GENETIC CONTROL OF FRUIT YIELD AND ITS COMPONENT CHARACTERS IN HOT PEPPER {*CAPSICUM ANNUUM* L.)

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FUFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY CROP SCIENCE DEGREE.

DECEMBER 2010

DECLARATION

I hereby declare that except for references to the work of other researchers which have been duly cited, this work is a result of my own original research and that this thesis has neither in whole nor in part been presented elsewhere for the award of another degree.

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DEDICATION

To my family for always being there for me.

ACKNOWLDGEMENT

I am most grateful to The Almighty God for showering me with His grace which flourished my thoughts to enable me complete my studies.

1 am highly indebted to my supervisors, Prof. K. Ofori and Prof. E. T. Blay for the time and patience they put into guiding me through this work.

1 humbly say thank you to Prof. Ofosu-Anim, Prof. Kumaga and Dr. Amoatey for their consistent encouragement and productive criticisms.

My sincerest appreciations and thanks are extended to Mr. Ankra, Mr. Agyekum, Mr. Appiah, Mr. Julius, Mr. Asante and Mr. Wahab for the various assistance they gave me through out my studies.

My profound sense of gratitude to Dr. Bernard Kankpeyeng, Ms. Yvonne Kugblenu and Mr. Majeed Morro for willingly offering their help anytime I needed it

Last but not least I acknowledge with all humility the assistance given to me by Mr. V. Suglo and Mr. A. C. Achaab.

ABSTRACT

A research was conducted from June 2008 to May 2009 with the main objectives to identify suitable hot pepper lines to be used in breeding for superior fruit yield and yield associated components based on their combining abilities, determine heterosis in the Fi generation, estimate heritability of various traits and correlation between yield and its associated characters. Eight (8) hot pepper lines were analysed in a line x tester fashion comprising six (6) lines and two (2) testers. Analysis of variance of the mean performances of the Fis and their parents revealed significant differences among the genotypes implying the presence of variability. Parents and crosses showed significant differences in both general and specific combining abilities respectively indicating the incidence of both additive and non-additive gene effects. 'BEK' was identified as the best combiner for fruit number/plant and earliness. The Fis expressed both positive and negative significant heterosis over better- and mid-parent values for all traits measured. Heritability was high for seed number, fruit length, number of primary branches, fruit weight, days to fruit set, days to first flower opening, fruit number per plant and plant height at flowering. It was low in fruit yield per plant Fruit number per plant was highly correlated with fruit yield per plant

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CHAPTER ONE

1.0 INTRODUCTION

Hot pepper *(Capsicum annuum L),* a spice cum vegetable crop belongs to the family *Solanaceae*. It is valued for its pungency, caused by a crystalline alkaloid called capsaicin, present in the placenta of the fruit It is an indispensable condiment and acts as a digestive stimulant. Pepper is an important ingredient in most dishes in Ghana and a cure for many rheumatic troubles. It is rich in vitamins C, A and B, potassium, phosphorus and calcium. Pepper contains more vitamin C than any other vegetable crop (Xuefeng, 1999).

Pepper is an important export commodity, earning Ghana some US $ 714,614 in 2008 (Ghana Export Promotion Council, 2008). Ghana with some 75,000ha of land under pepper cultivation is the second largest non-EU exporter of pepper to the UK after Kenya (CARDI database, 2006).

According to the Belize Trade Investment Guide (2004), the demand for hot pepper products and fresh hot peppers is increasing rapidly in North America, Europe and Asia This demand for specific hot peppers is largely driven by consumer ethnicity (Uganda Export Promotion Board, 2003). In 1999 the total value of fresh peppers imported by the USA was approximately US dollars 388m which increased by 61 % to US dollars 626m in 2003 (United Nations Statistics Division Commodity Trade Database,2004). The positive growth in foreign markets is a major incentive for local producers who recognize the potential of their crops. (Belize Trade Investment Guide, 2004). Hence it is important to develop pepper varieties that are not only higher yielding but also have improved yield-associated characteristics and quality standards in order not be kicked out of the pepper export market by the big players such as Spain, China and India.

There is an export potential for capsicum fruits with fresh appearance, uniformity in size and shape, and free from insect and disease damage (Capsicum leaflet, 2001). Diverse germpiasm resources exist for enhancement of the crop. Meanwhile only very few export varieties of pepper have been developed in Ghana namely, 'Legon 18', 'CRl shito adokpe' and 'CR1 mako Entos' (Bonsu, 2008). These varieties presently do not command high prices on the international market due to relatively low pungency and non uniform fruit size and shape among others (Ametekpe, 2008).

Pepper is one of the easiest crops for our rural farmers to cultivate. Its semi-perennial nature also makes it a preferred crop. It is a source of livelihood for many women in Ghana. Pepper is easy to dry and can be preserved for a very long time. The yield potential and total production of hot pepper fruits in Ghana is low due to poor yielding varieties and poor quality of fruits. Further exploitation of the pepper germpiasm in the country and from elsewhere is necessary for improving the pepper production through selection for direct production or for use as parents in a hybridization programme.

Most pepper varieties start flowering five (5) weeks after transplanting with duration of harvest of up to six (6) months with consistent high level management and a good amount of soil moisture (CARDI database, 2006). The major rainy season in Ghana starts from April and ends in early August and the minor, begins September and ends October (only in the south). This stresses the need for early maturing varieties to take advantage of the rainfall pattern such that pepper can be harvested many times before the rainy season is over. Early maturing crop would also mean farmers will get good yields when peppers are planted during the minor season.

One of the methods to achieve quantum jump in yield is heterosis breeding which starts with identification of worthy parents (Ganeshreddy *et al.*, 2008 a). Exploitation of heterosis in chilli has been recognized as a practical tool in providing the breeder with a means of increasing yield and other economic traits (Senevirathne and Kannangara, 2004).

For most crop improvement programmes, knowledge of combining ability of parents and crosses, and the gene effects involved in the inheritance of various traits is a pre-requisite. Yield heterosis is a variable trait and relies heavily on the parental combinations (Berke, 2000).

The objectives of this study were to:

a. Identify suitable parents to use in breeding for superior fruit yield and yield component characters based on combining ability.

b. estimate heterosis in Fi populations for various traits.

c. estimate heritability of yield and components of yield

d. assess correlation between yield and its component characters in Fi populations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin, Distribution and Uses of hot pepper

The *Capsicum* peppers originated in South America and spread into the New World tropics, before subsequent introduction into Asia and Africa (George, 1999). They are thought to have been introduced into West Africa by the Portuguese traders during the 15* Century (Purseglove, 1968). Pepper is the world's most important solanaceous crop after tomato (Yoon *et al*„ 1989) and is now widely grown throughout the tropics, sub-tropics and warmer temperate regions of the world (George, 1999).

In the early days of cultivation, chilli was used mainly for seasoning and as a medicinal plant whose effect was attributed to the pungency or hotness of the fruit Today, peppers are consumed fresh or processed as vegetables and spice. Around the world it is eaten by at least one out of every four persons, making it the most used spice after salt (Santana-Buzzy *et at*., 2002). Peppers are also valued as ornamental plants and for extracts used in various pharmaceutical and cosmetic products. Worldwide, the planting area of pepper is estimated at 1.25 million hectares with an average annual growth of 0.5%. 11.2 million tons of pepper is produced annually, of which 4.3 million tons are from Asian countries, such as India, Indonesia, China and Korea (Hung, 1996).

2.2 Classification and Botany

The *Capsicum* genus has a chromosome number of 2n=24 and consists of 25-30 species. Five (5) of these species are domesticated: *Capsicum annuum, C. frutescens, C chinense, C baccatum,* and *C. pubesecens.* The largest group of cultivated varieties are found among the *C. annuum* species which are grown worldwide (Eshbaugh, 1993). In tropical Africa the distinction among *C. annuum, C. chinense* and *C. frutescens* on species level is impractical and unfeasible hence they are treated as one species, C *annuum.* They are however distinguished at the cultivar level and classified into four; sweet pepper, chilli, bird pepper and aromatic pepper (Grubben and Denton, 2004).

