2. REVIEW OF LITERATURE

Judicious choice of parents for hybridization and the selection procedure adopted in the early generations are important among the factors on which success of breeding programme primarily depends. Genetic information, especially about the nature of combining ability, the type of gene action governing the inheritance of economic characters and the heterosis, is a prerequisite in identifying the suitable parents and designing the appropriate breeding programme. Among the different methods, the 'Line × Tester' analysis (Kempthorne 1957) is one of the important methods to study the combining ability and gene action.

A brief review of literature pertaining to the present study in chilli is presented under the following headings:

2.1 Combining ability
2.2 Gene action
2.3 Heterosis
2.4 Genotype environment interactions and stability analysis

2.1 Combining ability

The combining ability analysis provides a guideline for assessment of the relative breeding potential of parents and also elucidates the nature and quantum of different types of gene actions involved. The concept of combining ability, originally developed in maize by Richey and Meyar (1925), is now extensively applied in all crop plants. However, Sprauge and Tatum (1942) were the first to define the terms ‘general combining ability’ (GCA) and ‘specific combining ability’ (SCA). GCA designates the performance of a genotype in a series of crosses whereas, SCA designates performance of a specific cross combination. Study of combining ability is, therefore, important for the selection of superior parents for
heterosis and recombination breeding programmes. Meaningful genetic analysis of the quantitative traits can be said to have begun with the work of Fisher (1918). He partitioned the hereditary variances into three components, viz., additive portion resulting from the average effects of genes, dominance portion arising from intra-allelic interactions and epistatic portion associated with inter-allelic interactions.

Pandey et al. (1981) crossed 12 cultivars with three pollen parents and the parents plus their 36 $F_1$ hybrids were evaluated for nine yield component characters viz., yield/plant, number of fruits/plant, fruit length, fruit thickness, days to ripening of 50% fruits, days to 50% flowering, number of primary branches/plant, number of secondary branches/plant and plant height. Among the female parents ‘G4’, ‘G5’ and ‘CA1068’ had the highest general combining ability (GCA) effects for yield, number of fruits, earliness, height and number of branches and among the males ‘Pusa Jwala’ and ‘Pant C 2’ had the highest GCA effects. The estimates of specific combining ability effects showed that the best combinations for yield were ‘Kalayanpur Yellow × Pant C2’, ‘CA960 × Pusa Jwala’, ‘CAP63 × Sirhind’ and ‘Patna Red × Sirhind’. In general, crosses involving one or both parents with high GCA effects also exhibited high SCA effects. Khadi and Goud (1986) from an 11 × 11 half-diallel cross observed the parents ‘IC18190’ and ‘387 Local’ as good general combiners for yield traits, while ‘EC76459-2 × IC18190’ and ‘Purired × 387 Local’ were the good specific combiners with high mean yield.

Gaddagimath et al. (1988) crossed seven genotypes in all possible combinations and found that the parents ‘Jwala’ and ‘K34-35’ exhibited significant GCA effects for most of the characters namely flowers/plant, plant height, primary branches/plant, fruits/plant, average fruit weight and dry fruit yield/plant. A few cross combinations also showed significant SCA effects for yield and its components. Mishra et al. (1989) from 10 parents half-diallel revealed that ‘J218’ and ‘B.R. Red’ were the best general combiners for dry yield/plant, seed weight/fruit, number of seeds/fruit, number of fruits/plant, number
of primary branches/plant, fruit length, 50% flowering, weight of 10 dry fruits, 100-
seed weight, weight of 10 fresh fruits, fruit circumference, plant spread, plant
height and days to 50% maturity. ‘Pusa Jwala’ and ‘Lam X 235’ were the good
general combiners for dry yield/plant and number of fruits/plant. The cross ‘Pusa
Jwala × Sindur’ exhibited significant SCA effects for dry yield/plant, weight of 10
fresh fruits, seed weight/ fruit and number of seeds/ fruit.

Sahoo et al. (1989) from a 10 × 10 half diallel set of crosses involving
divergent parents observed that the crosses ‘S118-2 × Lam X 235’ and ‘Pusa
Jwala × Lam X 235’ expressed good SCA in both F₁ and F₂ generations for plant
height, plant spread, number of primary branches and fruits/plant. Bhagyalakshmi et al. (1991)
crossed six chilli cultivars in a non-reciprocal half diallel and reported that cultivars ‘LCA960’, ‘LCA206’ and ‘G4’ were the best
general combiners for yield/plant, plant height, branches/plant, days to flowering,
time for fruit maturity, fruit length, fruit girth, fruits/plant, fresh fruit weight, 100 dry
fruit weight, seeds/fruit, 100 seed weight and ascorbic acid content. On the basis
of absolute performance, SCA effects and heterosis, ‘LCA 206 × LCA 960’ was the
best yielding hybrid followed by ‘LCA 206 × LA 1079’.

