CHAPTER 2
LITERATURE REVIEW

2.1 Origin and Distribution

Chili has been known since the beginning of the Western World civilization and become an element of human food since 7500 B.E. (MacNeish, 1964; Purseglove *et al.*, 1981). Although the plant genus *Capsicum* is native to the American tropics, it has been recognized and cultivated extensively in almost every part of the world as it is one of the spices people have used popularly, and it was dispersed worldwide by the Spaniard and Portuguese merchants (Bosland, 1996; De Witt and Gerlach, 1990; Andrews, 1999). The center of *Capsicum* diversity is in the south-central region of South America (Eshbaugh, 1980; Hunziker, 1979; D'Arcy and Eshbaugh, 1974; Gonzalez and Bosland, 1991). Some major domesticate chili species have original geographic distribution in Brazil and/or part of Bolivia, while the wild species are collected for use occasionally. The center of origin of *C. annuum* is in the semi-tropical region of Mexico (Hernández-Verdugo *et al.*, 1999 , 2001; Andrews, 1995; Long-Solis, 1998; Whitmore and Turner, 2002). The other four domesticated species are believed to have ancestral home in South America (Eshbaugh *et al.*,1983; Walsh and Hoot, 2001; Denevan, 2001). The Amazonia (in northern region) is considered to be the center of origin of *C. chinensis* (Velez, 1991; Toquica *et al.*, 2003). Western Amazonia is possibly the center of origin of *C. frurescens*, a species cultivated not so extensively in Central America (Heiser, 1985; Hernández-Verdugo *et al.*,1999). Bolivia is considered to be the center of two domesticated species, *C. baccatum* and *C. pubesens* (Eshbaugh *et al.*, 1983; Eshbaugh, 1993; Greenleaf, 1986).

2.2 Botanical and Morphological

Chili (*Capsicum* spp.) belongs to the family Solanaceae and is closely related to potato, tree tomato, eggplant, husk or strawberry tomato (*Physalis pruinosa*), Cape gooseberry, African eggplant (*Solanum macrocarpon*, *S. aethiopicum*), tobacco, petunia, deadly night shade (*Atropa belladonna*), *Datura stramonium*, tree daturas (*Brugmansia*) and black night shade (*Solanum nigrum*) (Knapp, 2002; Hunziker, 2001; George, 1985; Bosland, 1994). *Capsicum* is generally diploid having 24 chromosomes while the wild species generally have 26 chromosomes. Recent studies indicate that the mild chili has chromosome number of 26 while the hot chili strains mostly have 24 chromosomes (Moscone *et al.*, 2003; Pickergill, 1991; Tong and Bosland, 2003). *C. annuum* has 24 chromosomes, generally with one or two pairs being acrocentric and 10 or 11 pairs being metacentric or sub-metacentric (Lanteri and Pickersgill, 1993).

Plant *Capsicum* is bushy plant, 1 - 6 feet (30 - 180 cm) tall, with smooth and glabrous stems. In the wild form, it is either annual herb or perennial shrub (Bailey, 1961). The healthy plant generally has several branches which grow out of the base of main stem making it looks like a cluster of plants with no main stem but having only main branches. Both main stem and branches of chili plant are characterized as soft wood in the early stages of plant growth and develop toward maturity into hard wood nature but they remain easily breakable. The stem is pubescent and green when plant is young but it becomes rounder and more glabrous when the plant grows older; and at the late development stages, nodes, branches and leaves of chili plant become brownish-grey colored or even purple in some varieties (Techawongstien, 2006).

Leave Chili leaves are either in ovate or elliptic series, acuminate, tapering and emarginating to the apex, smooth in surface, arranged in spiral form, with 2-3 leaves in varying size at the same node, erect and having no secondary branches (Bailey, 1961).