The crop grows to a height of 30-150cm with broad, ovate, shinny and glabrous leaves. Some however have tomentose leaves. The flowers are small measuring 0.6-1.3cm across. They are considered to be self-pollinating (Allard, 1960). On the other hand out-crossing of 7% - 91% has been discovered and it is therefore argued that *Capsicum* should be classified as a facultative pollinating species in field research (Tanksley, 1984).

C. annuum plants grow best in warm (15.6-23.9 °C), well drained, sandy or silty loam of moderate fertility. The plants are not particularly sensitive to soil pH but best results are obtained in the 6.0-6.8 range. Pepper is a warm season crop and needs a long season for maximum production (Everhart *et al,* 2002)

2.3 Variability in Plant Characteristics

Within the genus *C. annuum,* there is an abundance of genetic diversity for plant habit and, fruit and leaf characteristics to meet the demands for creating new plant types (USDA, 2008). Zogli (2006) in his characterization of pepper germplasm in Ghana also reported the existence of a wide variability in pepper

2.3.1 Plant Architecture

For most crop species plant growth habit changed dramatically as a result of domestication (Clark *et* a/., 2006). More extensive vegetative growth is found in the wild relatives that display highly branched and reduced apical dominance compared with its cultivated counterparts.

The pepper shoot is sympodial, displaying alternate vegetative and reproductive phases with a lot of variation in the extent of vegetative growth and axillary branching in the cultivated germplasm pool. Breeders select for increased reproductive and reduced vegetative growth. The strategy of selecting against vegetative growth has resulted in less photosynthesis for the developing fruit, often resulting in reduced total yield. This negative effect is easily offset by the ease of plant care, and reduction in space and nutrient requirements (Paran and Knaap, 2007).

2.3.2 Variability in fruit characteristics

Pepper is one of the solanaceous fruit crops that display an enormous diversity in fruit morphology. There are hundreds of varieties produced around the world, many differing significantly in shape, size, colour, taste and pungency (Xuefeng, 1999).

The domestication process of pepper involved the selection of beneficial alleles at a collection of loci underlying yield and quality of cultivated compared with its wild relative. The fruit of wild pepper is small (about 1cm long), erect, red-coloured, pungent, deciduous (falls off the plant when ripe) and soft - fleshed. Two of the key traits that were selected during domestication of the crop were non-deciduous fruit that remained on the plant until harvest and the change in position from erect to pendant fruit The latter change may be associated with an increase in fruit size, better protection from exposure to the sun and predation by birds (Eshbaugh, 1993).

2.3.2.1 Fruit Size, Shape and Weight

The size and shape of the fruit of C *annuum* are made up of the length and diameter. The progenitors of pepper bear fruits of much smaller sizes compared with the cultivated counterparts, and thus increased fruit size was a major selection criterion in *Capsicum* species. There are so many fruit shapes in hot pepper. Continued selection resulted in a large increase in shape variation and tremendous increase in fruit mass. Like fruit size, shape is also a quantitatively inherited character (Paran and Knaap, 2007). Fruit weight is a quantitatively inherited character and is controlled by many genetic loci, some with large effect and others with small effect This has made it challenging to identify the underlying genes despite extensive studies into the genetics of the trait in pepper as well as other solanaceous fruit crops (Grandillo, 1999; Doganlar *etal,* 2002; Chaim *etal,* 2006).

2.3.2.2 Fruit Yield

Different levels of yields are exhibited by hot pepper due to several factors. Some of the more important influences on hot pepper yields are the genetic potential of the cultivars, the meteorological conditions (water availability, solar radiation etc.), agronomic conditions such as land and soil preparation, pest and disease management, weed management, irrigation and plant nutrient supply (Adams, 2006). Variability in yields may also be affected by the type of production system used.

2.3.3 Fruit Ripening

Fruit ripening is a complex, genetically programmed process requiring the simultaneous expression of numerous genes and involving increased respiration rate and ethylene production. The metabolism shifts towards the production of carbohydrates, organic acids, proteins and secondary metabolic products. The chloroplast becomes differentiated into non-photosynthesising chromoplasts, leading to the degradation of chlorophyll and starch and to extensive structural rearrangements (Taller, 2006). Fruit ripening involves many biochemical processes leading to the production of carotenoids, aromatic compounds, sugars and fruit softening. Selection has resulted in yellow, orange and brown ripe fruit colours in addition to the wild-type red, which occurs in all cultivated pepper species. Ripening in pepper is non climacteric (Paran and Knaap, 2007).

2.3.4 Fruit taste and pungency

Capsaicin, the pungent principle in hot peppers is produced as a result of the presence of capsaicinoids. Capsaicinoid biosynthesis is restricted to the genus Capsicum and results from the acyiation of the aromatic compound, vanillylamine, with a branched-chain fatty acid. High pressure liquid chromatography (HPLC) analysis has shown that capsaicinoids are only found in the interlocular septa of pungent pepper fruits. Immunolocalization studies showed that capsaicinoid biosynthesis is uniformly distributed across the epidermal cells of the interlocular septum. Capsaicinoids are secreted from glandular epidermal cells into subcuticular cavities that swell to form blisters along the epidermis. Blister development is positively associated with capsaicinoid accumulation and blisters are not present in non-pungent fruit (Stewart *eta!.*, 2007).

2.4 Hybridization and Heterosis

Increased yield has been the ultimate aim of most plant breeders. Sometimes this is accomplished by providing varieties basically more productive, not because of specific improvements such as in disease resistance but as a result of generally greater physiological efficiency through the adjustment of the growth cycle of the plant Control of pollination is essential to making the particular types of mating patterns required in the several breeding methods. In hybridization methods with self-pollinators, crosses between selected strains are necessary to provide the segregation and recombination. (Allard, 1960).

Successful hybridization depends on the availability of healthy plants with an adequate number of flowers. Proper management of plants between sowing and flowering includes management of soil fertility, soil moisture, day length, and temperature as well as pest control. Both inadequate and excessive levels of soil fertility and moisture can result in plant development that is less than optimum for flower fertilization and retention. Elimination of plant stress during flowering and the early stages of seed development will increase the chances of obtaining a high percentage of successful hybridization and self-pollination (Major, 1980).

The main purpose of controlled pollination for hybridization by crossing different lines is to take advantage of hybrid vigour. It is a genetic phenomenon resulting from heterozygosity, usually described as superior Fi hybrid performance (Geleta and Labuschagne, 2004). Significant levels of heterosis in Fi hybrids is often the reason for the use of hybrid cultivars (Sousa and Maluf, 2003). Heterosis in Fi hybrids may be classified into mid-parent heterosis, in which the hybrid shows increased strength greater than the average of both parents, and better-parent heterosis, in which the hybrid's increased strength, is greater than that of the stronger parent Two leading hypotheses explain the genetic basis for the fitness advantage in heterosis. These are the over-dominance hypothesis and the general dominance hypothesis (www.akhalteke.info. 2009). The over-dominance hypothesis implies that the combination of divergent alleles at a particular locus will result in a higher fitness in the heterozygote than in the homozygote. General dominance hypothesis involves avoidance of deleterious recessive genes, such that heterozygous individuals will express fewer deleterious recessive alleles than its homozygous counterpart

2.4.1 Heterosis in Hot pepper

Lippert (1974) found significant heterosis in hybrids of chilli pepper for dry fruit weight per plant fruit length and percentage mature fruit at harvest Additive gene effects were found to be more important than non-additive effect in explaining the variability among the Fis for fruit number, dry fruit weight per plant fruit length and width, and total carotenoids of the *Capsicum* fruit

Mulge and Anand (1997) reported the presence of mid-parent heterosis and better-parent heterosis for seedling height, growth rate, leaf production per week and number of basal and secondary roots at transplanting. Similarly, Doshi eta/., (2001) assessed the magnitude of heterosis at the seedling stage and its predictability in chilli. Mid parent and better parent heterosis were maximum for seedling height 40 days after sowing (DAS) at 52.3% and 27% respectively. Heterosis over mid-parent and better parent observed for number of leaves per plant were 38.6% and 21.4%;

growth rate 67.1% and 33.1%; leaf production per week 18,4 % and 14%; and basal roots per plant 64.2% and 28.8 % respectively. Heterosis for green fruit yield per plant among the hybrids was 77.9% and 64.2% better than the mid-parent and better - parent respectively. The green fruit yield was also found to correlate significantly with all the traits evaluated.