Pandian and Shanmugavelu (1992) crossed 15 chilli lines and six testers
(3 inbreds and 3 hybrids) in a line × tester fashion and concluded that the line
‘1777’ and tester ‘K2’ were the best general combiners for plant height, number
of branches, number of fruits, fruit length, fruit girth, fruit weight with stalk, fruit
weight without stalk, number of seeds/fruit, seed weight/fruit and dry fruit
yield/plant. High genetic diversity was indicated by close agreement between
GCA and per se performance, and stated that performance was a more reliable
parameter than SCA effect for hybrid selection. Devi and Arumugam (1999)
conducted combining ability analysis in 30 chilli hybrids and their six parents and
adjudged the parent pungent chilli ‘K2’ as good general combiner for three
economic traits followed by ‘PKM 1’. The hybrids with ‘Low × Low’, ‘High × High’,
‘Low × High’, ‘Low × Medium’ and ‘High × Medium’ GCA parents exhibited high
SCA effects for all nine characters, viz., plant height, number of primary
branches, number of secondary branches, days to first flowering, number of fruits/plant, fruit weight, yield of fresh fruits/plant, dry fruit yield/plant, fruit length, fruit girth and fruit shape index clearly indicated the role of additive and non-additive gene action.

Shukla et al. (1999) reported that parents ‘Jwala’ and ‘Jagudan-103’ were good general combiners for green fruit yield and other important yield contributing components. About one-third of the hybrids depicted significant specific combining ability effects for green fruit yield. Gandhi et al. (2001) on the basis of combining ability analysis, identified the ‘IC119769’ and ‘Pusa Jwala’ as the best general combiners and combinations ‘HC44 × IC119769’ and ‘Pusa Jwala × IC119769’ as the best hybrids.

Lohithaswa et al. (2001), in his study on 10 parent diallel analysis excluding reciprocals, revealed that the parents ‘IHR-1822-1/3-1/5’, ‘Arka Lohit’ and ‘G-4’ were found to be good general combiners for fruit yield/plant. The heterosis values when considered alone were misleading, as there was no correspondence with per se performance. The best specific combiners involving parents with low GCA effects indicated the need for heterosis breeding and recurrent selection in the segregating generations for substantial improvement in fruit yield/plant. Jadhav et al. (2002) crossed six hot chilli cultivars (‘G-3’, ‘GAD Sel-35’, ‘Phule Sai’, ‘GCH-1’, ‘Delhi Red’, and ‘M-Sel-11’) with two paprika-type (‘GAD Sel-31’ and ‘Vietnam’) and reported that significant and positive GCA effects were exhibited by ‘G-3’ and ‘Vietnam’ for plant height, ‘GAD Sel-35’ and ‘G-3’ for fruit number, and ‘GCH-1’, ‘Delhi Red’, and ‘M-Sel-11’ for fruit weight. Crossing between ‘G-3’ and ‘Vietnam’ is recommended for developing desirable genotypes.

Nandadevi and Hosamani (2003) from six × six diallel design excluding reciprocals revealed that among the parents, ‘Pant C-1’, ‘KTPI-19’ and ‘RHRC-Cluster-Erect’ for green fruit yield/plant, and ‘RHRC-Cluster-Erect’, ‘Pant C-1’ and ‘PMR-52/88/K’ for resistance to leaf curl complex were the good general combiners. The superior crosses involving parents with low and high general
combining ability effects indicated that heterosis breeding will be appropriate for green fruit weight, green fruit yield/plant and leaf curl complex resistance. Pandey et al. (2003) studied combining ability for yield and its component traits in chilli using a line × tester mating system and revealed that the mean squares due to females, males and female × male were highly significant for all the traits namely, plant height, number of primary branches/plant, number of secondary branches/plant, number of fruits/plant, fruit length, fruit width and yield/plant. The higher values of specific combining ability (SCA) involving parents with low general combining ability (GCA) for almost all the characters indicated the preponderance of non-additive gene action for the expression of these characters. The parental cultivars ‘A-8’, ‘NA-12’ and ‘35-2’ were good combiners for several characters. The F₁ hybrids ‘651-61-10 × A-4’, ‘Assam 5B × A-8’ and ‘SPS-1 × A-8’ were the promising specific combinations for a number of characters including yield. One or both parental lines having high GCA effects were involved in crosses having better SCA effects. The preponderance of non-additive gene action for all the characters suggested that heterosis breeding might be effective for the improvement of yield and its contributing attributes in chilli.

