REVIEW OF LITERATURE

The aim and objectives of plant breeding programmes is selection of desirable traits to improve productivity of crop plants. Genetic information on various quantitative as well as qualitative traits, particularly of those that contribute to yield will be useful in implementation of the breeding programme. Okra is an important vegetable crop and the substantial improvement is necessary to enhance the productivity. Research work on okra improvement in the past was concentrated on the development of open pollinated varieties. At present, okra breeders are engaged in development of hybrids. The hybrid seed production is quite easy in okra. In past, number of scientists made efforts to understand extent of heterosis, combining ability of parental lines and nature of gene action. However, the literature on stability is inadequate. In present context, earlier studies on heterosis, combining ability, nature of gene action and G x E interaction has been reviewed in following manner.

2.1 Studies on heterosis

2.2 Studies on combining ability and nature of gene action

2.3 Studies on stability

2.1 HETEROSIS

The term heterosis was first used by shull (1914), which refers to the phenomena in which the F1 hybrid obtained by crossing the two genetically dissimilar homozygous individuals, shows increased or decreased vigour over the parental values. The expression of heterosis may be due to factors such as heterozygosity, allelic interaction such as dominance or over-dominance, non-allelic interaction or epistasis and maternal interactions. The degree of heterosis depends upon the number of heterozygous alleles. The term heterobeltiosis was coined by Fonseka and Patterson (1968), which refers to the increased or decreased vigour of F_1 over its better parent.

Singh *et al.* (1938) reported heterosis in okra for the first time while studying interspecific hybrids between *Hibiscus ficulneus* and *Hibiscus esculentus* and observed heterosis for most of the characters.

Ustinova (1946) reported hybrid vigour for earliness and plant height along with other characters in interspecific hybrids between *Hibiscus esculentus* and *Hibiscus manihot.*

Vijayranhawan and Warior (1946) recorded the increase in fruit weight, fruit size and number of fruits per plant in hybrids of Okra.

Venkatramani (1952) observed the increase in yield of Okra hybrids ranging from 5.4 to 14.5 per cent over the better parent. The increase in yield was attributed to production of more fruits per plant in okra. The plant height of hybrids was intermediate.

Joshi *et al.* (1958) recorded that out of 29 combinations, 11 combinations showed hybrid vigour over taller parent for plant height ranging from 0.2 to 18.5 per cent, while 12 hybrids were intermediate. Range of heterobeltiosis for number of branches was 1.2 to 25.3 per cent but only one combination i.e. Pusa Makhmali x Long White Darbhanga showed significant increase over better parent and eight hybrids were intermediate. Larger fruit size than superior parent was observed in 15 hybrids with a range of 0.17 to 34.78 per cent while 13 combinations were observed to be intermediate. Ten hybrids were superior to better parent for the character number of fruits per plant with a range of 9.68 to 62.12 per cent while, nine combinations were intermediate. Thirteen combinations gave higher fruit yield than superior parent ranging from 0.77 to 51.3 per cent.

Jalnai and Graham (1973) found that four crosses involving two Malaysian and two American varieties exhibited heterosis for early flowering, plant height and yield per plant.

Rao *et al.* (1974) recorded that out of 150 hybrids in okra 10 hybrids exhibited vigour for yield over standard check Pusa Sawani.

Singh *et al.* (1975) observed significant heterosis in 24 hybrids for the different characters viz., Plant height, number of branches per plant, first fruiting node, fruit length, fruit width, number of fruits per plant and yield per plant except days to flower. Range of heterosis for number of branches was between 0.32 to 33.34 per cent, while it was 0.73 to 38.03 per cent for number of fruits per plant, for yield pre plant, heterosis was observed in seven crosses with a range of 6.62 to 52.27 per cent.

Lal et *al.* (1975) recorded significant heterosis (4.76%) for days to first flower. For plant height, the heterosis was 14.29 to 32.11 per cent. Significant heterosis (13.64%) was observed for yield per plant. Similarly, significant heterosis (15.38%) was recorded for number of fruits per plant.

Kulkarni and Virupakshappa (1977) noted heterosis for the characters days to flower, plant height and number of fruits per plant. Cross Dwarf Green x AE-107 showed significant heterosis over the best parent for earliness and plant height. Similarly, significant heterosis for number of capsule per plant was shown by the cross, Sevendhari x AE-107.

Sharma and Mahajan (1978) reported significant heterobeltiosis for days to first flowering, fruit length, plant height, fruit weight and yield per plant.

Singh and Singh (1979a) found significant heterobeltiosis for days to flower (-9.45%), plant height (28.26%), number of branches per plant (64.55%), fruit length (23.15%), number of fruits per plant (71.46%) and fruit per plant (70.28%).

Ahale (1980) studied eight parents and their hybrids in diallel design and recorded heterosis for various quantitative characters viz., yield (58.50%), plant height (36.69%) and fruit length (37.75%). Negative heterosis was observed for the character maturity.

Pratap and Dhankar (1980) while studying 7 x 7 diallel analysis in okra observed that all hybrids were earlier than the better parent for days to flower and range of heterobeltiosis was from -1.59 to -2.06 per cent. Significant heterobeltiosis was recorded for number of branches per plant, ranging from 6.92 to 138.35 per cent, while for number of fruits per plant the range was from

23.33 to 23.94 per cent and for fruit weight was recorded in most of the crosses ranging from -21.34 to 16.63 per cent. Maximum significant heterosis for fruit yield per plant was recorded up to 49.44 per cent.

Elangovan *et al.* (1981) noted that, 16 hybrids showed positive heterosis over better parent for number of branches per plant. Heterosis was also observed for the characters fruit length (4.9%), earliness (5.26%), fruit width (19.90%) and yield (31.42%).

Thaker *et al.* (1982) found positive significant heterosis for the characters yield, fruits per plant and fruit length and also observed useful heterosis for fruit weight in okra.