Hundal and Singh (2001) crossed three (3) lines of chilli (*Capsicum annuum*) with fourteen (14) pollen parents in a line X tester fashion. After evaluation of the 17parents together with the forty-two hybrids, heterosis over better parent was estimated to be 55% for fruit length, 24.48% for fruit width, 111.27% for fruit weight and 66.55% for fruit number per plant. Heterosis over better parent was found to be as high as 316.26% for earliness. About 108% heterosis over better-parent was realised for total fruit yield.

Mamedove and Pyshnaja (2001) evaluated six (6) pepper cultivars and their fifteen (15) hybrids for heterosis in yield and yield components. The 15 crosses exhibited significant desirable heterosis over better parent for early yield and total yield. Five (5) of the hybrids were better than the better parent for number of days to flowering and fruit ripening. Heterosis over better parent was also reported for fruit number per plant, fruit length and girth, and pericarp thickness. Plant height, early flowering, fruit weight and fruit number per plant were found to correlate highly with yield.

Geleta and Labuschagne (2004) evaluated the performance of pepper hybrids and determined heterosis over mid-parent, high-parent and the standard control for various yield characteristics. Hybrids showed good overall performance for most of the characters compared with inbreds. Some of the hybrids were reported to have significantly out-yielded the standard control. All hybrids again outperformed the standard in terms of days to flowering and fruit maturity. Mid-parent, high-parent and standard heterosis were recorded for majority of the characters studied. High and positive mean mid-parent and standard heterosis were discovered for fruit yield, plant height, fruit diameter, fruit weight, pericarp thickness and fruit number per plant They concluded that pepper hybrids of higher yield potential, good fruit characteristics and early maturity can be developed using the appropriate parents.

In exploiting pepper lines for heterosis, heterobeltiosis and commercial heterosis for agronomic traits and yield, Senevirathne and Kannangara (2004) crossed six (6) parental lines in a diallel mating design. There were significant differences for most of the characters which indicated the presence of sufficient variability. Positive heterosis was observed in some crosses (1.4-81.8%) for plant height while others showed negative heterosis from -1.74 to -5.0%. Direct crosses showed high heterosis for canopy width as against low heterosis in reciprocals. The highest yield was recorded by crosses with the highest heterosis and heterobeltiosis for canopy width. Number of fruits per plant was also reported as having high heterosis and heterobeltiosis. Fresh fruit yield is the most significant character when considering the economic importance of pepper. Most hybrids (both direct and reciprocals) were noted to exhibit positive values of heterosis, heterobeltiosis and commercial heterosis. It was however discovered that none of the crosses of pepper showed consistency for all traits studied. Considerable amount of heterosis was observed in the desired direction in the majority of the cross combinations. On the other hand, Ze£evi£ *et aL,* (2004) in their work reported heterosis in the Fi generation for all researched traits and in all cross combinations to be very low.

Sousa and Maluf, (2003) reported that significant levels of heterosis in Fi hybrids are often the main reasons for the extensive use of hybrid cultivars of vegetable crops. This conclusion was made after they discovered that, mean squares indicated differences among treatments (a = 0.05) for all the assessed traits. Differences were similarly detected for the parent and heterosis effects.

Gomide *et al.,* (2006) obtained crosses of the parental lines which they evaluated together with a standard line. They observed heterosis among hybrids for total yield and mean fruit mass. Heterosis values relative to the standard cultivar ranged from 7.50 to 49.89% for early yield, 0.45 to 28.55% for total yield and 3.07 to 47.37% for mean fruit mass.

Kanthaswamy *et al.,* (2006) in a bid to elicit information on the physiological basis of heterosis in chilli, raised hybrids from both direct and reciprocal crosses. The hybrids were found to be superior in yield compared to the parents. Leaf area index was positively associated with yield and with net assimilation rate in all the hybrids which correlated positively with photosynthetic rate. High yielding genotypes were discovered to have high photosynthetic rate. The hybrids however exhibited negative heterosis in dry matter production. Growth rate was also found to be positively correlated with net assimilation rate and also with yield. Delayed flowering date was linked to decrease in assimilation rate.

Prasath and Ponnuswani (2008) investigated heterosis for morphological, yield and quality characters in paprika hybrids. Heterosis estimates over better parent ranged from 40.35 to 126.32% for dry yield per hectare. While some hybrids were also superior with respect to total extractable colour, they were low for capsaicin, dry yield and contributing characters.

2.5 Combining ability in hot pepper

Combining ability or productivity in crosses is the ability of parents or cultivars to combine with one another during the process of hybridization so that favourable genes/characters are transmitted to their progenies. Two types of combining ability, general and specific, have been recognized in quantitative genetics (Falconer and Mackay, 1996). Specific combining ability is the deviation in the performance of hybrids from the expected productivity based upon the average performance of lines involved in the hybrid combination, whereas general combining ability is the average performance of a line in a series of crosses. Therefore, the general combining ability value of a trait within a line has no meaning unless it is considered in relation to at least one other individual (Henderson, 1952). Genetically, general combining ability is due to genes which are largely additive in their effects while specific combining ability is due to the genes with dominance or intra-allelic gene interaction and epistasis or inter-allelic gene interaction (Panhwar *etal,* 2008).

The proper choice of parents based on their combining ability is of major importance in every breeding programme. This not only provides the necessary information regarding the choice of parents but also simultaneously illustrates the nature and magnitude of gene action involved in the expression of desirable traits (Ganeshreddy *et al*, 2008). It is especially useful in testing procedures, where it is desired to study and compare the performance of lines in hybrid combination (Fanhwar *et al.*, 2008).

A wide array of biometrical tools is available to breeders for characterizing the genetic control of economically important traits as a guide to deciding upon an appropriate breeding methodology. The line x tester mating design developed by Kempthorne (1957), provides reliable information on general and specific combining abilities effects of parents and their hybrid combinations respectively (Iqbal, 2007) This method is suitable for breeding both self and cross pollinated plants (Ceyhan, 2008).

Percentages and combining abilities for five fruit components in chilli peppers were analysed by Omar and Lippert (1975) by crossing nine (9) parents. There was an increase in endocarp percentage which they found to be associated with decreased seed content. Variability in fruit components among the Fi hybrids were attributed to general combining ability (GCA), suggesting additive gene action. However mean heterosis in the hybrids and mean squares for specific combining ability (SCA) were not significant for any fruit component

Prasath and Ponnuswani (2008) investigated combining ability for morphological, yield and quality characters in paprika hybrids. Estimates of general and specific combining abilities realised, except for leaf area index, dry yield per hectare and capsaicin content suggested the preponderance of additive gene action than non-additive. Some cross combinations had desirable specific combining ability effect for yield and its quality characters including fresh yield, dry yield, total extractable colour and capsaicin.

2.5.1 Combining ability in Vegetative growth

Doshi *et al.*, (2001) identified good combiners at the seedling stage and the predictability of combining ability in chilli. To achieve these, ten parental cultivars and their 45 hybrids were evaluated in the field for heterosis and combining ability. Significant variation was observed among genotypes for seedling height and number of leaves 40 days after sowing (DAS). Growth rate and basal roots per plant were also significantly different among the genotypes. Leaf production per week did not however vary.

2.5.2 Combining ability in Yield component characters

By crossing four divergent genotypes, Stevanovic et a/., (1996) evaluated the combining ability for yield and its components in pepper. The analysis of variance for combining ability in Fi and F2 were estimated. General combining ability and specific combining ability were significantly different in both generations. The GCA: SCA ratio was found to be larger than one (1) which they said indicated that, additive gene effect had a predominant role in the inheritance of yield and its components.

Mulge and Anand (1997) in an attempt to predict the combining ability for yield and yield components at seedling stage in sweet pepper, evaluated crosses developed from 12 powdery mildew resistant (PMR) lines and 3 susceptible ones. Results of the line x tester analysis and correlation studies suggested that the Fi hybrids with high SCA effects and parents with high GCA effects for yield and yield components can be indentified at the seedling stage using parameters such as height at transplanting and seedling growth rate since there was a positive correlation among these factors.