Patel et al. (2004) developed 48 chilli hybrids by crossing four genic male sterile lines and 12 male parents in a line × tester mating design and revealed significant differences among the parents, hybrids, parents vs. hybrids, lines and testers and their interactions for days to flower, plant height, primary branches/plant, number of fruits/plant, average fruit length, average fruit weight, average fruit girth and green fruit yield/plant with the exception of days to flower for testers, plant height, fruit girth and fruit weight for lines, and fruit length for both lines and testers. The significance of variance due to parents vs. hybrids and lines × testers for all traits suggested the existence of non-additive gene action. Estimates of GCA effects showed that the male sterile line ‘ACMS-4’ was a good general combiner for green fruit yield, fruits/plant, fruit length, fruit girth and plant height, whereas the male parents ‘ACH-77’, ‘ACS 92-3’, ‘ACS 2000-2’,
'ACS 2000-3', 'Punjab Guchhedar', 'RHRC-Perendent' and 'Resham Patti' were the good general combiners for green fruit yield and fruits/plant. 'ACS 2000-2' and 'Resham Patti' were also good general combiners for other yield-contributing traits. Out of 48 hybrids, seven were good specific combiners for green fruit yield and important yield contributing traits. Patil et al. (2005) evaluated 23 chilli cultivars and their 60 F_1's derived from line × tester analysis and observed genotypes '2591' and 'Pusa Jwala' as good general combiners. The crosses 'IIHR 1822-1/3-1/5 × Arka Lohit' and 'GPC 77 × PMR 57' were identified as good specific combiners for fruit yield and other related traits.

Srivastava et al. (2005) by following a line × tester approach in chilli, evaluated 45 crosses (15 × 3) along with 18 parents for plant height, number of branches/plant, fruit length and width, number of fruits/plant, vitamin C content, capsaicin percentage and red ripe fruit yield/plant. Among the testers, 'Pant Chilli 1' exhibited high general combining ability effects for red ripe fruit yield/plant and many other characters, whereas 'Chanchal' was identified as the best general combiner for capsaicin percentage. Among the 15 lines, '8803', 'Sel-12', 'Sel-7' and '399-5-2' were identified as good general combiners for red ripe fruit yield/plant and related characters. The crosses 'Sel-7 × Pant Chilli-1' and 'Sel-12 × Pant Chilli-1' showed high specific combining ability effects for red ripe fruit yield/plant and other yield contributing traits and recommended recurrent selection for the improvement of yield and quality in chilli. Venkatramana et al. (2005), from 8 × 8 diallel cross (including reciprocals), noticed the genotype 'VR-27' as the best general combiner for fruit yield/plant, while the crosses 'Punjab Gucchedar × Pant C-1' and 'Tiwari × EG-174' had greater SCA effects for fruit yield which may directly be used for commercial cultivation after further testing over a range of environments.

Zate et al. (2005), using two genetic male sterile lines as female and nine testers as males, found that male parents 'PP-977127', 'PP-977116', 'PP-977195-1', 'PP-977268' and 'PP-977421' were the good general combiners for yield/plant. The crosses 'AKC-8625 × PP-977268' and 'CA-960 × PP-977195-1'
exhibited significant specific combining ability effects for yield/plant. Shekhawat et al. (2007), by following line × tester mating design comprising of nine lines and two testers, revealed that the parents and F₁ crosses differed significantly for GCA and SCA effects for days to flowering, plant height, number of branches/plant, fruit length, fruit width, days to first harvest, number of fruits/plant, 1000-seed weight, pedicel length, number of seeds/fruit, red ripe fruit yield/plant, dry fruit yield/plant, vitamin C and capsaicin content. Lines ‘Sel-54’, ‘7722-1’ and ‘Sel. 16’ were good general combiners for red ripe and dry fruit yield/plant whereas, cross combinations namely, ‘2003 × 7950’, ‘Sel. 54 × 7950’, ‘Sel. 16 × Sel. A-4’ for red ripe yield and ‘Sel. 54 × 7950’, ‘A-28 × Sel. A-4’ and ‘7722-1 × 7950’ were the best specific combinations for dry fruit yield/plant and other yield contributing traits.

Jagadeesha and Wali (2008) studied 18 divergent lines and 45 F₁ hybrids and reported that the parents ‘VN-2’, ‘B-Kaddi’, ‘Arka Lohit’, ‘Phule-5’ and ‘LCA-312’ exhibited high GCA which may be utilized in recurrent selection programme for improvement in fruit quality traits. Khereba et al. (2008) found ‘166988’ as the best parent for early yield on the basis of general combining ability estimates. Cross combination ‘166988 × 159236’ was the best specific combiner for plant height, number of days to flowering, average fruit weight, fruit length, fruit diameter and total yield. Prasath and Ponnuswami (2008) reported the lines ‘Bydagi Kaddi’, ‘MDUY’ and ‘Arka Abir’ as the good general combiners for yield and quality characters. The cross combination ‘MDU Y x CO 4’ had desirable SCA effects for fresh yield, dry yield, total extractable colour and capsaicin.

