gca effects.

MSS_{sca} = Observed mean sum of squares due to sca effects.

Where mean sum of squares (MSS) due to gca effects of each parent was obtained as

$$g_i = \frac{1}{n+2} [Y_i + Y_{ii}] - \frac{2}{n} Y_{..}$$

Where, n = Number of parents

Y_i = Total of all crosses involving i^{th} parent as common over other parents.

Y_{ii} = Total of i^{th} parent

$Y_{..}$ = total of all crosses

Standard error to test the significance of gca effects was obtained as :

$$SE(g_i) = \left[\frac{n-1}{n(n-1)} \delta_e^2 \right]^{1/2}$$

Where, σ_e^2 = error mean square in ANOVA for combining ability analysis

When variance due to specific combining ability effects was significant, estimates of specific combining ability effects of each cross was obtained as:

$$S_{ij} = Y_{ij} - \frac{1}{n+2} [Y_{i.} + Y_{.i} + Y_{j.} + Y_{.j}] + \frac{2}{(n+1)(n+2)} Y_{..}$$

$Y_{i.}$ = Total of all progenies involving i^{th} parent as common

$Y_{.i}$ = Total of i^{th} parent

$Y_{j.}$ = Total of all progenies involving j^{th} parent as common parent

$Y_{.j}$ = Total of j^{th} parent

$Y_{..}$ = Total of all the crosses

Standard error to test the significance of sca effects was computed as

$$SE(S_{ij}) = \left[\frac{n^2 + n + 2}{(n+1)(n+2)} \delta_e^2 \right]^{1/2}$$

Variance due to gca and sca effects was estimated as :

$$\delta^2_{\text{gca}} = \frac{1}{2n} \left[Mg \frac{Me' + n(n-1)Ms}{n^2 - n + 1} \right]$$

$$\delta^2_{\text{sca}} = \frac{n^2}{2(n^2 - n + 1)} (Ms - Me')$$

$$\delta^2 = Me'$$

Where, MSS_{gca} and MSS_{sca} take the same meaning and cross with respect to gca and sca effects.

3.8 Overall status of a parent and cross with respect to gca and sca

Since yield and its component characters are correlated either positively or negatively, it is normal for a particular parent to manifest gca in the desirable direction for some characters and in the undesirable direction for others. In this context, the problem of ascertaining the status of a parent with respect to gca or a cross with respect to sca effects for characters under study assumes importance. Hence, the overall status of a parent or a cross with respect to gca and sca, respectively, was determined following the method suggested by Arunachalam and Bandyopadhyay (1979).

3.9 Overall status of a parent

The mean gca effects significant at 5 per cent was used as a norm for a parent and significant gca effects equal to or greater than the norm were given a score of +1 and the gca effects of the parents whose score was less than the norm was given a score of -1. Non-significant gca effects received zero score. Final score was obtained by summing the scores over all 11 traits. The mean of the final score was taken as final norm and the parents whose value exceeded the final norm were given high overall status (H) and the parents whose final score was less than final norm were given low overall status (L). The same procedure was followed for classifying the hybrids as high (H) or low (L) for their overall sca status.

3.10 Estimation of heterosis

The treatment mean values for each trait were used for estimation of heterosis over better parent (BP) and mid-parent (MP) as per the method given by Turner (1953).

The estimation of heterosis was done by using the following formulae

$$\text{Heterosis over better parent} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}}$$

$$\text{Heterosis over mid-parent} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}}$$

The following standard error (SE) was used to test the significance of heterosis.

$$\text{SE (BP heterosis)} = \sqrt{\frac{2M_4}{r}}$$

$$\text{SE (MP heterosis)} = \sqrt{\frac{2M_4}{3r}}$$

Where, M_4 = Error mean sum of squares in ANOVA table
of Combining Ability analysis
 r = Number of replications

3.11 Defining overall heterotic status of cross

As in the case of gca and sca, the magnitude and direction of heterosis would vary from character to character. However, a breeder would be interested in a method to decide whether a cross would be considered overall heterotic or not. The following logic (Arunachalam and Bandyopadhyay, 1979) was used to define a heterotic cross for every character; a cross was assigned a status 'B' if its mean

significantly exceeded that of the superior parent, otherwise a status W. The frequency of B's over all the characters could therefore be counted for every cross.

If P_1 is the mean of the superior parent and P_2 of the other parent, M , the value of the mid-parent and H , the value of the cross, four possibilities exist: (i) $H > P_1$, (ii) $P_1 > H > M$, (iii) $M > H > P_2$ and (iv) $P_2 > H$. When a cross is repeated indefinitely over time or space, it is possible to argue that the a priori probability of each of the events, in particular (i) = 0.25. When a cross is checked for heterosis over 11 characters, the number of B's it will score, will be determined by the binomial distribution, $(3/4 + 1/4)^{11}$, where, $P(B) = 1$ and $P(W) = 3/4$. The mean of the distribution = $11 \times 1/4 = 2.75$. This was chosen as the norm and thus crosses which scored 4 or more B's were taken to be overall heterotic.

3.12 Relationship between parental diversity and hybrid heterosis.

The method devised by Arunachalam and Bandyopadhyay (1984) was used to delineate parental divergence as measured by D^2 into four divergent classes (DC). To take into account the variable magnitude of parental divergence, the mean (M) and standard deviation (S) of the values of D^2 statistic were calculated. The divergence classes were defined as follows:

- 1 DC1 = $D^2 > \text{or} = (M+S)$
- 2 DC2 = $D^2 < (M+S)$ and $\text{or} = M$
- 3 DC3 = $D^2 > \text{or} = (M-S)$ & $< M$
- 4 DC4 = $D^2 > (M)$

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

Results of the present investigation are presented in this chapter under the following heads:

1. Analysis of variance
2. Mean performance
3. Components of genotypic variance
4. Combining ability
5. Heterosis
6. Relationship of parental diversity with hybrid heterosis
7. Reaction of varieties and hybrids to fruit borer infestation

4.1 Analysis of variance

The analysis of variance for 11 quantitative characters for parents and hybrids is presented in Table- 2.

It is evident that the genotypes differed significantly from each other for all the characters.

4.2 Mean performance

The mean performance of parents and hybrids for 11 quantitative characters are presented in Table -3 and Table-4, respectively.

4.2.1 Days to 50 percent flowering (DFF)

A significant difference was noticed for days to fifty percent flowering among the parents and hybrids with a wide range of 33.35 to 45.14 among the parents and 33.71 to 46.84 among the hybrids (Table-3and 4).

Table- 2: Analysis of variance for fruit yield and its components in okra.

Source	df	DFF	PH	PB	NOI	MIL	FL	FG	NOR	FW	NFP	YPP
Replication	2	41.40	2.96	0.119	0.42	17.91	0.56	0.47	85.12	0.018	2.63	7.52
Treatment (Parents + Hybrids)	54	695.76**	679.08**	12.94 *	11.64**	12985.24**	57.31**	5.34**	2717.44 **	110.06**	95.59**	91.11*
Error	108	137.86	7.22	4.07	3.55	858.25	10.75	0.91	725.26	0.13	11.94	47.22

** Significant @ p = 0.01

* Significant @ p = 0.05

DFF = Days to 50% flowering

PH = Plant height (cm)

PB = Primary branches per plant

NOI = Nodes per plant

MIL = Mean internodal length (cm)

FL = Fruit length (cm)

FG = Fruit girth

NOR = Number of ridges per fruit

FW = Average fruit weight (g)

NFP = Fruits per plant

YPP = Fruit yield per plant (g)

Table -3: Mean performance of parents for fruit yield and its components in okra.

Parent	DFF	PH	PB	NOI	MIL	FL	FG	NOR	FW	NFP	YPP
KA-006	45.14	65.35	1.79	4.98	13.11	9.42	5.33	7.02	21.72	9.59	208.35
Pusa Sawani	34.55	71.71	2.38	5.70	12.58	7.28	5.27	8.51	22.61	7.99	180.81
HRB-55	42.50	70.40	2.92	5.66	12.43	8.72	6.28	8.46	19.45	8.74	170.46
PB-266	34.53	88.37	2.77	8.82	10.03	21.39	10.12	8.69	31.81	10.77	342.48
101	38.80	71.03	2.21	6.51	10.92	19.57	8.36	7.70	28.57	16.11	460.16
114	37.25	70.31	3.26	7.57	9.26	15.58	4.51	6.68	31.45	20.50	644.89
Larma-1	33.65	87.55	4.27	8.63	10.17	13.65	4.69	9.55	39.63	25.50	988.64
Punjab Padmini	33.35	106.12	4.62	12.50	9.87	12.42	6.35	9.75	29.80	30.83	1022.43
Arka Abhay	33.67	92.39	3.54	11.37	9.34	17.60	7.26	6.56	31.46	30.53	992.53
HRB-9-2	34.70	115.27	3.67	12.01	9.63	19.53	5.00	7.64	20.75	29.34	608.88
MEAN	37.19	83.85	3.14	8.06	11.44	15.16	6.32	8.06	27.73	18.77	544.01
SEm \pm	0.86	1.10	4.88	0.25	0.69	3.40	1.46	0.51	0.32	1.83	7.561
C.D.at 0.05	1.29	1.65	7.32	0.37	1.03	5.1	2.19	0.76	0.48	2.74	11.75
C.D.at 0.01	1.80	2.31	10.08	0.52	1.44	7.14	3.06	1.07	0.67	3.84	13.25

DFF = Days to 50% flowering MIL = Mean internodal length (cm) FW = Average fruit weight(g)

PH = Plant height (cm) FL = Fruit length (cm) NFP = Fruits per plant

PB = Primary branches per plant FG = Fruit girth YPP = Fruit yield per plant (g)

NOI = Nodes per plant NOR = Number of ridges per fruit

Table -4: Mean performance of crosses for fruit yield and its components in okra

Crosses	DFF	PH	PB	NOI	MIL	FL	FG	NOR	FW	NFP	YPP
K-A006 × Pusa Sawani	44.40	72.45	1.93	6.27	11.56	12.28	5.70	4.77	30.80	4.68	144.20
KA-006 × HRB-55	35.43	60.17	2.07	5.17	11.78	14.54	5.38	5.50	36.40	5.72	208.32
KA-006 × PB-266	43.22	81.37	2.37	8.53	9.56	13.19	5.90	5.11	29.10	4.87	141.70
KA-006 × 101	37.40	87.37	2.60	8.90	7.15	16.16	7.42	9.54	39.20	8.43	330.44
KA-006 × 114	38.33	97.47	2.97	9.83	9.92	21.12	6.13	4.55	39.70	7.50	297.43
KA-006 × Larma-1	41.40	100.63	3.62	11.23	9.00	19.10	5.40	6.16	37.50	21.47	805.12
KA006XPunjab Padmini	39.90	98.30	3.50	12.30	7.99	19.60	6.15	5.62	30.60	28.70	879.28
KA-006 × Arka Abhay	40.97	96.73	3.60	11.67	8.29	13.63	5.53	6.11	27.30	30.40	828.87
KA-006 × HRB-9-2	46.84	60.17	1.20	6.97	8.64	18.20	6.43	5.43	18.61	29.37	545.21
Pusa Sawani × HRB-55	44.40	72.45	1.93	6.27	11.56	12.28	5.70	4.89	30.80	4.68	144.22
Pusa Sawani × PB-266	43.50	81.37	2.38	8.27	9.84	15.47	7.17	7.28	24.90	5.67	140.96
Pusa Sawani × 101	36.18	83.87	1.93	7.93	10.63	14.90	7.79	7.47	24.10	4.77	115.18
Pusa Sawani × 114	39.33	92.53	3.67	9.70	9.52	18.39	7.79	6.31	37.40	7.32	273.63
Pusa Sawani × Larma-1	33.91	70.67	1.24	7.20	9.82	13.76	5.25	3.92	24.60	20.40	502.20
Pusa Sawani × Punjab Padmini	41.90	85.43	1.47	11.4	9.86	18.63	6.46	4.63	30.40	22.57	686.12
Pusa Sawani × Arka Abhay	42.31	91.50	3.03	9.67	9.66	24.63	4.82	4.75	39.30	28.67	1127.65
Pusa Sawani × HRB-9-2	41.43	118.50	4.47	6.99	10.37	20.68	7.26	5.06	36.10	31.40	1133.55
HRB-55 × PB-266	42.12	82.10	2.75	8.37	9.82	17.51	6.36	5.89	24.30	6.03	146.90
HRB-55 × 101	39.24	82.10	1.74	8.57	9.58	15.67	6.02	5.98	27.30	6.67	182.31
HRB-55 × 114	39.30	77.50	1.48	7.63	10.15	13.65	7.10	5.54	27.70	6.60	182.86
HRB-55 × Larma-1	42.12	76.50	2.31	7.85	8.72	12.33	5.68	3.82	20.13	20.3	565.65
HRB-55 × Punjab Padmini	42.59	87.47	2.78	8.85	9.88	13.71	6.43	4.62	23.54	22.70	534.19
HRB-55 × Arka Abhay	37.86	78.37	1.92	8.03	9.76	14.65	4.39	3.74	19.75	32.67	644.61
US 7105 (Standard check)	40.61	85.60	2.11	7.65	8.62	11.50	7.51	6.99	24.26	9.85	469.72

Table-4: *Contd...*

Crosses	DFF	PH	PB	NOI	MIL	FL	FG	NOR	FW	NFP	YPP
HRB-55×HRB-9-2	44.86	70.67	1.24	7.20	9.82	13.76	5.25	3.91	24.68	34.70	854.21
PB-266×101	40.20	94.50	3.13	9.61	9.84	18.70	6.60	6.43	29.87	25.67	463.13
PB-266×114	36.28	98.50	3.52	9.97	9.88	15.50	7.27	5.52	28.53	7.71	219.72
PB-266×Larma-1	33.75	83.47	2.67	8.73	9.56	17.23	6.60	8.21	26.52	20.40	541.32
PB-266×Punjab Padmini	33.71	100.56	3.33	10.03	10.19	24.23	5.67	7.25	33.66	12.23	411.07
PB-266×Arka Abhay	44.83	71.43	1.57	7.60	9.40	6.67	5.20	7.28	23.45	6.27	146.68
PB-266×HRB-9-2	44.37	54.93	1.24	5.67	9.76	11.73	4.39	6.17	18.74	5.23	97.69
101×114	35.70	98.43	3.71	10.07	9.78	11.12	7.23	7.46	34.37	20.10	690.12
101×Larma-1	35.57	57.50	1.11	6.03	9.53	12.30	7.30	8.15	25.58	4.63	118.30
101×Punjab Padmini	35.40	81.83	1.90	8.27	9.90	23.43	9.17	10.24	30.59	8.30	252.92
101×Arka Abhay	35.53	99.50	4.30	9.93	10.38	14.53	5.33	6.13	28.75	16.20	465.53
101×HRB-9-2	37.86	78.37	1.92	8.03	9.76	14.65	4.39	3.71	19.74	6.73	132.87
114×Larma-1	36.71	70.67	1.24	7.20	9.82	13.76	5.25	3.92	24.66	5.56	136.86
114×Punjab Padmini	41.90	85.43	1.47	8.67	9.86	21.46	6.46	4.67	30.42	6.54	198.81
114×Arka Abhay	42.31	91.50	3.03	9.67	9.48	24.63	4.82	4.74	39.31	7.22	283.87
114×HRB-9-2	41.43	118.50	4.47	11.43	10.37	20.68	7.26	5.04	36.13	19.33	275.54
Larma-1×Punjab Padmini	38.89	120.37	5.20	12.29	9.80	21.46	7.76	6.45	39.54	14.55	1138.63
Larma-1×Arka Abhay	39.30	77.50	1.48	7.63	10.15	13.65	7.10	5.55	27.72	6.60	182.86
Larma-1×HRB-9-2	43.50	81.37	2.38	8.27	9.84	15.47	7.58	7.21	24.91	5.67	169.75
Punjab Padmini×Arka Abhay	43.50	81.37	2.38	8.27	9.84	15.47	7.63	7.32	24.91	5.98	157.56
Punjab Padmini×HRB-9-2	43.50	81.37	2.38	8.27	9.84	15.47	7.17	7.17	24.87	5.78	140.96
Arka Abhay×HRB-9-2	38.60	87.70	2.37	8.59	9.59	14.99	7.86	7.54	25.12	5.98	153.69
SE ±	0.66	2.21	0.15	0.25	0.11	0.58	0.15	0.22	0.89	1.49	7.49
CD at 5%	0.99	3.31	0.22	0.37	0.16	0.87	0.22	0.33	1.33	2.23	8.23
CD at 1%	1.38	4.64	0.31	0.52	0.23	1.21	0.31	0.46	1.86	3.12	5.77

DFF= Days to 50%
flowering
FW= Average fruit
weight (g)

PH= Plant height (cm)
FL= Fruit length (cm)

PB = Primary branches
per plant
NFP= Fruits per plant

NOI= Nodes per plant
YPP= Fruit yield per
plant (g)

MIL= Mean internodal
length(cm)
FG = Fruit girth

FG = Fruit girth
NOR= Number of
ridges

The parent, Punjab Padmini flowered as early as 33.35 days in contrast to the parent KA-006 that flowered in 45.14 days. The other parents, which were early to flowering were Larma-1 (33.65), Pusa Sawani (34.55), PB-266 (34.53) and HRB-9-2 (34.70). As far as hybrids were concerned HRB-55×HRB-9-2 was found to be late by completing flowering in 44.86 days. The hybrids that took less number of days to flowering was PB-266×Punjab Padmini (33.71 days) followed by PB-266×Larma-1 (33.75).

4.2.2 Plant height (cm)

A significant difference was noticed for plant height among the parents and hybrids with a wide range of 70.31 cm to 115.27 cm among the parents and 54.93 cm to 120.37 cm among the hybrids.

Among the parents the maximum plant height was registered by HRB-9-2 (115.27 cm) followed by the parents Punjab Padmini (106.12 cm), Arka Abhay (92.39 cm) and PB-266 (88.37 cm) in that order. Among the hybrids, it ranged from 54.93 cm (PB-266×HRB-9-2) to 120.37 cm (Larma-1×Punjab Padmini) followed by Pusa Sawani×HRB-9-2 (118.50 cm) and 114×HRB-9-2 (118.50 cm).

4.2.3 Primary branches per plant

A significant difference was noticed for primary branches per plant among the parents and hybrids with a wide range of 1.79 to 4.62 among the parents and 1.11 to 5.2 among the hybrids.

The parent Punjab Padmini showed highest number of branches per plant of 4.62 and the lowest was shown by the parent KA-006 (1.79). Among the hybrids,

101×Larma-1 exhibited lowest numbers of branches (1.11) and the highest was observed in Larma-1×Punjab Padmini (5.20).

4.2.4 Number nodes per plant

A significant difference was noticed for number of nodes per plant among the parents and hybrids with a wide range of 4.98 to 12.50 among the parents and 5.17 to 12.30 among the hybrids.

It was observed that the lowest number of nodes was present in the parent KA-006 (4.98) and highest in Punjab Padmini (12.50). The hybrid KA-006×Punjab Padmini (12.30) exhibited highest number of nodes and lowest nodes were in KA-006×HRB-55 (5.17).

4.2.5 Mean internodal length (cm)

A significant difference was noticed for mean internodal length among the parents and hybrids with a wide range of 9.26 cm to 13.11 cm among the parents and 7.15 cm to 11.78 cm among the Hybrids.