Changani and Shukla (1985) reported significant positive heterosis over mid-parent and better parent in all hybrids. Pusa Sawni x Red Wonder showed the highest heterosis and heterobeltiosis to the extent of 49.29 and 32.79 per cent, respectively.

Agrrado and Rasco (1986) reported significant heterosis (75%) over better parent for fruit yield. They also observed significant heterosis for the characters plant height, pod length, number of pods per plant, days to flowering, internodal distance and pod diameters.

El-Maksoud *et al.* (1986) recorded heterosis for all the characters except fruit length. The extent of heterosis was 143.87% for plant height, 85.76% for days to flowering, 149.20% for number of fruit per plant and 124.93% for fruit weight.

Poshiya and Shukla (1986a) reported that degree of heterosis was higher for number of pods per plant and yield per plant, medium for first fruiting node, number of nodes on main stem and plant height, while relatively smaller for remaining traits. Hybrid New Selection x AE-91 manifested highest heterosis over mid-parent (29.94%) and better parent (27.77%) for yield per plant.

Vijay and Manohar (1986a) reported heterobeltiosis to the extents of (7.84%) for days to 50 per cent flowering, (53.73%) for pod number,(14.39%) for pod weight,(25.29%) for pod length,(12.22%) for pod thickness,(32.49%) for pod yield,(20.27%) for height at first fruiting node,(32.49%) for plant height,(63.33%) for number of branches and (27.29%) for internodal distance.

Sheela *et al.* (1988) studied fifteen crosses in Okra and recorded negative heterosis for days to flowering and plant height. Standard heterosis of 29.41% was recorded for the character capsule weight. Range of relative heterosis for the character seeds per capsule was -10.40 to 34.14 per cent whereas range was -19.04 to 2.91 per cent for heterobeltiosis and 0.30 to 27.88 per cent for standard heterosis.

Wankhade (1989) reported heterosis over better parent for yield and yield contributing characters.

Chantana and Vicharat (1990) studied mid-parent heterosis in most of the hybrids for the characters number of branches per plant, plant height, number of pods per plant and yield per plant.

Chaudhry *et al.* (1991a) recorded significant heterosis over check, Selection 6-2 (Harbhajan) for the characters days to anthesis, fruit weight and plant height. The cross, Pusa Makhmali x Punjab Padmini manifested highest heterosis for number of fruits per plant and yield per plant and showed overall best performance.

Verrarangavathatham and Irulappan (1991) reported that promising combinations for high yield were AE-974 x AE-180 (P2 x P6), AE-974 x Punjab Padmini (P2 x P1) and AE-974 x Pusa Sawani (P2 x P4). Out of these AE-974 x Pusa Sawani was the highest yielder i.e. 317 g/plant.

Sivagmasundhari *et al.* (1992) observed higher positive heterosis for yield and yield components like fruits per plant, fruit weight and fruit length.

Kumbhani *et al.* (1993) recorded hybrid vigour in okra with eight parents and twenty eight hybrids found heterosis for yield. Two hybrids were showing high heterosis for yield, Padra 18-6 x K5 (21.62%) and Punjab Selection x K5-312 (43.53%). The high heterosis for yield per plant was reported to have resulted from the combined effect of heterosis for yield component characters such as number of pods per plant, pod length, pod girth, plant height and internodal length.

Mandal and Dana (1993) recorded heterosis inbreeding depression in six parental diallel of F1 and F3 generations without reciprocals and observed maximum heterobeltiosis for earliness. The crosses Selection-10 x Punjab Padmini and Selection-4 x Punjab Padmini showed significant heterosis over the best parent for both plant height and fruits per plant.

Dayasagar (1994) studied 6 parental diallel and recorded significant heterobeltiosis for total yield per plant. Significantly heterosis was also noticed in some crosses for number of fruits per plant, fruit weight, fruit length and fruit girth. Cross Pusa Sawani x Parbhani Kranti exhibited highest heterobeltiosis for yield per plant (95.98%).

Mohamad *et al.* (1994) during their study of crosses from four okra varieties observed heterosis for characters like pod weight, flower earliness, number of pods per plant and total yield per plant.

Bauri and Kabir (1996) recorded highest heterobeltiosis for yield and yield contributing characters in the crosses Pusa Sawani x Parbhani Kranti and Pusa Sawani x Arka Anamika.

Patil *et al.* (1996a) observed significant heterotic effects over better parent for yield per plant (121.7%) while studying 10 x 10 half diallel, significant heterotic effects were also observed for plant height (24%), days to 50 per cent flowering (70.4%), internodal length (251.5%), pod length (128.1%) and total pods per plant (53.7%).

Singh *et al.* (1996a) while studying the magnitude of heterobeltiosis in 8 x 8 diallel reported heterosis to the extent of (-6.60%) for days to first flowering, (-16.31%) for node to early flowering, (-5.88%) for days to first fruiting, (98.8%) for total yield, (83.33%) for number of fruits per plant, (16.84%) for fruit length, (21.64%) for average fruit weight and (30.82%) for plant height.

More and Patil (1997) reported that the overall mean heterosis over mid-parent and better parent was highest for fruit yield/plant, 5.65% and 28.94% respectively. It was mostly owing to the heterotic effects of number of fruits/plant, number of fruits/picking and weight of fruit. The average values for inbreeding depression for fruit yield/plant and other characters were similar to those of heterosis, but lower in magnitude. A close relationship between heterosis and inbreeding depression was observed suggesting preponderance of non-additive gene action.

Pathak and Syamal (1997) reported significant heterobeltiosis for days to 50% flowering (-13.04%), Plant height (19.54%), branches per plant (100.67%), fruit per plant (28.83%), pod length (12.25%) and fruit diameter (11.65%). Heterobeltiosis for pod yield per plant ranged from -34.86 to 62.66 per cent.

Panda and Singh (1998) studied heterotic effects and inbreeding depression for six characters in twenty crosses of okra and recorded highest values of heterosis for pod yield and number of pods per plant. The extent of heterosis was (45.62%) for pod yield and (28.32%) for all number of pods per plant.