Flower Chili flower has white or greenish white or even purple petals in radial symmetry. Inflorescences either solitary or 2-3 flowers develop from the axil or the same node in reclinate nature. The calyx is campanulate having five or more truncate tips with small teeth which grow larger after the flower blooming. The short tube shaped corolla is glaborous carrying five trumpet-like valvate petals. The flowers have five stamens at the end of the corolla and filaments attached to the oblong anthers which each comprises two lengthwise chambers. The glaborous ovary of 2-4 carpels contains plenty ovule. The style is either filaform or claviform with gummy or non-gummy stigma (Bailey, 1961).

Fruit Chili fruit is a berry or dry pod attached to the flat or cup-shaped calyx. The fruit shape and size are highly variable. The fruit skin is smooth, rather dry while the pericarp is coriaceous and the walls seem invisible. In the pod, there are numerous seeds in flat disc shape with thick and clear ribbed margin as well as curved embryo. The fruits of *Capsicum* can be mild or very pungent depending on the capsaicinoids in seeds and fruit walls (Bailey, 1961).

Chili in genus *Capsicum* is diverse in variety encompassing a wide range of plant characteristics from mild bell peppers to hot chilies and including 20-30 wild species and five domesticate cultivars (Eshbaugh, 1993; Bosland and Votava, 2000). At present the five domesticated species namely *C. annuum*, *C. baccatum*, *C. chinense*, *C. frutescens* and *C. pubescens* are grown prevalently worldwide (Berke, 1999; Bosland, 1994; Bosland and Votava, 2000; Hundal and Dhall, 2004; Moscone *et al.*, 2007; Pozzobon *et al.*, 2006), particularly *C. annuum* which is cultivated most extensively and in every region of the world due to its diversity in plant habit especially the fruit morphological features such as shape, size, color, as well as differentiated by floral and seed morphology and color (Andrews, 1995; 1998; 1999; De Witt and Bosland, 1996). Moreover, pepper, chili, chilli, aji, paprika and *Capsicum* are the names used interchangeably to describe the plant and fruit characteristics of this plant genus (De Witt and Bosland, 1996).

Chilies contain numerous chemical elements such as steam-volatile oil, fatty oils, capsaicinoids, carotenoids, vitamin, protein, fiber and mineral elements (Bosland and Votava, 2000; Krishna De, 2003). Many constituents of chilies are important in terms of nutrition, smell, aroma, texture and color. Mature chili fruits particularly are rich sources of vitamin C (Osuna-GarcÍa *et al.*, 1998; Marin *et al.*, 2004), vitamin A, vitamins B_1 and B_2, calcium, iron and phosphorus (Bosland, 1992). The greatly interesting chemical contents in chili peppers include capsaicinoids which is an alkaloids giving strong hotness, abundant carotenoids which has nutritional values, and colors (Britton and Hornero-Méndez, 1997; Hornero-Méndez *et al.*, 2002; Pérez-Gálvez *et al.*, 2003). The great variation in terms of forms, colors, shapes, flavors, pungency and aromas has made chili peppers important worldwide as an ingredient in various culinary preparations such as salads, pickles, paprika, curry powder as well as in the manufacturing of chili sauce and chili powder, and also as a coloring agent in cosmetic products. Chili pepper has become the world's most popular seasoning and spice replacing black pepper (Andrew, 1995; 1999; Bosland, 1994; Bosland and Votava, 2000).

2.3 Male sterility

CMS in chili was first found in *C. frutescens* (Martin and Crawford, 1951). Later on, Peterson (1958) reported the finding on male sterility in *C. annuum* which was a result of the interaction between cytoplasm (S-type) and gene in nucleus (*ms*). Subsequently, he conducted a study on PI 164853, an imported chili variety from India which was utilized as the genetic source for producing CMS hybrid seeds. It was found that the male sterility trait in chili is controlled by the recessive gene in nucleus (*ms* or *rf*) together with the gene in cytoplasm, while the production of viable pollen is controlled by one dominant gene (*Ms* or *Rf*) (Peterson, 1958; Novak *et al.*, 1971; Wang *et al.*, 2004).