Among the parents, the maximum internodal length was observed in KA-006 (13.11 cm) followed by Pusa Sawani (12.58 cm) and the minimum were in the parent 114 (9.26 cm). The hybrid KA-006×HRB-55 (11.78 cm) exhibited highest internodal length and it was minimum in KA-006×101 (7.15 cm).

4.2.6 Fruit length (cm)

A fairly high variability was observed for this character, which ranged from 7.28 cm (Pusa Sawani) to 21.39 cm (PB-266). Among the hybrids it ranged from 6.67 cm (PB-266×Arka Abhay) to 24.63 cm (114×Arka Abhay) and (Pusa Sawani×Arka Abhay). Apart from Punjab Padmini (12.42), the parents, HRB-9-2 (19.53 cm), 101(19.57 cm) and Arka Abhay (17.60 cm) were also found to possess relatively longer pods. The hybrid PB-266×Punjab Padmini also exhibited fairly higher pod length of 24.23 cm.

4.2.7 Fruit girth (cm)

Variability with respect to this character was limited as reflected from the narrow range. The lowest fruit girth was recorded in the parent 114 (4.51 cm) and highest was in PB-266 (10.12 cm). Among the hybrids it ranged from 4.39 cm (101×HRB-9-2, HRB-55×Arka Abhay, and PB-266×HRB-9-2) to 9.17 cm (101×Punjab Padmini)

4.2.8 Number of ridges per fruit

A significant difference was noticed for number of ridges per fruit among the parents and hybrids with a wide range of 6.56 to 9.75 among the parents and 3.71 to 10.24 among the hybrids.

The parent Arka Abhay (6.56) possessed the least number of ridges per fruit. Whereas, the fruits of Punjab Padmini (9.75) was observed with highest number of ridges. Among the hybrids, 101×HRB-9-2 produced least number of ridges of 3.71. While, 101×Punjab Padmini (10.24) exhibited highest number of ridges.

4.2.9 Average fruit weight (g)

A significant difference was noticed for average fruit weight among the parents and hybrids with a wide range of 19.45 g to 39.63 g among the parents and 18.61 g to 39.54 g among the hybrids.

The lowest fruit weight was observed in HRB-55 (19.45 g) and the highest was observed in Larma-1 (39.63 g) among the parents. Among the hybrids it ranged from 18.61 g (KA-006×HRB-9-2) to 39.54 g (Larma-1×Punjab Padmini).

4.2.10 Number of fruits per plant

A significant difference was noticed for number of fruits per plant among the parents and hybrids with a wide range of 7.99 to 30.83 among the parents and 4.63 to 34.70 among the hybrids.

A fairly higher variability was observed among hybrids compared to parents as reflected from the range. The parent, Pusa Sawani (7.99) manifested lower number of fruits while Punjab Padmini (30.83) exhibited highest number of fruits followed by Arka Abhay (30.53). The fruits were less in 101×Larma-1 (4.63) in contrast to HRB-55×HRB-9-2 which manifested fruits number as high as 34.70 followed by HRB-55×Arka Abhay(32.67).

4.2.11 Fruit yield per plant (g)

A significant difference was noticed for fruit yield per plant among the parents and hybrids with a wide range of 170.46 g to 1022.43 g among the parents and 115.18 g to 1138.63 g among the hybrids.

For this character HRB-55 (170.46 g) showed the lowest fruit yield. Whereas, Punjab Padmini (1022.43 g) exhibited highest fruit yield among the parents. Among hybrids, it ranged from 115.18 g (Pusa Sawani×101) to 1138.63 g (Larma-1×Punjab Padmini).

4.3 Components of genotypic variance

The estimates of components of variation and genetic ratios are presented in Table-5. It was observed that the estimate of additive genetic variation was significant with respect to days to 50 per cent flowering, plant height, mean internodal length, number of ridges, number of fruits per plant and fruit yield per plant. Contrastingly, the estimates of H_1 and H_2 (both are estimates of dominance genetic variation) were highly significant for all the traits *viz.*, number of primary branches, mean internodal length, fruit length, fruit girth, number of ridges, fruit weight, number of fruits per plant and fruit yield per plant under study. The estimate of F, which is a measure of covariance between additive and dominance gene effects at different loci, was negatively significant for pod yield per plant. The environmental component of variation *i.e.*, 'E' was significant for days to 50 per cent flowering and pod yield per plant.

The ratio $(H_1/D)^{1/2}$ which is the measure of the degree of dominance was more than unity for all the characters except days to 50 per cent flowering and number of ridges per plant.

The ratio $H_2/4H_1$ was different from 0.25 for all the characters. Another ratio

Table- 5: Estimates of components of genetic variation for fruit yield and its components in okra

Components	DFF	PH	PB	NOI	MIL	FL	FG	NOR	FW	NFP	YPP
D	409.58**	1289.74**	0.81	5.81	771.4**	26.18	3.19	-907.16*	41.04	85.03**	278.4**
H ₁	361.01**	1017.7**	4.62**	15.8**	107.99**	78.69**	8.76**	457.67**	153.52**	487.01**	853.7**
H ₂	170.79**	867.05**	3.87**	13.5**	4779.3**	65.46**	6.53**	1840.09	127.93**	392.25**	502.7**
F	-3.51	1.95	1.36	6.78	-13	-31.68	-5.13	-1.23	50.93	9.71	-444.1**
h ²	-31.07**	-0.66	0.8	0.65	949.69**	2.22*	-0.01	-289.75**	2.24*	21.5**	531.76**
E	224.62**	2.41**	0.01	0.03	6.1	0.04	0.06	8.42	0.04	0.32	2.4**
(H ₁ /D) ^{1/2}	0.20	1.87	2.4	1.65	1.18	1.73	1.66	0.46	1.93	2.39	2.13
H ₁ /4H ₁	0.23	0.21	0.21	0.21	0.11	0.21	0.16	0.32	0.21	0.2	0.23
$\frac{(4DH_1)^{1/2} + F}{(4DH_1)^{1/2} - F}$	0.012	0.96	1.08	0.99	1.02	0.9	0.80	0.08	1.45	0.06	0.056
No. of effective Factors	1.02	0.16	1.03	1.21	0.24	2.46	1.36	1.58	0.46	1.68	0.02
Heritability(ns)	44.8	48.3	19.5	18.8	14.97	15.69	15.08	-16.09	18.54	15.6	18.65
r(p ₁ w _r + v _r)	0.46**	-0.22**	0.2083	-0.67	0.84	-0.28	0.581	0.0075	0.027	-0.27	-0.016
b(w _r - v _r)	0.87**	0.47**	0.34	0.97*	0.98**	23.86**	0.58**	0.58**	0.34	0.99**	0.78**
t ² .	45.81**	22.59**	0.9	0.25	1.49**	12.33**	523**	631.93**	0.2	21.87**	12.7**

** Significant @ p = 0.01

* Significant @ p = 0.05

DFF = Days to 50% flowering

PH = Plant height (cm)

PB = Primary branches per plant

NOI = Nodes per plant

MIL = Mean internodal length (cm)

FL = Fruit length (cm)

FG = Fruit girth

FW = Average fruit weight (g)

NFP = Fruits per plant

YPP = Fruit yield per plant (g)

NOR = Number of ridges per plant

$\frac{(4DH_1)^{1/2} + F}{(4DH_1)^{1/2} - F}$ was less than unity for all the characters except primary

branches, mean internodal length and fruit weight per plant.

The number of genes controlling each character did not exceed two. The characters days to 50 per cent flowering and plant height exhibited high narrow sense heritability. Whereas, rest of the characters showed a moderate narrow sense heritability.

The estimates of regression coefficient of variance of progeny family means within family means within an array on covariance of progeny family means within an array with the means of their non-common parents deviated significantly from unity with respect to days to 50 per cent flowering and fruit yield per plant.

The correlation coefficient between mean of the common parent of an array and parental order of dominance for each array was significant for only three characters *viz.*, days to 50 per cent flowering, plant height and mean internodal length.

4.4 Combining ability

Analysis of variance for combining ability for different characters is presented in Table-6. It is clear that, the parents under study differed significantly from each other with respect to their gca effects for all the characters. Similarly, the hybrids synthesized from these parents were also found to be significantly different from each other with respect to their sca effects for all the traits.

Table- 6: Analysis of variance for combining ability in okra

Source	df	DFD	PH	PB	NOI	MIL	FL	FG	NOR	FW	NFP	YPP
gca	9	205.65**	204.72**	25.59**	5.26**	4975.44**	26.91**	1.41**	715.59**	49.14**	78.44**	58716.5**
sca	45	237.17**	230.68**	31.25**	3.6*	4188.2**	17.54**	1.85**	943.85**	34.19**	106.7**	104134.55**
Error	108	12.24	2.4	1.35	2.25	1286.08	3.58	0.33	108.42	4.44	0.31	1392.4

** Significant @ p = 0.01

* Significant @ p = 0.05

DFD = Days to 50% flowering

NOI = Nodes per plant

NOR = Number of ridges

FW = Average fruit weight (g)

PH = Plant height (cm)

MIL= Mean internodal length (cm)

FL = Fruit length (cm)

YPP = Fruit yield per plant (g)

PB = Primary branches per plant

FG = Fruit girth

NFP= Fruits per plant

4.4.1 Combining ability effects

The estimates of gca effects of parents are summarized in Table-7.

4.4.1.1 Days to 50 per cent flowering

All the parents manifested significant gca effects except Larma-1 and HRB-9-2 for this character. The parent 114, manifested highest negative gca effect of (-4.1) followed by Arka Abhay (-2.34) and PB-266 (-2.30).

4.4.1.2 Plant height

Significant gca effects were noticeable for this character among the parents except 114 and Larma-1. Five parents manifested significant positive gca effects among them; the highest gca effect was shown by Punjab Padmini (13.26) followed by KA-006 (7.31), 101 (4.79) and HRB-55 (4.53) in that order.

4.4.1.3 Primary branches

In general, the parents showed lower magnitude of gca effects for this trait. The parent, Punjab Padmini (0.99) exhibited highest significant gca effect in contrast to PB-266 (-0.57) which showed lowest significant gca effect.

4.4.1.4 Number of nodes per plant

All the parents except Pusa Sawani expressed significant gca effects. Three parents namely, Punjab Padmini (15.52), followed by 101 (4.29) and KA-006 (3.92) exhibited significant positive gca effect in this order. The rest of the parents

Table-7: Estimate of gca effects of parents for fruit yield and its components in okra.

parents	Days to 50% flowering	Plant height	Primary branches	Number of nodes per plant	Mean Internodal Length	Fruit Length	Fruit girth	Number of ridges	Fruit weight	Number of fruits per plant	Fruit yield per plant
KA-006	-0.52**	7.31**	0.29**	3.92**	0.11**	2.94**	3.58**	0.70	1.95**	0.10**	12.53
Pusa Sawani	-1.16**	-4.50**	0.001	0.02	-0.06**	-3.88*	-1.37**	-1.42*	-0.85**	-0.05**	-25.31**
HRB-55	2.61**	4.53**	0.20	-1.40*	0.03*	-1.01*	1.26**	5.05**	-1.60**	-0.11**	-32.74**
PB-266	-2.30**	-10.05**	-0.57**	-8.38**	-0.13**	-4.09**	-2.33**	-3.05**	-1.20**	-0.10**	-29.32**
101	7.3**	4.79**	-0.18**	4.29**	-0.004**	-1.13*	-1.24**	-2.93**	-0.56**	0.12**	15.23*
114	-4.1**	-1.21	0.07	-2.20**	-0.01	-1.12**	1.53*	-1.08*	0.65**	-0.07**	10.23
Larma-1	-0.16	-1.23	-0.52**	-3.01**	-0.06**	-0.33	-2.56**	-0.91**	-1.04**	0.01**	9.87
Punjab Padmini	1.11**	13.26**	0.99**	15.52**	0.19**	4.40**	5.49**	9.46**	4.91**	0.18**	57.42**
Arka Abhay	-2.34**	-16.21**	-0.24**	-6.34**	-0.15**	-2.15**	-1.51**	-1.72**	-1.44**	-0.10**	-41.23**
HRB-9-2	-0.44	3.31**	-0.04	-2.42**	0.08**	6.37**	-3.21**	-4.1**	-0.81**	0.02**	23.52**

** Significant @ p = 0.01

* Significant @ p = 0.05

expressed significant negative gca effect, highest negative gca effect was given by Arka Abhay (-6.34).

4.4.1.5 Mean internodal length

All the parents showed significant gca effects except 114 with the parent Punjab Padmini expressing highest significant positive gca effects of (0.19). Maximum negative gca effects was shown by Arka Abhay (-0.15).

4.4.1.6 Fruit length

Three parents namely, Punjab Padmini, KA-006 and HRB-9-2 manifested significant gca effects. HRB-9-2 exhibited highest positive significant gca effect of 6.37 and highest negative significant effect was contributed by PB-266 (-4.09).

4.4.1.7 Fruit girth

All the parents expressed significant gca effects for this trait. The parent Punjab Padmini (5.49) showed highest positive gca effect followed by KA-006 (3.58) and 114 (1.53). Three parents *viz.*, HRB-9-2 (-3.21), Larma-1 (-2.56) and PB-266 (-2.33) exhibited significant negative gca effects in that order.

4.4.1.8 Number of ridges per fruit

As far as this trait was concerned, all the parents except KA-006 expressed significant gca effects. Of these, Punjab Padmini (9.46) and HRB-55 (5.05) expressed significant gca effects in decreasing order. Seven parents manifested significant negative gca effects with 101 (-2.93) expressing highest negative significant gca effect.

4.4.1.9 Fruit weight

Three parents showed significant positive gca effects. Among them, the highest significant positive gca effect was manifested by Punjab Padmini (4.91) followed by KA-006 (1.95) and 114 (0.65) exhibited significant positive gca effects.

4.4.1.10 Number of fruits per plant

For this trait, all the parents exhibited significant gca effects, although, they were of lower magnitude. However, four parents expressed significant positive gca effects, the highest being exhibited by Punjab Padmini (0.18) followed by KA-006 (0.10) and HRB-9-2 (0.02).

4.4.1.11 Fruit yield per plant

Three parents expressed positive significant gca effects. Among them, the highest significant positive gca effect was manifested by Punjab Padmini (57.42) followed by HRB-9-2(23.52).

4.4.2 Overall status of gca effects

Table-8 shows the parents which are showing overall status for their gca effects. Since the various quantitative traits are correlated either positively or negatively, it is usual to find for a particular parent, gca in the desirable direction for some characters and in the undesirable direction for others. The parents KA-006, HRB-55 and Punjab Padmini were identified as parents with high overall gca effects. The rest of the parents were having low gca effect.

Table-8: Overall general combining ability status of parents in okra

Parent	Total score	Overall gca status
KA-006	7.00	H
Pusa Sawani	-4.00	L
HRB-55	1.00	H
PB-266	-7.00	L
101	-2.00	L
114	-4.00	L
Larma-1	-2.00	L
Punjab Padmini	7.00	H
Arka Abhay	-7.00	L
HRB-9-2	-2.00	L

Final norm = -1.3

H = high

L = Low

4.4.3. Specific combining ability effects

The estimate of specific combining ability effects of 45 hybrids for different attributes is presented in Table-9.

4.4.3.1 Days to fifty per cent flowering

Out of 45 crosses, 11 hybrids expressed significant negative sca effects in the desirable direction. The hybrids KA-006×Arka Abhay (-7.89) followed by HRB-55×Larma-1 (-5.64) and KA-006×HRB-55 (-5.64) exhibited significant negative sca effects in desirable direction.

4.4.3.2 Plant height (cm)

As many as 13 hybrids exhibited positive significant sca effects out of 45 crosses for plant height, which ranged from 6.06 (HRB-55×Arka Abhay) to 12.83 (KA-006×Arka Abhay). Other crosses, Pusa Sawani×114 (11.97) and Pusa Sawani×PB-266 (11.23) also showed comparatively higher significant positive sca effects.

4.4.3.3 Primary branches

Of the 45 hybrids, 17 crosses registered significant sca effects in the desirable direction; the highest being expressed by KA-006×Arka Abhay (1.08) followed by KA-006×Pusa Sawani (0.89), KA-006×PB-266 (0.86) and 101×HRB-9-2 (0.86).

Table- 9: Estimates of sca effects of crosses for fruit yield and its components in okra.

Crosses	DFP	PH	PB	NOI	MIL	FL	FG	NOR	FW	NFP	YPP
KA-006 × Pusa Sawani	-2.6*	-6.32*	0.89**	12.56**	0.23**	3.52**	6.01**	0.06**	-2.32*	-3.25**	-66.23**
KA-006 × HRB-55	-5.64**	9.8**	0.7**	22.1**	-0.24**	-30.46**	3.71**	0.02	10.07**	2.06**	71.55**
KA-006 × PB-266	0.77	1.97	0.86**	-2.17	0.15	-3.24**	4.07**	-0.001	5.20**	-2.45**	14.25
KA-006 × 101	1.77	-0.51	0.75**	9.69**	0.14**	0.17	3.8**	-0.07**	12.61**	0.44	-24.23
KA-006 × 114	-1.69	-15.26**	0.01	-14.26**	0.23**	0.95	0.36	0.01	2.26	0.52	-254.72**
KA-006 × Larma-1	3.99**	-5.63*	-0.51*	10.02**	0.005	-0.26	-0.58	-0.02	-5.23**	1.25	10.74
KA-006 × Punjab Padmini	0	0.95	0.14	1.82	0.08**	9.94**	1.89	0.15**	-0.02	2.14**	-23.88
KA-006 × Arka Abhay	-7.89**	12.83**	1.08**	17.74**	-0.06**	-7.14**	-0.75	-0.14**	4.46**	3.59**	-78.32**
KA-006 × HRB-9-2	-5.64**	-6.29*	0.17	2.09	-0.01	-10.6**	3.85**	-0.05**	2.45*	-0.3	-65.48**
Pusa Sawani × HRB-55	0.78	6.57*	0.28	7.77**	-0.01	20.56**	1.75*	0.6**	5.71**	2.41**	124.33**
Pusa Sawani × PB-266	-0.01	11.23**	0.26	-2.58	-0.09	0.09	4.21**	-1.23**	1.25	-3.25**	22.13
Pusa Sawani × 101	-3.69**	7.68**	0.43*	-9.56**	0.24**	8.56**	7.53**	0.15**	4.92**	2.18**	12.71
Pusa Sawani × 114	-2.39*	11.97**	-0.78**	9.78**	-0.007	0.88	-5.23**	0.001	-1.56	0.89	23.51
Pusa Sawani × Larma-1	-3.65**	-7.52**	-0.12	-15.72**	-0.5**	1.56	0.92	0.002	3.54**	0.56	175.96**
Pusa Sawani × Punjab Padmini	0.04	0.29	0.6**	1.69	0.09**	5.97**	-0.47	0.12**	2.78*	2.69**	101.56**
Pusa Sawani × Arka Abhay	4.12**	-5.63*	0.63**	-2.85	0.52**	4.56**	1.23*	0.99**	9.78**	0.23	24.31
Pusa Sawani × HRB-9-2	-0.09	0.66	-0.07	5.68**	-0.21**	-0.01	-2.74**	0.01	-9.87**	-2.12**	22.58
HRB-55 × PB-266	1.4	-5.1	0.17	5.68**	0.1	2.26	0.44	0.12**	4.74**	2.05**	17.98
HRB-55 × 101	0.64	0.77	-0.44*	-2.82	0.06	-4.14**	0.65	-0.07**	0.96	0.64	-17.88
HRB-55 × 114	-0.09	-3.32	0.75**	-3.39	-0.09	-8.3**	-3.83**	0.03*	-0.15	-0.99	-132.52**
HRB-55 × Larma-1	-5.64**	7.9**	-0.83**	-12.1**	-0.16**	-36.87**	-6.02**	-0.04*	2.79*	-1.7*	-142.32**
HRB-55 × Punjab Padmini	1.4	9.18**	0.14	16.38**	0.25**	3.17*	4.16**	0.1**	5.52**	-8.79**	164.23**
HRB-55 × Arka Abhay	2.14*	6.06*	0.57**	5.85**	0.1**	12.23**	1.62*	0.14**	3.37**	0.99	31.25*
HRB-55 × HRB-9-2	-1.95*	0.64	0.59**	7.61**	-0.17**	9.72**	-2.75**	-0.06**	9.03**	2.58**	-12.11
PB-266 × 101	-0.68	-8.28**	0.01	1.71	0.1	-0.46	1.07*	0.01	-0.99	0.04	120.32**

Table- 9: Contd...