Ahmed *et al.,* (1999) crossed several pepper varieties to study heterosis and combining ability. Heterosis over better parent for yield and earliness were observed. Variances due to general combining ability (GCA) and specific combining ability (SCA) were found to be significant which was perceived to indicate the involvement of both additive and non-additive gene effects in the expression of all characters considered.

Legesse (2000) implicated both additive and non-additive gene effects for yield and yield contributing characters in *Capsicum annuum L.* In a field experiment, twenty one (21) Fi hybrids together with their seven (7) diverse parental lines were evaluated for the kind of genetic control involved in the heritability of the characters studied. Comparison of means and GCA effects revealed that in majority of the characters, parents that were good general combiners also possessed high mean values whereas for earliness and fruit length, parents with good GCA did not always exhibit good per se performance. None of the hybrids exhibited significant SCA effects for all characters investigated over 2 seasons. Crosses which showed best SCA effects, had at least one of the parental lines being a good general combiner. This he said was an indication that, at least one parent with a good general combining ability was essential for heterosis breeding. Crosses with common parents also recorded values which were at par with each other. Evidence that hybrids with superior per se performance also had significant SCA effects was established and this was said to reveal the close agreement between crosses selected on the basis of SCA and per se performance. Legesse (2000) iterated that these findings were an indication of the importance of heterosis breeding for effective utilization of non-additive genetic variance since it had a dominant role in the improvement of the characters studied.

Employing the line x tester analysis, Patel *et al.*, (2002) evaluated chilli hybrids for eight yield characters including days to flowering plant height, number of primary branches per plant, fruits per plant, fruit length among others. There were significant differences among the parents, hybrids, parents verses hybrids (lines and testers, and their interactions) for almost all attributes. They recorded no significant differences for days to flowering for testers, plant height, fruit girth and fruit weight for lines and fruit length for both lines and testers. Non-additive gene action was suggested for the significance of variances due to parents verses hybrids and lines x testers for the traits examined. Combining ability (both GCA and SCA) variances were significant for all traits except the GCA for fruit length and weight, and SCA for number of primary branches per plant. This indicated the importance of genetic variances for the inheritance of the traits. Additive components were found to be larger than non-additive components of variance for days to flowering fruits per plant and green fruit yield.

Singh and Chaudhary (2005), in evaluating line X tester crosses including high yielding testers observed significant differences among parents vs crosses for all characters except number of primary branches and 100-seed weight. The interaction between line x tester also showed significant differences for as many as 10 characters. Four characters which did not show significant difference were fruit length, fruit diameter, 100-seed weight and capsaicin content Based on general combining ability (GCA) and per se performance some varieties were identified for best yield and yield components. The parents having significant positive general combining ability effect for yield per plant also showed positive general combining ability effect for one or more yield components. Several crosses showed positive specific combining ability for various characters. It was observed that the best Fis were not the cross combinations which showed maximum SCA effects. The best general combining tester and line respectively for total fresh fruit yield per plant had Fis exhibiting negative specific combining ability effects. The highest desirable specific combining ability effects were shown for ascorbic acid and capsaicin content The conclusion was that additive gene effect was in action.

In a research on the combining ability for yield and its component traits in chilli, Pandey *et al* (1981), suggested that heterosis breeding might be effective for improvement of yield and its contributing attributes in chilli. He developed Fis in a line x tester fashion. Mean squares due to females, males and female X male interaction were found to be highly significant for all traits evaluated. Higher values of specific combining ability over general combining ability were reported for all characters indicating the preponderance of non-additive gene action for the expression of these characters.

In perspective of breeding for high yielding hybrid pepper, Zou *et al.*, (2007) estimated the combining ability of net photosynthesis rate at different phases of flowering. Fifteen (15) cross combinations together with their 6 parents were used during the study. Large differences were discovered not only in general combining ability(GCA) effects among the parents at the various phases of flowering and fruit setting but also in the specific combining ability effects among the hybrids. Large GCA effects were recorded in late parents while early parents had low GCA effects. The comparison of the SCA and GCA variances showed higher SCA variances. Heritability was low for the character investigated compared to environmental influence. The net photosynthesis rate was found to be related to leaf and fruit setting characters. They concluded that the combining ability of net photosynthesis rate at different stages of flowering and fruit setting are positively correlated with those of yield per plant

Using 12 elite lines of hot pepper genotypes to estimate the genetic components of variation, Fekadu *et al.*, (2008) revealed that significant variation existed among progenies obtained from hybridization (crosses or Fi populations) for traits including dry fruit yield per plant number of branches per plant, plant height, number of fruits per plant days to maturity, fruit length and single fruit weight Days to maturity and number of fruits per plant were found to be affected by dominant components while, for all others both dominant and additive genetic components were significant Over-dominance governed the expression of majority of traits except for plant height Unequal distribution of genes with positive and negative effects among the parents were revealed for the entire lot of traits which they said was an indication for the need for caution in selecting hot pepper parents for breeding purposes. The observed variations were found to be genotypic in origin since the broad sense heritability ranged from 0.85 to 0.96.

In conducting combining ability analysis in chilli, Ganeshreddy *et al.,* (2008) employed the line by tester mating system. Analysis of variance revealed significance due to lines for fruit yield per plant only. The line by tester interaction variance was found to be insignificant for all traits considered. Variances due to replications were found to be significant only for plant spread, number of fruits per plant, average fruit weight, pericarp thickness, number of seeds per fruit and fruit yield per plant They found the specific combining ability variance to be higher than the general combining ability variance indicating the predominance of dominance variance. Dominance variation was therefore said to be greater than additive variance for all the characters.

Milerue (2008) reported that Fi hybrid lines yielded higher in particular than parental lines which were landraces. Fruit quality was also found to be better than those of male parents. The fruits were discovered to have good shape, smooth skin and were big in size. The results for determining pungency using spectrophotometer in comparison with man test were different. Heterosis percentage was also found to be high. Pungency of the Fi hybrids tested was higher than that of the parents. The results showed that pungency is controlled by poly-genes. Dominant action of these genes was reported. Pungency was also reported to be controlled by environment (Milerue, 2008).

2.5.3 Combining ability in Fruit Quality traits

In a study on the inheritance of capsinoids, Zewdie *et al.,* (2001) found that the general and specific combining ability effects were significant indicating additive and non-additive gene actions. High capsinoid contents were associated with high positive general combining ability of the parents which also indicates the predominance of additive gene action in capsinoid inheritance.

Capsicum annuum L breeding lines grown in Minas Gerais, Brazil, were studied to identify superior hybrids for fruit yield and quality as well as determine mode of gene action involved in the expression of economically important traits. Gomide *et ah,* (2006) obtained crosses of the parental lines which they evaluated together with a standard line. General combining ability of parental lines and specific combining ability of the parental combinations were estimated.

Gomide *et al.,* (2008) evaluated the combining ability among sweet pepper breeding lines in order to find superior hybrids for fruit quality and to infer on the mode of gene action involved in the expression of fruit quality. They realised evidence of heterosis among the hybrids for fruit diameter and insertion depth of the peduncle. They associated the insertion depth of the peduncle with recessive alleles. The hybrid generated were said to have commercial potential.

Zhenhui and Ming (1993) explored combining ability of five main quality traits in pepper. The traits were capsaicin content, fruit wall thickness, ascorbic acid content, fruit dry matter content and fruit soluble sugar content. A high V_6/V_p ratio was observed for all five traits which they attributed to additive gene effect The total combining ability of the traits studied was positively and significantly correlated with the practical value. The estimated general combining ability was high for fruit wall thickness, fruit dry matter content and capsaicin content. The practical value of the Fi population was also high. The conclusion was drawn that, the cultivars used were good as parents when breeding for increased fruit wall thickness, fruit dry matter content and fruit capsaicin content.

2.6 Gene Action in Yield Characters of Hot Pepper

Jabeen *et al*, (1999) revealed significant differences among pepper lines in fruit characters. Both phenotypic and genotypic coefficients of variation were high for fruit yield per plant, fruit number per plant, seed number per fruit, pericarp thickness and average fruit weight They found heritability in the broad-sense for all traits to be high. This high heritability was associated with genetic advance reported for fruit yield per plant fruit number per plant, seed number per fruit pericarp thickness as well as average fruit weight It was concluded that all characters studied had fixable additive gene effects and were therefore reliable for making effective selection.