Reddy et al. (2008) evaluated 14 parents and their 40 hybrids for fruit yield and yield components and found that the line × tester interaction variance was significant for all the traits. ‘Arka Lohit’, ‘SKAU-SC-965-5’, ‘GPC-82’, ‘SKAU-SC-1003’ and ‘SKAU-SC-304-1’ were the good general combiners while ‘SKAU-SC-1005 × Kiran’, ‘SKAU-SC-1003 × Arka Lohit’, ‘SKAU-SC-65-5 × Kiran’, ‘SKAU-SC-618-2 × GPC-82’ and ‘SKAU-SC-814-2 × GPC-82’ were the good specific combiners for days to flowering, plant height, number of primary branches,
number of secondary branches, plant spread, number of fruits/plant, fruit length, fruit width, average fruit weight, pedicel length, pericarp thickness, number of seeds/fruit, seed weight/fruit and fruit yield/plant. Rego et al. (2009) crossed eight lines of *Capsicum baccatum* in a complete diallel way revealed that GCA effects of the parents and SCA effects of the crosses were significant.

### 2.2 Gene action

Khadi and Goud (1986), from 11 × 11 half-diallel cross, reported that the variances for GCA and SCA were significant for all eleven traits studied with higher magnitude of the former for 10 traits. Singh and Rai (1986) from 8 × 8 half-diallel cross revealed specific combining ability variance was higher than general combining ability variance for all the traits namely, days to flower, plant height, number of branches, fruit length, fruit width, fruits/plant and fruit yield/plant while heritability estimates were relatively low for all traits. Non-additive gene effects were important for all the traits while partial dominance was important for fruit length, fruits/plant and fruit yield/plant and advocated recurrent selection for obtaining desirable segregants.

Gopalakrishnan et al. (1987) crossed four chilli lines in half-diallel and found involvement of both additive and non-additive gene action for the control of plant height, primary branches/plant, fruit length and days to flower. Sahoo et al. (1989) from a 10 × 10 half diallel set of crosses involving divergent parents in the F₁ and F₂ indicated that plant height, plant spread, number of primary branches and fruits/plant were conditioned by additive and non-additive gene effects and over-dominance played an important part in their expression.

Bhagyalakshmi et al. (1991), from six parents non-reciprocal half diallel, observed both additive and non-additive gene action with predominance of latter for days to 50% flowering, fruit length, fresh fruit weight, 100-dry fruit weight and 100-seed weight. Jadhav and Dhumal (1994) from generation mean analysis of two intervarietal crosses observed additive gene effects for fruit length; dominance gene effect for yield and number of fruits/plant, and both additive and dominance gene effects for plant height and fruit perimeter. They suggested the production of hybrids (if feasible) or reciprocal recurrent selection to exploit all types of gene action to achieve genetic improvement in yield and its components.
Devi and Arumugam (1999) crossed six chilli varieties (3 pungent and 3 non-pungent) in a six × six diallel mating design and revealed that additive gene action was more important than non-additive gene action for plant height, number of primary branches, days to first flowering, number of fruits/plant, fruit weight, yield of fresh fruits/plant, dry fruit yield/plant and fruit girth except fruit length and suggested that pedigree breeding together with recurrent selection can be used to exploit additive and dominance effects simultaneously for the improvement of chilli. Shukla et al. (1999) studied 24 F₁’s, developed from 11 parents and found that non-additive gene effects were responsible for the expression of days to flowering, plant height, number of primary branches, number of secondary branches, number of fruits/plant, days to fruit ripening and fruit yield/plant while additive gene effects were important for fruit length and girth.

Anandanayaki and Natarajan (2000) reported dominant gene action for plant height, days to 50% flowering and dry fruit yield while additive and dominance effects for branches/plant and fruits/plant. Lohithaswa et al. (2001) revealed the preponderance of non-additive gene action for days to maturity, plant spread, number of secondary branches, fruit length, fruit diameter, number of seeds/fruit, number of fruits/plant, dry weight of fruits/plant and capsaicin content except for fruit length and fruit diameter.

Jadhav et al. (2002) reported that variances due to general combining ability (GCA) and specific combining ability (SCA) were high for plant height, fruit number, fruit length, fruit weight, and fruit yield with the dominance of non-additive gene actions over additive gene actions in the inheritance of these traits. Doshi (2003) reported that the additive and dominance components were significant for number of days to flowering, plant height, number of primary branches/plant, number of fruits/plant, fruit length, fruit girth, fruit weight, number of days to maturity, total capsaicin content and fruit yield/plant. However, the additive component was greater than the dominant component for primary branches/plant, plant height, fruit weight and total capsaicin contents.
Nandadevi and Hosamani (2003) revealed the predominance of non-additive gene effects for six of the 10 characters studied (days to 50% flowering, fruit length, fruit diameter, pedicel length, pericarp thickness, number of seeds/fruit, green fruit weight, number of fruits/plant, green fruit yield/plant and resistance to leaf curl complex). Kumar (2004) found higher magnitude of general combining ability (GCA) variance than specific combining ability (SCA) variance for days to first flowering, number of primary branches, plant height, fruit length, single fruit weight, number of fruits/plant and capsaicin content which indicated the preponderance of additive gene action and pedigree breeding can be used to improve these characters.