Crosses	DFE	PH	PB	NOI	MIL	FL	FG	NOR	FW	NFP	YPP
PB-266 × 114	-1.27	2.03	-0.5*	-10.23**	0.01	0.81	-1.93	-0.06**	-0.38	-1.03	-28.32*
PB-266 × Larma-1	3.95**	6.16*	-0.4*	7.53**	0.35**	0.94	1.48**	0.01	6.08**	1.2	12.56
PB-266 × Punjab Padmini	0.04	4.91	0.67**	7.78**	0.15**	0.22	1.85*	0.05**	-0.04	-7.52**	29.98
PB-266 × Arka Abhay	-0.64	-11.45**	-0.43*	-1.49	0.02	4.13**	-2.97**	-0.04*	-0.69	0.69	-23.55
PB-266 × HRB-9-2	0.78	6.57*	0.28	7.77**	-0.01	-5.51**	1.75*	0.6**	5.71**	2.41**	-207.45**
101 × 114	-2.4*	-20.65**	-2.99**	-0.69	-0.32**	6**	5.62**	-0.02	1.65	2.06**	-12.53
101 × Larma-1	2.23*	-13.2**	-0.78**	-12.45**	-0.06**	0.26	-2.25**	-0.05**	-16.28**	-1.2	-21.44
101 × Punjab Padmini	2.5*	3.8	0.54**	-7.75**	-0.24**	-5.14**	4.03**	0.06**	-5.23**	-2.18**	28.39*
101 × Arka Abhay	3.18**	0.47	-0.07	-23.12**	0.01	4.85**	0.39	0.06**	-12.89**	1.38	-27.81*
101 × HRB-9-2	2.4*	3.96	0.86**	7.35**	-0.21**	4.72**	-5.62**	0.03*	0.32	0.76	-41.23**
114 × Larma-1	-1.14	-4.2	0.4*	6.74**	-0.05*	5.48**	-2.87**	0.03*	5.12**	2.35**	24.41
114 × Punjab Padmini	-0.18	12.6**	0.09	-23.98**	-0.45**	-2.42**	-3.39**	-0.03	-4.14**	0.34	176.56**
114 × Arka Abhay	-0.32	-5.13	0.56**	2.37	-0.02	12.32**	1.3	-0.05**	-0.83	2.42**	29.31*
114 × HRB-9-2	1.54	-7.2**	-2.63**	5.57**	0.12**	-4.01**	-0.88	-0.02	3.97**	-1.22	14.45
Larma-1 × Punjab Padmini	1.18	5.66*	0.74**	7.93**	0.02	-3.19**	2.07**	-1.25**	0.85	0.48	29.65*
Larma-1 × Arka Abhay	0.54	-8.32**	-0.47*	-9.94**	0.19**	-0.96	-10.54**	-0.01	-14.25**	-0.49	14.89
Larma-1 × HRB-9-2	-0.32	-12.9**	-0.2	-16**	0.15**	18.26**	0.44	0.14**	-0.68	-7.89**	-298.15**
Punjab Padmini × Arka Abhay	-5.64**	-6.29*	0.17	2.09	-0.01	-5.6**	3.85**	-0.05**	2.45*	-0.3	-195.56**
Punjab Padmini × HRB-9-2	1.68	1.52	-0.53**	-10.89**	-0.01	20.56**	7.94**	2.62**	-15.48**	4.14**	-36.12*
Arka Abhay × HRB-9-2	1.95*	0.07	-0.29	0.06	0.09**	2.58	-12.65**	-2.58**	-10.68**	0.29	16.67

** Significant @ p = 0.01

* Significant @ p = 0.05

DFE= Days to 50%
floweringPH= Plant height
(cm)PB = Primary branches per
plant

NOI= Internodes per plant

MIL= Mean internodal
lengthFW= Average fruit
weight (g)FL= Fruit length
(cm)

NFP= Fruits per plant

YPP= Fruit yield per plant (g)

NOR = Number of ridges

FG = Fruit girth

4.4.3.4 Number of nodes per plant

A total of 19 hybrids manifested positive significant sca effects. The hybrid, KA-006×HRB-55 (22.1) expressed highest significant positive sca effects followed by KA-006×Arka Abhay (17.74) and HRB-55× Punjab Padmini (16.38).

4.4.3.5 Mean internodal length

As many as 12 crosses manifested negative significant sca effects in the desirable direction. A wide range of sca from -0.06 (KA-006×Arka Abhay) to -0.45 (114× Punjab Padmini) was noticed for this trait.

4.4.3.6 Fruit length

A total of 17 crosses exhibited significant positive sca effects out of 45 hybrids; the highest positive significant sca effect was noticed in the cross Punjab Padmini×HRB-9-2 (20.56) and Pusa Sawani× HRB-55(20.56) and the lowest was shown by the cross, HRB-55×Punjab Padmini (3.17).

4.4.3.7 Fruit girth

As many as 20 crosses manifested significant positive sca effects for this trait. The cross, which showed highest significant positive sca effect, was Punjab Padmini×HRB-9-2 (7.94) followed by Pusa Sawani×101 (7.53) and KA-006×Pusa Sawani (6.01).

4.4.3.8 Number of ridges per fruit

Of the 45 hybrids, 18 hybrids expressed significant effects for this trait. The hybrid, Punjab Padmini×HRB-9-2 (2.62) manifested the highest positive sca effect followed by Pusa Sawani×Arka Abhay (0.99) and KA-006×Punjab Padmini (0.15).

4.4.3.9 Fruit weight

As many as 20 crosses exhibited positive significant sca effects for fruit weight per plant which ranged from -2.32 (KA-006× Pusa Sawani) to 12.61 (KA-006×101) among the significant hybrids

4.4.3.10 Number of fruits per plant

Out of 45 hybrids, 13 showed significant positive sca effects for this trait. The hybrid, Punjab Padmini×HRB-9-2 (4.14) expressed highest significant positive sca effects followed by the crosses, KA-006×Arka Abhay (3.59) and Pusa Sawani×Punjab Padmini (2.69).

4.4.3.11 Yield per plant

A total of twelve hybrids manifested significant sca effects from among 45 crosses. The hybrid 114×Punjab Padmini (176.56) manifested the highest positive significant sca effects followed by Pusa Sawani×Larma-1 (175.96) and HRB-55×Punjab Padmini (164.23) in that order.

Table-12: overall specific combining ability status of crosses in okra

Table-10: Overall specific combining ability status of crosses in okra.

Males Females	KA-006	Pusa Sawani (L)		HRB-55 (H)		PB-266 (L)		101 (L)		114 (L)		Larma-1 (L)		Punjab Padmini (H)		Arka Abhay (H)		HRB-9-2 (L)	
		TS	SS	TS	SS	TS	SS	TS	SS	TS	SS	TS	SS	TS	SS	TS	SS	TS	SS
KA-006 (L)		4	H	3	H	-3	L	4	H	2	H	1	H	4	H	4	H	2	H
Pusa Sawani (L)				4	H	0	L	5	H	0	L	-3	L	5	H	-7	L	-3	L
HRB-55 (H)						4	H	-3	L	-2	L	-6	L	9	H	6	H	-1	L
PB-266 (L)								0	L	-2	L	5	H	3	H	-1	L	4	H
101 (L)										0	L	-6	L	-2	L	1	H	-1	L
114 (L)												3	H	2	H	2	L	0	L
Larma-1(L)														2	H	-3	L	0	L
Punjab Padmini(H)																3	H	-5	L
Arka Abhay (H)																		-2	L
HRB-9-2 (L)																			

TS = Total score

Final score = 0.44

H = High overall sca status

L = Low overall sca status

SS = sca status

(H) = High overall gca status of parents

(L) = Low overall gca status of parents

Table- 11: Estimate of variance due to gca and sca effects for fruit yield and its components in okra.

Character	Variance		
	GCA	SCA	GCA/SCA
Days to 50 per cent flowering	205.6	237.1	1:0.86
Plant height	204.7	230.68	1:0.96
Primary branches	0.56	1.05	1:2.11
Number of nodes	5.26	5.60	1:1.06
Mean internodal length	4975.4	4188.2	1:1.84
Fruit length	26.91	17.54	1:1.65
Fruit girth	1.41	1.85	1:1.31
Number of ridges	715.59	934.85	1:1.56
Fruit weight	49.14	51.19	1:1.04
Number of fruits per plant	78.44	106.68	1:1.36
Fruit yield per plant	39.62	81.25	1:2.05

4.4.4 Overall sca status of the crosses

From the results it is evident that nearly 50 per cent of the crosses i.e., 22 hybrids had high (H) overall sca status across the 11 traits and the remaining 23 hybrids had low (L) overall sca status (Table-10).

4.4.6 Relationship between overall gca and sca status

A perusal of Table-10, clearly indicated that the crosses involving one parent with high gca and the other with low overall gca status expressed high overall sca status more frequently than those involving both the parents with either low or high overall gca status.

4.4.5 Variance due to gca and sca effects

It could be observed from Table-11, that variance due to SCA was more than that of GCA for all the characters except for days to 50 percent flowering and plant height.

4.5 Heterosis

Estimates of better, standard and mid-parent heterosis for different characters are presented in Table-12.

4.5.1 Days to fifty per cent flowering

Heterosis in the negative direction is considered as an indication of earliness. Six hybrids showed significant negative mid-parent heterosis and the

Table- 12: Estimates of heterosis for fruit yield and its components in okra

Cross	DFF			PH		
	MPH	BPH	SH	MPH	BPH	SH
KA-006 × Pusa Sawani	11.43**	28.50**	9.33**	5.72**	1.03	-15.36**
KA-006 × HRB-55	-19.15**	-16.63**	-12.76**	-11.35**	-14.50**	-29.71**
KA-006 × PB-266	8.50**	25.16**	6.43**	5.87**	-7.92**	-4.94*
KA-006 × 101	-10.89**	-3.60*	-7.90**	28.13**	23.00**	2.07
KA-006 × 114	-6.95**	2.89*	-5.61**	43.70**	38.63**	13.87**
KA-006 × Larma-1	5.09**	23.03**	1.95	31.63**	14.94**	17.56**
KA006 × Punjab Padmini	1.67	19.64**	-1.75	14.66**	-7.37**	14.84**
KA-006 × Arka Abhay	3.97**	21.68**	0.89	22.64**	4.70*	13.00**
KA-006 × HRB-9-2	17.33**	34.98**	15.34**	-33.37**	-47.80**	-29.71**
Pusa Sawani × HRB-55	15.25**	28.50**	9.33**	1.96	1.03	-15.36**
Pusa Sawani × PB-266	25.94**	25.97**	7.12**	1.66	-7.92**	-4.94*
Pusa Sawani × 101	-1.35	4.71*	-10.91**	17.51**	16.96**	-2.02
Pusa Sawani × 114	9.55**	13.83**	-3.15*	30.31**	29.03**	8.10**
Pusa Sawani × Larma-1	-0.56	0.77	-16.50**	-11.25**	-19.28**	-17.44**
Pusa Sawani × Punjab Padmini	23.42**	25.63**	3.18*	-3.92*	-19.50**	-0.20
Pusa Sawani × Arka Abhay	24.04**	25.66**	4.19*	11.52**	-0.96	6.89**
Pusa Sawani × HRB-9-2	19.65**	19.91**	2.02	26.75**	2.80*	38.43**
HRB-55 × PB-266	9.36**	21.98**	3.72*	3.42*	-7.10**	-4.09*
HRB-55 × 101	-3.47*	1.13**	-3.37*	16.10**	15.58**	-4.09*
HRB-55 × 114	-1.44	5.50**	-3.23*	10.16**	10.09**	-9.46**
HRB-55 × Larma-1	10.62**	25.17**	3.72*	-3.13*	-12.62**	-10.63**
HRB-55 × Punjab Padmini	12.30**	27.70**	4.88*	-0.90	-17.57**	2.18
HRB-55 × Arka Abhay	-0.59	12.44**	-6.77**	-3.72*	-15.17**	-8.45**
HRB-55 × HRB-9-2	-9.69**	29.27**	10.47**	-23.88**	-38.69**	-17.44**
PB-266 × 101	9.64**	16.40**	-1.01	18.57**	6.94**	10.40**
PB-266 × 114	1.09	5.06**	-10.66**	24.15**	11.46**	15.07**
PB-266 × Larma-1	-1.00	0.29	-16.89**	-4.99*	-5.43**	-2.37**
PB-266 × Punjab Padmini	-0.68	1.07	-16.99**	3.41*	-5.24**	17.48**
PB-266 × Arka Abhay	31.47**	33.14**	10.39**	-20.97**	-22.69**	-16.55**
PB-266 × HRB-9-2	28.18**	28.49**	9.26**	-46.05**	-52.35**	-35.83**

** Significant @ p = 0.01

* Significant @ p = 0.05

Table-12:Contd...

Cross	DFF			PH		
	MPH	BPH	SH	MPH	BPH	SH
101 × 114	-6.11**	-4.16*	-12.09**	39.28**	38.58**	14.99**
101 × Larma-1	-1.81	5.70**	-12.41**	-27.48**	-34.32**	-32.83**
101 × Punjab Padmini	-1.87	6.14**	-12.83**	-7.62**	-22.89**	-4.40*
101 × Arka Abhay	-1.95	5.52**	-12.51**	21.77**	7.70**	16.24**
101 × HRB-9-2	3.02**	9.10**	-6.77**	-15.87**	-32.01**	-8.45**
114 × Larma-1	3.55**	9.09**	-9.60**	-10.46**	-19.28**	-17.44**
114 × Punjab Padmini	18.70**	25.63**	3.18*	-3.16*	-19.50**	-0.20
114 × Arka Abhay	19.26**	25.66**	4.19*	12.48**	-0.96	6.89**
114 × HRB-9-2	15.16**	19.39**	2.02	27.71**	2.80	38.43**
Larma-1 × Punjab Padmini	16.09**	16.61**	-4.24*	24.30**	13.43**	40.62**
Larma-1 × Arka Abhay	16.79**	16.79**	-3.23*	-13.86**	-16.12**	-9.46**
Larma-1 × X HRB-9-2	27.29**	29.27**	7.12**	-19.76**	-29.41**	-4.94*
Punjab Padmini × Arka Abhay	29.81**	30.43**	7.12**	-18.02**	-23.32**	-4.94*
Punja b Padmini × HRB-9-2	27.85**	30.43**	7.12**	-26.49**	-29.41**	-4.94*
Arka Abhay × HRB-9-2	12.92**	14.64**	4.94*	-15.54**	-23.92**	2.45*

** Significant @ p = 0.01

* Significant @ p = 0.05

BPH = Better parent heterosis
 SH = Standard heterosis
 MPH = Mid-parent heterosis
 DFF = Days to 50 per cent flowering
 PH = Plant height

Table-12:Contd...

Cross	DFF			PH		
	MPH	BPH	SH	MPH	BPH	SH
101 × 114	-6.11**	-4.16*	-12.09**	39.28**	38.58**	14.99**
101 × Larma-1	-1.81	5.70**	-12.41**	-27.48**	-34.32**	-32.83**
101 × Punjab Padmini	-1.87	6.14**	-12.83**	-7.62**	-22.89**	-4.40*
101 × Arka Abhay	-1.95	5.52**	-12.51**	21.77**	7.70**	16.24**
101 × HRB-9-2	3.02**	9.10**	-6.77**	-15.87**	-32.01**	-8.45**
114 × Larma-1	3.55**	9.09**	-9.60**	-10.46**	-19.28**	-17.44**
114 × Punjab Padmini	18.70**	25.63**	3.18*	-3.16*	-19.50**	-0.20
114 × Arka Abhay	19.26**	25.66**	4.19*	12.48**	-0.96	6.89**
114 × HRB-9-2	15.16**	19.39**	2.02	27.71**	2.80	38.43**
Larma-1 × Punjab Padmini	16.09**	16.61**	-4.24*	24.30**	13.43**	40.62**
Larma-1 × Arka Abhay	16.79**	16.79**	-3.23*	-13.86**	-16.12**	-9.46**
Larma-1 × X HRB-9-2	27.29**	29.27**	7.12**	-19.76**	-29.41**	-4.94*
Punjab Padmini × Arka Abhay	29.81**	30.43**	7.12**	-18.02**	-23.32**	-4.94*
Punja b Padmini × HRB-9-2	27.85**	30.43**	7.12**	-26.49**	-29.41**	-4.94*
Arka Abhay × HRB-9-2	12.92**	14.64**	4.94*	-15.54**	-23.92**	2.45*

** Significant @ p = 0.01

* Significant @ p = 0.05

BPH = Better parent heterosis
 SH = Standard heterosis
 MPH = Mid-parent heterosis
 DFF = Days to 50 per cent flowering
 PH = Plant height

Table-12:Contd...