Ahmed *et al.* (1999) recorded wide range of heterosis over better parent for all the characters. Number of pods per plant recorded maximum heterosis (74.77%) followed by average pod weight (62.59%), number of branches per plant (52.50%), pod yield per plant (36.66%), number of seeds per pod (36.59%), Plant height (26.75%), internodal length (-26.11%), pod length (17.92%) and fruit girth (1.12%).

Pawar et *al.* (1999a) while studying the magnitude of heterosis in 10 x 10 diallel excluding reciprocals observed that the cross combination Kheda-11 x Pusa Sawani showed the highest mid-parent heterosis (41.43%) for yield per plant, For number of pods per plant, only one cross Pusa Sawani x HRB-55 exhibited positive significant heterobeltiosis of (20.23%).

Sood (1999) studied F_1 and F_2 generations of 8 x 8 diallel crosses and noticed that four crosses i.e. P-7 x ABY, P-7 x ANK, P-7 x PKT and PKT x ABY exhibited the maximum heterosis for fruit yield over the standard check. Two crosses PSN x ABY and HBN x ABY had significant heterosis and inbreeding vigour in F_1 and F_2 generations for fruit yield per plant and fruits per plant and they reported that such crosses have the potential to import desirable transgressive segregants in later generations which may lead to the development of a high yielding variety.

Pathak *et al.* (2001) studied heterobeltiosis in 18 hybrids and reported that the heterobeltiosis for pod yield per plant ranged from -34.86 per cent (Arka Abhay x EC 16511) to 62.66 per cent (7D-2 x EC 16511).

Yadav (2002) reported that In general, considerable heterosis over superior and economic parent was observed for all the characters with studying to estimate the heterosis in 10 parental superior and economic lines of okra and their 45 F1s and F2s.Observations were recorded for number of days to flower, plant height, number of branches per plant, length of first fruiting node, length and width of fruit, number of fruits per plant and yield per plant.

Singh *et al.* (2002) revealed that, Heterobeltiosis in okra ranged from -141 percent for length of fruits to 185 percent for number of fruits per plant. Maximum beneficial heterobeltiosis for weight of fruits per plant (yield per plant) was 67.51%. In general, hybrids showed a wide range of heterotic effects for each character. It was further revealed that most of the high heterotic cross combinations for different characters showed high inbreeding depression in F2 generation. This may be due to that the most part of heterobeltiosis was accounted for dominance and dominance x dominance type of epistatic interactions and less for additive x dominance type of gene effect.

Rewale *et al.* (2003) reported significant heterotic effects in positive direction for all eight yields and yield contributing characters. The crosses SOH-02 x PK and SOH-02 x GF exhibited desirable negative and significant heterotic effects for all characters. The cross DVR-3 x G-6 had recorded significant heterosis for yield per plant, fruit per plant, nodes per plant and plant height. The crosses JHDO-5 x PK (153.43%) and NOL – 101 x G-6 (143.79%) showed higher magnitude of heterosis over better parent.

Bhalekar *et al.* (2004) studied heterosis for yield and yield attributes in okra, recorded highest significant heterosis for fruits per plant and yield per plant in Varsha Uphar x Lorm 1, Arka Anamika x Parbhani Kranti and Arka

Anamika x Lorm 1. The highest heterosis over better parent for yield was in A.A.D.F. 1 x Arka Anamika (19.29%) followed by Arka Anamika x Lorm 1 (14.85%), Varsha Uphar X Lorm 1(15.13%) and Arka Anamika X Parbhani Kranti (13.96%).

Borgaonkar *et al.* (2005) while studying heterosis using 8 x 8 diallel design found that 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% flowering, number of days to first picking and fruit girth. No. 129 X JNDO-5 exhibited the greatest heterobeltiosis (52.22%) for yield per plant.

Singh *et al.* (2006) studied 60 crosses and reported significant heterosis in 16 crosses for days to 50% flowering, in 17 crosses for 1st fruiting node, fruit length and fruit yield/plant, 22 crosses for fruit weight, 21 crosses for fruit diameter, 26 crosses for plant height, 18 crosses for internodal length, 2 crosses for number of branches per plant and 19 crosses for number of fruits per plant.

Mamidwar and Mehta (2006) studied heterobeltiosis for yield and yield components using 14 x 3 Line x tester design. Among the hybrids, heterobeltiosis was greatest in Daftari-1 x Arka Abhay for number of days to first flowering and number of days to 50% flowering, VRO-6 x Parbhani Kranti for fruit weight and fruit yield per plant, VRO-5 x Arka Abhay for fruit length and plant height, OV x Arka Anamika for number of seeds per fruit and VRO-3 x Arka Anamika for 100 seed weight.

Senthilkumar *et al.* (2007) while studying the magnitude of heterosis in 6 x 6 diallel including reciprocals observed that the cross combination Punjab Padmini x Parbhani Kranti showed the highest standard heterosis of (86.80 %) for fruit yield per plant.

Desai *et al.* (2007) studied 28 crosses and reported Parbhani Kranti x Gold Finger recorded superior performance for plant height, nodes plant-1, fruit weight, fruit plant-1, and yield plant-1.

Hosamani *et al.* (2008) in Line x Tester analysis observed that cross "IC-90044 x Parbhani Kranti expressed high mean values compared to the parents and hybrids for number of fruits per plant (27.00) and fruit yield per plant (422.33 g). This cross exhibited 6.63% desirable heterosis over standard check for the same trait which contributes to high yield.

Dabhi *et al.* (2009) studied heterosis for fruit yield and its component using 12 x 4 Line x Tester, recorded maximum heterosis of (32.08%) KS-404 x Arka Abhay and (20.04%) PB-266 x Arka Abhay for fruit yield. Maximum heterosis over better parent of 66.67% was observed for number of nodes at first flowering in the hybrid JOL-1 x Punjab-7 whereas, the highest standard heterosis was depicted by the hybrid KS-404 x Punjab-7 of (49.62%) for number of fruits per plant.