Patel et al. (2004) from a line × tester mating design, revealed that the variances due to general (GCA) and specific combining ability (SCA) were significant for days to flower, plant height, primary branches/plant, fruits/plant, fruit length, fruit weight, fruit girth and green fruit yield/plant indicating the importance of both genetic variances for the inheritance of these traits. Significance of only GCA for fruit length and fruit weight and that of SCA for primary branches/plant was observed. Additive component was larger than the non-additive components of variance for days to flower, fruits/plant and green fruit yield. Ajith and Anju (2005) noticed the predominance of additive and dominance × dominance interactions in ‘Jwalasakhi × Ujwala’ for fruit weight and suggested the suitability for improvement through hybridization followed by selection.

Patil et al. (2005) observed higher magnitude of specific combining ability variance compared to general combining ability variance for all the traits indicated the predominance of non-additive gene action from a line × tester analysis. Srivastava et al. (2005) found greater role of non-additive gene action in the inheritance of plant height, number of branches/plant, fruit width, number of fruits/plant, vitamin C content, capsaicin percentage while, additive gene action played an important role for fruit length and red ripe fruit yield/plant.
Venkataramana et al. (2005) observed highly significant variances for general combining ability (GCA) and specific combining ability (SCA) for all the characters suggesting the importance of both additive and non-additive gene action. The SCA variance played an important role in the genetic control of days to 50% flowering, days to 50% ripening, fruit width, plant height, number of fruits/plant and green fruit yield/plant while additive gene action was observed for fruit length. Saritha et al. (2005) from a line × tester analysis involving five lines (‘RHRC-50-1’, ‘PMR-14’, ‘PMR-19’, ‘Tiwari’ and ‘AVRDC-95-06’) and nine testers (‘Arka Abhir’, ‘Arka Lohit’, ‘Byadgi Dabbi’, ‘Byadgi Kaddi’, ‘PMR-21’, ‘PMR-39’, ‘PMR-57’, ‘Punjab Guchhedar’ and ‘Punjab Surkh’) revealed significant variance among females for plant height, fresh fruit yield/plant, dry fruit yield/plant and ascorbic acid content and among males for plant height and ascorbic acid content. Variance for line × tester interaction was highly significant for plant height, primary branches, fruit length, fruits/plant, fresh fruit yield/plant, dry fruit yield/plant, number of seeds/fruit, ascorbic acid content, capsanthin and oleoresin contents which indicated the major role of non-additive gene action in the expression of these characters. Significant GCA variance was observed for majority of the traits except primary branches and seeds/fruit whereas all the above characters exhibited significant SCA variance. This indicates that majority of the characters are governed by both additive and non-additive gene action with the predominance of the latter.

Kamboj et al. (2006), from generation mean analysis, observed the predominance of additive gene action in the inheritance of fruit length and fruit weight and advocated simple selection, recurrent selection, heterosis breeding and hybridization followed by selection as the appropriate strategy for exploitation of the present genetic material of chilli. Kamboj et al. (2007) reported that additive gene effects were important for the expression of plant height, fruits/plant and dried red fruit yield/plant whereas dominance gene effects were found predominant for the control of branches/plant and fresh red fruit yield/plant. They suggested simple or pedigree selection, heterosis breeding and reciprocal recurrent selection or full sib selection in the populations for the improvement of these characters.
Jagadeesha and Wali (2008) observed higher proportion of additive gene effects for fruit related traits and that of non-additive gene action for seed related traits. Khereba et al. (2008) utilized seven chilli pepper parental inbreds in a line × tester mating design and observed the major role of non-additive gene effects in the inheritance of plant height, average fruit weight, fruit diameter, fruit length, early yield and total yield.

Marame et al. (2008) crossed 12 genotypes in half-diallel fashion and obtained significant variations among the progenies for dry fruit yield/plant, number of branches/plant, plant height, number of fruits/plant, days to maturity, fruit length and single fruit weight. Only dominant component, for days to maturity and dry fruit yield/plant and both dominance and additive genetic components were significant for all other traits. Prasath and Ponnuwami (2008) observed that the estimates of GCA and SCA variance were significant for plant height, branches/plant, days to first flowering, days to 50% flowering, fruits/plant, fruit length, fruit girth, seeds/fruit, individual green fruit weight, individual dry fruit weight, fresh yield/plant, total extractable colour and with the preponderance of additive gene action while non-additive gene action was important for capsaicin content.

Reddy et al. (2008) found higher specific combining ability variance than general combining ability variance for days to flowering, plant height, number of primary branches, number of secondary branches, plant spread, number of fruits/plant, fruit length, fruit width, average fruit weight, pedicel length, pericarp thickness, number of seeds/fruit, seed weight/fruit and fruit yield/plant which indicated the predominance of non-additive gene action. The line × tester interaction variance was also significant for all traits. Rego et al. (2009) reported that both additive and non-additive effects influenced almost all the characters for the performance of hybrids.
Kamboj et al. (2011) from generation mean analysis, estimated gene effects for six characters viz., plant height, plant spread, branches/plant, fruits/plant and total fresh and dried red fruit yield/plant. Additive gene effects were important for the expression of plant height, plant spread, fruits/plant and dried red fruit yield/plant. However, dominance gene effects were found predominant for the control of branches/plant and fresh red fruit yield/plant.