Cross	PB			NOI		
	MPH	BPH	SH	MPH	BPH	SH
KA-006 × Pusa Sawani	-7.43**	10.00**	-8.53**	17.42**	10.00**	-18.04**
KA-006 × HRB-55	-12.10**	-29.11**	-1.90	-2.82**	-8.66**	-32.42**
KA-006 × PB-266	3.95*	-14.44**	12.32**	23.62**	-3.29*	11.50**
KA-006 × 101	30.00**	17.65**	23.22**	54.92**	36.71**	16.34**
KA-006 × 114	17.62**	-8.90**	40.76**	56.65**	29.85**	28.50**
KA-006 × Larma-1	19.47**	-15.22**	71.56**	65.03**	30.13**	46.80**
KA006 × Punjab Padmini	9.20**	-24.24**	65.88**	40.73**	-1.60	60.18**
KA-006 × Arka Abhay	35.08**	1.69	70.62**	42.75**	2.64*	52.55**
KA-006 × HRB-9-2	-56.04**	-67.30**	-43.13**	-17.95**	-41.97**	-8.89**
Pusa Sawani × HRB-55	-27.17**	-33.90**	-8.53**	10.39**	10.00**	-18.04**
Pusa Sawani × PB-266	-7.57**	-14.08**	12.80**	13.91**	-6.24**	8.10**
Pusa Sawani × 101	-15.9**	-18.91**	-8.53**	29.89**	21.81**	3.66*
Pusa Sawani × 114	30.14**	12.58**	73.93**	46.19**	28.14**	26.80**
Pusa Sawani × Larma-1	-62.71**	-70.96**	-41.23**	0.49	-16.57**	-5.88**
Pusa Sawani × Punjab Padmini	-58.00**	-68.18**	-30.33**	25.27**	-8.80**	49.02**
Pusa Sawani × Arka Abhay	2.36	-14.41**	43.60**	13.3**	-14.95**	26.41**
Pusa Sawani × HRB-9-2	47.77**	21.80**	111.85**	-21.06**	-41.80**	-8.63**
HRB-55 × PB-266	-3.34**	-5.82**	30.33**	15.61**	-5.10**	9.41**
HRB-55 × 101	-32.16**	-40.41**	-17.54**	40.84**	31.64**	12.03**
HRB-55 × 114	-52.1**	-54.60**	-29.86**	15.34**	0.79	-0.26
HRB-55 × Larma-1	-35.74**	-45.90**	9.48**	9.87**	-9.04**	2.61
HRB-55 × Punjab Padmini	-26.26**	-39.83**	31.75**	-2.53*	-29.20**	15.69**
HRB-55 × Arka Abhay	-40.56**	-45.76**	-9.00**	-5.70**	-29.38**	4.97*
HRB-55 × HRB-9-2	-62.37**	-66.21**	-41.23**	-18.51**	-40.05**	-5.88**
PB-266 × 101	25.7**	13.00**	48.34**	25.38**	8.96**	25.62**
PB-266 × 114	16.75**	7.98**	66.82**	21.66**	13.04**	30.33**
PB-266 × Larma-1	-24.15**	-37.47**	26.54**	0.06	-1.02	14.12**
PB-266 × Punjab Padmini	-9.88**	-27.92**	57.82**	-5.91**	-19.76**	31.11**
PB-266 × Arka Abhay	-50.24**	-55.65**	-25.59**	-24.72**	-33.16**	-0.65
PB-266 × HRB-9-2	-61.49**	-66.21**	-41.23**	-45.56**	-52.79**	-25.8**

** Significant @ p = 0.01

* Significant @ p = 0.05

Table-12:Contd...

Cross	PB			NOI		
	MPH	BPH	SH	MPH	BPH	SH
101 × 114	35.65**	13.80**	75.83**	43.04**	33.03**	31.63**
101 × Larma-1	-65.74**	-74.00**	-47.39**	-20.34**	-30.13**	-21.18**
101 × Punjab Padmini	-44.36**	-58.87**	-9.95**	-12.99**	-33.84**	8.10**
101 × Arka Abhay	49.57**	21.47**	103.79**	11.07**	-12.66**	29.80**
101 × HRB-9-2	-34.69**	-47.68**	-9.00**	-13.28**	-33.14**	4.97*
114 × Larma-1	-67.07**	-70.96**	-41.23**	-11.11**	-16.57**	-5.88**
114 × Punjab Padmini	-62.69**	-68.18**	-30.33**	-13.60**	-30.64**	13.33**
114 × Arka Abhay	-10.88**	-14.14**	43.60**	2.11	-14.95**	26.41**
114 × HRB-9-2	29.00**	21.80**	111.85**	16.75**	-4.83*	49.41**
Larma-1 × Punjab Padmini	16.99**	12.55**	146.45**	16.33**	-1.68	60.78**
Larma-1 × Arka Abhay	-62.10**	-65.34**	-29.86**	-23.7**	-32.89**	-0.26
Larma-1 × X HRB-9-2	-40.05**	-44.26**	12.80**	-19.86**	-31.14**	8.10**
Punjab Padmini × Arka Abhay	-41.67**	-48.48**	12.80**	-30.71**	-33.8**	8.10**
Punja b Padmini × HRB-9-2	-42.58**	-48.48**	12.80**	-32.52**	-33.84**	8.10**
Arka Abhay × HRB-9-2	-34.26**	-35.42**	12.28**	-26.52**	-28.48**	12.28**

** Significant @ p = 0.01

* Significant @ p = 0.05

BPH = Better parent heterosis
 SH = Standard heterosis
 MPH = Mid-parent heterosis
 PB = Primary branches
 NOI = Number of internodes

Table-12:Contd...

Cross	MIL			FL		
	MPH	BPH	SH	MPH	BPH	SH
KA-006 × Pusa Sawani	-10.00**	-8.10**	34.11*	47.07**	30.36**	6.78**
KA-006 × HRB-55	-7.75**	-5.22**	36.66**	60.31**	54.35**	26.43**
KA-006 × PB-266	-17.37**	-4.68*	10.90**	-14.38**	-38.34**	14.70**
KA-006 × 101	-40.49**	-34.52**	-17.05**	11.49**	-17.42**	40.52**
KA-006 × 114	-11.31**	7.12**	15.08**	68.96**	35.56**	83.65**
KA-006 × Larma-1	-22.68**	-11.50**	4.41*	65.58**	39.93**	66.09**
KA006 × Punjab Padmini	-30.46**	-19.04**	-7.31**	79.49**	57.81**	70.43**
KA-006 × Arka Abhay	-26.15**	-11.24**	-3.83*	0.89	-22.56**	18.52**
KA-006 × HRB-9-2	-24.01**	-10.28**	0.23	25.73**	-6.81**	58.26**
Pusa Sawani × HRB-55	-7.56**	-6.99**	34.11**	53.50**	40.83**	6.78**
Pusa Sawani × PB-266	-12.96**	-1.89	14.15**	7.92**	-27.68**	34.52**
Pusa Sawani × 101	-9.53**	-2.65*	23.32**	10.99**	-23.86**	29.57**
Pusa Sawani × 114	-12.82**	2.80*	10.44**	60.89**	18.04**	59.91**
Pusa Sawani × Larma-1	-13.67**	-3.44*	13.92**	31.49**	0.81	19.65**
Pusa Sawani × Punjab Padmini	-12.16**	-0.10	14.39**	89.14**	50.00**	62.00**
Pusa Sawani × Arka Abhay	-11.86**	3.42*	12.06**	84.80**	39.94**	114.17**
Pusa Sawani × HRB-9-2	-6.62**	7.68**	20.30**	54.27**	5.89**	79.83**
HRB-55 × PB-266	-12.56**	-2.09	13.92**	16.31**	-18.14**	52.26**
HRB-55 × 101	-17.94**	-12.27**	11.14**	10.78**	-19.93**	36.26**
HRB-55 × 114	-6.41**	9.61**	17.75**	12.35**	-12.39**	18.70**
HRB-55 × Larma-1	-22.83**	-14.25**	1.16	10.24**	-9.67**	7.22**
HRB-55 × Punjab Padmini	-11.39**	0.10	14.62**	29.71**	10.39**	19.22**
HRB-55 × Arka Abhay	-10.34**	4.49*	13.23**	11.32**	-16.76**	27.39**
HRB-55 × HRB-9-2	-10.97**	1.97	13.92**	-2.58*	-29.54**	19.65**
PB-266 × 101	-6.06**	-1.89	14.15**	-8.69**	-12.58**	62.61**
PB-266 × 114	2.44	6.69**	14.62**	-16.15**	-27.54**	34.78**
PB-266 × Larma-1	-5.35**	-4.68*	10.90**	-1.66	-19.45**	49.83**
PB-266 × Punjab Padmini	2.41	3.24*	18.21**	43.33**	13.28**	110.70**
PB-266 × Arka Abhay	-2.94*	0.64	9.05**	-65.79**	-68.82**	-42.00**
PB-266 × HRB-9-2	-0.71	1.34	13.23**	-42.67**	-45.16**	2.00

** Significant @ p = 0.01

* Significant @ p = 0.05

Cross	MIL			FL		
	MPH	BPH	SH	MPH	BPH	SH
101 × 114	-3.07**	5.61**	13.46**	-36.73**	-28.63**	-3.30*
101 × Larma-1	-9.63**	-6.29**	10.56**	-25.95**	-37.15**	6.96**
101 × Punjab Padmini	-4.76*	0.30	14.85**	46.30**	19.57**	103.48**
101 × Arka Abhay	2.47	11.13**	20.42**	-21.82**	-25.75**	26.35**
101 × HRB-9-2	-5.01**	1.34	13.23**	-25.06**	-25.14**	27.39**
114 × Larma-1	1.08	6.04**	13.92**	-5.85**	-11.68**	19.65**
114 × Punjab Padmini	3.08*	6.47**	14.39**	53.29**	37.74**	86.61**
114 × Arka Abhay	1.94	2.37	9.98**	48.46**	39.94**	114.27**
114 × HRB-9-2	9.79**	11.98**	20.30	17.8**	5.89**	79.83**
Larma-1 × Punjab Padmini	-2.20*	-0.70	13.69**	64.63**	57.92**	86.61**
Larma-1 × Arka Abhay	4.05**	8.67**	17.75**	-12.64**	-22.44**	18.70**
Larma-1 × X HRB-9-2	-0.61	2.18	14.15**	-6.75**	-20.79**	34.52**
Punjab Padmini × Arka Abhay	2.45	5.35**	14.15**	3.06*	-12.10**	34.52**
Punja b Padmini × HRB-9-2	0.92	2.18	14.15**	-3.16*	-20.79**	34.52**
Arka Abhay × HRB-9-2	1.11	2.35	11.25**	-19.26**	-23.25**	29.32**

** Significant @ p = 0.01

* Significant @ p=0.05

BPH = Better parent heterosis
SH = Standard heterosis
MPH = Mid-parent heterosis
MIL = Mean internodal length
FL = Fruit length

Table-12:Contd...

Cross	FG			NOR		
	MPH	BPH	SH	MPH	BPH	SH
KA-006 × Pusa Sawani	7.55**	8.16**	-24.10**	-38.57**	-43.95**	-28.70**
KA-006 × HRB-55	-7.32**	-14.33**	-28.36**	-28.94**	-34.99**	-17.79**
KA-006 × PB-266	-23.62**	-41.70**	-21.44**	-34.95**	-41.20**	-23.79**
KA-006 × 101	8.40**	-11.24**	-1.20	29.62**	23.90**	42.60**
KA-006 × 114	24.59**	15.01**	-18.38**	-33.58**	-35.19**	31.99**
KA-006 × Larma-1	7.78**	1.31	-28.10**	-25.65**	-35.50**	-7.92**
KA006 × Punjab Padmini	5.31**	-3.15*	-18.11**	-32.98**	-42.36**	-15.99**
KA-006 × Arka Abhay	-12.15**	-23.83**	-26.36**	-10.01**	-12.96**	-8.67**
KA-006 × HRB-9-2	24.29**	20.64**	-14.38**	-25.92**	-28.93**	-18.83**
Pusa Sawani × HRB-55	-1.30	-9.24**	-24.10**	-42.37**	-42.20**	-26.91**
Pusa Sawani × PB-266	-6.82**	-29.15**	-4.53*	-15.35**	-16.23**	8.82**
Pusa Sawani × 101	14.31**	-6.82**	3.73*	-7.83**	-12.22**	11.66**
Pusa Sawani × 114	59.30**	47.82**	3.73*	-16.92**	-25.85**	-5.68**
Pusa Sawani × Larma-1	5.42**	-0.38	-30.09**	-56.59**	58.95**	-41.41**
Pusa Sawani × Punjab Padmini	11.19**	1.79	-13.98**	-49.29**	-52.51**	-30.79**
Pusa Sawani × Arka Abhay	-23.06**	-33.61**	-35.82**	-36.96**	-44.18**	-29.00**
Pusa Sawani × HRB-9-2	41.38**	37.76**	-3.33*	-37.34**	-40.54**	-24.36**
HRB-55 × PB-266	-22.44**	-37.15**	-15.31**	-31.31**	-32.22**	-11.96**
HRB-55 × 101	-17.76**	-27.99**	-19.84**	-25.99**	-29.31**	-10.61**
HRB-55 × 114	31.60**	13.06**	-5.46**	-26.82**	-34.52**	-17.19**
HRB-55 × Larma-1	3.56*	-9.55**	-24.37**	-57.58**	-60.00**	-42.90**
HRB-55 × Punjab Padmini	1.82	1.26	-14.38**	-49.26**	-52.62**	-30.94**
HRB-55 × Arka Abhay	-35.16**	-39.53**	-41.54**	-50.00**	-55.79**	-44.10**
HRB-55 × HRB-9-2	-6.91**	-16.40**	-30.09**	-51.43**	-53.78**	-41.55**
PB-266 × 101	-28.57**	-34.78**	-12.12**	-21.54**	-26.01**	-9.89*
PB-266 × 114	-0.62	-28.16**	-3.20*	-28.17**	-36.48**	-17.49**
PB-266 × Larma-1	-10.87**	-34.78**	-12.12**	-9.98**	-14.03**	22.72**
PB-266 × Punjab Padmini	-31.15**	-43.97**	-24.50**	-21.37**	-25.64**	8.37**
PB-266 × Arka Abhay	-40.16**	-48.62**	-30.76**	-4.52*	-16.23**	8.82**
PB-266 × HRB-9-2	-41.93**	-56.62**	-41.54**	-24.43**	-29.00**	-7.77**

** Significant @ p = 0.01

* Significant @ p = 0.05

Table-12:Contd...

Cross	FG			NOR		
	MPH	BPH	SH	MPH	BPH	SH
101 × 114	12.35**	-13.52**	-3.73*	3.76*	-3.12*	11.51**
101 × Larma-1	11.88**	-12.68**	-2.80*	-5.51**	-14.66**	21.82**
101 × Punjab Padmini	24.68**	9.69**	22.10**	17.36**	5.03**	53.06**
101 × Arka Abhay	-31.75**	-36.24**	-29.03**	-14.03**	-20.39**	-8.37**
101 × HRB-9-2	-34.28**	-47.49**	-41.54**	-51.63**	-51.82**	-44.54**
114 × Larma-1	14.13**	11.94**	-30.09**	-51.69**	-58.95**	-41.41**
114 × Punjab Padmini	18.97**	1.73	-13.98**	-43.15**	-52.10**	-30.19**
114 × Arka Abhay	-18.10**	-33.61**	-35.82**	-28.4**	-29.04**	-29.15**
114 × HRB-9-2	52.68**	45.20**	-3.33**	-29.61**	-34.03**	-24.66**
Larma-1 × Punjab Padmini	40.58**	22.20**	3.33**	-33.16**	-33.85**	-7.56*
Larma-1 × Arka Abhay	18.83**	-2.20	-5.46**	-31.10**	-41.88**	-17.04**
Larma-1 × HRB-9-2	56.45**	51.60**	0.93	-16.11**	-24.50**	7.77**
Punjab Padmini × Arka Abhay	12.12**	5.10**	1.60	-10.24**	-24.92**	9.42**
Punjab Padmini × HRB-9-2	26.34**	12.91**	-4.53*	-17.54**	-26.46**	7.17**
Arka Abhay × HRB-9-2	28.22**	8.26**	4.66*	6.20**	-1.31	7.86**

** Significant @ p = 0.01

* Significant @ p = 0.05

BPH = Better parent heterosis
 SH = Standard heterosis
 MPH = Mid-parent heterosis
 FG = Fruit girth
 NOR = Number of ridges per fruit

Table-12:Contd...

Cross	FW			NFP		
	MPH	BPH	SH	MPH	BPH	SH
KA-006 × Pusa Sawani	38.96**	36.22**	26.96**	-46.76**	-51.20**	-52.49**
KA-006 × HRB-55	76.83**	67.59**	50.04**	-37.59**	-40.35**	-41.93**
KA-006 × PB-266	8.72**	-8.52**	19.95**	-52.16**	-54.78**	-50.56**
KA-006 × 101	55.9**	37.21**	61.58**	-34.4**	-47.67**	-14.42**
KA-006 × 114	49.33**	26.23**	63.64**	-50.15**	-63.41**	-23.86**
KA-006 × Larma-1	22.25**	-5.37**	54.58**	22.37**	-15.80**	117.97**
KA006 × Punjab Padmini	18.79**	2.68*	26.13**	42.01**	-6.91**	191.37**
KA-006 × Arka Abhay	2.67*	-13.22**	12.53**	51.55**	-0.43*	208.63**
KA-006 × HRB-9-2	-12.36**	-14.32**	-23.29**	50.89**	0.10	198.17**
Pusa Sawani × HRB-55	46.46**	36.22**	26.96**	-44.05**	-46.45**	-52.49**
Pusa Sawani × PB-266	-8.49**	-21.72**	2.64*	-39.55**	-47.35**	-42.44**
Pusa Sawani × 101	-5.82**	-15.65**	-0.66	-60.41**	-70.39**	-51.57**
Pusa Sawani × 114	38.36**	18.92**	54.16**	-48.61**	-64.29**	-25.69**
Pusa Sawani × Larma-1	-20.95**	-37.93**	1.40	21.83**	-20.00**	107.11**
Pusa Sawani × Punjab Padmini	16.01**	2.01	25.31**	16.28**	-26.79**	129.14**
Pusa Sawani × Arka Abhay	45.37**	24.92*	62.00**	48.86**	-6.09**	191.07**
Pusa Sawani × HRB-9-2	66.51**	59.66**	48.80**	68.23**	7.02**	218.78**
HRB-55 × PB-266	5.19**	-23.61**	0.16	-38.19**	-44.01**	-38.78**
HRB-55 × 101	13.70**	-4.45*	12.53**	-46.32**	-58.60**	-32.28**
HRB-55 × 114	8.84**	-11.92**	14.18**	-54.86**	-67.80**	-32.99**
HRB-55 × Larma-1	-31.86**	-49.21**	-17.02**	18.57**	-20.39**	106.09**
HRB-55 × Punjab Padmini	-4.41*	-21.01**	-2.97*	14.73**	-26.37**	130.46**
HRB-55 × Arka Abhay	-22.41**	-37.22**	-18.59**	66.39**	7.01**	231.68**
HRB-55 × HRB-9-2	22.79**	18.94**	1.73	82.25**	18.27**	252.28**
PB-266 × 101	-1.06	-6.10**	23.12**	91.00**	59.34**	160.61**
PB-266 × 114	-9.8**	-10.31**	17.60**	-50.69**	-62.39**	-21.73**
PB-266 × Larma-1	-25.76**	-33.08**	9.32**	12.49**	-20.00**	107.11**
PB-266 × Punjab Padmini	9.27**	5.82**	38.75**	-41.20**	-60.33**	24.16**
PB-266 × Arka Abhay	-25.87**	-26.28**	-3.34*	-69.64**	-79.46**	-36.35**
PB-266 × HRB-9-2	-28.69**	-41.09**	-22.75**	-73.92**	-82.17**	-46.90**

** Significant @ p = 0.01

* Significant @ p = 0.05

Table-12:Contd...