Singh *et al.* (2009) observed heterosis for pod size, pod weight, yield per plant and number of seeds per pod through diallel cross.

Wammanda *et al.* (2010) reported significant heterosis over better parent for earliness, plant height and fruit number per plant in 9 x 9 diallel cross analysis of okra.

Akhtar *et al.* (2010) studied heterosis in 30 hybrids and reported that the maximum heterosis (55.20%) for fruit per plant, followed by number of branches per plant (47.21%), green fruit length (37.83%), Plant height (35.22%), number of seeds per fruit (34.50%), number of fruits per plant (30.32%), green fruit weight (19.87%), days to 50% flowering (-17.03%), days to 50% flowering (-22.86%) and fruit diameter (-15.49%).

Patel *et al.* (2010) while studying heterosis, heterobeltiosis and inbreeding depression for fruit yield and their attributes, reported that positive and significant heterobeltiosis was observed in KS-404 x HRB-108-2 and VRO-5 x GO-2 for fruit length and fruit yield per plant. Similarly, significant and positive relative heterosis has been depicted in KS-404 x HRB-108-2 for number of nodes per plant, number of fruits per plant, and fruit length and in VRO-5 x GO-2 for number of fruits per plant and fruit yield per plant. Moderate to high amount of inbreeding depression was observed for all the traits.

Kachhadia *et al.* (2011) studied heterosis for fruit yield and its component traits over three environments and reported maximum heterosis over better parent of (66.87%) for number of branches per plant in the hybrid Pant Bhendi x HRB-55, highest standard heterosis was depicted by the hybrid JOL-06-S-5 x HRB-55 of (78.43%) for fruit yield per plant. The 3 crosses manifested significant and desirable heterobeltiosis and standard heterosis viz., JOL-06-S-5 x HRB-55 (47.05 and 78.43 %), JOL-06-3 x Pusa Sawani (37.89 and 36.08%) and GO-2 x Parbhani Kranti (24.34 and 63.04%).

Vachhani *et al.* (2011) studied heterosis and inbreeding depression for fruit yield and yield components in F_1 and F_2 generations of 10 x 10 diallel crosses excluding reciprocals and reported that high magnitude of heterotic effects detected for fruit yield per plant, number of fruits per plant, 10-fruits weight and internodal length. The cross combination AOL-99-24 x Ajeet -121 expressed the highest heterobeltiosis along with high magnitude of inbreeding depression for fruit yield per plant.

Kumar (2011) studied 42 crosses from 7 x 7 diallel including reciprocals and found that the standard heterosis ranged from -23.95 to 55.96 per cent for fruit yield per plant. The cross Pusa A4 x Punjab Padmini exhibited the highest magnitude of heterosis (43.23 and 55.96%) for fruit yield per plant, (14.81 and 52.44%) for number of branches per plant, (13.52 and 29.78%) for number of fruits per plant over better parent and Sakthi.

Singh and Singh (2012) studied 45 crosses for ten characters including pod yield per plant over three different environments and reported that 4 crosses showed high per se performance and heterobeltiosis across the environments.

Bassey *et al.* (2012) while studying 42 crosses from 7 x 7 diallel including reciprocals for 16 morphological characters. Highest better parent heterosis of (131.15%) for number of branches per plant recorded from the cross Lady Finger x Jokoso.

2.2 COMBINING ABILITY AND NATURE OF GENE ACTION

The combining ability analysis gives useful information regarding the selection of parents in terms of performance of their hybrids. Selection of parents on the basis of phenotypic performance alone is not a sound procedure, since phenotypically superior lines may not lead to expected degree of heterosis. Therefore, selection of potential parents, based on genetic information and knowledge of their combining ability is very important. The combining ability concept was first proposed by Sprague and Tatum (1942) in corn. According to them, the general combining ability (*gca*) is the comparative ability of the line to combine with other lines. It is deviation of the mean performance of all the crosses involving a parent from overall mean. Specific combining ability (*sca*) was defined as the deviation in the performance of specific cross from the performance expected on the basis for general combining ability effects of parents involved in the crosses. A positive general combining ability (*gca*) indicates a parents that produces above average progeny, whereas parent with negative general combining ability (*gca*) effects produces progeny that performs below average of the population. Specific combining ability (*sca*) can be either negative or positive and *sca* always refers to specific cross and never to particular parent by itself.

The most commonly used designs for combining ability studies are line x tester (L x T) and diallel analysis. Combining ability analysis following line x tester technique given by Kempthorne (1957). These are frequently used for testing the performance of lines in hybrid combinations. It is also useful in characterizing the nature and magnitude of gene action involved in controlling the quantitative traits.

The general and specific combining ability effects and variances obtain from a set of F1s would enable a breeder to select desirable parents and crosses for each of the quantitative components separately. Sprague and Tatum (1942) from their result concluded that, the general combining ability was largely the result of additive gene action, while the specific combining ability due to dominance, epistasis and genotypic environment interaction.

The reports of earlier workers on combining ability and gene action in okra it can be stated that days to first flowering, days to 50 per cent flowering, number of branches per plant, plant height, number of fruits per plant, days to edible fruit maturity, number of ridges on fruit, fruit length, fruit diameter, fruit weight, number of seeds per fruit and fruit yield showed predominance of GCA variance implying additive gene action. SCA variance and non-additive genetic control were also observed for all the above characters in okra. Whereas for plant height both additive and non-additive gene actions were predominant. The yield is a complex character where a majority of workers have reported the predominance of SCA variance implying non-additive gene action.

Joshi *et al.* (1958) studied the combining ability in 6 parents and their 29 hybrids that eight edge varieties were better combiner showing good general and specific combining ability effects. Best *gca* effects and highest average yield was obtained when long White Darbhanga (8 edged) was used as female parent. Long white Darbhanga and Pusa Makhmali were the best specific combiners and recorded the highest yield.