In order to determine the genetic values for fruit number and weight of Fi and F2 generations of some crossed pepper genotypes, hybrids were developed by crossing divergent genotypes belonging to different cultivars of the species *Capsicum annuum* L. In F2 generation partial dominance existed. It was again established that in the F3, hybrid populations formed by using the pedigree method of selection had traits which are more valuable for further breeding than hybrid population formed by using bulk method (ZeCevid *et al*, 2004).

Doshi (2003) reported that additive components were significant for all characters except number of primary branches per plant. Two measures of dominance that is HI (dominance effect) and H2 (proportion of dominance due to positive and negative gene effects) were also found to be significant for the traits studied. The additive component was however estimated to be higher than the dominant factors for plant height, fruit volume, fruit weight, total chlorophyll and total capsaicin content, which was said to indicate the preponderance of additive gene action.

Sousa and Maluf (2003) concluded that, non-additive genetic effects predominated in the control of all the assessed traits. The presence of significant epistasis was detected for fruit dry matter per plant, capsaicin yield per plant and number of seeds per plant In these cases epistasis was said to be largely responsible for the expression of heterosis. For traits where no epistasis genetic action was detected, heterosis was explained by dominant gene action, which varied from incomplete to probable over- dominance.

2.7 Heritability Estimates in Pepper

Natural variation within the cultivated germplasm pool of pepper will continue to be exploited in the development of superior cultivars compared with parental accessions (Paran and Knaap, 2007). Beside the selection of the parental lines to be used in a breeding programme, it is also important to find the heritability of the traits of interest The degree to which the variability of a quantitative character may be transmitted to the progeny is referred to as heritability (Poehlman 1959).

The heritability of a metric character expresses the proportion of the total variance that is attributable to differences in breeding values, and this determines the degree of resemblance between relatives. The most important function of heritability in the genetic study of metric characters is its predictive role, expressing the reliability of the phenotypic value as a guide to the breeding value. If a breeder chooses individuals to be parents according to their phenotypic values, his success in changing the characteristics of the population can be predicted oniy from knowledge of the degrees of correspondence between phenotypic values and breeding values. This correspondence is measured by $h^2 = V_A/V_P$ (Falconer and Mackay, 1996) or when using the combining abilities, the proportion of the variance of general combining ability to the sum of the variances of the general and specific combining abilities, and error variance (Dhillon *et al*, 2006). This is heritability in the narrow sense or simply heritability and is of greater importance to the plant breeder than broad-sense heritability (Dhillon *et al*, 2006 and, Falconer and Mackay, 1996). Broad-sense heritability, V_G/V_P expresses the extent to which individuals' phenotypes are determined by the genotypes (Poehlman 1959).

2.8 Genetic Relationships Between Traits

Correlation between characters is a frequent feature of plant breeding. They may arise from linkage or from developmental genetic interaction, with or without a purely phenotypic component The developmental-genetic kind is by far the commonest Correlations due to linkages tend to disappear as recombination goes on over generations and would not be expected to present a prolonged obstacle if negative (Simmonds, 1980). Because of the presence of genetic correlations among characters, selection even if it operates directly only on a single character, also affects many other characters. For this reason the estimation of the genetic correlation is of considerable importance both for the application of quantitative genetic theory in artificial selection and for the understanding of evolutionary processes in natural populations (Simmonds, 1980).

The genetic correlation value offers a measure of the inter-relationship between characters and may explain the degree of relationship between characters genetically rather than phenotypic correlation (Haryanto, 2002). Simple correlations, multiple regression and stepwise regression analyses are usually some of the methods employed to understand the association between traits. A positive correlation is favourable while the reverse is true of negative correlation. The effect at a predetermined overall intensity of selection, of a positive correlation, is to raise the levels of selection for the characters involved and vice versa (Simmonds, 1989)

In any estimation procedure it is necessary to estimate both the value of the statistic itself and also the associated confidence limits .The estimation of confidence limits for the genetic correlation is difficult and even in the restricted cases where estimation methods have been worked out the statistical behaviour is not well understood. An alternative approach was the use of Pearson's product moment correlation between family means, for which the usual methods of estimating confidence intervals on correlation can be applied (Via, 1984, Roff and Prezoisi, 1994)

Marcelis and Hofman-eijer (1997) investigated the effects of number of seed on competition and dominance among fruits in *Capsicum annuum.* They realised a linear increase in individual fruit weight with increasing seed number. Seed number was again found to affect growth rate of fruits. When seed numbers were low, the probability of fruits even setting was positively related to seed number. Fruit size was also discovered to show a positive relationship with seed number.

Considering work done by the above workers and many others it could be realised that, there is vast knowledge and information available on the genetic control of yield and its component characters in hot pepper (C. *annuum*) which may be exploited by researchers during breeding programmes. This information would aid in the recognition and selection of parents for optimum results based on the goals of the breeding programme. Line x tester analysis has been used by many workers in the investigation of combining ability and gene action, and has proved to be ideal for providing sufficient information for analysis. Heterosis is an intrinsic component of any hybridization programme. It has also been advocated that heritability and genetic correlation of characters are very important in crop improvement programmes.

CHAPTER THREE

3.0 MATERIALS AND METHODS

The experiment was conducted at the University of Ghana, Crop Science Department located in the Coastal Savanna Zone of Ghana (Ghana falls within latitude 4,44° S and 11,11° N and longitude 3,11° W and 1,11° E) between 15th June, 2008 and 21st June, 2009. The research was in two parts. The first was the generation of the Fi hybrid seed. This was followed by field evaluation of the Fis and their parents.

Temperatures during the experimental period were generally high with a minimum range of 22.8°C -24.7°C and maximum of 29.0°C - 33.6°C. The relative humidity over the same period was between 55% and 94% while rainfall was generally low with the highest occurring in December 2008 as 137.7mm. The monthly figures of average temperature, rainfall and maximum and minimum humidity and their mean monthly values over the period are shown in Table 1.

Table 1: Climatic data during the period of the study (June, 2008 - May, 2009)

Month and Year	Temperature (°C)		Rainfall (mm)	Relative Humidity (%)	
	Min.	Max		Max.	Min.
June 2008	23.7	30.0	101.4	94	75
July, 2008	23.3	29.4	99.8	93	73
August, 2008	23.1	29.0	64.1	92	74
September, 2008	23.3	30.0	28.7	93	71
October, 2008	23.8	31.7	94.1	93	66
November, 2008	24.3	32.4	109.7	94	67
December, 2008	24.3	32.6	137.7	93	66
January, 2009	22.8	33.0	8.2	88	55
February, 2009	24.7	33.2	9.5	93	62
March, 2009	24.7	33.6	33.3	91	64
April, 2009	24.3	32.8	126.8	86	64
May, 2009	24.5	32.5	73.4	93	66
Mean monthly values	23.9	31.6	73.9	92	67

Source: Meteorological Services Agency, Mpehuasem, Accra

3.1 Generation of the Fi Hybrid Seed

The Fi hybrid seed was produced in a pot experiment in the Sinna Garden, Crop Science Department from 15th June - 28th December 2008.

3.1.1 Genetic Material

The pepper germplasm collection used in the research was obtained from Crop Science Department at the University of Ghana, Vegetable Producers and Exporters Association of Ghana (VEPEAG) and Agricultural Research Station, Kade.

Variety	Source
'Marconi hot*	Crop Science Department, University of Ghana
'BEK'	Agricultural Research Center, University of Ghana, Kade
'Legon 18'	Crop Science Department, University of Ghana
•AA/05/008'	Crop Science Department, University of Ghana
'AA/05/016'	Crop Science Department, University of Ghana
'Singapore'	Crop Science Department, University of Ghana
Long red Cayenne	Crop Science Department, University of Ghana
'MI-2'	Vegetable Producers and Exporters Association of Ghana(VEPEAG)

Table 2: Sources of the Hot pepper parents used in the study

The parents used in the study were made up of pepper lines with different growth habits, branching habits and flower position (Table 3, page 43). All of them however have green stems, flowers with white corolla and they bear green immature fruits that turn red on ripening.