2.3 Heterosis

Heterosis is the superiority of F$_1$ hybrid over the parents in a given characteristic, assessed not by absolute value and appearance but by its usefulness for practical advantages in given environments. Plant hybrids were first described by Koelreuter in 1766. Bruce (1910) reported that hybrid vigour was due to the presence of dominant genes in the hybrids. Heterosis in desirable direction (hybrid vigour) is the ultimate aim of a breeder. From the point of view of commercial exploitation of heterosis, the increased or decreased vigour of the hybrids over the standard check, i.e., standard/economic heterosis is of utmost importance than heterobeltiosis (over the better parents) or the average heterosis (over the average performance of parents).

Pandey et al. (1981) identified three crosses superior for yield/plant and fruit number/plant over the best parent. A cross was also observed with height less than either of the parents. Rao and Chhonkar (1982) reported significant positive heterosis for thirteen crosses over the mean parental value (2.2 to 30.9%) and three crosses over the better parent (2.1 to 12.5%) for ascorbic acid content. The ascorbic acid content of these three crosses ranged from 185.0 to 284.9 mg/100 g fruit.

Meshram and Mukewar (1986) observed four hybrids with significant heterosis over the superior parent for fruit yield, and suggested the use of male sterile lines in the exploitation of heterosis. Gopalakrishnan et al. (1987) crossed the four chilli lines ‘Jwala’, ‘Pant C1’, ‘CA33’ and ‘CA23’ non-reciprocally and found ‘Jwala × Pant C1’ as the best hybrid for yield followed by ‘Jwala × CA23’. All the hybrids showed average heterosis for earliness and three hybrids showed heterobeltiosis.
Ashtankar and Jaipurkar (1988) reported mid heterosis in most of the hybrids for the eight traits studied and also recorded significant heterobeltiosis for yield (up to 23%) in six out of 13 hybrids. Thomas and Peter (1988) reported the significant favourable heterosis for days to flowering, days to green fruit harvest, days to fruit ripening, plant height, fruit length, fruit perimeter, fruit weight and green fruit yield/plant in the intervarietal crosses involving six bell pepper lines and hot chilli line ‘KAU Cluster’. The best-yielding cross 'Bell Boy × KAU Cluster' revealed a standard heterosis of 108.3 per cent over ‘Pant C1’ for yield with desirable plant and fruit characteristics followed by ‘672 Hungarian Wax × KAU Cluster’.

Mishra et al. (1989) reported that hybrid ‘Pusa Jwala × Sindhur’ showed heterosis over the better parent for dry yield/plant and also for fresh fruit weight, number of seeds/fruit and dry yield/plant. On the other hand, Ram and Lal (1992) observed significant relative and standard heterosis in the desired direction for all the characters except for pods/plant with the highest standard heterosis for pod yield/plant in the cross ‘NP46A × Kalyanpur Yellow’.

Subashri and Natarajan (1999) noticed positive residual heterosis for yield/plant in crosses ‘CA 94 × CA 86’, ‘CA 94 × CA 133’ and ‘CA 133 × CA 84’ while only ‘CA 133 × CA 84’ exhibited positive residual heterosis for number of fruits/ plant and fruit weight. Gandhi et al. (2000) reported that out of 15 hybrids, four exhibited significant heterobeltiosis, while 11 were significantly heterotic over the standard check variety for dry fruit weight/plant. Taking into consideration the per se performance, heterosis and SCA effects, ‘HC44 × IC119769’ was the best hybrid followed by ‘Jwala × IC 119769’.

Milerue and Nikornpun (2000) observed that ‘KY 1-1 × Nhum Khiew Maejo’, ‘CF21789 × Nhum Khiew’ and ‘KY 1-1 × Nhum Khiew’ showed high percentage of heterosis for pungency. Burli et al. (2001) noticed ‘P3 × P8’ with the highest negative heterobeltiosis (-10.26%) for days to 50% flowering while all the crosses showed negative heterosis over better parent for plant height. Significant positive heterobeltiosis was expressed by ‘P6 × P7’ for fruit length (3.82%) and for fruit weight (2.25%). Significant heterobeltiosis was recorded for
'P1 × P8' (8.57%) and ‘P1 × P7’ (6.46%) for number of fruits. All the crosses under study showed significant heterobeltiosis for dry fruit yield/plant except ‘P5 × P8’. Hybrids expressing high magnitude of heterobeltiosis also showed high per se performance for the number of fruits, fruit weight and dry fruit yield/plant. ‘P1 × P8’ was identified as the best hybrid for exploiting hybrid vigour.