Rao and Ramu (1979) reported that variances due to *gca* and *sca* were observed to be highly significant for all the characters but the magnitude of *gca* was more in case of days to flowering, number of pods per plant and yield per plant indicating the role of additive gene action for three traits. Magnitude of *sca* variance was more for plant height and seeds per pod indicating predominant role of non-additive gene action.

Sharma and Mahajan (1978) examined 64 hybrids and 20 parents recorded that *sca* effects were higher for all the characters like days to flower, number of fruits per plant, fruit length and diameter, number of ridges per fruit, plant height and yield per plant indicating predominance of non-additive gene effects. The tester Pusa Sawani was reported to be the best general combiner for all the characters except for fruit diameter and fruit weight.

Singh and Singh (1978) estimated genetic variances by full sib and half sib analysis among the F_1's and F_2's population of 125 hybrids obtained by crossing 25 lines with 5 testers. Predominant role of non-additive gene action was observed in both the germinations and five parents were found to be good combiners. The per cent contribution to the sum of squares due to hybrids was higher than due to lines testers for all the characters except internodal distance in the F_1 and for internodal distance, plant height and first fruiting node in F_2, indicating high estimate of variance due to specific combining ability.

Pratap and Dhankar (1980) reported that *gca* and *sca* variances were highly significant for all the characters except fruit yield per plant. The ratio of genetic components indicated the additive genetic effects for days to 50 per cent flowering and both additive and non-additive effects for fruit yield per plant. The estimates of *sca* indicated that no cross combination was consistently good for all the characters.

Elangovan *et al.* (1981) studied combining ability using 14 lines and 4 testers, for most the characters predominance of non-additive gene action was confirmed as the *sca* variances were greater than *gca* variances. Tester AE 108 and line AE 1068 were reported to be good general combiners for yield of fruits per plant. Tester AE 180 was also good combiner for number of branches, fruit length and fruit width. High *sca* effects were expressed in hybrids involving high x high or high x medium or low x low combiners.

Singh and Singh (1984) observed that none of the parents was found to be good general combiner for all the traits; however one each was superior combiner for fruits per plant and fruit length, two for fruit thickness and plant height including yield per plant in the $F_1$and F_2 generations. In most of the characters, *gca* effects were high in magnitude indicating presence of additive genetic variation whereas in some of the characters including yield the variances due to *sca* effects were high indicating predominance of non-additive genetic variance.

Poshiya and Shukla (1986b) studied 7 x 7 diallel excluding reciprocals and reported significant mean squares due to specific combining ability for fruit per plant. But for other traits like days to 50 per cent flowering, fruit length, number of fruits per plant and nodes on main stem, both general and specific combining ability effects wassignificant, Pusa Sawani and Pegrin for days to 50 per cent flowering. AE-91 and Pegrin for fruit length, Kheda-8 and Pusa Sawani for fruit girth, new selection, AE-91 and Pegrin for nodes on main stem and Pegrin for nodes on main stem were good general combiners. New selection x AE-91 appeared to be desirable cross combination to be exploited for pod yield.

Vijay and Manohar (1986b) reported that the *gca* effects were highly significant for all the characters except height at first fruiting node. *Sca* effects were highly significant for all the characters.

Chaudhari *et al.* (1991b) reported that Pusa Makhmali was good combiner for yield per plant, fruit weight, fruits per plant and fruit diameter. Pusa Sawani x P-7 had shown the highest *sca* effects for yield per plant and fruits per plant. Dominance component of variance were greater than the additive components for traits indicating the role of non-additive gene action.

Veeraragavathatham and Irulappan (1991) observed that *gca* variance were significant for most of the traits which indicated the predominance of additive gene action.

Sundahri *et al.* (1992) noticed that the *gca*/*sca* ratios were less than unity indicating the role non-additive gene action. Arka Abhay was the best general combiner for yield and number of fruits per plant.

Arora (1993) indicating the study on combining ability in F_1 and F_2 generation of 10 x 10 diallel reciprocals observed that both additive and non-additive genetic variance were important for all the characters. The non-additive components were more for yield fruit weight and additive component was predominant for rest of the characters.

Chavandhal and Malkhandale (1994) studied 36 hybrids resulting through 9 x 9 diallel excluding reciprocals and noticed that *gca* and *sca* variance was highly significant for all the characters. The ratio *gca* /*sca* was less than unity indicating the preponderance of non-additive gene action for five characters *viz.* Plant height, pod length, pods per plant, pod weight, yield per plant except for days to 50 per cent flowering which was governed by additive gene action. High specific combining ability effects in hybrids were having high x high or high x medium combiners.

Patel *et al.* (1994) reported that the ratio of *gca* /*sca* indicating the predominance of non-additive gene action for dry seed yield per plant , number and weight of seeds per pod and 1000 seed weight and additive gene action for rest of the characters.

Panda and Singh (1995) reported that the general combining ability effects of lines for all the characters except number of branches per plant and specific combining ability effects for plant height, number of fruits, length of fruit and yield per plant were significant. HRB-9-2 recorded high *gca* effects for plant height, number of fruits and yield per plant. Arka Anamika also showed good *gca* effects for all the characters under study except days to first flower appearance and girth of fruit. The F_1 hybrids gave the best performance when earlier one or both parental lines having high *gca* effects for yield and its contributing characters were involved in the crosses.

Poshiya and Vashi (1995) while studying the relationship between heterosis and combining ability for yield and yield contributing characters reported that the best heterotic hybrids were not the cross combinations that exhibited maximum *sca* effects. However they observed a close relationship between the mean performances of the hybrids with *sca* effects indicating that selection of hybrids based on per se performance is equally effective. He also studied 9 x 9 diallel set for combining ability and noticed that both additive and non-additive variances were important for all characters studied. However, the variances due to *gca* were higher in magnitude than their respective *sca* counter parts for all the characters. They also noted that the per se performance of the parents give a good indication of their *gca* effects.