3.1.2 Fruit characteristics of parental material

The fruits of the parent material did not differ much in fruit shape. All of them were elongated in shape except ‘Marconi hot' which was triangular. They were of variable length and diameter. The fruits were pointed at the blossom end with calyx margins ranging from dentate to entire. Annular constiction was either present or absent (Figure 1).

Figurel: Fruits of the hot pepper lines used in the research. Clockwise from arrow; ‘Marconi hot", 'Singapore', 'MI-2', 'AA/05/008', 'AA/05/016', 'BEK’, 'Legon 18’ and Long red cayenne.

3.1.3 Raising of Parental Crop

Seed boxes were filled with soil and the soil sterilized using hot water sterilization. Seeds of each pepper variety were sown in single rows in the boxes making sure the varieties did not mix. Three week old seedlings were pricked out into seed boxes and watered with a starter solution containing lg/1 of NPK 15-15-15. The seedlings were raised in seed boxes till they were five (5) weeks old. Standard nursery management practices were carried out during this period.

A soil-mix containing 10 ton/ha of well decomposed cow dung manure was used in filling pots. The pots were arranged in single rows for each variety and watered right before transplanting the seedlings. The five week old seedlings were transplanted singly into the pots (eight pots per variety). A starter solution containing 6 g/1 of NPK compound fertilizer was then applied to each pot at 100 ml/pot All agronomic practices were undertaken to raise a good and healthy crop. There was a severe case of pepper mosaic virus attack on the plants. 2 ml/1 of Pyrinex (insecticide) was applied against the whitefly which transmits the virus. After the application of the insecticide the pepper plants were pruned so that virus-free new flushes would emerge. The pruning was also to remove apical dominance and increase branching, and hence number of flowers.

3.1.4 The Crossing Technique

Before hybridization commenced all the plants were checked for trueness to type and any off-types removed. At flowering the varieties were crossed with each other. Line X tester crosses were made with 6 varieties as lines crossed with 2 testers. The lines were 'AA/05/008', 'AA/05/016', 'BEK', 'Marconi hot', 'Singapore' and 'long red cayenne', while 'Legon 18' and 'Ml-2' served as testers. Each of the lines was inter - crossed with the two testers.

The flowers of the lines (females) were emasculated during the late bud stage in preparation for cross-pollination. During emasculation, petals of young unopened flowers of the lines (female) were opened and checked to ensure that the anthers had not already dehisced. After that, the anthers were removed with a pair of forceps. After emasculation of the lines, pollen was collected from the testers (males) and used to dust the stigma of the hand-emasculated flowers. Each pollinated flower was tagged with a tag that showed the date of crossing and cross combination. Pollen from each tester was applied to a separate plant of the line. Very few crossings were successful. The plants were maintained throughout the period till December 28th, 2008 with crossings made anytime flowers were present

All equipment used during the crossing exercise were sterilized with 70% alcohol to prevent contamination of the stigmatic surface by micro organisms and extraneous pollen (from another plant). A head lope was used to magnify the flowers so as to make emasculation and picking of the pollen from the testers easier. All flowers on the lines which opened before they could be crossed were removed to reduce fruit population on each plant and give the hand pollinated flowers a better chance to set fruits. A few flowers of both the lines and testers were however allowed to set fruit to provide seeds of the parental lines.

Fully ripe pepper fruits of both the cross combinations and parents were harvested and the seeds extracted separately from each fruit The seeds were dried and stored in a laboratory refrigerator.

3.2 Field evaluation of Fis and Parents

3.3.1 Description of study site and field planting

Within the period of January 15th to 30th June 2009 the Fi hybrid and their parents were evaluated in the field. The study site was the University of Ghana research farm. The soil belongs to the Adenta series, a Kaolinitic pateustalf (Gbokie, 2008). The plot used for the experiment was previously cropped to *Solenum melogena.*

3.2.1.1 The Physico-chemical properties of soil at experimental site

Soil analysis was conducted to establish the precise physical and chemical properties of the soil of the field where the Fis and their parents were evaluated. The soil was sandy loam in texture with a pH of 5.4 (H_2O), high in Nitrogen (0.28 %),

P (22.72 ppm), K (0.72 me/100 g soil) but low in organic carbon (0.28). Total phosphorus was 830 ppm.

3.2.2 Establishment of the nursery

Seedlings of the ten (10) Fi hybrids and their eight (8) parents were raised at the university farm in seed trays filled with hot water sterilised soil. Seeds of the different varieties were sown singly in the cells of germination cell trays with a single variety/row. Each row was labelled. The trays were set under a net cage to prevent whitefly and other insect attack. Watering was done to maintain good soil moisture content Weeds growing between the seedlings were removed. The soil nutrients were replenished three weeks after sowing with NPK 15-15-15 fertilizer dissolved in water at 0.5g/L. The seedlings were transplanted on to the field when they were five weeks old.

3.2.3 Experimental design

The experimental setup was a randomised complete block design with three replications. Each experimental unit consisted of a single row plot of 2.8 m length comprised of seven plants with within row and between row distances of 0.40 m and 0.90 m respectively. There were eighteen entries (10 Fis and 8 parents). A total of twenty (20) rows per replication were made with the first and last rows serving as borders.

The entries in the experiment were: 'Marconi hot', 'Singapore', 'BEK', Long red cayenne, 'Legon 18', 'MI-2', 'AA/05/008', 'AA/05/016', 'Marconi hot* x 'Legon 18', 'Singapore' x 'Legon 18', 'Long red cayenne'x 'Legon 18', 'BEK' x 'Legon 18', 'AA/05/008* x 'Legon 18', 'AA/05/016' x 'Legon 18', 'Singapore' x 'MI-2', 'AA/05/008' x 'MI-2', 'BEK' x 'MI-2' and 'AA/05/016' x 'MI-2'.

3.2.4 Land preparation and planting

Well decomposed manure was broadcasted on the field at 10 t/ha and the field ploughed, harrowed and all unwanted material such as plastics removed. Lining and pegging were done to mark out the field and the positions of the rows and plants. The 5 week old seedlings were transplanted singly onto single rows 0.90 m apart and

0.4 m within the rows. A starter solution was applied to the freshly transplanted seedlings and each row labelled.

3.2.5 Cultural Practices

3.2.5.1 Weed control

The weeds in the field were controlled through hand weeding. Weeding was done when necessary to rid the field of weeds and also to aerate the soil.

3.2.5.2 Irrigation

The seedlings were transplanted during the dry season hence regular irrigation of the field was done to maintain the soil moisture. Watering was done in the morning and late afternoon each day until the rains started in April and plants were only watered on days when there was no rain. Portable water was used for irrigation.

3.2.5.3 Crop protection

During the growing period, there was an infestation of the field with grass hoppers and other insects. Pyrinex, a broad spectrum insecticide was applied at 2 ml/1 together with Kocide (a copper based fungicide) at 0.4 g/1. Kocide was applied to prevent fungal attack of the aerial portions of the plants.

There were *Sclerotium spp* and *Fusarium spp* (both of them fungi) infections in the root zone of the plants diagnosed by the pathology laboratory of the Crop Science Department Weekly soil drenches of Topsin (fungicide) was applied for 4 weeks. Plants showing signs and symptoms of the infection were also rogued out and disposed of.

3.2.5.4 Soil nutrient management

Before the field was ploughed, well decomposed cow dung manure was applied at a rate of 10 ton/ha to improve upon the soil organic matter and the nutrients content. The grasses and other plant materials that were cut during the ploughing were not removed from the field but allowed to rot in order to improve the soil.

Inorganic nutrient supplements were in the form of a starter solution of 6 g/1 NPK 15-15-15 applied at 100 ml per plant at transplanting. Fourteen (14) days after transplanting, NPK 15-15-15 was applied at 6 g per plant. A top dressing of 3 g per plant of Sulphate of ammonia was applied two weeks after the application of the NPK and a second dose given two weeks afterwards.

3.2.5.5 Harvesting

The ripe pepper fruits were harvested by hand picking. Fruits from each record plant were separated from the others and labelled with the variety or cross combination, plant number and replication number. Harvesting was done over an eight week period.

