Chapter II

REVIEW OF LITERATURE

The available literature pertaining to heterosis, combining ability, graphic analysis, components of phenotypic variation and correlations in Capsicum annuum L. is reviewed as under:

Heterosis

Heterosis as measured by F₁ values exceeding the mean of the parents or over the superior parent, has been reported in Capsicum for characters such as early maturity, plant height, fruit size and productivity - both as fruit number and total weight (Deshpande, 1933; Pal, 1945; Martin, 1949; Betlach, 1965, 1967; and Maruthina, 1969).

Parents of diverse origin when crossed exhibit hybrid vigour as reported by Angali (1957) in chillies. Angali (1957, 1967) observed that pepper hybrids were superior to the parents for earliness and yield. Carlsson (1962) reported that number of fruits was generally intermediate between large and small fruited varieties, but in crosses where both the parents had either large or small fruits, heterosis for number and yield was observed.

Betlach (1965) used four varieties as seed parents in crosses with twelve other varieties in sweet
pepper. The heterosis was most marked in fruit number, and in a year with exceptionally warm weather the hybrid vigour was expressed by an increase in both the number and weight of the fruit. Betlach (1967), working with similar material, reported that $F_1$ progeny showed increase in yield and number of fruits. Brauer (1963), Betlach (1967) and Popova, Majnove and Mihajlov (1970) did not observe any heterosis for ascorbic acid in chillies, while contrary to their findings, Chroboczek, Karasinska, Mizersowa and Fajkowska (1986) reported that, in general, hybrids in chillies had a higher ascorbic acid content than that of the parents.

In studies of three pepper combinations heterosis with respect to the average number of seeds per fruit was manifested in $F_1$ (Popova and Mihailov, 1968), while heterosis was not present for carotene and it was inherited intermediately (Brauer, 1962 and Popova et al., 1970).

Masrutina (1969) noted in a cross of white pepper and early round pepper that heterosis for yield was 22-48 per cent and that it exceeded the standard variety by 50-60 per cent. In interspecific crosses of Capsicum, heterosis was even observed in $F_2$ and $F_3$ generations over mid-parental value for fruit number and plant height; however, in yield it manifested only in $F_1$ (Nagaich, Sethi and Chaubey, 1972). Marin and Lippert (1975) did not find any mean heterosis for any of the components of fruit,
while Lippert (1975) noticed hybrid vigour in all the fruit characters studied though it was significant (27.4 per cent) in total dry weight per plant only.

In a diallel cross involving nine chilli varieties, heterosis over the mid-parent was manifested in yield, per plant, fruit number, number of seeds per fruit, days to maturity and days to flowering. Maximum heterosis was expressed in yield followed by fruit number and number of seeds per fruit. However, the magnitude was low for plant height and fruit size (Singh, 1972).

Hybrid vigour can be commercially exploited in pickle group of chillies and the characters exhibiting heterosis were fruit number per plant, plant height and fruit length (Singh, Singh and Mittal, 1973).

Combining Ability

The concept of combining ability originally developed in maize is now extensively used and applied in all the crop plants. Sprague and Tatum (1942) defined general combining ability as the average performance of a line in hybrid combinations and the term specific combining ability as to refer to those cases, in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. In general combining ability, genes with additive effects are most important, while specific combining
ability is more dependent on genes with dominance and epistatic effects. Specific combining ability involves both dominance and epistasis, while general combining ability is dependent mostly on additive effects and additive x additive type of epistasis (Sprague and Tatum, 1942; Griffing, 1956 b). Griffing (1956 a, b) expounded the method used by Sprague and Tatum (1942). He developed techniques for working out general and specific combining ability effects along with the general and specific combining ability variances associated with the lines. He discussed eight different types of analysis resulting from combination of four different crossing systems together with two alternative models with regard to sampling nature of the material. The diallel cross method should be taken advantage of after selecting a few (about 10) varieties on the basis of per se performance. This method provides an intensive comparison among varieties and might be used to assess long potentialities of raw material (Gilbert, 1958). But in self pollinated crops, the phenotypically equally promising parents do not always produce superior offspring in the segregating generations, while certain combinations nick well and give superior segregants (Allard, 1960). Thus performance of parents is not always a good index of superior combining ability. Intervarietal crosses of *Canavalia annua* L. showing high specific combining ability for earliness, yield and plant vigour
have been reported by many workers (Pal, 1945; Daskalov and Martazov, 1955; Papov and Hristov, 1958; Garbatov, 1960; Marikov, 1960; and Smarazov and Kurjatnikova, 1963, 1964). Good combining early parents resulted in hybrids of high quality, early maturity and high yield (Daskalov and Papova, 1960). Betlach (1965) noted that good combinations maintained their superiority throughout the growing season and also both in favourable and less favourable years. A high yielding cross combination of red pepper produced better yields than either of the parents even in F2 generation (Fujii et al., 1959).