Shinde *et al.* (1995) studied combining ability using 8 x 8 diallel excluding reciprocals and observed significant mean sum of squares due to both general and specific combining ability for plant height, number of nodes on main stem, number of pods per plant, pod length, pod weight, number of seeds per pods. *gca* effects suggested that No. 108 for number of nodes on main stem, No. 100 for number of seeds per pod, IIHR-10 for plant height, Parbhani Tillu for pod length and Japan okra for pod weight were the best general combiner. Crosses viz., Japan okra x Parbhani Tillu, Japan okra x No. 108 and Parbhani Tillu x No. 168 be exploited for green fruit yield per plant.

Sivakumar *et al.* (1995) noticed that Punjab -7 was the best general combiner for fruit yield and number of fruits per plant. Non-additive gene action was important for number of fruits, individual fruit weight, length girth ratio and fruit yield, while additive gene action was notice for days to first flowering, node number of first flower and plant height.

Wankhade *et al.* (1995) reported predominant role of non-additive type of gene action in the inheritance of all the characters excepting days to flower. Out of twelve parents, Vaishali Vadhu and Local Akola were found best general combiners and they exhibited significant *gca* effects for five and four characters respectively.

Dhankar *et al.* (1996) reported that variance due to *sca* was highly significant for all the characters viz., fruit yield per plant, number of fruits per plant, days to flowering, days to first picking, number of branches, length of fruit, diameter of fruit and plant height.

Patil *et al.* (1996b) reported that the *gca*/*sca* ratio were less than unity for majority of the characters indicating the role of non-additive gene action. The parent PI-489782 was the best general combiner for marketable yield, total number of pods per plant and plant height. High positive significant *sca* effects for marketable yield were shown by the crosses IHR-4 X PI 489782, Pusa Sawani X Smooth Green and Pusa Sawani X PI 489782. They also noticed that the parents having average of high *gca* status throw out a hybrid having high *sca* component and high heterosis.

Singh *et al.* (1996) studied combining ability using 8 x 8 diallel and observed that *gca* and *sca* variances were highly significant for all the characters studied i.e. days to first flowering, plant height, average fruit weight, number of fruits per plant and total yield per plant. Predominance of non-additive gene action was observed for all the characters under study including total yield which may be exploited by developing F_1 hybrids in okra.

Ahmed *et al.* (1997) reported that variances due to *gca* and *sca* were highly significant for all characters but variances due to *sca* were higher than *gca* indicating predominance of non-additive gene actions for all the characters except fruit girth.

Ramesh-Pathak (1998) in their study on line and tester analysis reported that 8 out of 18 crosses exhibited significant positive *sca* effects for pod yield per plant and most of crosses exhibiting *sca* effects had at least one parent with good *gca* .

Pawar *et al.* (1999b) studied combining ability in 45 hybrids and 10 parents and found that none of the parents was a good general combiner for all the characters studied. However, parents HRB-55, Pusa Sawani, DL-1-87-5 and Jo-5 were good general combiners for yield per plant and many other traits and could be used in crossing programme to isolate superior segregants. Estimates of *sca* effects revealed that no cross combination was consistently good for all characters studied.

As reported by Nichal (2000), combining ability for days to first flowering, plant height, number of primary branches on main stem, number of fruiting nodes on main stem, number of fruits per plant, average fruit weight, fruit length, and yield per plant were highly significant 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 characters.

Sood (2001) observed that in general per se performance of the parents was closely related with the *gca* effects. Parbhani Kranti, P-7, Harbhajan, Pusa Sawani, Arka Abhay, (Sel-4) and Arka Anamika were good combiners for fruit yield and its contributing characters. Most of the crosses with high *sca* effects had at least one good general combiner parent. The best specific combination for fruit yield were P-7 x Sel-4, P-7 x Parbhani Kranti and Parbhani Kranti x

Sel-4 which involved both the parents with high *gca* effects these can be exploited to isolated transgressive segregants in early generations.

Prakash et al. (2002) in their study on line x tester analysis using 7 lines and 3 testers for estimating combining ability for yield and yield components (days to flowering, first fruiting node, height of first fruiting, stem hairiness, plant height, number of branches, number of nodes, fruit weight, fruit length, fruit girth, and number of fruits per plant) was studied in 21 F1 hybrids developed from 7 okra cultivars, revealed that the estimates of general and specific combining ability and their ratio indicated the predominance of non-additive gene action for all traits. Four out of 10 parents are found best general combiners for fruit yield per plant, as well as Two out of 21 hybrids which exhibited favorable *SCA* effects for the majority of the characters, can be exploited in breeding for improved yield.

Duzyaman (2002) while studying an 8 x 8 half-diallel analysis was performed by using okra genotypes of Indian, West-African, USA and Turkish origins revealed that general or specific combining abilities in yield of promising crosses were obtained particularly in combinations among genotypes of different eco-geographic origin. The possibilities of selecting the parental material for further breeding work and a combination breeding based on additive gene effects are discussed.

In a study involving 6x6 diallel crosses of okra (*Abelmoschus esculentus* (L.) Moench) Liou.-Minli (2002) reported that Days to flowering, number of fruits per plant, yield, fruit diameter and fruit weight were controlled by additive and non-additive genes. The reciprocal effects were significant for days to flowering, number of fruits per plant, fruit length and fruit weight

Rewale *et al.* (2003) studied combining ability using 9 x 7 Line x Tester observed that DVR-4 and SOH-02 among the lines and Arka Anamika among testers showed good *gca* effects for yield and yield attributes. Among the hybrids NK-01 x Ankur – 40 and JNOO-5 x Arka Anamika showed best performance for yield, number of seeds per fruit and plant height.