3.4 Data Collection

Twelve (12) characteristics were recorded on 5 non-border plants in each row for each of the entries. The measurements taken were:

3.3.1 Plant height at flowering (cm)

Distance from the soil surface to the topmost leaf petiole base was measured with a meter rule on the day the first flower (s) opened. This measurement was done for each of the five record plants of each entry.

3.3.2 Canopy diameter (cm)

The canopy of each plant was measured with a rule immediately after the first harvest Measurements were at the widest points.

3.3.3 Number of days to first flower opening

This was recorded as the number of days from transplanting of seedlings to the day of first flower opening on each of the record plants in a single row plot.

3.3.4 Days to fruit set

Ten (10) flowers on each plant were tagged at anthesis and observed till the first fruit set A fruit was considered 'set' when it was 0.5 cm long. The period from transplanting to the day the fruit reached 0.5 cm long was recorded.

3.3.5 Days to first fruit Ripening

This was considered as the period between transplanting and the day of first fruit ripening.

3.3.6 Number of fruits per plant

Fruits harvested as well as fully matured fruits that dropped off from each plant were counted for all the record plants in each entry and the average taken. This was taken over the eight weeks of harvesting.

3.3.7 Fruit yield per plant (g)

The ripe fruits of each of the eight harvests for each plant were weighed and the average found. The total weight of the fruits from all the 8 harvests was then recorded as the fruit yield per plant

3.3.8 Number of seeds per fruit

Ten (10) ripe fruits of each of the entries were cut open with a sharp knife, the seeds extracted, counted and the average calculated.

3.3.9 Number of primary branches

The branches attached to the main stem of each plant were counted after the last harvest

3.3.10 Fruit diameter (cm)

The width of the widest point of the 10 ripe fruits of the second harvest was measured for each record plant of all eighteen entries. The mean was then calculated.

3.3.11 Fruit weight (g)

Using an electronic balance the weight of 10 ripe fruits per plant from the second harvest was taken for each entry. The average of the ten fruits was recorded as the fruit weight

3.3.12 Fruit length (cm)

This was measured as the average fruit length of 10 ripe fruits of the second harvest using a 30cm rule from the point of pedicel attachment to the blossom end.

3.5 Data Analysis

Data analysis was carried out with GenStats statistical software version 9 (GenStat 2007). The components of variance were extracted from the analysis of variance.

3.4.1 Estimation of combining ability

Information on the nature and magnitude of gene action was obtained using the line X tester analysis designed by Kempthorne (1957).

a. Estimation of General combining ability effects

$$\text{Lines: } 0_{(} = \frac{xI}{tr} - \frac{x}{itr}$$

$$\text{Tester: Oi} = 7^{*} \frac{^{x}J}{Ir} - \frac{x}{itr}$$

Where,

gi = combining ability

1 = number of lines(female parents)

t = number of testers(male parents)

r = number of replications

Xi= total of the FI resulting from crossing the ith line with all the testers.

Xj = total of all crosses of j01 tester with all the lines

x...= total of all crosses

b. Estimation of specific combining ability (SCA) effects.

c Li

V r tr Ir Itr

Where, = total of Fi resulting from crossing i1*1 lines with j^{th} testers; and I, t, r, Xj, Xj and X... are same as above.

In the case of 'Long red cayenne'x 'Legon 18' and 'Marconi hot' x 'Legon 18' crosses no SCA term was calculated since they were able to cross with only one tester and therefore GCA could not be separated from SCA. The average combining ability or breeding value (C) was estimated instead. This value is the difference of a cross from the population mean (Simmonds, 1987).

3.4.2 Heterosis

Estimation of the Fi hybrid performance was calculated as the estimate of heterosis over mid-parent and better parent using formulae adopted by Geleta and Labuschagne (2004).

a. Heterosis over mid-parent values

b. Heterosis over better-parent

$$\frac{(FI-BP)}{BP} \times 100$$

Where, MP = Mid-parent value (Average value of the two parents involved in a particular cross).

BP = Better parent value (Value of the better of the two parents in a cross combination).

Heterosis values were statistically tested for significance using the student t-test (Sousa and Maluf, 2003).

3.4.3 Heritability Estimates

Narrow sense heritability estimate of each of the plant traits studied was estimated using parent-offspring regression as suggested by Simmonds (1989). Regression was done using the means of the offspring and the mid parent values.

The regression coefficient, represented estimate of the narrow-sense heritability.

3.4.1.4 **Association between Yield and its Component Characters.**

Correlation between the yield and other associated components was estimated by finding the correlation coefficient between the yield values and each of the other characters.

CHAPTER FOUR

4.0 RESULTS

4.1 Qualitative variation in parental and hybrid populations

Morphological differences in growth habit, branching habit, fruit colour, flower position and corolla spot colour, were observed among the parents and their Fi plants (Table 3). The Fi plants of crosses were differed from each other in terms of plant architecture, flower as well as fruit characteristics. All the hybrids, like their parental lines had white hypocotyls and green stem colour.

4.1.1 Plant architecture

The Fi hybrid population generated from the different crosses exhibited variable types of growth and branching habits (Table 4). The growth habit was either erect or intermediate. Fis and parents exhibited either dense or intermediate forms of branching habits.

4.1.2. Inflorescence of the parental lines and Fi Hybrids

All parents together with their crosses each had one flower per axil except 'BEK'. However the crosses, 'BEK' x 'Legon 18' and 'BEK' x 'MI-2' also had only one flower per axil, though 'BEK' exhibited multiple flower number per axil. Apart from the cross between 'BEK' and 'Legon 18' which had a mixture of both erect and pendant flower positions, all other crosses and their parents had flowers which were pendant, erect or intermediate. Corolla colour was white in all parents and their crosses while corolla spot colour was either white or purple (Table 4).

Table 3: Characteristics of the paren tal and Fi hybrid populations

Parent/Cross	Growth habit	Branching habit	Immature fruit colour	Flower position	Corolla spot colour
Parents					
'Marconi hot'	Erect	Sparse	Light green	Pendant	White
'BEK*	Erect	Dense	Green	Erect	White
'Legon 18'	Intermediate	Dense	Green	Pendant	White
'AA/OS/008'	Erect	Sparse	Dark green	Pendant	Purple
'AA/05/016'	Erect	Intermediate	Green	intermediate	White
'Singapore'	Erect	Intermediate	Green	Pendant	White
'Long red Cayenne'	Intermediate	Dense	Green	intermediate	White
'Ml-2*	Intermediate	Dense	Green	intermediate	White
FiCrosses					
'Marconi hot' x 'Legon 18'	Erect	Intermediate	Light green	Pendant	White
'BEK' x 'Legon 18'	Intermediate	Dense	Green	Mixture of erect and pendant	White
'AA/0S/008' x 'Legon 18'	Erect	Dense	Green	Pendant	Purple
AA//05/016x 'Legon 18*	Erect	Dense	Green	Pendant	Purple
'Singapore' x 'Legon 18'	Erect	Intermediate	Green	Pendant	White
'Long red cayenne'x 'Legon 18'	Intermediate	Dense	Green	Intermediate	White
'BEK* x 'Ml-2'	Intermediate	Dense	Green	Intermediate	White
'AA/05/008'x 'MI-2'	Erect	Intermediate	Green	Intermediate	Purple
AA//05/O16X 'Ml-2'	Erect	Intermediate	Green	Pendant	White
'Singapore' x 'Ml-2'	Erect	Intermediate	Green	Intermediate	White

4.1.3 Fruit characteristics of the hybrid population

The immature fruit colour of all the crosses was green except that of'Marconi hot[1] x 'Legon 18' which was light green (Table 4). All of them however were red on ripening. The calyx margin of the fruits of the various crosses ranged from entire to dentate with 'Marconi hot' x 'Legon 18', 'AA/05/016' x 'Legon 18', 'BEK' x 'MI-2' and 'AA/05/016' x 'MI-2' exhibiting intermediate forms. Calyx annular constriction was either present or absent and the fruit shape at the blossom end was pointed in fruits of all cross combinations. Fruits of the Fis showed characters that were generally intermediate between their respective parents (Figures 2 to 11).