Variances due to general and specific combining ability were reported to be highly significant for yield, number of fruits, fruit length and girth, leaf length and width, plant height, earliness, number of seeds per fruit, flowering, maturity and ascorbic acid content. Variance due to specific combining cross effects was higher than that of general combining ability effects for yield and *vice versa* for all the other characters. Thus gene interactions were more important for yield and additive effects for other characters, in chilli material. In general, all the crosses with high specific combining ability involved either parent that was high or average combiner for the trait under consideration (Kumar, 1969; Brar, 1971; Singh, 1972 and Kaul, 1974).
Mazel and Lippert (1975) while working with a set of nine chilli varieties and their 36 biparentals found that the contribution of general combining ability variances was more for component percentage of chilli fruit i.e. endocarp, seed, stem, placent and exocarp. Later, Lippert (1975) using the same material reported that for fruit length and breadth and fruit number, variances due to general combining ability were more important than the specific combining ability variances. However, fruit weight per plant was not significantly different in the crosses and thus the type of gene action involved could not be estimated.

**Inheritance Studies**

The information on the mode of inheritance and gene action for quantitative characters is of immense use to the plant breeder for deciding the appropriate breeding procedures to be followed. Jinks and Hayman (1953), and Hayman (1954, 1958) gave an algebraic approach for the analysis of diallel crosses. This is an extension of the system described by Fathar (1949) which is based on partitioning of second degree statistics, i.e. variances and covariances. From the diallel cross analysis, the estimates of overall dominance, distribution of genes among parents, estimates of genetic parameters and combining ability effects, are obtained from the statistics of $F_1$
progenies. The same principle can be extended to the study of subsequent generations which help in the detection of non-allergic type of gene interactions.

Yield and its Components

In earlier studies, Dale (1928) concluded from Capsicum crosses involving parents with mean fruit length of 2.3 cm and 1.57 cm that the fruit length was controlled by multiple genes with proportionate rather than additive effects. In chillies, additive component of genetic variance was more important than dominance variance and the degree of dominance was partial for fruit length (Batra, 1971) while Kaul (1974) noted the presence of non-allergic interactions with partial dominance for this trait. Fruit breadth, in a cross of "wide" (1.60 cm) by "narrow" (1.22 cm) in Capsicum, produced a heterotic $F_1$ (1.77 cm) and the extremes of $F_2$ exceeded the parental values. The number of factors was not determined but considered to be a low number (Deshpande, 1933). The absence of non-allergic interactions with partial dominance for fruit diameter has been reported by Batra (1971) and Kaul (1974).

In the earlier studies, small number of fruits was reported to be incompletely dominant over large number of fruits in chillies (Sakai, 1952). But later on, over-dominance with greater magnitude of dominance genetic
variance was observed by Kumar (1969) and Brar (1971), whereas partial dominance and additive gene effects were reported by Singh (1972) and Kaul (1974). The heritability estimates (broad sense) for fruit number were high in chillies (Nandpuri, Gupta and Thakur, 1971).

Fruit size in pepper was observed to be controlled by several factors (Webber, 1932). The minimum number of genes controlling fruit length, fruit width, and number of seeds per fruit in Capsicum were 0.79, 9.52 and 6.51 respectively (Miyazawa, 1953). In certain studies (Dale, 1931, and Khambanonda, 1950), long fruit size in Capsicum has been reported to be dominant over small fruit size. However, Sakai (1952) observed the small fruit size to be partially dominant over large fruit size. Partial dominance for fruit size has also been reported by other workers (Kumar, 1969; Brar, 1971; and Singh, 1972), while complete dominance was observed by Kaul (1974). There had been controversial reports regarding the type of gene action in the inheritance of fruit size in chillies, where Kumar (1969) and Singh (1972) observed epistatic type of gene interactions, Brar (1971) and Kaul (1974) obtained additive type of gene action for this trait. Number of seeds per fruit was found to be under the control of additive gene effects with partial to complete dominance (Singh, 1972).
In chillies fruit yield exhibited over-dominance, greater magnitude of non additive genetic variance and predominance of epistasis as reported by various workers (Kumar, 1969; Brar, 1971; Singh, 1972; and Kaul, 1974). High heritability (broad sense) was reported for yield, by Nandpuri et al. (1971). Brar (1971) indicated the equal existence of dominant and recessive genes, while Singh (1972) and Kaul (1974) observed the asymmetrical distribution of dominant and recessive genes in parents with greater frequency of genes that had positive effect on yield.