Shifriss (1997) collected natural CMS plants for classification and study, and found that male sterility is governed by the gene in the nucleus and the interaction between cytoplasm and the nuclear gene. CMS chili is caused by the pollen cell division under normal meiosis process from microspore mother cell stage to tetrad stage but the pollens fail to develop into gametes. The pollen is separated from the anther sac cell due to the abnormally swollen tapetum which produces pressure on the ovule sac and because the mitochondria in tapetum has high vacuole content and there is no accumulation of sporopollenin on pollen surface causing tapetum to disintegrate. CMS can also be caused by the rearrangement of chromosomes and some chromosomes might be damaged leading to abnormality and impairing the genetic system in its functioning during the beginning, progressing, and ending of final meiotic stage especially at the ending point of TII, the beginning point of cytokinensis and the disintegration of callose in CMS plants (Luo *et al.*, 2006, Nikolova *et al.*, 2010). It is maternally inherited with a specific gene whose expression inhibits the production of viable pollen or male gametes and is the cause of incompatibility between nucleus and cytoplasm (Hanson, 1991; Lee *et al.*, 2008a; 2008b; Budar *et al.*, 2003; Hanson and Bentolila, 2004; Chase, 2007; Hanson and Folkerts, 1992; Küch and Wricke, 1995; Min *et al.*, 2008; Ivanov and Dymshits, 2007; Bentolila *et al.*, 2002) which is in turn is associated with the new open reading frame (ORFs) resulted from the recombination within mitochondrial genome (Kim *et al.*, 2007; Schnable and Wise, 1998; Linke and Börner, 2005; Budar and Pelletier, 2001).

CMS is a trait of economic importance in the production of hybrid seeds and the CMS systems have been found in more than 150 crop types (Hanson, 1991; Schnabel and Wise, 1998) including beet (Ducos *et al.*, 2001; Kawanishi *et al.*, 2010; Sadoch *et al.*, 2003), carrot (Chahal *et al.*, 1998; Nakajima *et al.*, 2001; Wolyn and Chahal, 1998), maize (Cui *et al.*, 1996; Liu *et al.*, 2001), onion (Havey, 2000; Pathak, 1997; Melgar and Havey,.2010), petunia (Bentolila *et al.*, 2002), rice (*Oryza sativa* L.) (Kazama and Toriyama, 2003; Akagi *et al.*, 2004; Komori *et al.*, 2004), rye (Steinborn *et al.*, 1993; Stojałowski *et al.*, 2005; Stojałowski *et al.*, 2011), sorghum (Tang *et al.*, 1996), sunflower (Horn *et al.*, 1991; Moneger *et al.*, 1994; Sabar *et al.*, 2003), wheat (Ahmed *et al.*, 2001; Rathburn *et al.*, 1993; Song and Hedgcoth, 1994a; 1994b), *Brassica napus* (Brown, 1999; Delourme *et al.*, 1994; Grelon *et al.*, 1994; Li *et al.*, 1998), radish (*Raphanus sativus* L.) (Brown *et al.*, 2003; Desloire *et al.*, 2003; Koizuka *et al.*, 2003) and *Phaseolus vulgaris* (Mackenzie and Chase, 1990). The utilization of the CMS system for the production of hybrid seeds helps save time and labor involved and hence can reduce production cost by as far as 47%, while enhancing the seeds purity (Wang *et al.*, 2006; Yang, 2008). Chili is generally capable of self-pollination (Onus and Pickersgill, 2004). Allogamy often needs some effect of insects and wind for cross-pollination (Odland and Porter, 1941; Tanksley, 1984; Raw, 2000) and the success is 2-90 % depending on many factors (Pickersgill, 1997).

Male sterility is distinguished into three types (Briggs and Knowles, 1976) as follows:

1. Genetic male sterility - Male sterility in this type is controlled by a pair of recessive genes (*ms*) which are the mutant of dominant gene (*Ms*) in nucleus. Plant

with *MsMs* and *Msms* genotypes will produce fertile pollens while that with *msms* genotype will produce sterile pollens. The crossing of *msms* and *Msms* genotypes will yield seeds producing plants with fertile pollens as well as those with sterile pollens at 1:1 ratio. This type of male sterility is found in more than 50 crop species especially in self-pollinating crops such as soybean, cotton, tomato, potato and chili.