Saeed *et al.* (2004) studied inheritance of characteristics in okra under normal and drought conditions through 6 x 6 diallel techniques. Green Velvet and Parbhani Kranti showed highest *gca* effects under drought condition for fresh fruit yield per plant and seed yield per plant. The combinations NO.8 x Green velvet, Green velvet x Parbhani Kranti, DLPG x Parbhani Kranti and Chienese Red x Clemson spineless showing the highest specific combining ability effects under drought conditions.

Bendale *et al.* (2004) reported that among the parents, Gold finger was found to be a good general combiner and among the hybrids cross Parbhani Kranti x Gold finger showed the highest positive significant specific combining ability value for fruit yield plant-1.

Rajendra *et al.* (2005) evaluated 6 hybrids of okra for combining ability and recorded significant *gca* and *sca* for 10 characters. Cultivar AB-2 was a good general combiner for number of days to flowering, number of fruits per plant and yield per plant. Cultivar AB-1 was a good general combiner for number of days to flowering, number of first fruiting node, number of fruits per plant and yield per plant. Cultivar BO-2 was a good general combiner for internode length. Parbhani Kranti was a good general combiner for plant height and fruit length and width.

Dahake and Banger (2006) studied combining ability using 8 x 8 diallel set reported predominance of non-additive gene action for all the characters. The mean sum of squares due to general combining ability and specific combining ability were significant for all the characters.

Kumar *et al.* (2006) studied 18 crosses through 6 x 3 Line x Tester and reported that the combining ability variances indicated the preponderance of non-additive gene action for all the characters. Lines ML, TCR 2056, GL and testers PK and PP were the superior performers for seed yield per plant based on general combining ability effects.

Senthilkumar *et al.* (2007) studied 6 x 6 diallel including reciprocals and reported the mean of the direct crosses differed significantly from that of their reciprocal crosses for all the traits in most of the cross combinations. Reciprocal differences may be due to the confounded effect of the cytoplasm and maternal genotypes. Existence of reciprocal differences was due to the presence of over dominance.

Weerasekara *et al.* (2008) while studying the combining ability for yield and its components in okra reported that the parents KAO-52, KAO-61, KAO-

10, KAO-25 and KAO-35 were good general combiner for days to 50% flowering and parents KAO-16, KAO-61, KAO-52 and KAO-AA were good general combiners for the number of seeds per fruit, while cross KAO-53 x KAO-18 was found with significantly highest *sca* effects for yield per plant.

Srivastav *et al.* (2008) reported that the ratio of *gca*/*sca* indicated the predominance of additive gene for pod length, pod diameter and pod weight.

Khanpara *et al.* (2009) while studying combining ability through 8 x 3 Line x Tester mating method and reported that the gene action was predominantly additive for days to 50% flowering, days to first picking, number of nodes per plant, plant height, number of branches per plant, fruit length and fruit yield per plant, while predominance of non-additive gene action was observed for internodal length and fruit girth.

Dabhi *et al.* (2010) studied combining ability for 11 characters over three environment and observed that the preponderance of non-additive gene action in expression of days to first flower opening, number of nodes at first flowering, days to first picking, number of nodes per plant and fruit length, whereas additive type of gene action was predominant in expression of internodal length, plant height, 10-fruits weight, fruit girth, number of fruits per plant and fruit yield per plant.

Singh and kumar (2010) studied 21 F_1's and F_2's through diallel technique excluding reciprocals reported that the selection of okra crop can be based on the combination of two characters, i.e. length of first fruiting node with length of fruit with width of fruit and number of fruits per plant for higher yield while the cross KS-401 x Pusa Sawani showed high specific combining ability effects as well as per se performance in F_1 and F_2 generations.

Kachhadia *et al.* (2011) while studying the combining ability for fruit yield and its component over environments reported that the pooled analysis of variances revealed the preponderance of non-additive gene action in the expression of yield and all the yield contributing characters except fruit girth, which was governed by the additive gene action. Among the hybrids JOL-06-S-5 x HRB-55, JOL-06-S-8 x JOL-06-S-1 and GO-2 x Parbhani Kranti had high *sca* effects for fruit yield per plant and other related traits.

Reddy *et al.* (2012) studied 45 hybrids resulting through half diallel fashion and noticed that the preponderance of non-additive gene action involved in the inheritance of plant height, internodal length, days to 50% flowering, first number of marketable fruits per plant, total yield per plant and yellow vein mosaic virus infestation on fruits and plants and additive gene action involved in the inheritance of number of branches per plant and fruit and shoot borer infestation on fruits and shoots. The crosses IC29119-B x IC99716, IC27826-Ax IC111443, IC89976 x IC111443 and IC90107 x IC111443 found with superior specific combining ability for total and marketable yield per plant.

2.3 STABILITY (G x E INTERACTION)

Phenotype of an individual is determined by the effects of its genotype and environment surrounding it. The effects of genotype and environment on phenotype may not be always independent. The phenotypic response to change in environment is not same for all genotypes; and the consequences of variation in phenotype depend upon the environment. Very often breeders encounter situations where the relative rankings of varieties change from location to location and/or form year to year or season to season. The interplay in effect of genetic and non-genetic on development is termed as genotype-environment interaction (Comstock and Moll, 1963). The ability of genotype to produce a narrow range of phenotype in different environments can be called as stable (Lewis, 1954). According to Frey (1964), a variety having wide or good adaptability is one which gives consistently superior performance over several environments. According to Allard and Bradshaw (1964) "a variety which can adjust its genotypic or phenotypic state in response to transient fluctuations in environments in such way that it gives high and stable economic returns for place and year is termed as well buffered".

A review of findings pertaining to phenotypic and genotypic stability in okra presented below.

Adetunji and Chheda (1989) while studying seed yield stability of okra using 10 newly developed lines and 5 varieties in 8 different environments (planting at different times for 3 consecutive years) through regression method of stability analysis noticed that the mean differences between environments, the varieties and their interactions were highly significant.