**Morphological Characters**

Webber (1911) crossed two medium sized varieties, 'Golden Dawn' which had few, coarse and horizontal branches and 'Red Chilli', having many fine and erect branches; he obtained F₂ segregates both giant and dwarf in comparison to the parents. Tallness in chillies was reported to be dominant over dwarfness and was inherited monogenically (Dale, 1931). Analysis from the F₂ generation of the cross 'Santaka' x 'Truhart Perfection', however, indicated that three pairs of polymeric genes were involved in the inheritance of plant height (Dempsey, 1960).

Partial dominance with little complementary type of gene action was observed by certain workers (Kumar, 1969 and Singh, 1972); complete dominance and
appreciable amount of non-additive gene effects by 
Brar (1971); and additive as well as dominance effects 
in equal proportions with partial dominance has been 
reported by Kaul (1974), for plant height. The 
heritability estimates in broad sense were high for plant 
height in chillies (Nandpuri et al., 1971).

Miyazawa (1953) from the inheritance studies 
on Capsicum annuum L. concluded that genes governing 
leaf length and breadth were 1.59 and 8.92 respectively. 
Khan and Munir (1954) estimated that leaf size was 
conditioned at least by five genes. The leaf size of F₁ 
hybrìde was intermediate between the parents size 
(Carlsson, 1962). Additive genetic variance was more 
predominant for leaf length and breadth and both the leaf 
measurements showed partial dominance (Kumar, 1969). 
Component analysis indicated that for number of branches 
per plant additive genetic variance with partial to 
complete dominance pronounced (Kaul, 1974) while 
heritability estimates in broad sense were of medium 
order (Nandpuri et al., 1971).

Quality Characters

Significant varietal differences for ascorbic acid, have been reported in sweet pepper by Stouty and 
Andre (1965) and in hot pepper by Sainbhi, Padda and Singh 
(1972). Ascorbic acid content improves with the ripening
of fruit (Petersin, 1953; Rickovin, 1956; Spaldon and Pavna, 1961). Higher amount of vitamin C in red chillies than in green chillies was observed by Mishra and Khatei (1969) and Cambria, Casoli and Bruno (1971). However, Saindi et al. (1972) noted ascorbic acid content of varieties NP-46, NP-50, Sulamukhi Black, Lovinga, Long Red, Abhak-12 and Fakhabadi was the highest in the pink fruits, whereas in the varieties Rajpura Long, All Season and Gurdaspur Black, there was continuous increase in ascorbic acid with increase in maturity from green to red. But, on the contrary, Garde (1970) reported that vitamin C ranged from 160 to 200 mg/100 g in green fruit and from 127 to 170 mg/100 g in ripe fruit. However, in one of the samples of fresh red peppers the value as high as 1190.5 mg/100 g of tissue, has been recorded (Santa Maria and Ruiz De Assin, 1961).

Vitamin C content of C. annuum, C. chinense, C. pendulum, C. frutescens, C. microcarpus and C. praetermissus varied between and within species (Cambria et al., 1971). The highest values were obtained with C. annuum cultivars and the lowest with C. pendulum. Rampal (1965) pointed out that ascorbic acid also varied with polyplody levels in 10 red pepper varieties and their corresponding tetraploids, it ranged from 35.4 to 91.2 mg/100 g and from 40.6 to 154.0 mg/100 g respectively.
The mean values of $F_1$ were generally close to the geometric mean of the parents and that only in exceptional cases, the $F_1$ hybrids possessed a higher ascorbic acid content than that of superior parent (Gyroffy, 1949). Betalech (1967) and Popova et al. (1970) found that the inheritance of the character was intermediate, while Chroboczek et al. (1966) reported that the hybrids had, in general, higher ascorbic acid contents. In generation studies, the reports are contradictory; complete dominance was involved in the inheritance of this character, magnitude of dominance and additive variance was same and distribution of positive and negative genes in parents was symmetrical (Singh, 1972). Partial dominance, absence of non-allelic interactions significance of both the additive and dominance components of variance and relatively higher magnitude of the additive component have been indicated by Brau (1971) and Keul (1974).