2. Cytoplasmic male sterility - This is controlled by gene in cytoplasm and is maternally inherited. CMS has been documented in more than 80 crop species, 25 genera and 8 families such rice, sorghum, wheat, tobacco, onion and petunia. The symbol S refers to sterile cytoplasm while F or N refers to normal cytoplasm. The crossing between male sterile plant and normal male parent plant will yield completely sterile F_1 because the infertility trait regulated by gene in female parent's cytoplasm will be transferred to the progeny only through ovum while the fertile male parent has no cytoplasm and thus does not carry mitochrondrial genes.

3. Cytoplasmic genetic male sterility - This type of male sterility systems is caused by the interaction between nuclear genes and cytoplasmic genes. There are two types of cytoplasms, S and F or N like male sterility in the second type but in this type there are also restorer genes, the nuclear genes that can bring back fertility to S cytoplasm. The restorer gene might be a pair of gene and it is designated *Rf* or *Ms*. If the *Rf* gene is dominant, it can cause plant having S cytoplasm to produce viable pollen. However, the *Rf* or *Ms* gene can suppress S cytoplasm only when the latter has S *rfrf* or S *msms* genotype. This system of male sterility is of great use in the large scale commercial breeding of some crop plant hybrids. It can also be used in breeding with self-pollination plants if the latter can produce large enough amount of pollens by a quite simple technique; for example, when a CGMS plant is identified, the CGMS trait can be transfered to the desirable crop variety or line by back-breeding namely by crossing the male sterility line with male parent of the original line (Laosuwan, 1983). The sterility naturally influenced by both nuclear and cytoplasm are commonly found in many crops such as *Phaseolus vulgaris*, *Brassica napus*, beet, carrot, maize, onion, petunia, rice, rye, sorghum, sunflower and wheat (Küch and Wricke, 1995).

2.4 Male Sterility and Breed Improvement

Male sterility is useful for plant breeding programs in two natures namely for production of hybrids of various crops (Frankel and Galun, 1977; Sneep and Hendriksen, 1979) and for breed improvement of self-pollinating crops. The production of hybrid seeds utilizing male sterility trait involves the following plant varieties:

1.. A-line. It is the male sterile variety obtained from back-crossing. In the case of cytoplasmic male sterility, the A-line will have S *rfrf* or S *msms* genotypes.

2. B-line. It is the maintainer line of A-line and is isogenic line with N *msms* and N *msms* genotypes.

3. C-line. It is the restorer line for the production of hybrids in certain crops. The C-line variety must contain fertility restoration genes. The C-line will have N/S *RfRf*, N/S *Rfrf* or N/S *MsMs,* N/S *Msms* genotype in the cases of cytoplasmic male sterility and cytoplasmic genetic male sterility types in which the fertility restoration genes might be designated the C-line.

Duvick (1959) utilized the CMS traits for the production of heterotic hybrid seeds, a procedure which helps save the cost of emasculation and which becomes common at present for the commercial production of hybrid crops including onion, yam, maize, sorghum and petunia. In the future, this technique can be applied to hybrid production in sweet corn, red table beets, fodder beets, fodder sorghum, carrot and ornamental pepper. Novak *et al.* (1971) experimented on the CMS chili variety identified by Peterson (1958) and found that the ratio between fertile pollen and sterile pollen population to be 3:1 in various hybrid combinations and F_2 generations. Yoo (1990) developed male parental lines for hybrids from crossing between Peterson's CMS chili variety and 270 established varieties and found 152 and 66 F_1 lines to have N *rfrf* (N *msms*) and N/S *RfRf* (N/S *MsMs*) genes, respectively, while the remaining 52 hybrids could not be classified for their genetic types.