Kumar and Lal (2001) observed significant heterosis over mid parent, better parent and standard parent for number of fruits/plant, number of seeds/fruit, fresh and dry fruit yield/plant. Superior hybrids with regard to yield and yield components were ‘Pant Sel 13 × Sel 1’, ‘BC 24 × Pant Sel 13’ and ‘HC 28 whereas, crosses ‘Pant Chilli 1 × BC 24’ and ‘BC1 × LCA 304’ were superior for days to harvest. Patel et al. (2001) estimated heterosis by crossing three lines (‘Jwala’, ‘S-49’, and ‘G-4’) and eight testers (‘Jagudan-103’, ‘Gujarat Chilli-1’, ‘Resham Patti’, ‘Kumathi’, ‘SG-5’, ‘Anand Chilli-1’, ‘DPS-120’, and ‘ACS 92-1’) for yield and yield components (days to flowering, plant height, number of primary branches, number of fruits/plant, fruit length, fruit girth, fruit weight, days to fruit ripening, and fruit yield/plant). The cross ‘S-49 × DPS-120’ exhibited significant standard heterosis (15.30%) for green fruit yield. However, the maximum relative heterosis (92.04%) and heterobeltiosis (85.38%) for green fruit yield was observed in cross ‘G-4 × Anand Chilli-1’. Negative estimates of heterotic effect for most of the characters may be attributed to intra-allelic interactions.

Singh and Hundal (2001) crossed three lines of chilli with 14 pollen parents in a line × tester fashion and noticed that heterosis over better parent was 55 per cent for fruit length, 24.48 per cent for fruit width, 111.27 per cent for fruit weight, 66.55 per cent for fruit number, 316.26 per cent for early yield, and 108.17 per cent for total yield. The crosses ‘Punjab Guchhedar × RHCH Up’ and ‘Lt-2 × Lorai’ manifested maximum heterosis for fruit number and total yield, respectively. Thiruvelavan et al. (2002) developed 20 male sterile-based hybrids using twenty diverse male parents and these were evaluated along with the control variety for plant height, primary branches/plant, days to 50% flowering, fruit length, fruit girth, dry fruit weight, seeds/fruit, fruits/plant, fresh fruit
yield/plant and dry fruit yield/plant. The hybrids performed better than the control cultivar ‘CO 2’ in terms of yield and yield attributes and out of these, ‘MS 1 × CA 119’ was the most heterotic hybrid for number of fruits/plant and yield/plant.

Linganagouda et al. (2003) reported maximum heterosis over better parent in desirable direction for plant height (‘10 x 4’) and primary branches/plant (‘11x1’). Prasad et al. (2003) from nine × nine half diallel mating design involving one bell pepper cultivar (‘Arka Gaurav’) and eight hot pepper advanced breeding lines reported superior hybrids namely, ‘Arka Gaurav × VR-1’ for earliness, ‘VR-2 × VR-47’ for fruit length, ‘Arka Gaurav × VR-2’ for fruit width, ‘VR-47 × VR-55’ for number of fruits/plant, and ‘VR-2 × VR-55’ for dry fruit yield/plant. Crosses ‘VR-2 × VR-55’ and ‘VR-1 × VR-2’ were superior over the best parent and standard control with respect to dry fruit yield/plant and number of fruits/plant, respectively.

Gondane and Deshmukh (2004) studied heterosis in 33 chilli hybrids obtained by involving three male sterile lines and found that most of the hybrids expressed positive and significant heterosis over mid-parent, better parent and standard check. The cross combinations ‘Jwala × GP-90’, ‘AKC-86-25 × GP-313’, ‘CA-960 × GP-22’ and ‘AKC-86-25 × GP-314’ were the best crosses on the basis of high heterobeltiosis and standard heterosis for most of the characters viz., days to 50% flowering, plant height, main branches/plant, fruits/plant, seeds/fruit, 100 seed weight, ascorbic acid and wet red chilli yield/plant and could be used for commercial exploitation of heterosis. Patel et al. (2004) from a line × tester mating design using five genetic male sterile lines and eight male genotypes of chilli observed that hybrids ‘ACMS-2 × LCA-206’ and ‘ACMS-2 × LCA-206’ exhibited the greatest positive significant heterosis over the mid and better parents, respectively. None of the hybrids was superior to the control for green fruit yield. Hybrids ‘ACMS-4 × GVC-101’ and ‘ACMS-2 × GVC-101’ exhibited the greatest significant positive heterosis and heterobeltiosis for capsaicin content.

Senevitne and Kannangara (2004) crossed six parental lines of chilli in all possible combinations including reciprocals (full diallel). Of the crosses assessed, plant height showed the highest average heterosis in the cross ‘IR ×
Pant C1’. ‘Pant C1 × PBC 470’ expressed 235 and 227 per cent average heterosis and heterobeltiosis for number of fruits/plant, respectively. The crosses ‘Pant C1 × Pusa Jwala’ and ‘IR × Jawahar’ recorded the highest commercial heterosis for fruits/plant and fresh fruit yield/plant, respectively. The cross ‘Pusa Jwala × MI 1’ exhibited the highest heterosis and heterobeltiosis for fresh fruit yield, fruit length and fruit width. Kumar et al. (2005) observed that the relative heterosis and heterobeltiosis for capsaicin content ranged from -46.15 to 89.16 and -55.30 to 72.52 per cent, respectively with 14 and ten crosses showed positive and significant relative and economic heterosis, respectively. The relative heterosis, heterobeltiosis and standard heterosis estimates varied from 38.30 to 119.47, 7.88 to 90.78 and -34.35 to 91.94 per cent for yield/plant, respectively.