Vitamin 'A' has been reported in terms of B carotenes by several workers in Capsicum spp. Hybrids were observed to be intermediate and did not record any heterosis in $F_1$ generation (Brauer, 1962, 1963; and Popova et al., 1970). Lippert (1975) recorded data in nine parent diallel crosses of chillies regarding total carotenoids and observed that additive component was more important in the inheritance of this trait.
The spicy flavour or pungency so characteristic of the Capsicum is due to the alkaloid capsaicin (Thresh, 1876; Nelson, 1910). A lot of variability exists in chillies and the various ranges of capsaicin contents had been recorded by several workers: 0.406 to 3.264 mg (Flor, 1954); 7.5 to 29.4 mg (Ananthaswami et al., 1960); 195-769 mg (Cesol and Fuzi, 1962) and 30-100 mg/100 g (Kisgyorgy et al., 1962); 0.45-1.84 (Kamalam and Rajamani, 1965) and 0.27 to 1.13 per cent (Ramanujam and Tirumalachar, 1966). Soil conditions and climate particularly temperature appeared to be responsible for variable levels of pungency in peppers from different localities (Erwin, 1932; Miller and Fineman, 1937). Ohta (1962) considered high night temperatures particularly favourable for high capsaicin content.

Relying on the organoleptic methods, several workers reported that pungency was dominant to non-pungency and inherited monogenically (Deshpande, 1935; Ramiah and Pillai, 1935; Miller and Fineman, 1937; Greenleaf, 1952; and Dempay, 1960). Brauer (1962) noted that capsaicin content was intermediate in inheritance and from the correlation studies postulated that involvement of more than one gene. Ohta (1962 b) using the paper chromatography and thresh-hold method recorded that pungency tended to be dominant in F₁ and very wide variation occurred in F₂.
and BC generations. Ramanujam and Tirumalacher (1966, 1967) and Quaglitti et al. (1969) used the spectrophotometric techniques for the determination of capsaicin content and postulated that the trait was polygenically inherited. High heritability (broad sense) of 90 per cent was reported by Ramanujam and Tirumalacher, (1967). Capsaicin content did not show any heterosis and appeared to be under the control of epistatic factors (Brauer, 1963).

Correlation Studies

Correlation studies are helpful in selecting for complex traits on the basis of their association with simply observable characters. However, in vegetable crops like Capsicum such studies are limited.

In chillies, Giardani (1965) noted positive association between number of fruits and green matter and also between fruit length and width, while negative relationship existed between number of fruits per plant and the mean weight of the fruit. The leaf size showed a positive relationship with fruit size, while fruit number was negatively correlated with fruit size (Carlsson, 1962).

Legg and Lippert (1966) studied variability and correlations in chillies and observed that number of mature fruits was negatively correlated with that of fruit length, fruit width and average fruit weight. Fruit weight
was also reported to be positively correlated to fruit length and width.

Nandpuri, Gupta and Thakur (1970) reported that yield in chillies was positively associated with 100 seed weight, fruit size, fruit number, branches number and plant height but they did not notice a significant correlation between the days to first flowering and days to first fruit maturity.

Singh, Kallo and Mehrotra (1972) worked the association of plant characters with yield in chilli varieties. Yield per plant of dry chillies was found to be positively correlated with primary and tertiary branches and fresh weight of fruits; fruit number was also positively associated with fresh weight of fruits, number of branches, plant height and days to flowering.

According to Singh (1972) positive correlations were observed in chilli varieties; yield per plant with number of fruits per plant, fruit size and plant height; number of seeds per fruit with fruit number and plant height with fruit number; negative relationship between fruit number and fruit size, while number of seeds with yield, fruit number and plant height; plant height with fruit size and ascorbic acid with all the characters studied, did not show any relationship.

The correlation of fruit size with number of seeds was positive and high at both high and low temperatures (Rylski, 1973).
Regression analysis has also been reported in chillies. Three fruit characters, namely fruit per plant, fruit size and seed size accounted for 92.53 per cent of the phenotypic variation of fruit yield (Mandpuri et al., 1970). In another study, fruit size and fruit number appeared to be the only two characters, which contributed directly to yield (Singh, 1972).

Pungency is associated with small fruit size in Capsicum (Senathiraja, 1926; Ramiah and Pillai, 1935; Kamalam and Rajamani, 1965) and thus pungent varieties tend to be small fruited. Strains with thick fleshed pods were observed to be milder than strains with thin walled pods and similarly, long slender pods were less pungent than short wide-shaped pods (Anonymous, 1951). Ohta (1960) found a low correlation \( r = -0.21 \) between capsaicin content to dry matter and fresh weight of ripe fruits. Dempsey (1960) established from \( F_2 \) data linkage between pungency and erect fruit position with a cross over value of \( 0.3443 \pm 0.0387 \).

The percentage of capsaicin content and weight of placenta was observed to be positively correlated (Brauer, 1962; Ramanujam and Tirumalachar, 1966).