However, Lee (2001) further delimited the difference between two groups of unstable male sterility in F_1 generation:- the first group in which chili plants having sterile gene when grown in low temperature condition can become normal and produce pollens and the other group in which the male sterile chili plants can produce both normal and abnormal pollens resulting in substantial seed abortions (Lee *et al.*, 2008a; 2008b). To reduce the cost of hybridization, this male sterility trait was exploited for the improvement of female parental lines (Basset, 1986) for the production of F_1 hybrid seeds as well as for breeding chili cultivars that produce fruits having intense pungency and other characteristics desired by the markets. CMS trait can also be exploited for large scale production of hybrid plant seeds to avoid the dependence on hand emasculation and pollination (Kim *et al.*, 2006).

Patel *et al.* (2001) produced F_1 seeds of hot chilies utilizing *ms* gene which controls male sterility; enabling a more convenient, speedy and economic way to produce hybrid seeds. Gill and Gill (1996) conducted a comparative efficiency study between the natural mode and human-assisted mode of CMS chili pollination by planting CMS chili and normal chili genotype at 3:1 alternate plants per row and found that the production of viable seeds by natural pollination reduced by 50 to 70 %. Nikolova *et al.* (2001) studied CMS in domesticated genotypes and in the hybrids from CMS parents and the experimental results revealed the prevalent presence of homozygous recessive (*msms*) feature in F_2 generation while the *Ms* gene which expresses the absolute dominance feature was found in Msms genotype in female parents of F_1 and F_2 generations.

Dejan *et al.* (2007) developed new hybrid lines from crossing between *ms-3* chili varieties and selected genotypes from the germplasm collection to obtain the progeny characterized with high yield, good quality fruits and short time to maturity for harvesting. The experiment was conducted under controlled conditions for comparison of development among various chili cultivars and the Mona F_1, the new hybrid, received a particular attention. Hwang and Kim (1998) selected 6 *Phytopthora capsici* resistant varieties and 4 native chili cultivars for the segregation of CMS (A-line), maintainer (B-line) and GMS which are the vulnerable varieties. Their trials involved the crossing between A-line and resistant varieties and that between A-line and vulnerable varieties for fertility scoring and found F_1 generation of all 6 resistant parents were fertile indicating that the resistant varieties contain N(S)*ms+ms+* , the sterility removal gene; while discovered that among the 4 native varieties, Chilsung, Subi and Punggak are maintainer line with N *msms* gene and Kami is a restorer with N(S) *ms+ms+* gene.

2.5 Molecular Marker

Recently, molecular techniques have been applied for distinguishing N-cytoplasm from S-cytoplasm. SCAR markers procedure was developed to discern the difference in fragment structure of *coxII* and *atp6* genes in chili mitochondria (Kim *et al*., 2001; Kim and Kim, 2005). Kim and Kim (2006) selected *atp6* gene while in the work of Kim *et al.* (2007) *orf 456* gene was used for identifying male fertile or normal (N) and male sterile (S) chilies. Gulyas *et al.* (2006) employed a SCAR marker called CRF-SCAR to detect the *Rf* (*MS*) genetic distance which was found to be 4.8 cM. Zhang *et al*. (2000) used two markers, OP13$_{1400}$ and OW19$_{800}$, in the RAPD protocol to determine the *Rf* (*MS*) genetic distance and the results were 0.37 and 8.12 cM, respectively. Jo *et al*. (2010) developed three groups of markers with 1.4, 3.2 and 14 cM distances from *Rf* locus and the CRF-SCAR marker has become the marker ever developed to be used most extensively in the detection of restorer line.