Cross	FW			NFP		
	MPH	BPH	SH	MPH	BPH	SH
101 × 114	14.53**	9.28**	41.67**	9.81**	-1.95**	104.06**
101 × Larma-1	-24.99**	-35.45**	5.44**	-77.75**	-81.84**	-52.99**
101 × Punjab Padmini	4.81*	2.65*	26.09**	-64.64**	-73.08**	-15.74**
101 × Arka Abhay	-4.21*	-8.61**	18.51**	-30.53**	-46.94**	64.47**
101 × HRB-9-2	-19.95**	-30.91**	-18.63**	-70.39**	-77.06**	-31.68**
114 × Larma-1	-30.61**	-37.77**	1.65	-75.83**	78.20**	-43.55**
114 × Punjab Padmini	-0.67	-3.28*	25.39**	-74.52**	-78.79**	-33.60**
114 × Arka Abhay	24.97**	24.99**	62.04**	-71.70**	-76.35**	-26.70**
114 × HRB-9-2	38.43**	14.88**	48.93**	-22.43**	-34.12**	96.24**
Larma-1 × Punjab Padmini	13.90**	-0.23	63.98**	-48.34**	-52.81**	47.72**
Larma-1 × Arka Abhay	-22.01**	-30.05**	14.26**	-76.44**	-78.38**	-32.99**
Larma-1 × HRB-9-2	-17.49**	-37.14**	2.68*	-79.32**	-80.67**	-42.44**
Punjab Padmini × Arka Abhay	-18.67**	-20.82**	2.68*	-80.51**	-80.60**	-39.29**
Punjab Padmini × HRB-9-2	-1.60	-16.54**	2.51*	-80.79**	-81.25**	-41.32**
Arka Abhay × HRB-9-2	-3.77**	-20.15**	3.54*	-80.02**	-80.41**	-39.28**

** Significant @ p = 0.01

* Significant @ p = 0.05

BPH = Better parent heterosis
 SH = Standard heterosis
 MPH = Mid-parent heterosis
 FW = Fruit weight
 NFP = Number of fruits

Table-12:Contd...

Cross	YPP		
	MPH	BPH	SH
KA-006 × Pusa Sawani	-25.89**	-30.79**	-69.30**
KA-006 × HRB-55	9.99**	-0.01	-55.65**
KA-006 × PB-266	-48.55**	-58.63*	-69.83**
KA-006 × 101	-1.14	-28.19**	-29.65**
KA-006 × 114	-30.28**	-53.88**	-36.68**
KA-006 × Larma-1	34.52**	-18.56**	71.40**
KA006 × Punjab Padmini	42.88**	-14.00**	87.19**
KA-006 × Arka Abhay	38.04**	-16.49**	76.46**
KA-006 × HRB-9-2	33.43**	-10.46**	16.07**
Pusa Sawani × HRB-55	-17.89**	-20.24**	-69.30**
Pusa Sawani × PB-266	-46.13**	-58.84**	-69.99**
Pusa Sawani × 101	-64.06**	-74.97**	-75.48**
Pusa Sawani × 114	-33.72**	-57.57**	-41.75**
Pusa Sawani × Larma-1	-14.11**	-49.20**	6.91**
Pusa Sawani × Punjab Padmini	14.05**	-32.89**	46.07**
Pusa Sawani × Arka Abhay	92.21**	13.61**	140.07**
Pusa Sawani × HRB-9-2	43.54**	86.17**	141.32**
HRB-55 × PB-266	-42.72**	-57.11**	-68.73**
HRB-55 × 101	-42.18**	-60.38**	-61.19**
HRB-55 × 114	-55.15**	-71.64**	-61.07**
HRB-55 × Larma-1	-2.40**	-42.79**	20.42**
HRB-55 × Punjab Padmini	-10.44**	-47.75**	13.73**
HRB-55 × Arka Abhay	10.85**	-35.05**	37.23**
HRB-55 × HRB-9-2	119.21**	40.29**	81.86**
PB-266 × 101	15.40**	0.65	-1.40
PB-266 × 114	-55.49**	-65.93**	-53.22**
PB-266 × Larma-1	-18.67**	-45.25**	15.24**
PB-266 × Punjab Padmini	-39.77**	-59.79**	-12.49**
PB-266 × Arka Abhay	-78.03**	-85.22**	-68.77**
PB-266 × HRB-9-2	-79.46**	-83.96**	-79.20**

** Significant @ p = 0.01

* Significant @ p = 0.05

Table-12: *Contd...*

Cross	YPP		
	MPH	BPH	SH
101 × 114	24.90**	7.01**	46.92**
101 × Larma-1	-83.67**	-88.03**	-74.81**
101 × Punjab Padmini	-65.88**	-75.26**	-46.16**
101 × Arka Abhay	-35.91**	-53.10**	-0.89
101 × HRB-9-2	-75.14**	-78.18**	-71.71**
114 × Larma-1	-83.24**	-86.16**	-70.86**
114 × Punjab Padmini	-76.15**	-80.56**	-57.67**
114 × Arka Abhay	-65.33**	-71.40**	-39.57**
114 × HRB-9-2	-56.05**	-57.27**	-41.34**
Larma-1 × Punjab Padmini	13.24**	11.37**	142.41**
Larma-1 × Arka Abhay	-81.54**	-81.58**	-61.07**
Larma-1 × X HRB-9-2	-78.75**	-82.83**	-63.86**
Punjab Padmini × Arka Abhay	-84.36**	-84.59**	-66.46**
Punja b Padmini × HRB-9-2	-82.72**	-86.21**	-69.99**
Arka Abhay × HRB-9-2	-80.81**	-84.52**	-67.28**

** Significant @ p = 0.01

* Significant @ p = 0.05

BPH = Better parent heterosis
 SH = Standard heterosis
 MPH = Mid-parent heterosis
 YPP = Yield per plant

maximum was noticed in the cross, KA-006×HRB-55 (-19.15%) and minimum was by HRB-55×101 (-3.47%).

Among the 45 crosses, three crosses exhibited negative significant better parent heterosis. The highest was noticed in the hybrid, KA-006×HRB-55 (-16.63%) followed by 101×144 (-4.16) and KA-006×101 (-3.62%).

The results indicated that as many as 20 hybrids expressed significant negative standard heterosis. The maximum was contributed by the cross, PB-266×Punjab Padmini (-16.99%) followed by PB-266×Larma-1 (-16.89).

4.5.2 Plant height

Positive heterosis is preferred for this character due to its positive association with pod yield. As many as 22 crosses showed significant positive mid-parent heterosis. The cross, KA-006×114 exhibited the highest mid-parent heterosis of 43.70% followed by 101×114 (39.28%), KA-006×Larma-1 (31.63%) and Pusa Sawani×114 (30.31%) for this trait.

From among the 45 crosses, 14 showed significant positive better parent heterosis. The crosses KA-006×114 (38.63%) followed by 101×114 (38.58%) and Pusa Sawani×114 (29.03%) in that order, were superior for plant height.

As many as 16 hybrids manifested significant standard heterosis with the cross, Larma1×Punjab Padmini (40.62%) recording highest significant positive standard heterosis followed by 114×HRB-9-2 (38.43%).

4.5.3 Primary branches

Among the 14 hybrids which were positively significant for mid-parent heterosis, the cross, 101×Arka Abhay (49.57%) manifested highest positive significant for mid-parent heterosis followed by Pusa Sawani×HRB-9-2 (47.77%) and KA-006×Arka Abhay (35.08%).

The crosses, 114×HRB-9-2 and Pusa Sawani×HRB-9-2 exhibited highest positive significant better parent heterosis of 21.80 per cent followed by 101×Arka Abhay (21.47%) and KA-006×101(17.65%).

Twenty six hybrids manifested significant positive standard heterosis for number of branches. The highest was noticed in the cross, Larma-1×Punjab Padmini (146.45%) followed by the crosses Pusa Sawani×HRB-9-2 (111.85%) and 114×HRB-9-2 (111.85%) over the commercial check US-7109.

4.5.4 Number of internodes per plant

Positive heterosis for this trait is considered as an indicator of higher yield. As many as 23 hybrids expressed significant positive mid-parent heterosis; the highest was noticed in the cross, KA-006×Larma-1 (65.03%) followed by KA-006×114 (56.65 %) and KA-006×101(54.92%).

Twelve crosses manifested significant positive better parent heterosis for this trait; the highest being manifested by the cross, KA-006×101 (36.71%) followed by HRB-55×101 (31.64%) and 101×114 (33.04%).

The cross, Larma-1×Punjab Padmini recorded the highest positive significant standard heterosis of 60.78% followed by KA-006×Punjab Padmini (60.18%) and KA-006×Arka Abhay (52.55%).

4.5.5 Mean internodal length

Negative heterosis is preferred for this trait, as it would provide more fruiting points in the plant. For this character, 32 crosses exhibited significant negative mid-parent heterosis. Among them the lowest was contributed by the cross, Larma-1×Punjab Padmini(-2.2%) and the highest was noticed in the cross, KA-006×101 (-40.49%) followed by KA-006×Punjab Padmini (-30.46%) and KA-006×Arka Abhay (-26.15%).

Significant negative better parent heterosis for this trait ranged from Pusa Sawani×101 (-2.65%) to KA-006×Punjab Padmini (-19.04%).

Three crosses accounted for significant negative standard heterosis among 45 crosses and the highest was noticed in the cross, KA-006×101(-17.05%) followed by KA-006 ×Punjab Padmini (-7.31%) and KA-006×Arka Abhay (-7.31%) over the commercial check US –7109.

4.5.6 Fruit length

Positive heterosis is preferred for this trait. As far as this character is concerned, As many as 28 crosses represented positive significant mid-parent heterosis. The highest was noticed in the cross, Pusa Sawani× Punjab Padmini (89.14%) followed by Pusa Sawani× Arka Abhay (84.88%) and KA-006×Punjab Padmini (79.49%). The lowest was shown by the cross, Punjab Padmini×Arka Abhay (3.06%).

17 crosses were noticed to express significant positive better parent heterosis. The highest heterosis was manifested by the cross, Larma-1×Punjab Padmini (57.92 %) followed by the crosses, KA-006×Punjab Padmini (57.81%) and KA-006×HRB-55 (54.35%)

Of the 45 crosses 42 crosses accounted for positive significant standard heterosis. The highest significant positive standard heterosis resulted from the cross, 114×Arka Abhay (114.27%) followed by Pusa Sawani×Arka Abhay (114.17%) over the commercial check US-7109.

4.5.7 Fruit girth

With the positive heterosis preferred, the highest significant mid-parent heterosis was registered by the cross, Pusa Sawani×114 (59.30%) and the lowest was noticed in the cross, HRB-55×Larma-1 (3.56%).

Fourteen crosses exhibited significant positive better parent heterosis. The highest being expressed by the cross, Larma-1×HRB-9-2 (51.60%) followed by Pusa Sawani×114 (47.82%) and 114×HRB-9-2 (45.20 %).

Five out of 45 crosses showed significant positive standard heterosis. The highest being exhibited by the cross, 101×Punjab Padmini (22.10%) followed by Arka Abhay×HRB-9-2 (4.66%) compared to the commercial check US-7109.

4.5.8 Number of ridges per fruit

Negative heterosis is preferred for this trait, lowest negative significant mid-parent heterosis was registered by the cross HRB-55×Larma-1 (-57.58%) and 41 crosses were negatively significant.

It was observed that 41 crosses registered significant better parent heterosis in the desirable direction. The cross HRB-55×Larma-1 (-60.00%) registered lowest significant heterosis.

As far as standard heterosis was concerned, 31 crosses registered significant standard heterosis. The cross 101×HRB-9-2 (-44.54%) registered lowest significant heterosis.

4.5.9 Fruit weight (g)

Positive heterosis is preferred for this trait; the highest positive significant mid-parent heterosis was observed in the cross, KA-006×HRB-55 (76.83%) followed by Pusa Sawani×HRB-9-2 (66.51%).

Fifteen crosses expressed significant positive better parent heterosis. Among them the highest heterosis was observed in the cross, KA-006× HRB-55 (67.59%) followed by Pusa Sawani× HRB-9-2 (59.66%), KA-006× 101 (37.5%) and KA-006× 114 (26.86%).

As many as 33 hybrids expressed significant positive standard heterosis while, seven crosses showed negative significant heterosis. The cross, Larma-1 × Punjab Padmini manifested standard heterosis as high as 63.98% followed by

KA-006 × 114 (63.64%) and 114 × Arka Abhay (62.04%) over the commercial check US-7109.

4.5.10 Number of fruits per plant

As far as this character was concerned, with positive heterosis being desirable for this trait, the cross, PB-266 × 101 (91.00%) recorded the highest positive significant mid-parent heterosis followed by HRB-55 × HRB-9-2 (82.25%).

Five crosses showed positive significant better parent heterosis. The best cross was 114 × Larma-1 with significant positive better parent heterosis of 78.20% followed by PB-266 × 101 (59.34%), HRB-55 × HRB-9-2 (18.27%).

The estimate of standard heterosis varied considerably and ranged from 24.16% (PB-266 × Punjab Padmini) to 252.28% in the cross HRB-55 × HRB-9-2 followed by Pusa Sawani × HRB-9-2 (218.78%) and KA-006 × Arka Abhay (208.63%).

4.5.11 Fruit yield per plant

Positive heterosis is the most desirable sign in any crop. The estimate of mid-parent heterosis with positive significance ranged from KA-006 × HRB-55 (9.99%) to HRB-55 × HRB-9-2 (119.21%).

The results of the present study revealed that among significantly positive heterotic crosses, the cross Pusa Sawani × HRB-9-2 of 86.17% followed by HRB-

55 × HRB-9-2 (40.29%) and Pusa Sawani × Arka Abhay (13.61%) recorded the highest better parent heterosis.

With regard to standard heterosis, the highest positive standard heterosis was shown by Larma-1 × Punjab Padmini (142.41%) followed by Pusa Sawani × HRB-9-2 (141.32%) and HRB-55 × HRB-9-2 (140.07%).

4.6 Overall status of heterosis

As many as 22 crosses were found to be overall heterotic across the 11 characters (Table-13). Among these, eight hybrids involved KA-006 as one of the parents, reinforcing the potential of this parent.

4.7 Relationship of parental diversity with sca and heterosis.

A perusal of Table-14, clearly indicated that the number of hybrids with high (H) overall sca were more in H × L (14) than either in H × H (3) or L × L (5) category of crosses. Also, their number of overall heterotic crosses was more in H × L (19) than either in H × H (2) or L × L (3) category of crosses (Table-15). Further, it was interesting to note that, given a heterotic cross, the conditional probability of finding it to be a H × L combination was higher (0.66) than the probability of finding it to be either H × H (0.09) or L × L (0.23) combinations. Mean, standard deviation and range of divergence value was calculated (Table-15) for grouping parental divergence into four divergent classes (Table-16)

Table-13: Promising hybrids based on overall heterosis

Sl.no	Overall heterotic hybrids	Parental gca status
1	KA-006 × Pusa Sawani	H × L
2	KA-006 × HRB-55	H × H
3	Pusa Sawani × 101	L × L
4	KA-006 × 114	H × L
5	KA-006 × Punjab Padmini	H × H
6	Pusa Sawani × Punjab Padmini	H × L
7	PB-266 × HRB -9-2	L × L
8	Pusa Sawani × HRB-55	H × L
9	HRB-55 × PB-266	H × L
10	HRB-55 × Arka Abhay	H × L
11	HRB-55 × Punjab Padmini	H × H
12	PB-266 × Punjab Padmini	H × L
13	KA-006 × HRB-9-2	H × L
14	Punjab Padmini × Arka Abhay	H × L
15	Larma-1 × Punjab Padmini	H × L
16	KA-006 × Arka Abhay	H × L
17	114 × Punjab Padmini	H × L
18	114 × Larma-1	L × L
19	KA-006 × 101	H × L
20	PB-266 × Larma-1	L × L
21	KA-006 × Larma-1	H × L
22	101 × Arka Abhay	L × L

Table-14: Distribution of high specific combinations and heterotic crosses in relation to gca status of parents in okra

Category of the class	Number of crosses			Conditional Probability of finding it to be under the category
	Under the category	With high overall sca status	With high overall heterotic status	
H × H	3	3	2	0.095
H × L	20	14	19	0.666
L × L	22	5	3	0.238

Table- 15: Mean (m), standard deviation (s) and range of divergence values.

Statistic	Value
Mean	4987.16
Standard deviation	4567.67
Maximum D^2	14903.77
Minimum D^2	35.22

Table-16: Grouping of parental divergence into four divergence classes (DC)

Sl. No	DC	D^2 Statistic	
1	DC1	$D^2 > \text{or} = (M+S)$	$D^2 \geq 9954.83$
2	DC2	$D^2 (M+S)$ and $>\text{or} = M$	$9954.83 \leq D^2 < 4987.16$
3	DC3	$D^2 > \text{or} = (M-S)$ & $< M$	$4987.16 \leq D^2 < 419.49$
4	DC4	$D^2 > (M)$	$D^2 < 419.49$

4.8 Limits to parental divergence

The probabilities of overall heterotic crosses (that is the crosses showing high magnitude of positive heterosis for more than three characters) were found to be higher in DC2 followed by DC1 (Table-17).

5. Experiment IV - Reaction of varieties and hybrids to fruit borer damage

All the ten varieties and 45 hybrids of okra were screened for reaction to fruit borer based on the scale given by Nath (1966). The percentage infestation of fruit borer and classification of genotypes is given in Tables-18 and 19.

Out of 55 entries screened for fruit borer incidence, none of the genotypes was in Grade I (immune/ no damage), only two genotypes and nine hybrids were in Grade II (1 to 5% resistant) that is Larma-1 and HRB-55 and eight hybrids, PB-266×Larma-1, 114× Punjab Padmini, Arka Abhay×HRB-9-2, Pusa Sawani×Arka Abhay, HRB-55×Punjab Padmini, Arka Abhay× HRB-9-2, Larma-1×Punjab Padmini, KA-006× Larma-1 and KA -006×Punjab Padmini. Grade III (6 to 15%) group accommodated two parents namely 114 and Pusa Sawani and seven hybrids showed moderate resistance and three lines and 20 hybrids showed moderately susceptible reaction to fruit borer infestation in grade IV (16-30% infestation), and remaining three parents and 10 hybrids showed susceptible reaction to fruit borer in grade V (more than 30% of fruit infestation). Among 45 hybrids, only two varieties and eight hybrids were relatively resistant for fruit borer reaction.

Table-17: Distribution of heterotic crosses in different divergent classes (DC)

DC	No of crosses in class	No of overall heterotic crosses	Per cent overall heterotic crosses
DC1	6	3	50.00
DC2	15	10	66.33
DC3	24	10	41.66
DC4	0	0	0.00

Table-18: Classification of okra genotypes with respect to their reaction to fruit borer damage.

Sl No.	Entry	Per cent fruit damage	Grade	Remarks
1	KA-006	22.74	4	Moderately susceptible
2	Pusa Sawani	11.12	3	Moderately susceptible
3	HRB-55	18.7	4	Moderately susceptible
4	PB-266	43.88	5	Susceptible
5	101	70.72	5	Susceptible
6	114	9.00	3	Moderately resistant
7	Larma-1	16.96	4	Moderately susceptible
8	Punjab Padmini	36.39	5	Susceptible
9	Arka Abhay	19.56	4	Moderately susceptible
10	HRB-9-2	78	5	Susceptible

Table-19: Classification of okra hybrids with respect to their reaction to fruit borer damage

Sl No.	Entry	Per cent fruit damage	Grade	Remarks
1	KA-006×PusaSawani	12.32	3	Moderately resistant
2	KA-006×HRB-55	14.5	3	Moderately resistant
3	KA-006×PB-266	21.2	4	Moderately susceptible
4	KA-006×101	25.6	4	Moderately susceptible
5	KA-006×114	12.56	3	Moderately resistant
6	KA-006×Larma-1	16.98	4	Moderately susceptible
7	KA-006×PunjabPadmini	4.25	2	Resistant
8	KA-006×ArkaAbhay	28.2	4	Moderately susceptible
9	KA-006×HRB-9-2	27.55	4	Moderately susceptible
10	PusaSawani×HRB-55	19.6	4	Moderately susceptible
11	PusaSawani×PB-266	46.5	5	Susceptible
12	PusaSawani×101	78.65	5	Susceptible
13	PusaSawani×114	10.15	3	Moderately resistant
14	PusaSawani×Larma-1	4.86	2	Resistant
15	PusaSawani×PunjabPadmini	45.78	5	Susceptible
16	PusaSawani×Arkaabhay	4.45	2	Resistant
17	PusaSawani×HRB-9-2	17.64	4	Moderately susceptible
18	HRB-55×PB-266	47.25	5	Susceptible
19	HRB-55×101	75.62	5	Susceptible
20	HRB-55×114	16.54	4	Moderately susceptible
21	HRB-55×Larma-1	17.65	4	Moderately susceptible
22	HRB-55×PunjabPadmini	2.57	2	Resistant
23	HRB-55×ArkaAbhay	25.55	4	Moderately susceptible
24	HRB-55×HRB-9-2	17.5	4	Moderately susceptible
25	PB-266×101	82.59	5	Susceptible
26	PB-266×114	12.55	3	Moderately resistant

Table19: Contd..