Singh and Chaudhary (2005) observed considerable heterosis for total fresh yield/plant ranged from 7.40 (‘IC-119367 × Pusa Sadabahar’) to 33.24 per cent (EC-305591 × Punjab Lal) whereas, only four showed positive and significant heterosis over the better parent for number of fruits/plant. Crosses exhibiting high heterosis for total fresh yield/plant were also good heterotic crosses for number of fruits/plant, fruit length and number of seeds/fruit. Zate et al. (2005) noticed that the branch number on the main stem and fruit length were the most important characters contributing to the heterosis over better parent for yield/plant.

Adapawar et al. (2006), from line × tester analysis, observed that three hybrids (‘CA-960 × GP-172’, ‘Jwala × GP-150’ and ‘Jwala × GP-172’) consistently exhibited the highest heterosis for yield and number of fruits/plant. Shankarnag and Madalageri (2006) crossed three cytoplasmic genic male sterile lines of chilli with seven diversified pollen parents in a line × tester design and observed that the extent of heterobeltiosis and economic heterosis was 37.22 and 55.10 per cent for plant height, 51.85 and 55.61 per cent for plant spread (east-west), 59.46 and 46.32 per cent for plant spread (north-south), -26.15 and -17.94 per cent for days to first flowering, 9.16 and -14.13 per cent for fruit length,
44.53 and 10.83 per cent for fruit diameter, 94.63 and 84.25 per cent for number of fruit per plant and 181.10 and 27.43 per cent for total green fruit yield, respectively. The cross ‘L5 x T14’ recorded the highest heterosis for fruit number and total green fruit yield.

Satish and Lad (2007) noticed that the magnitude of heterobeltiosis and standard heterosis in desirable direction was the highest for number of secondary branches/plant followed by plant height, days to maturity and days to 50% flowering. Based on considerable beneficial heterotic response, the hybrids ‘Jayanti × G-4’, ‘Phule Suryamukhi × GA’ and ‘Arka Lohit × Phule Jyoti’ could be considered for exploitation of hybrid vigour. Prasath and Ponnuswami (2008) produced Hybrids by utilizing six diverse genotypes, namely ‘Arka Lohit’, ‘MDU Y’, ‘S 1’, ‘Arka Abir’, ‘Bydagi Kaddi’ and ‘Co 4’ and observed heterobeltiosis ranged from 40.35 to 126.32 per cent for dry yield/hectare. Based on per se performance, heterosis and SCA effects, the hybrids ‘Bydagi Kaddi × Arka Abir’ and ‘MDU Y × CO 4’ were found superior in respect of total extractable colour and low capsaicin besides dry yield and contributing characters.

Kamble et al. (2009) studied the magnitude of heterosis in 45 crosses and reported pronounced hybrid vigour for total fruit yield and most of the yield components. The crosses ‘KCP02 × CW’, ‘KCP12 × CW’, ‘KCP14 × BGM’ and ‘KCP01 × BL’ showed significant heterosis over commercial check for yield/plant, ‘KCP11 × BGM’ for plant height, ‘KCP02 × BL’ for number of tertiary branches/plant, ‘KCP10 × BL’ for days to 50 per cent flowering, ‘KCP05 × BGM’ for per cent fruit set, ‘KCP09 × BL’ for number of fruits/plant and ‘KCP11 × CW’ for early yield/plant. Sitaresmi et al. (2010) reported that hybrid ‘IPB C8 × IPB C19’ had the highest heterosis for fruit weight/plant while, hybrid ‘IPB C8 × IPB C15’ have same for number of fruits/plant. Crosses among introduced and local genotypes resulted in a high heterosis values.

2.4 **Genotype environment interactions and stability analysis**

If a set of plant genotypes is grown over a range of environments, the genotypes do not behave in the same relative way in all the environments. This interplay of genetic and non-genetic forces is known as genotype × environment
(G × E) interactions (Comstock and Moll, 1983). The relative importance of G × E interactions was pointed out by Sprague and Federer (1951). Sprague (1966) has described the usefulness of G × E interactions in detail. The literature on this aspect in chilli is rather limited and available information is presented as under:

Singh et al. (1989) observed significant variance effects due to environment and G × E interaction and found ‘A8’ and ‘A36’ as the most stable varieties. Roy et al. (1997) found that genetic variation among 23 genotypes and genotype × environment interactions were highly significant. ‘DC24’ and ‘DC11’ performed best under a wide range of environments and were recommended for future breeding programmes. Reddy and Sadashiva (2003) reported ‘MI-2’ as the most stable genotype in wide range of environments for its yield potential, earliness and acceptable fruit type in market.