Kim (2005) employed a CAPS marker called OPP13-CAPS to measure the *Rf* (*MS*) genetic distance which was 0.7 cM. Later, Kim *et al.* (2006) further improved the Cleaved Amplified Polymorphic Sequence (CAPS) technique to help discern the difference between chili having *RfRf* gene and that having *rfrf* gene by increasing the amount of DNA through PCR method and the AFRF8CAPS marker could lead to the finding of *Rf* genetic distance at 1.8 cM and the amplified DNA was tested for *RfRf* and *rfrf* genetic difference using restricted *Rsa* I enzyme and it was found the polymorphism to be 200 and 100 bp respectively. The speedy and precise identification of S-cytoplasm, N-cytoplasm and restorer-of-fertility (*Rf*) genotype in the early stage of plant development will be extremely useful for chili breed improvement programs (Yoo, 1990; Kim and Kim 2005).

2.6 Combining Ability

Combining ability explains the quantitative traits of individual parents. There are 2 type of combining ability: general combining ability (gca) and specific combining ability (sca). Sprague and Tatum (1942) proposed the seminal concept of combining ability in corn. According to them, gca is the comparative ability of the line to combine with other lines expressed by the deviation of the mean performance of all the crosses involving a parent away from overall mean while sca is defined by the deviation in the performance of a specific cross from the performance expected on the basis of gca effects of the parents involved in the crosses. A positive gca indicates a parent having the capability to produce progeny above the average cross while parent with negative gca effects will produce progeny that performs below the population mean, but the sca can be either positive or negative (Virmani *et al*., 2003). The information (or knowledge) on the genetic variation among the F_1 population will be helpful in the selection of suitable parents in breed improvement programs (Thul *et al.* 2009). The line × tester technique advanced by Kempthorne (1957) has been commonly used for testing the combining ability of the parental lines in hybrid plant breeding programs and this technique is particularly useful when there exist large number of parental lines as candidates for producing hybrids with performance expected on the basis of the parents' gca. Legesse (2000) conducted a test on the effects of combining ability on yield and yield attributes in chili such that the results can be applied for crossing hybrids possessing the desirable characteristics. The gca and sca values from the analysis of variance are most critical for the study of yield and its components as they can indicate the additive and the non-additive effects in genetic control.

Rego *et al.* (2009) studied gca and sca of hybrid chilies and their parental lines involving the fruit quality and yield which were found to be different at statistically significant levels in almost all characteristics except the sca values of height of the first bifurcation; and specifically almost all characteristics of the parents had the effects on the performance of the crosses. Sreekala and Raghava (2003) examined the gene action, combining ability and heterosis in African marigold (*Tagetes erecta* L.) for genetic improvement in terms of enhanced carotenoid content in petals on the basis that total carotenoid and luetein are controlled by dominace (non-additive) gene action while the magnitude of xanthophylls esters is regulated by both additive and non-additive gene actions.

Zuo *et al.* (2007) explained the perspective of breeding high yielding chili hybrids by analyzing the combining ability in the nature of net photosynthesis rates of the hybrids and parents at different stages of flowering and fruit setting as the number of fruits per plant will vary positively with such rate and the combining ability is the most crucial parameter for breeding high photosynthesis hybrid pepper varieties. Ahmed *et al.* (1999) reported the high general combining ability in almost every characteristic of Shalimar long and Elephant Trunk chilies while the Punjab Lal, G-4 and Pusa Jwala varieties expressed high gca in terms of number of fruits and four combinations of the crosses had high sca values for yield. Pandey *et al.* (2003) undertook a study on the combining ability for yield and its components in hot chili (*Capsicum annuum* L.) using line × tester mating system and found most crop characteristics studied had sca values higher than gca values indicating that the performance expression was the result of non-additive gene effect. Consequently, if one parent or both parents have high gca values then the hybrid offspring will also have high sca values as well. The breeding for outstanding features in hybrid lines, thus, can be efficient for improved yield and other attributes of hot chilies.

2.7 Heterosis

Karladee (2002) described the heterosis occurrences associated with the high yielding ability which can be assessed for the purpose of breed improvement. Heterosis is defined as the phenomena in which a particular trait of F_1 hybrids is superior to that of the landrace parents when grown in a comparable production conditions (Hochholdinger and Hoecker, 2007). There are three criteria to estimate the heterotic effect for use in breeding programs (Karladee, 2002).