Sl No.	Entry	Percent Fruit damage	Grade	Remarks
27	PB-266 × larma-1	3.54	2	Resistant
28	PB-266 × Punjab Padmini	29.98	4	Moderately susceptible
29	PB-266 × Arka Abhay	17.56	4	Moderately susceptible
30	PB-266 × HRB-9-2	82.56	5	Susceptible
31	101 × 114	8.54	3	Moderately resistant
32	101 × Larma-1	32	5	Susceptible
33	101 × Punjab Padmini	19.65	4	Moderately susceptible
34	101 × Arka Abhay	12.52	4	Moderately susceptible
35	101 × HRB-9-2	56.5	5	Susceptible
36	114 × Larma-1	10.54	3	Moderately resistant
37	114 × Punjab Padmini	4.78		Resistant
38	114 × Arka Abhay	17.57	4	Moderately susceptible
39	114 × HRB-9-2	65	5	Susceptible
40	Larma-1 × Punjab Padmini	2.26	2	Resistant
41	Larma-1 × Arka Abhay	2125	4	Moderately susceptible
42	Larma-1 × HRB-9-2	17.56	4	Moderately susceptible
43	Punjab Padmini × Arka Abhay	20.25	4	Moderately susceptible
44	Punjab Padmini × HRB-9-2	62.5	5	Susceptible
45	Arka Abhay × HRB-9-2	4.58	2	Resistant

DISCUSSION

V DISCUSSION

Most of the breeding procedures in the past were empirical in nature and were based on the breeding structure of the crops. Substantial evidence, however, has been accumulated now to support the view that the breeding procedures can successfully be deployed across the boundaries of pollinating systems in crop plants. This became practicable mainly due to a greater understanding of the nature of gene action and components of genotypic variance for different agronomic traits in crop plants through sophisticated biometrical techniques. Now it is widely accepted that the nature of gene action and past history of selection are as important as the breeding strategy for their improvement.

Whereas, the predominance of additive gene action dictates the type of selection methods to be followed, the predominance of non-additive gene action warrants the use of heterosis breeding. However, the conventional procedure of indiscriminate hybridization on a massive scale entails colossal wastage of resources. Greater success can be achieved by judicious choice of parents for hybridization based on genetic divergence and /or combining ability. In fact, Qualset (1979) opined that most often asked question among the plant breeders is how to choose the parents for crossing? Choosing the parents for hybridization combines the art and science of plant breeding.

Great opportunities are won or lost in decisions made when choosing among the crosses for exploitation. In this context, predicting the magnitude and frequency of heterotic crosses assumes greater significance as divergent parents usually produce greater heterosis than those between closely related ones as was pointed out by Moll and Stuber (1971). However, Moll *et al.*, (1956) observed that heterosis increased with increased divergence, but extremely divergent crosses resulted in a decrease in heterosis. Furthermore, Cress (1966) demonstrated that

“genetic diversity is necessary for significant heterosis but not sufficient to guarantee it”.

It is in this background, the present investigation was undertaken to understand the nature of gene action involved in the expression of different quantitative traits, to arrive at suitable criteria to choose appropriate parents for hybridization and to explore possible limits if any to parental divergence for the occurrence of heterosis.

The results of the present investigation are discussed under the following heads:

1. Analysis of variance
2. Mean performance
3. Components of genotypic variance
4. Combining ability
5. Heterosis
6. Relationship of parental diversity and gca with hybrid sca and heterosis
7. Fruit borer infestation levels

5.1 Analysis of variance

There is a reason to believe that the parents and their hybrids were significantly different from each other for all the characters as evident from ANOVA. This could be because of the diverse nature of the parents, which in turn has produced diverse hybrids, thus justifying the selection of parents for the study. This further provided justification for detection and estimation of components of genotypic variance, combining ability of the parents and the crosses and heterosis.

5.2 Mean performance of parents and hybrids

The parents differed widely in their mean performance for all the characters except plant height and fruit weight. On the contrary, the hybrids varied widely with respect to all the characters. No single parent or a cross, exhibited desirable performance for all the characters. This is expected because the yield and its components are correlated either negatively or positively depending on the particular combination of genes in each parent and the cross.

Among the crosses, PB-266×Punjab Padmini and PB-266×Larma-1 were earlier to flower. The parent Punjab Padmini and the crosses, Larma-1×Punjab Padmini exhibited highest fruit yield per plant. As far as number of fruits was concerned, Punjab Padmini was the best among the parents and the cross HRB-55×HRB-9-2 among the hybrids.

The parent Punjab Padmini expressed highest mean performance for characters *viz*; plant height, primary branches, number of internodes, number of ridges, number of fruits per plant and yield per plant. Singh and Sood (1999) also reported this parent manifesting highest mean performance for these characters. Similarly, the hybrid, Larma-1×Punjab Padmini showed highest mean performance for plant height, primary branches, fruit weight and fruit yield per plant.

It was interesting to note that, Punjab Padmini was one of the parents in majority of the crosses, which manifested highest mean performance for all the characters suggesting the potentiality of Punjab Padmini to nick well with the other parents. These results are similar to the ones reported by Singh and Richaria (1999), Shinde *et al.*(1995) and Vijay and Manohar (1986).

5.3 Components of genotypic variance

The development of a breeding strategy hinges mainly on the support provided by genetic information on the inheritance of major quantitative characters associated with yield, quality or for that matter any economic trait of concern to the breeder. To derive such genetic information, it is necessary to conceive a genetic model in relation to the material that is proposed to be utilized. These processes will, in turn, involve in most cases, the designing of a suitable mating system to fit into the chosen genetic model. Diallel crossing is one such mating system enjoying universal application in plant breeding. In the present study, ten diverse genotypes of okra were crossed in 10×10 half diallel mating design to estimate the components of genotypic variation and the results of the same are discussed below.

Before discussing the results on the estimates of components of variation, an examination for fulfillment of the assumptions of the diallel analysis is important as far as reliability of these estimates are concerned. In the present study the significance of regression coefficient between variance of progeny family means within an array and covariance of progeny family means from unity as well as significance of t^2 value suggested the failure of the assumption of diallel analysis for all the characters except for primary branches and fruit weight per plant.

Therefore, the estimates of additive and dominance components of variation may be confounded with non-allelic interactions when these are present. Nevertheless, the estimates of additive and dominance components still have some predictive value and indicate their relative importance to a certain degree. Hence, the components of variation and other genetic ratios are discussed and their implications are drawn thereof, even for the characters for which diallel assumptions failed.

Additive genetic variance was found to be predominantly significant for the expression of days to fifty per cent flowering and plant height. While dominance genetic variation was predominant for the expression of plant height, fruit weight, number of fruits per plant and fruit yield per plant. Therefore, dominance genetic variance being non-fixable, developing homozygous lines through any selection scheme is limited. Heterosis breeding in general is likely to be most effective for the improvement of fruit yield, while simple selection would be effective in breeding okra with desired maturity duration.

The estimate F, which measures the covariance of additive and dominance effects over the loci, although, varied both in direction and magnitude. The 'F' was significant and negative for pod yield per plant suggesting higher frequency of recessive alleles, they being either increasers or decreaseers in the parental lines. The non-significance of F for all characters except number of fruits per plant and number of ridges indicated equal frequency of dominant and recessive alleles controlling these characters irrespective of whether they being increasers or decreaseers in the parental lines.

The asymmetric distribution of increasing and decreasing alleles controlling all the characters in the parental lines could also be inferred from the ratio of $H_2/4H_1$, which is deviant from 0.25 and the departure from unity of the ratio

$$\frac{(4DH_1)^{1/2} + F}{(4DH_1)^{1/2} - F}$$

In biometrical genetics, breeders are found to work in terms of the average effects of all the gene differences affecting the characters under consideration. These may, however, be resolved into small groups of genes whose effects are statistically separable under certain assumptions and whose numbers are thus capable of estimation. These smallest units of hereditary material recognizable in

biometrical genetics are referred to as effective factors, which may or may not be synonymous with single genes in any particular case (Mather and Jinks, 1982). In the present study, the estimate of the number of effective factors employed is based on 'H', rather than 'D' statistic. This will be a minimal estimate because it assumes equality and absence of oppositions in the 'h's for the individual genes which may not be met in practice. Moreover, the process of estimation involves a number of other assumptions and hence the estimate of the effective number of factors is subject to severe limitations from utility point of view. Further, estimates of additive factors from the 'H' statistic indicate nothing about genes that do not contribute to the 'H' statistic. Obviously, in the present study, the estimates of the number of effective factors are low for all the characters. Nevertheless, it can be concluded that at least one group of genes is involved in the inheritance of all the characters.

The estimates of narrow sense heritability were relatively high only for days to fifty per cent flowering and plant height, which is obvious from the predominance of additive genetic variation for these two characters. Therefore, simple selection may prove effective in altering these two characters as desired by the breeders. Contrastingly, the estimates of narrow sense heritability were of lower magnitude for all other characters and therefore simple selection may not be fruitful in improving these characters. Hence, it could be suggested that hybrid-breeding programme may be the most useful method to improve these characters as already mentioned while discussing the implications of the components of genotypic variance in the beginning of this section.

The positive significant correlation co-efficient between the parental order of dominance for each array and the mean of the common parent of the array suggests that increasing genes are recessive for days to fifty per cent flowering and plant height. Alternatively, the genes, which tend to delay the maturity, are

recessive in nature. On the contrary, genes, which tend to increase plant height in the parental strains, tend to be dominant, as evident from significant negative coefficient between parental orders of dominance and mean of common parent of the array. However, for the remaining characters, dominant genes contained in the parental strains were equally positive and negative. i.e., dominant genes at some loci were increasers while those at the other loci were decreasers.

5.4 Combining ability

From the ANOVA of combining ability, it was evident that parents differed significantly from each other with respect to their gca effects for all the characters. As in principle, gca effects are measures of breeding value of the parents which in turn, are also measures of additive effects of the parents. Significance of parents for their gca effects implies the significance of their breeding and additive values. Similarly, hybrids also differed significantly from each other for all the characters with respect to their sca effects. This suggested the involvement of non-additive based epistasis in the expression of the hybrids.

5.4.1 General combining effects

Days to fifty per cent flowering

The parents 114, Arka Abhay and PB-266 were found to be good general combiners for early flowering implying that these parents transmit additive genes for early flowering in cross combinations. Therefore, these three parents could be used as one of the parents to obtain early flowering hybrids. Earlier, Bendale *et al.* (2004), Thakur *et al.* (1981) and Sambumurthy and Ranganathacharyalu (1998) identified three genotypes exhibiting good general combining ability for early flowering in okra.

If the breeder wishes to develop late flowering hybrids or is interested in isolating late flowering homozygous genotypes, the parents HRB-55 and 101 could be used as one of the parents as these manifested good general combining ability effects for late flowering in segregating populations.

Plant height

The estimates of gca effects differed significantly both in magnitude and direction. However, only three parents namely, KA-006, HRB-55 and Punjab Padmini were found to produce desirable progeny as revealed from their highly significant positive gca effects. Bendale *et al.* (2004), Chaudhary *et al.* (1991) and Poshiya and Vashi (1995) have also identified Punjab Padmini as a good general combiner for plant height, thus establishing the superiority of Punjab Padmini in producing good progeny in combination with other parents.

Number of fruits per plant

All the parents expressed significant gca effects of which three parents, Punjab Padmini, KA-006 and HRB-9-2 expressed highly significant positive gca effects indicating that they have the ability to produce the progeny with higher number of fruits per plant.

From the above discussion it could be visualized that no single parent was a good general combiner for all the characters in the desirable direction. Nevertheless, Punjab Padmini was found to be a good general combiner for all the characters except days to fifty per cent flowering and fruit length. The present study establishes the potential of Punjab Padmini in producing good progeny. Its significant positive gca effects suggests its ability to transmit additive and increasing genes.

A word of caution is worth mentioning here because it is obvious that combining abilities can be used numerically only in the context in which they are calculated. The gca effects of parents are relative and depend upon the overall mean of the crosses of the chosen set of parents.

5.4.2 Overall status of gca effects

Since, the various quantitative traits are correlated either positively or negatively, it is usual to find for a particular parent, gca in the desirable direction for some characters and in the undesirable direction for others. This was found to be true in the present investigation also as could be seen from the discussion on gca effects that no single parent was a good general combiner for all the characters studied. The problem of ascertaining the status of a parent with respect to gca over a number of characters assumes importance in this context. As such, following the method proposed by Arunachalam and Bandyopadhyay (1979), the parents were classified as high (H) and low (L) overall general combiners.

From Table-8, it could be observed that only three of the ten parents namely, HRB-55, Punjab Padmini and KA-006 had high overall gca status. Similar reports were also obtained by Bandyopadhyay and Arunachalam (1980) in *Brassica campestris*, Miller and Marani. (1963), Srivastava *et al.* (1997) and Murthy and Ranganathacharyalu (1998) in okra. The results on the high overall gca status reinforce the utility of Punjab Padmini and KA-006 as potential parents for hybridization.

5.4.3 Specific combining ability effects

Days to fifty percent flowering

The cross, KA-006×Arka Abhay was found to be the best specific combination in the desirable direction as revealed from its significant negative sca effects. Of the 45 crosses, only ten showed significant sca effects; majority of the crosses were of high×low combination i.e., one of the parents had significant positive gca effect while the other had significant negative effect. This suggested the requirement of parental diversity in terms of gca effects for realizing superior hybrids.

Primary branches

By and large the involvement of dominance and dominance-based epistasis must have resulted in the production of ten hybrids with highly positive significant sca effects. Among these ten hybrids, KA-006×Arka Abhay was found to be best specific combiner followed by KA-006×Pusa Sawani and KA-006×PB-266. Among the three hybrids two were of high×low type, further indicating the usefulness of parental diversity in terms of their gca effects for superior expression of hybrids.

Number of internodes per plant

Of the 34 hybrids which exhibited significant sca effects, KA-006×HRB-55 and KA-006×Arka Abhay expressed the highest significant positive sca effect and was found to be a good specific combiner followed by HRB-55×Punjab Padmini.

Number of fruits per plant

The estimates of sca effects for number of fruits per plant varied widely. As many as 13 hybrids showed positive significant sca effects suggesting the major role of non-allelic interaction. The hybrid, Punjab Padmini×HRB-9-2 was the best specific combination followed by KA-006×Arka Abhay, Pusa Sawani×Punjab Padmini. All these crosses were diverse for their gca effects suggesting the necessity of involving diverse parents with respect to their gca effects for evolving superior hybrids.

Fruit weight

Positive significant sca effects of as many as 18 hybrids suggested the non-additive gene action expression of fruit weight, which in fact is true as from the results on SCA and GCA variances. Veeraraghavathatham and Irulappan (1990) have also reported several crosses manifesting significant sca effects for fruit weight in okra.

It was interesting to note that two hybrids Pusa Sawani×HRB-9-2 and PB-266×Larma-1 involved both the parents with negative significant gca effects. This is an instance of low general combiners producing better specific combinations. Such behaviour has been attributed to overdominance and epistasis (Peng and Virmani, 1990). These findings are in agreement with those of Rajani *et al.* (2001), Vermani and Vidyasagar (2000), Bendale *et al.* (2003), Patil *et al.* (1996), Dumbre *et al.* (1990), Ishkumar *et al.* (1975) and Kulkarni *et al.* (1978)

From the discussion on hybrid sca effects, it is evident that, none of the cross combinations were desirable with respect to their sca effects for all the traits

studied; different cross combinations expressed significant sca effects in desirable direction for different characters. Nevertheless, the cross KA-006×Arka Abhay was identified as good specific combination for four important yield attributing characters out of the 11 traits, viz., days to 50 per cent flowering, plant height, primary branches per plant and number of internodes per plant. Another hybrid, Punjab Padmini×HRB-9-2 was found to be a desirable specific combination for fruit length, fruit girth, and number of fruits per plant.

Further, majority of the best specific combinations for most of the characters were also of High×Low type. This clearly establishes the necessity of involving diverse parents as measured by their gca effects to realize high frequency of crosses with high sca effects. This enables the breeder to synthesize only better crosses more often than wasting the limiting resources in producing poor crosses.

5.4.3 Overall sca status of the crosses

As observed for gca effects, none of the crosses were of good specific combination for all the 11 traits studied. Hence, to determine the status of sca effects of crosses over all the traits, a method proposed by Arunachalam and Bandyopadhyay (1979) was employed. From the results it is evident that nearly 50 per cent of the crosses i.e., 22 hybrids had high (H) overall sca status across the 11 traits and the remaining 23 hybrids had low (L) overall sca status (Table-10). Bandyopadhyay and Arunachalam (1980) in *Brassica campestris*, Lokprakash *et al.* (1995) in rice, Vermani and Vidyasagar (1999) and Mamidwar and Mehta (2004) in okra have also reported crosses with high overall sca status.

Based on overall gca effects, the crosses were classified into H×H (both the parents in the hybrid with high overall gca status), H×L (one parent with high and

the other parent with low overall gca status) and L×L (both the parents in a hybrid with low overall gca status).

5.4.5 Relationship between overall gca and sca status

A perusal of Table-10 clearly indicated that the crosses involving one parent with high gca and the other with low overall gca status expressed high overall sca status more frequently than those involving both the parents with either low or high overall gca status. For example, 14 crosses exhibited high overall sca status, which involved one parent with low and the other with high overall gca status (Table-16). Thus, the present study establishes the superiority of high×low combinations in producing crosses with high overall sca status. Bandopadhyay and Arunachalam (1980) in *Brassica campestris*, Singh and Richharia (1978), Lokprakash *et al.*(1995) in rice and Patil *et al.* (1996(a)) in okra have also reported superiority of high×low combinations for realizing high frequency of superior hybrids.

The role of high×low combination in throwing out transgressive segregants was first explained by Langham (1961). Hence, it may be concluded that the crosses involving one parent with high and the other with low overall gca status would be useful in further breeding programmes to isolate desirable segregants in advanced generations.

5.4.4 Variance due to gca and sca

The variances due to sca effects for all the characters except for days to fifty per cent flowering and plant height were significant, suggesting the major role of non additive gene action in the inheritance of these traits. Mehta *et al.* (2001), Bendale *et al.* (2004) and Patil *et al.* (1996(a)) have also reported the

importance of non-additive gene action in the expression of pod yield and its components in okra. Hence, heterosis breeding would be the most preferred method to improve these traits. However, days to fifty per cent flowering and plant height seemed to be predominantly under the control of additive gene action. Predominance of additive gene action is also evident from the higher additive genetic variation (D) than the dominant genetic variation (H_1). Thus, simple selection would be fruitful in manipulating these characters depending on the need of the breeder.