Ariyo (1990) studied 20 genotypes of okra in 4 environments on the basis of days to flowering, branches per plant, plant height, pods per plant, pod weight and pod yield per plant reported that genotype x environment interaction might not always be adequately explained by a linear function of the environment. Heritability estimates showed that branches per plant was under strong genotypic influence. Most genotypes were unstable for the characters studied.

Gondane and Lai (1993) reported that pooled variances were significant GE interaction for all the characters studied except primary branches per plant. The main effects as well as linear and non-linear components of GE interaction were highly significant; the linear components was predominant IC10643 and 138/2 exhibited best stability for most of the components, whereas Pusa Sawani were stable for 5 traits.

Mandal and Dana (1994) studied 30 genotypes across 4 environments for phenotypic stability in okra and found that strain 6316 and Pusa Sawani was the most stable genotypes with respect to days to 50% flowering. White Velvet showed highest stability for days to first harvest and strain 7116 was most stable for plant height.

Paiva and Costa (1994) while studying stability of okra in 11 cultivars and 20 of their hybrids during 2 winter and summer season and observed that highest stability was shown by cv. Santa Cruz 47 and hybrids Santa Cruz 47 x Piranema, BGH4888 x Santa Cruz 47 and Clemson Spineless x Santa Cruz 47. The hybrids Santa Cruz 47 x Clemson Spineless gave the highest average yield (184-286 g/plant), but had significant low stabiltiy. Genotypes showed responsiveness to climatic changes, the percentage of stable hybrids was 3 times higher than that of stable cultivars.

Lotito *et al.* (1996) reported that the hypothesis of equal stability of varieties could not be refuted for the three seed production traits tested. The absence of interaction with the environment for frequency of seeds with delayed permeability allowed the possibility of performance assessment and selection of the trait for one site.

Poshiya and Vashi (1997) studied stability in 9 genotypes and 36 hybrids obtained through diallel cross and found that variances due to genotype (G), environment (E) and G x E interaction was highly significant. Both the linear and non-linear components of G x E Interactions were significant. Gujarat Okra-1 and 2 hybrids (Parbhani x Padra 18-6 and Gujarat Okra -1 x Perkins Long Green) exhibited the best stability in the environments. Overall, hybrids had higher yields and stability than their parents.

Ariyo *et al.* (2000) studied genotype x environment interaction in 15 cultivars of okra during early, mid and late rainy seasons of 1991, 1992 and 1994 and found that the differences between environments accounted for 27% of the total variation while cultivar x environment interaction accounted for

31%. The first, second and third interaction axes captured 48%, 31% and 7% respectively of the total variation due to G x E interaction. The seasons differed in main and interaction effects from year to year. Late season was the most variable in interaction while mid-season had the least variation in the main effect. Varieties in 1991-early and 1991-late seasons showed opposite response while varieties in 1992-late and 1994-late seasons exhibited similar response.

Kanwar *et al.* (2006) reported that G x E interactions were significant for number of seeds per pod, seed weight per pod, seed yield per hectare, seed germination and seed vigour index. Linear and non-linear components equally contributed G x E interactions in number of seeds per pod, seed weight per pod, seed yield per hectare and seed germination. Linear component was significant against non-linear component in seed vigour index only. Punjab-8 and Punjab Padmini were stable for all characters, however all the genotypes were stable for seed yield per plant and seed vigour index.

Jindal *et al.* (2009) while studying G x E interaction in 12 inbreeds and their 66 F_1's for five different fruit traits in okra reported that the mean squares of genotypes were highly significant for all the characters indicating presence of genetic variability among the genotypes. The mean squares due to environments were also significant for all the traits indicating that the varying environments were effective in influencing the performance of the genotype. The cross NDO-10 x S-2 was found stable for fruit weight, all the parents and hybrids were found stable for fruit length under unfavorable environments but their performance cannot be predicted with greater accuracy due to significant deviation from regression.

Dabhi *et al.* (2010) studied 48 hybrids and their 16 parents and found significant differences among the genotypes (G), environments (E) and G x E interaction for all the characters (except number of nodes at first flowering for environment and G x E interactions) indicating variable response of different genotypes for various traits under varied environmental conditions. Non-linear component (pooled deviation) also played an important role for all the characters except for number of nodes at first flowering and fruit length.

Ramya and Senthilkumar (2010) evaluated 35 genotypes in three different environments for their stability have been reported that characters days to first flowering, number of fruits per plant, plant height and single plant yield were significant for G x E interaction. The genotypes viz., Pusa A4, Parbhani Kranti, Varsha Uphar, Punjab Padmini, Hissar Unnat, PB 266, Co 1, Harbhajan, Arka Abhay and AOL-03-01 were found to have significantly higher regression coefficient along with desirable mean value for the trait pod yield per plant.

Kachhadia *et al.* (2011) while studying stability in okra reported that the significant differences among the genotypes (G), environments (E) and G x E interactions for all the characters (except number of branches per plant for environments and fruit girth for G x E interactions) indicating variable response of different genotypes for various traits under varied environmental conditions. The G x E interactions was significant for all the characters (except fruit length) suggesting the genotypes responded considerably to the environmental fluctuations for all the traits. Significant pooled deviation for all the traits, except internodal length, number of fruits per plant and fruit yield per plant indicated difficulty in predicting the performance of genotypes over environments for these characters.

Kumar (2011) studied stability in 5 parents and 8 hybrids for seven different fruit traits in okra and found that significant pooled deviation for all the traits except fruit length indicated predominance of non-linear component. Estimates of stability parameters revealed that no genotypes were stable for all the traits. The parent Punjab Padmini and the hybrids, Punjab Padmini x Varsha Uphar and Parbhani Kranti x Punjab Padmini were found to have significantly higher regression coefficients along with desirable mean value for the trait fruit yield per plant.

Alake and Ariyo (2012) while studying G x E interaction in twenty five West African genotypes of okra in five different environments reported that significant ($P<0.01$) G x E interaction for seed yield. NGAE-96-0060 and NGAE-96-0063 were found as stable genotypes.