1. Heterosis of F_1 hybrid over mid parent

$$\% \text{ Heterosis (H)} = [(F_1 - MP) / MP] \times 100$$

Whereas F_1 = mean of F_1 population

MP = mean of both parents (mid-parent) = $(P_1 + P_2) / 2$

2. Heterosis of F_1 hybrid over better parent or heterobeltiosis

$$\% \text{ Heterobeltiosis (HB)} = [(F_1 - BP) / BP] \times 100$$

3. Relative heterosis of F_1 and F_2 hybrids of the same parents.

$$\% \text{ Heterosis (H)} = [(F_1 - F_2) / F_2] \times 100$$

Whereas F_2 = mean of F_2 population

Hybrid chilies are used widely in crop production due to the heterotic trait in chili (Guo *et al.*, 1981). Assessment for the breeding of hybrids is based on the heterotic expression. Ahmed *et al.* (1999) reported the heterosis in 6 hybrid lines obtained from all possible combinations without reciprocals. The Shalimar long and SPE-1 mating gave the hybrid with heterobeltiosis for yield and earliness. Law-Ogbomo and Law-Ogbomo (2010) reported on their experiments in sweet peppers in years 2006 and 2007 in the humid tropical region of Nigeria involving 6 varieties namely TEA14, California wonder PS, California wonder 300, N22, N23, Long yellow sweet and one local genotype (Benin local). They found TEA14 line to have better vegetative characteristics and 6.21 t/ha yield while Benin local performed poorest at 2.02 t/ha whereas the average output was 3.86 t/ha in 2006 and 3.84 t/ha in 2007.

Burli *et al.* (2001) presented the findings on the crossing of six hot chili varieties namely, G-3, GAD Sel-35, Phule Sai, GCH-1, Delhi Red and M-Sel-11, with two lines of paprika including GAD Sel-31 and Vietnam that all the hybrid population exhibited negative heterobeliosis for plant height and fruit width while 30 hybrids had negative heterosis over better parent for days to 50 % flowering and fruit width but positive for plant height, number of branches per plant and fruit length. Sousa and Maluf (2003) studied hybrid heterosis and assessed the quantitative genetic characters in hot chili (*Capsicum chinense* Jacq.) from the diallel crosses of five hot chili lines and performed the analysis on total yields and the extent of resistance to *Xanthomonas capestris pv. resicatoria*. From their study, the heterosis for all horticultural characteristics of the 10 F_1 hybrids appeared to be conferred by the non-additive gene effect more than the additive one; however, epistasis was found to have the effect on dry fruit weight per plant, capsaicin content per plant and number of seeds per fruit. Generally, the expression of heterosis in their study was largely the result of dominant gene action ranging from the level of incomplete dominance to overdominance.

Prasad *et al.* (2003) also conducted a study on hybrid heterosis in hot chilies. Six hybrid lines were produced from half diallel 9 × 9 crossing of one bell pepper varity Arka Gaurav with 8 advanced breeding lines of hot chilies namely VR-1, VR-2, VR-42, VR-14, VR-17, VR-27, VR-47 and VR-55. The hybrid VR-2 × VR-55 appeared to obtain the highest dry fruit weight per plant among all hybrids under trial and outperformed the controlled line as well as the better male or female parent while the hybrid VR-1 × VR-2 had greater number of fruits per plant in comparison with the controlled line as well as the better male or female parent. Meshram and Mukewar (1986) undertook a test of hybrid heterosis in hot chilies (*Capsicum annuum* L.) by top-crossing procedure involving 12 different genotypes and a MS line. Among the 12 F_1 lines, the hybrid MS × K-2 exhibited positive heterosis over the better parent (157 %) and outperformed the male parent at statistically significant level. The next most outstanding were MS × Pant-C-1, MS × Japanese bunch and MS × Bhiwapur local varieties which had heterosis for days to flower, plant height, number of primary branches, fruit length and number of fruits per plant. Their study findings suggest that the MS chilies can be utilized for commercial production of vigorous hybrids.