5.5 Heterosis

Magnitude of heterosis and cheaper methods of hybrid seed production are the prerequisites for the success of a heterosis breeding programme. Lower penetration of F_1 hybrids in okra could be attributed to these factors. Several researchers have reported heterosis in okra, with highly variable magnitude. However, the availability of rich genetic resource would help develop heterotic hybrids. Further, this provides an opportunity for the breeders for selecting the transgressive segregants.

In the present study, 45 hybrids derived from 10×10 half diallel mating system were evaluated for the extent of heterosis over mid-parent, better parent and standard check for fruit yield and its contributing characters. The estimates of heterosis are presented in Table-12 and the discussion is mainly centered on three most important traits given below.

Days to fifty per cent flowering

Of the 45 crosses, four crosses exhibited negative better parent heterosis; three hybrids manifested negative significant better parent heterosis, among them

the highest was shown by the cross KA-006×HRB-55 (-16.63%). The highest significant negative standard parent heterosis was shown by the cross PB-266×Punjab Padmini (-16.99%). The cross, KA-006×HRB-55 showed significant negative mid-parent heterosis (-19.15%). Further, all these cross combinations were of High×Low gca category suggesting requirement of parental diversity for realizing heterotic hybrids. Similar observations were also reported by Singh *et al.* (2002), Sivakumar *et al.* (1999), Sood and Jamwal (1999), Sood and Kalia (2001) and Elmaksoud *et al.* (1986) in okra.

Number of fruits per plant

Four crosses exhibited significant positive mid parent and better parent heterosis for this trait. The cross, PB-266×101 had the highest positive significant mid-parent heterosis. The hybrid, 114×Larma-1 exhibited highest better parent heterosis followed by PB-266×101.

With regard to standard heterosis, the hybrid HRB-55×HRB-9-2 expressed highest heterosis followed by Pusa Sawani×HRB-9-2 and KA-006×HRB-9-2 over the commercial check, US-7109. Similar observations were made by Bendale *et al.* (2004), Singh and Sood (1999), Shukla *et al.* (1990) and Raman and Ramu (1963).

Fruit yield per plant

The cross HRB-55×HRB-9-2 manifested highest heterosis over mid parent; the cross Pusa Sawani×HRB-9-2 over better parent and Larma-1×Punjab Padmini over standard check. Pathak and Syamal (1997) have also identified Punjab Padmini as one of the parents in most hybrids, for majority of the traits studied. Further, most of the hybrids which expressed significant standard parent heterosis,

were of high×low gca combination suggesting the necessity of inclusion of diverse parents in realizing heterotic hybrids.

Several research workers *viz.*, Indurani (2000), Borgaonkar *et al.* (2006), Desai *et al* (2007) and Pankaj *et al.* (2004) have also reported higher better parent heterosis in okra.

From the above discussion, it could be observed that no single hybrid expressed significant desirable heterosis over mid-parent, better parent and standard check for all the 11 characters studied. Nevertheless, the hybrid, Larma-1×Punjab Padmini manifested significant standard heterosis for six characters *viz.*, plant height, number of internodes, primary branches, number of ridges, fruit weight and fruit yield per plant. The same hybrid expressed significant better parent heterosis for fruit length.

Most of the heterotic hybrids, except for days to fifty per cent flowering, involved one parent with high general combining ability indicating the utility of crossing parents contrasting for their gca effects for realizing heterotic hybrids. A few high×high and low×low cross combinations also exhibited significant standard, better and mid-parent heterosis suggesting additive×additive type of epistasis. This is true even with the hybrids with high specific combining ability effects as discussed earlier under specific combining ability. Thus, the study clearly establishes the necessity of the use of diverse parents with respect to their gca effects in realizing hybrids with high heterosis and specific combining ability effects.

Several earlier researchers like Pawar (1999), Indurani (2000) and Yadav (2005) also concluded that highly heterotic crosses involved at least one good

general combining parent in okra, thus strengthening the conclusions drawn in the present study.

5.5.1 Overall status of heterosis

As in the case of gca and sca effects, the magnitude and direction of heterosis also varied with character. However, a breeder would be interested in a method to decide whether a cross could be considered overall heterotic or not. Therefore, the logic proposed by Arunachalam and Bandyopadhyay (1979) was used to find a solution for this. Based on this logic, in the present study, as many as 22 crosses were found to be overall heterotic across the 11 characters (Table-14). Among these 22 crosses, eight hybrids involved KA-006 as one of the parents, reinforcing the potential of this parent.

5.6 Relationship of parental diversity with hybrid sca and heterosis.

A perusal of Table-14, clearly indicated that the number of hybrids with high (H) overall sca were more in H×L (14) than either in H×H (3) or L×L (5) category of crosses. Also, the number of overall heterotic crosses was more in H×L (19) than either in H×H (2) or L×L (3) category of crosses. Further, it was interesting to note that, given a heterotic cross, the conditional probability of finding it to be a H×L combination was higher (0.66) than the probability of finding it to be either H×H (0.09) or L×L (0.23) combination. Thus, the present investigation clearly established the unique superiority of H×L crosses. Superiority of H×L crosses was also reported by the studies of similar nature in *Brassica campestris* (Arunachalam and Bandyopadhyay, 1981), pearl millet (Arunachalam and Reddy, 1981); Reddy and Arunachalam, 1981), rice (Lokaprakash *et al.* 1995) and Veeraraghavathatham and Irulappan (1990). The concept of obtaining heterosis by mating divergent genotypes is not new and the

literature is abundant where the superiority of crosses derived from contrasting genotypes, which in the present study were designated as H and L, has been amply demonstrated.

By utilizing exotic (and temperate)×Indian (and tropical) and dwarf×tall crosses, several hybrids and varieties were evolved in sorghum (Rao, 1972). The high×low method of breeding was described in excellent detail by Langham (1961). The theoretical analysis (Cress, 1966) for the occurrence of heterosis indicated that high magnitude of heterosis could be realized if there is directional dominance and wide difference in gene frequency between the parents involved in the cross for different characters.

Thus, the superiority of H×L crosses in the production of heterotic hybrids in okra would be of practical utility to a breeder. When a breeder has to attempt successful hybridization economically (in terms of time, cost and number of crosses), it is worthwhile to start with the H×L type of crosses, followed by L×L for realizing hybrids with high heterosis and sca effects.

5.7 Limits to parental divergence

It is increasingly being realized that crosses between divergent parents usually produce greater heterosis than those between closely related ones as was pointed out by Hayes and Johnson (1939) and East and Hays (1912). But when divergent parents are crossed, heterosis is not found to occur always (Cress, 1966). It is therefore, essential to explore the possible limits to parental divergence within which there are reasonably high chances for the occurrence of heterosis. In the present study, an attempt has been made to examine the existence of such limits to parental diversity for the occurrence of heterosis in plant height, number of primary branches, number of internodes and number of fruits per plant. The results of the same are discussed below.

The probability of overall heterotic crosses (that is the crosses showing high magnitude of positive heterosis for more than 3 characters) was found to be higher in DC2 followed by DC1 (Table-18). It is evident that the parental divergence should be in the limits as defined in DC1 followed by DC2. Alternatively, if the parental divergence is too small, there is meager chance for the occurrence of heterotic crosses. In contrast to the results obtained in the present study, Arunachalam and Bandyopadhyay (1984) showed the superiority of DC2 over DC1 in groundnut and brown sarson. The present study also indicated considerable superiority of DC2 and DC3 classes. The concept that there are limits to parental divergence for optimum expression of heterosis was also set by past studies on crosses among divergent geographic races in maize (Srivastava and Arunachalam, 1977). Thus, the present study establishes the necessity of involving intermediate divergent parents to realize heterotic hybrids. Arunachalam *et al.* (1984(b)) in ground nut, Main and Bahl (1989) in chickpea and Singh and Richaria (1993) in rice have also found higher frequency of heterotic cross coupled with higher magnitude of heterosis for pod yield and its components in crosses between the parents with intermediate divergence than between extreme ones. However, contradictory results were reported by Mridula and Billore (1990) in fababean and Raut *et al.* (1991) in Mung bean who failed to observe any correspondence between parental divergence and heterosis.

5.8 Reaction to fruit borer damage

Okra is subjected to attack by many insect pests of which the fruit borer, *Earias* spp, (Lepidoptera-Noctuidae) is the major one causing damage to an extent of 3.5-90 % (Krishnaih *et al.*, 1976). The larvae bore in to the growing shoots, buds and tender fruits resulting in their shedding and consequently affecting the fruit quality and yield to a considerable extent. Most of the present day cultivars

are susceptible to this pest (Gupta and Yadav, 1978). There are two major species of fruit borer, *Earias insulana* and *Earias vitella* of which *E. vitella* is the dominant one and *E. insulana* is negligible.

In the present study, an attempt was therefore made to find pest resistant genotypes among 10 varieties and 45 hybrids. As many as ten lines showed susceptible reaction. However, eight hybrids; KA-006×Punjab Padmini (4.25 % fruit infestation), Pusa Sawani×Larma-1(4.86%), Pusa Sawani×Arka Abhay(2.0%), HRB-55×Punjab Padmini (4.8%), PB-266×Larma-1(4.86%), 114×Punjab Padmini (4.86%), Larma-1×Punjab Padmini (2.26%) and Arka Abhay×HRB-9-2 (4.58%) were in grade two (1-5 %) while grade three accommodated 7 crosses (6-15 % infestation), such as hybrids KA-006×Pusa Sawani, KA-006×HRB-55, KA-006×114, Pusa Sawani×114, PB266×114,101×114 and 114×Larma-1 which were moderately resistant.

Among the moderately resistant group, the cross, 101×114 (8.54 %) showed lowest infestation followed by Pusa Sawani×114, (10.15 %), 114×Larma-1 (10.54 %), PB-236 (10.1 %) and variety Pusa Sawani (11.12 %). The resistant Arka Abhay×HRB-9-2 had very low mean yield performance (153.69 g) while the hybrid Larma-1×Punjab Padmini had resistant reaction to fruit borer along with considerable mean yield (1138.63 g). The cross PB-266×Larma-1 also had a considerable mean yield (541.32 g) along with moderate resistance to fruit borer along with a considerably higher standard heterosis over commercial check for yield. Hence, Larma-1×Punjab Padmini may be used as a potent hybrid for further breeding programmes for both yield as well as fruit borer resistance, which helps in increasing the profit by reducing the spraying cost for insect control. Multilocation testing of these lines against varying populations of fruit borer should be useful in order to confirm the stability of resistance. Other hybrids having significant and higher standard heterosis for yield were highly susceptible.

5.8 Future line of work

1. The parents Larma-1, 114 and HRB-9-2 are suggested for use as one of the parents to synthesize early maturing hybrids.
2. It is worthwhile to involve Larma-1, Punjab Padmini and HRB-55 as one of the parents to evolve hybrids with higher pod yield coupled with more number of fruits
3. It would be desirable to advance the hybrids, Larma-1×Punjab Padmini, KA-006×HRB-55, to isolate high yielding genotypes from segregating generations.
4. It is worthwhile to initiate crosses involving divergent parents in terms of their gca effects and or genetic divergence to realise higher frequency of heterotic hybrids.
5. It would be desirable to advance the hybrid, Larma-1×Punjab Padmini and KA-006×Punjab Padmini for the production of fruit borer resistant hybrids coupled with higher yield.



Plate-1: general view of experimental plot



Plate-2: borer resistance and borer susceptible hybrids

Larma-1 × Punjab Padmini

PB-266 × 101



Plate-3:Fruits of high heterotic hybrid, Larma-1×Punjab Padmini

SUMMARY

V1 Summary

An investigation was undertaken to evaluate diverse genotypes of okra for their combining ability, to assess nature and magnitude of components of genotypic variation, to understand the relationship between overall gca, sca and heterosis and to explore parental divergence for the occurrence of heterosis. The material for the study comprised of ten parents, which were crossed in 10×10 half diallel fashion to synthesize 45 single cross hybrids. The 10 parents along with their 45 crosses were evaluated in randomized complete block design with 3 replications at the experimental plots of Dept of GPB, UAS, Bangalore during winter 2007-08.

The salient features of present investigation are summarized here under.

Punjab Padmini expressed highest mean performance for earliness, primary branches, number of internodes, number of fruits per plant and fruit yield per plant.

Among the crosses, Larma-1×Punjab Padmini, manifested highest mean performance for primary branches, fruit weight and fruit yield per plant.

Both additive and dominant genetic variances were significant for days to 50 per cent flowering, plant height, mean internodal length, number of fruits per plant and yield per plant while dominance genetic variation was predominant for plant height, fruit weight, number of fruits per plant and fruit yield per plant.

For fruit yield per plant, recessive alleles were more frequent, they being either increasers or decreaseers in the parental lines. For all other characters,

dominant and recessive alleles are equally frequent in the parental lines irrespective of whether they were increasers or decreaseers.

The genes which tend to delay the flowering were found to be recessive in nature in the parental lines. On the contrary the genes which tend to increase plant height in the parental strains were dominant.

No single parent was a good general combiner for all the characters in the desirable direction. However, Punjab Padmini was found to be good general combiner for all the characters except for days to 50 per cent flowering, plant height, number of internodes, mean internodal length and number of ridges. Punjab Padmini, KA-006 and HRB- 9-2 were found to be over all high general combiners across the 11 characters.

None of the cross combinations expressed desirable sca effects for all the characters studied. However, KA-006×Arka Abhay was identified as good specific combination for days to 50 per cent flowering, plant height, primary branches and number of internodes. The cross, Punjab Padmini×HRB-9-2 expressed good specific combination for fruit length, fruit girth, number of fruits per plant and fruit yield per plant. The hybrids involved one parent with high and another with low general combining ability status. Majority of the best specific combinations for most of the characters involved at least one high general combining parent. The crosses which involved one parent with high and other with low overall gca status expressed high overall sca status more frequently than the crosses involving one or both the parents with either low or high overall gca status.

Variance due to sca effects was more than that of gca effects for all the characters except days to 50 per cent flowering and plant height suggesting the major role of non-additive gene action in the inheritance of these traits.

The hybrid, Larma-1×Punjab Padmini expressed significant standard heterosis for plant height, number of internodes, primary branches, fruit length and fruit yield per plant.

Most of the highly heterotic hybrids for all the characters except number of ridges per plant, involved one parent with high and the other with low gca. As many as 23 hybrids were found to be overall heterotic across the 11 characters.

The number of hybrids with high overall sca status was higher in H×L category than either in H×H or L×L category of crosses. Further, the conditional probability of finding a heterotic cross as a H×L combination was higher than the probability of finding it to be either H×H or L×L combination. The present investigation clearly establishes the unique superiority of H×L crosses. It is suggested that when a breeder has to attempt successful hybridization economically it is worth while to start with H×L type of crosses followed by L×L for realizing hybrids with high heterosis and SCA effects.

The parents which had moderate genetic divergence between them produced higher frequency of heterotic crosses than the parents which had extreme genetic divergence, indicating the existence of limits to parental divergence for optimum expression of heterosis.

REFERENCES

VI References

- Adeniji, O. T. and Kehinde, N .B., 2007, Combining ability and genetic components for length and width of pod in West African okra (*Abelmoschus esculentus*). *Agril. J.*, **2**(1): 71-76.
- Ahmed, N., Hakim, M. A., and Zargar, G. H., 1997, Combining ability studies in okra (*Abelmoschus esculentus* (L.) Moench). *Veg. Sci.*, **24**(2): 95-98.
- Ahmed, N., Hakim, M.A. and Gandroo, M.Y., 1999, Exploitation of hybrid vigour in okra (*Abelmoschus esculentus* (L) Moench). *Indian J. Hort.*, **56** (3): 247-251.
- Allard, R. W., 1961, Relationship between genetic diversity and consistency of performance in different environments. *Crop Sci.*, **1**: 47-133.
- Anonymous, 2005, Export Statistics for ABTTO and Food Products, published by Agriculture Produce Export and Marketing Development Authority.
- Anonymous, NCPH, 2005, Precision Farming Development Centre, Government of India, Khanpur.
- Ariyo, O. J., 1993, Multivariate analysis and choice of parents for hybridization in okra (*Abelmoschus esculentus* (L.) Moench). *Theor. Appl. Genet.*, **74**: 361-363.
- Arunachalam, V. and Bandyopadhyay, A., 1979, Are “multiple cross-multiple pollen hybrids” an answer for productive populations in *Brassica campestris* (var.) brown sarson?. *Theor. Appl. Genet.*, **54**: 203-207.
- Arunachalam, V. and Reddy, B. B., 1981, Evaluation of heterosis through combining ability in pearl millet II. *Maharashtra Agri. Univ.*, **16** (3): 357-359
- Arunachalam, V. and Bandyopadhyay, A., 1984, Limits to genetic divergence for the occurrence of heterosis- Experimental evidence from crop plants. *Indian J. Genet .*, **44** (3): 548-554.
- Arunachalam, V., Bandyopadhyay, A., Nigam, S.N. and Gibbins, R.W., 1984(b), Heterosis in relation to genetic divergence and specific combining ability in groundnut (*Arachis hypogea* L.). *Euphytica*, **33**: 33-39.

- Bandyopadhyay, A. and Arunachalam, V., 1980, Are “multiple cross-multiple pollen hybrids” an answer for productive populations in *Brassica campestris* (var.) brown sarson? *Theor. Appl. Genet.*, **16**(3): 357-359.
- Borgaonkar, S. B., Vaddoria, M. A., Dhaduk, H. L. And Poshiya, V. K., 2005, Heterosis in okra (*Abelmoschus esculentus*). *Agri. Sci. Dig.*, **25**(4): 251-253.
- Borgaonkar S. B., Poshiya, V. K., Sharma, K. M., Savargaonkar, S. I. and Minakshi Pati, 2006, Heterosis studies in okra. *Intl. J. Pl. Sci.*, Muzaffarnagar. **1**(2): 246-248.
- Bendale, V. W., Madav, R .R., Pethe, U .B., 2004, Heterosis and combining ability of okra (*Abelmoschus esculentus*). *J. Soils and Crops.*, **14**(2): 269-272.
- Bendale, V .W., Atanur, S. S., Bhave, S. C., Mehta , J. L. and Pethe, U. B., 2003, Genetic Divergence for yield and yield components in okra. *Orissa J. Hort.*, **31**(1): 30-34.
- Bendale, V. W., Madav, R. R., Bhave, S. G. and Pethe, U. B., 2004, Heterosis and combining ability of okra (*Abelmoschus esculentus*) cultivars. *South Indian Hort.*, **56**: 269-271.
- Bhalekar, S. G., Desai, V. T., Nimbalkar, C. A., 2004, Heterosis studies in okra. *J. Maharastra Agril. Univ.*, **29** (3): 360-362.
- Bhalla, S., Verma, B. R. and Thomas, T. A., 1990, Screening of okra germplasm for field resistance to fruit-borer, *Earias spp.* *Indian J. Entomol.*, **51**: 224-225.
- Brar, K. S., Arora, S. K. and Ghai, T. R., 1994, Losses in fruit yield of okra due to *Earias spp.* as influenced by dates of sowing and varieties. *J. Insect Sci.*, **7**: 133-135.
- Chaudhary, D.R., Kumar, Vidyasagar, J. and Sharma, S. K., 1991, Line×Tester analysis of combining ability in okra (*Abelmoschus esculentus* (L.) Moench). *South Indian Hort.*, **39**: 337-340.
- Chauhan, S and Singh, Y., 2002, Heterosis studies in okra. *Veg. Sci.*, **29**(2): 116-118.

- Cress, C. E., 1966, Heterosis of the hybrid related to gene frequency differences between two populations. *Genetics*, **53**: 269-274.
- Das, A. K., Mishra, S. N., Mishra, R. S., 1996, Components of genetic variance and degree of dominance for yield contributing traits in okra, *Orissa. J. Hort.*, **24**(1/2): 18-20.
- Dash, G. B. and Mishra, P. K., 1997, Variation and character association of fruit yield and its component characters in okra (*Abelmoschus esculentus* (L.) Moench). *Curr. Agric. Res.*, **8**: 23-217.
- Desai, S. S., Bendale, V. W., Bhawe, S. G. and Jadhav, B. B., 2007, Heterosis for yield and yield components in okra (*Abelmoschus esculentus* (L.) Moench). *J. Maharashtra Agric. Univ.*, **32** (1): 41-44.
- Dhankar, B. S., and Dhankar, S. K., 2001, Heterosis and combining ability studies for some economic characters in okra. *Haryana J. Hort. Sci.*, **30**(3/4): 230-233.
- Dumbre, A. D., Pawar, P. K., and Pawar, B. B., 1990, Combining ability studies in sesame through diallel analysis. *J. Maharashtra Agric. Univ.*, **15** (2): 211-214.
- Duzyaman, E. and Vunel, H., 2002, Different approaches of the improvement process in some local okra varieties. *Acta Hort.*, **579**: 139-144.
- East, E. M., and Hayes, H. K., 1912, Heterozygosis in evolution and plant breeding, USDA, Bureau of Plant Industry Bulletin., **243**: 1-58.
- Elmaksoud, M.A, Helai, R.M. and Mohammed, M.H., 1986, Studies on an intervarietal cross and hybrid vigour in okra. *Ann. Agric. Sci.*, **29**(1): 431-438.
- Ghai, T. R., Arora, D., Jindal, S. K. and Singh, P., 2005, Assessment of genetic divergence based on nutritional quality and agronomic traits in okra (*Abelmoschus esculentus* (L.) Moench). *J. Genet. Pl. Breeding*, **59** (1): 1-6.
- Griffing, B., 1956, Concept of General and specific combining ability in relation to diallel crossing systems. *Aust. J. Biol. Sci.*, **9**: 463-493.
- Gupta, R. N. and Yadav, R. C., 1978, Varietal resistance of okra (*Abelmoschus esculentus* (L.) Moench) to the borers, *Earias spp. Ind. J. Entomol.*, **40**: 436-437.

- Hayes, H. K., and Johnson, I. J., 1939, The breeding of improved selfing of corn. *J. American Soc. Agron.*, **31**: 710-724.
- Hayman , B. I., 1954 The Theory and analysis of diallel crosses. *Genetics*, **39**: 789-809.
- Indurani, C., Veeraragavathatham, D. and Auxcitia., 2000, Studies on the development of F₁ hybrids in okra (*Abelmoschus esculentus*) with high yield and resistance to YMV. *South Indian Hort.*, **51**(1-6): 219-226.
- Ishkumar, Saini, S. S. and Gagneja, M. R., 1975, Combining ability analysis for yield and yield components in rice. *Crop Improvement.*, **2**: 55-59.
- Jindal , S. K. and Grai, M. T. S., 2005, Diallel analysis for fruit yield and its components in okra. *Veg. Sci.*, **32** (1):30-32.
- Jinks, J. L., 1954, The Analysis of continuous variation in a diallel cross of *Nicotiana rustica* varieties. *Genetics*, **39**: 767-788.
- Jinks, J. L., and Hayman, B. I., 1953, The analysis of diallel crosses Maize. *Genetics Cooper. News letter.*, **27**: 48-54.
- Joshi, Hardas., Bose, T K. and Som, M. G., 1956, *Vegetable crops in India*. Naya Prakash, Calcutta, pp, 606-622.
- Kanchan, M. W., Todkar, L. P., Navale, P. A., 2007, Combining ability studies for seed oil content in okra. *J. Maharashtra Agric. Univ.*, **32**(1): 22-24.
- Korla, B. N. and Sharma, P. P., 1988, Inheritance of seed characters in okra (*Abelmoschus esculentus* (L) Moench). *Farm Sci. J.*, **3** (1): 9-13.
- Krishnaiah, K., Tandon, P. L., Mathur, A.L. and Jaganmohan, N., 1976, Evaluation of insecticides for the control of major insect pests of okra., *Ind. J. Agric. Sci.*, **46**: 178-186.
- Kulkarni, R .S., Swamy Rao, T. and Virupakshappa, K ., 1978, Combining ability in bhendi. *Genetic Agrarian*, **32**: 245-258.
- Kumar, N. S. and Anandan, A., 2006, Combining ability and heterosis for yield characters in okra (*Abelmoschus esculentus*). *Intl. J. Plant Sci.*, **1**(1): 127-129.

- Kumar, S. K., Siram. P. and Kuruppiyah, P., 2006, Studies on combining ability in okra (*Abelmoschus esculentus*). *Indian J. Hort.*, **63**(2): 182-184.
- Langham, D. G., 1961, The high-low method of crop improvement. *Crop. Sci.*, **1**: 376-378.
- Liou-MinLi, Guo-Kieweri, Wu-Shutu, 2002, Combining ability analysis of yield components in okra.. *J. Agri For.*, **51**(2): 1-9.
- Lokaprakash, R., Sivakumar, G., Mahadevappa, M., Shankare Gowda, B. T., Kulkarni, R. S. and Shashidhar, H. E., 1995, Heterosis and combining ability across the traits in selected lines of rice. *Mysore J. Agric. Sci.*, **29** (3): 204-207.
- Mahal, M. S. and Lal, H., 1993, Standardization of a technique for screening okra germplasm for resistance against cotton jassid, *Amrasca biguttula* (Ishida). *J. Insect Sci.*, **6**: 223-225.
- Mahalanobis, P. C., 1936, On the generalized distance in statistics. *Proc. Nat. Inst. Sci., India*. **2**: 49-55.
- Main, M. A.. K. and Bahl, P. N., 1989, Genetic divergence and hybrid performance in chickpea, *Indian J. Genet.*, **49**: 119-124.
- Mamidwar, S. R., Mehta, N., Pethe, V. B., 2004, Heterosis and combining ability of okra (*Abelmoschus esculentus* (L.) Moench.). *J. Interacademia*, **10**(1): 269-272.
- Mather, K. and Jinks, J. H., 1982, (BIOMETRICAL GENETICS) : The study of continuous variation. Chapman and Hall, London, 3rd Edn, 396 pp.
- Mehta, N., Asati, B. S., and Mamidwar, S.R., 2001, Heterosis and gene action in okra *Bangladesh. J. Agri. Res.*, **32**(3):421-432.
- Mehta, Y. R., 2007, Vegetable growing in Uttar Pradesh. Bureau Agric. Inf. U. P. Lucknow.
- Miller, V. E. and Marani, A., 1963, Heterosis and combining ability in diallel crosses of upland cotton (*Gossypium hirsutum* L.). *Crop. Sci.*, **3**: 441-444.
- Moll, R. H., Lonquist, J. H., Velez Fortuno, J. and Johnson, E. C., 1956, The relationship of heterosis and genetic divergence in maize. *Genetics*, **52**: 139-142.

- Moll, R. H. and Stuber, C.W., 1971, Comparisons of response to alternative selection procedures initiated with two populations of maize (*Zea mays* (L.)). *Crop. Sci.*, **11**: 706-711.
- More, D. C. and Patil, H. S., 1997, Heterosis and Inbreeding depression for yield and yield components in okra. *Indian. J. Agric Res.*, **41**(3):141-148.
- Mridula Bargale and Billore, S. R., 1990, Parental diversity, heterosis and inbreeding depression over environments in faba bean. *Crop. Improv.*, **17**(2): 137-137.
- Murthy, J. S. V. S. and Ranganathacharyalu., 1998, Comining ability studies in diallel crosses of Cotton. *Ann. Agri. Res.*, **19**(4): 441-444.
- Nath, P., 1966, Seasonal Pests of Crops, *Indian Farming.*, **3**(4): 8-11.
- Nichal, S. S., Datke, S. B., Deshmukh, D. T., Patil, N. P. and Ujjainkar, V. V. 2001, Diallel analysis for combining ability studies in okra (*Abelmoschus esculentus* (L.) Moench). *Ann. Crop. Physiol.*, **14**(2): 120-124.
- Pal, A. K. and Hossain, M., 2000, Combining ability analysis for seed yield, its components and seed quality in okra (*Abelmoschus esculentus* (L.) Moench). *J. Interacademia*, **4**(2): 216-223.
- Panda, P. K. and Singh, K. P., 1999, Heterosis and inbreeding depression for yield and pod characters in okra. *J. Maharastra. Agril. Univ.*, **23**(3): 249-251.
- Pankaj-Tripathi Yadav, J. R., Tiwari, S. K. and Rajendra Kumar, 2004, Useful heterosis and inbreeding depression for yield and its components in okra. *J. Hort.*, **17**(3): 227-233.
- Panse, V. G. and Sukhatme, P. V., 1985, Statistical methods for agricultural workers. Indian Council of Agriculture Research, New Delhi, pp. 361.
- Pathak, R., Syamal, M. M. and Singh, A. K., 2001, L×T analysis for yield and its components in okra. (*Abelmoschus esculentus*). *Ann. Agri. Res.*, **22**(1): 22-24.
- Patil, Y.B., Madalgeri, B. B., Patil, S. S., Hosamani, R. M. and Biradar, B. D., 1996(a), Implications of heterosis combining ability and *perse* performance of crosses involving diverse okra types. *Karnataka. J. Agric. Sci.*, **9**(2): 294-300.

- Patil, Y. B., Madalgeri, B. B., Biradar, B. D. and Girish Patil, 1996(b)), Heterosis studies in okra. *Karnataka J. Agri. Sci.*, **9**(3): 478-482.
- Pawar, V. Y., Poshia, V. K. and Dhaduk, H. I., 1999, Heterosis studies in okra (*Abelmoschus esculentus*). *Gujarath Agriculture University Res. J.*, **25** (1): 26-31.
- Peng, J. Y. and Virmani, S. S., 1990, Combining ability for yield and its related traits in relation to breeding in rice. *Oryza*, **27**: 1-10.
- Poshiya, V. K. and Shukla, P. T., 1995, Heterosis studies in okra (*Abelmoschus esculentus*). *GAU Res. J.*, **11**(2): 21-25.
- Poshiya, V. K. and Vashi, P. S., 1995, Combining ability analysis over environments in okra (*Abelmoschus esculentus*). Dept. of Agril. Botany. *Gujarath Agriculture University, Junagar*.
- Prakash, M., Kumar, M. S., Saravanan, K., Kannan, K. and Ganeshan, J., 2002, Line×Tester analysis in okra. *Ann. Agri. Res.*, **23**(20): 233-237.
- Pumble, G. D., 1983, Genetic investigation on characters related to biological nitrogen fixation, growth and yield in Groundnut. Ph. D., Thesis submitted to Indian Agriculture Research Institute, New Delhi.
- Qualset, C. O., 1979, Mendelian genetics of quantitative characters with reference to adaptation and breeding in wheat. Proc. Fifth Int. wheat genetics symp., Indian Soc. *Genetics and plant Breeding*, New Delhi, **2** : 577-590.
- Rajani, B., Manju, P., Manikantan Nair. and Saraswathy, P., 2001, Combining ability in okra (*Abelmoschus esculentus*). *J. Trop. Agri.*, **93**(2): 66-69.
- Rajendra Kumar Yadav, J. R., Pankaj Tripathi and Tiwari, S. K., 1990, Evaluating genotypes for combining ability through diallel analysis in okra. *Indian J. Hort.*, **62**(1): 88-90.
- Raman, K. R. and Ramu, N., 1963, Studies on intervarietal crosses and hybrid vigour in bhendi. *Madras Agric. J.*, **60**: 90-91.
- Rao, E. R., 1948, The utilization of multiple measurements in problems of biological classification. *J. Roy. Stat. Soc.*, **10**: 159-203.

- Rao, N. G. P., 1972, SORGHUM BREEDING IN INDIA : Recent developments in sorghum in seventies (eds. Rao, N. G. P. House, L. R.), pp. 101-142. New Delhi, Bombay, Calcutta, Oxford and IBH.
- Raut, N. D., Mridula Bargale and Billore, S. D., 1991, Divergence analysis and heterosis in mung bean. *Crop. Improv.*, **18**(2) : 94-98.
- Reddy, B. B. and Arunachalam, V., 1981, Evaluation of heterosis through combining ability in pearl millet-I, single crosses. *Indian J. Genet.*, **42**(1): 59-65.
- Sambamurthy, J. S. V. and Ranganathacharyalu, N., 1998, Studies on combining ability in bollworms tolerant lines of upland cotton (*Gossypium hirsutum* L). *Annals Agric. Res.*, **19**(20): 227-228.
- Shinde, C. A., Kulkarni, U. G., Ansingakar, A. S. and Nerkar, Y. 1995, Combining ability in okra (*Abelmoschus esculentus* (L.) Moench.). *J. Maharashtra Agril. Univ.*, **20**(1):58-60.
- Shinde, L. A., Kulkarni, U.G., Ansingakar, A. S. and Nerkar, Y. S., 1995, Combining ability in okra. *J. Maharashtra Agric. Univ.*, **20**(1): 58-60.
- Shoba, K. and Marippan, S., 2002, Heterosis studies in okra (*Abelmoschus esculentus*) for some important biometrical traits. *Acta. Hort.*, **752**: 56-59.
- Shukla, A., Pathak, S. C. and Agarwal, R. K., 1997, Effect of some plant odors in the breeding environment on fecundity and hatching of okra shoot and fruit borer, *Earias vitella* fab under laboratory conditions. *Crop Res.*, **13**: 157-161.
- Shukla, A.K., Gautham, N.C., Tiwari, A. K. and Chaturvedi, A.K. 1990, Heterosis and combining ability in okra (*Abelmoschus esculentus* (L.) Moench). *Veg. Sci.*, **16**(2): 191-192.
- Singh, A. K. and Sood, S., 1999, Heterosis and inbreeding depression in okra. *Indian J. Hort.*, **56**(1): 67-72.
- Singh, B. and Singh, S. P., 2003, Combining ability studies in okra (*Abelmoschus esculentus* (L.) Moench). *Plant Archives*, **3**(1): 133-136.
- Singh, B. K., Singh, A. K. and Singh, H. M., 2005, Relative resistance of okra germplasm/varieties against shoot and fruit borer, *Earias vitella* under field conditions. *shushupa*, **12**: 131-133.

- Singh, B., Singh, S. P., Yadav, J. R. and Kumar. R., 2002, Heterobeltiosis and inbreeding depression in okra (*Abelmoschus esculentus* (L.) Moench). *Plant Archives*, **220**: 127-132.
- Singh, B., Srivastava, D. K., Singh, S. K., Yadav, J. R. and Singh, S. P., 2001, Combining ability studies in okra, *Progr. Agric.*, **1**(1): 29-33.
- Singh, N., Arora, S. K., Ghai, T. R. and Dillon, T. S., 1996(a), Combining ability studies in okra (*Abelmoschus esculentus* (L.) Moench). *Punjab Vegetable Grower*. 31: 6-9.
- Singh, N., Arora, S. K., Ghai, T. R. and Dillon, T. S., 1996(b), Heterobeltiosis studies in okra (*Abelmoschus esculentus* (L.) Moench). *Punjab Vegetable Grower*. 31: 18-24.
- Singh, O. K., Gulshan Lal and Rai, P. M., 1993, Performance of okra cultivars under Tarai condition of U.P. *Annals Agri. Res.*, **14**: 220-222.
- Singh, R. S. and Richaria, A. K., 1999, Combining ability for certain quantitative characters in rice. *Oryza*, **15**: 34-38.
- Singh, S. B. and Pal, A. K., 2006, Line×Tester analysis of combining ability in okra. *Indian J. Hort.*, **63**(4): 397-401.
- Sivakumar, S., Ganesan, J. and Sivabramanian, V., 1999, Studies on heterosis breeding in okra. *South Indian Hort.*, **45**(3&4): 107-171.
- Sood, S. and Jamwal, R. S., 1999, Studies on genetic divergence and Interrelationship yield components in seed crop of okra. *Indian J. Hort.*, **47**(1): 85-87.
- Sood, S. and Kalia, P., 2001, Heterosis and combining ability studies for some quantitative traits in okra (*Abelmoschus esculentus* (L.) Moench). *Haryana J. Hort. Sci.*, **30**(1/2): 92-94.
- Sood, S. and Sharma, S. K., 2001, Heterosis and gene action for economic traits in okra *Sabrao* . *J. Breeding. Genet*, **33**(1): 41-46.
- Sood, S., 1999, Heterosis and inbreeding depression in okra (*Abelmoschus esculentus* (L.) Moench). *Advances in Hort and Forestry.*, **6**: 63-71.

- Srivastava, J. P., Singh, H. P. and Singh, M. P., 1997, Genetic divergence and nature of heterosis in okra. *Indian J. Agric. sci.*, **47**(11): 546-551.
- Srivastava, P. S. L. and Arunachalam, V., 1977, Heterosis as a function of genetic divergence in Triticale. *Zeits. Pflanzenzuchtung*, **78**: 269-275.
- Sundari, S., Irulappan, I., Arumugam, R. and Jayasankar., 1992, Combining ability in okra (*Abelmoschus esculentus* (L.) Moench.). *South Indian. Hort.*, **40**: 27-29.
- Thakur, D. N., Desai, K.B., Tikka, S.B. and Patel, K. K., 1981, Combining ability for fruit yield and its components in okra (*Abelmoschus esculentus* (L.) Moench.), *Gujarath Agricultural University Res. J.*, **8**: 14.
- Vahab, M. A., Devi, S. N., Mathew, S. M. and Prabhakaran, P. V., 1994, Genetic divergence in okra (*A. esculentus* (L.) Moench). *Hort. J.*, **7**: 117-120.
- Vasline, A. Y. and Ganesan, J., 1995, Heterosis and Combining ability for certain characters in bhendi. *J. Crop. Improv.*, **22** (1):113-114.
- Veeraragavathatham, D. and Irulappan, I., 1991, Combining ability analysis in certain okra (*Abelmoschus esculentus*) hybrids and parents. *South Indian Hort.*, **39**(4): 193-199.
- Veeraraghavathatham, D. and Irulappan, I., 1990, Genetic analysis in okra (*Abelmoschus esculentus* (L.) Moench). *South Indian Hort.*, **38**: 75-82.
- Vermani, A. and Vidya Sagar., 1999, Implications of mean performance, heterosis and specific combining ability effects on performance of okra crosses. *Crop Res.*, **92**(4): 288-290.
- Vijay, O. P. and Manohar, M. S., 1986, Combining ability in okra. *Indian J. Hort.*, **43**(1/2): 133-139.
- Wankhade, R. K., Kale. P. B. and Dod, V. N., 1997, Studies on heterobeltiosis on okra *PKV Res. J.*, **21**(1):1-4.
- Yadav, J. R., kumar, R., Singh, B., Srivastava, J. P., 2005, Unmasking heterosis artifact in okra. *J. Maharastra Agril. Univ.*, **2**(1): 44-48.