Table 4: Fruit characteristics of the Fi hybrid populations

Fi hybrid	Immature fruit colour	Calyx margin	Calyx annular constriction
'Marconi hot* x 'Legon 18'	Light green	Intermediate	Present
'BEK* x'Legon 18'	Green	Dentate	Present
'AA/05/016'x'Legon 18*	Green	Intermediate	Absent
AA//05/008 x 'Legon 18'	Green	Dentate	Present
'Singapore' x 'Legon 18'	Green	Entire	Present
'Long red cayenne'x 'Legon 18'	Green	Dentate	Present
'BEK* x'MI-2'	Green	Intermediate	Present
'AA/05/016' x'MI-2*	Green	Intermediate	Absent
AA//05/008 x 'MI-2'	Green	Dentate	Present
'Singapore' x 'Mf-2'	Green	Entire	Present

Fruits of Fts (in the middle) with their respective parents

Fig 2: 'BEK' BEKVLegon 18* Legon 18'

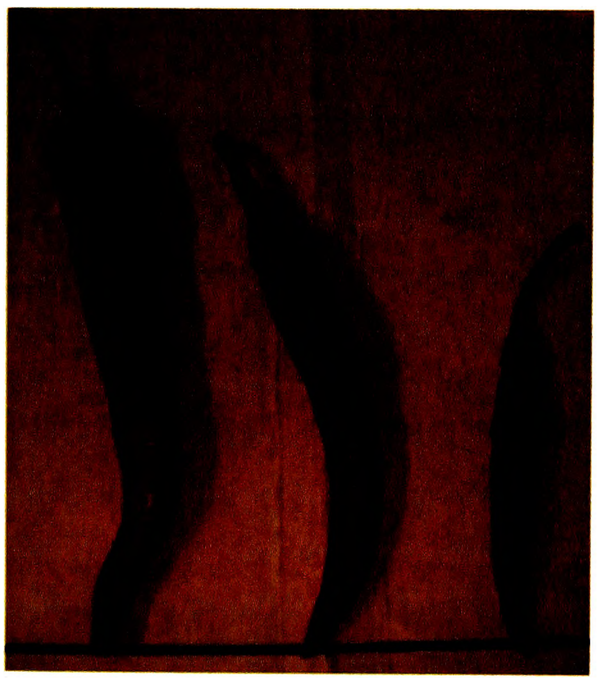

Fig 3: AA/005/008 AA/005/008x'MI-2* 'MI-2'

Fig 5: AA/005/008 AA/005/008 Legonl8
*x*Legon18

Fig 6: AA/005/016 AA/005/016 'Legon 18'
X'Legon 18'

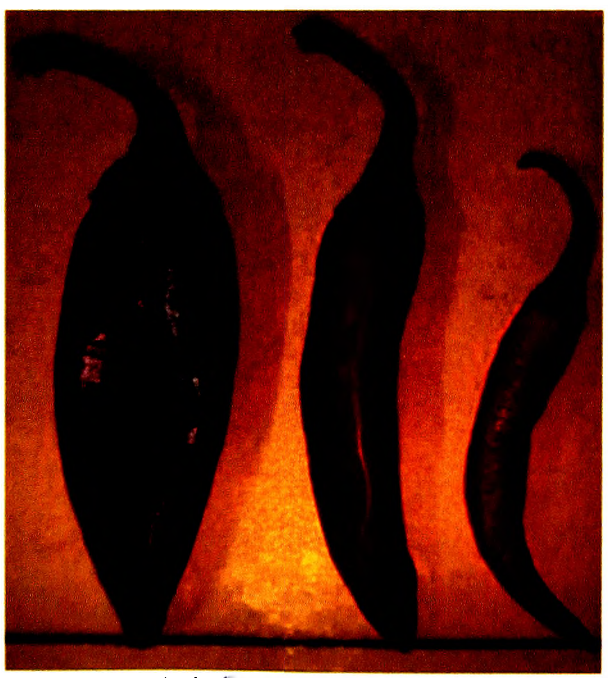

Fig 7: 'Marconi hof 'Marconi hotYLegon 18' 'Legon 18'

**Fig 8: 'Long red Tong red x *Legonl8' 'Legonl8'
Cayenne' cayenne'**

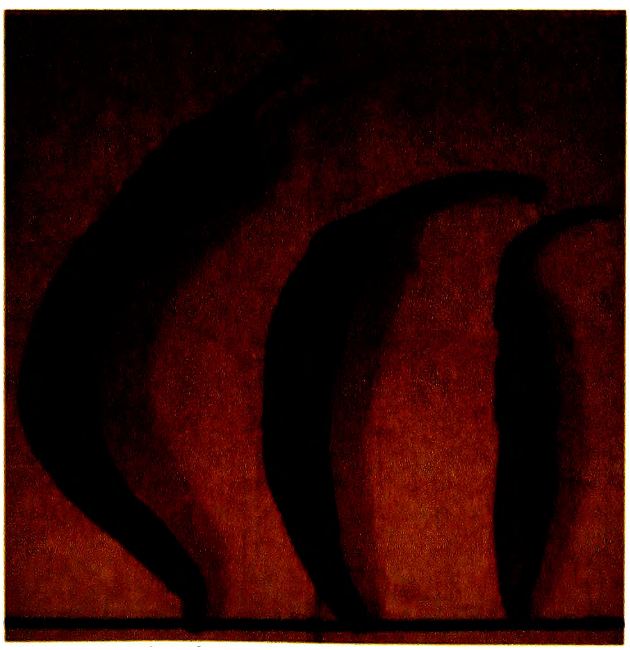

Fig 9:'AA/05/016' 'AA/05/016' x 'MI-2' 'MI-2'

Fig 10: ‘Singapore’ 'Singapore’x ‘MI-2’ ‘MI-2’

Fig 11: ‘Singapore’ 'Singapore^Legon 18’ 'Legon 18'

4.2 Quantitative Analysis of Traits in Hot Pepper

4.2.1 Vegetative Characteristics

There were significant differences (p<0.05, 0.01 and 0.001) among the parents together with their hybrids for vegetative characters measured (Table 5). Plant height at flowering ranged from 22.4 cm in 'MI-2' to 45.0 cm in 'AA/05/008' (Table 6). Among the crosses, 'Singapore' x 'Legon 18' exhibited the highest plant height at flowering (41.5 cm) and 'BEK' x 'MI-2' recorded the lowest at 26.8 cm. 'Legon 18' had the highest number of primary branches at 12 per plant among the parents while 'Marconi hot' gave the lowest number. The cross between 'AA/05/016' and 'MI-2' recorded the lowest number of primary branches (8), while 'Long red cayenne' and 'Legon 18* had the highest of 14 branches.

Canopy diameter was highest at 74.3 cm and lowest at 40.1 cm in 'Singapore' x 'Legon 18' and 'BEK' respectively.

Table 5: Mean squares for growth characteristics of breeding populations of pepper

Source of variation	Degrees of freedom	Mean squares: Plant height at flowering (cm)	Number of primary branches	Canopy diameter (cm)
Replication	2	27.471NS	0.68NS	9.15NS
Genotypes	17	89.272***	7.19***	247.89***
Parents	7	135.56***	6.02***	227.04***
Parents vs Crosses	1	0.92NS	0.77NS	2351.22***
Crosses	9	58.87***	8.50***	31.95NS
Lines	5	119.39***	4.06**	161.76***
Testers	1	266.00*	10.67*	209.214*
Line x testers	5	27.24**	11.32***	20.01NS
Error	34	7.05	0.52	11.26

*, **, **: Significant at 5%, 1% and 0.1% respectively.
NS: Not significant at 5%

Table 6: Vegetative characters of parental and hybrid generations from line x tester analysis in pepper

Parents/Crosses	Plant height at flowering (cm)	No. of primary branches	Canopy diameter (cm)
Line			
'Marconi hot'	34.3	8	46.5
'Singapore'	32.2	10	52.7
'BEK'	26.4	9	40.1
Long Red Cayenne	32.5	11	61.2
'AA/05/008'	45.7	9	48.3
'AA/05/016'	34.0	10	55.0
Testers			
'Legon 18'	35.7	12	66.4
'MI-2'	22.5	9	54.6
Crosses			
'Marconi hot' x 'Legon 18*	32.3	9	68.4
Long Red Cayenne x 'Legon 18'	32.3	14	67.3
'Singapore' x 'Legon 18'	41.5	10	74.3
'Singapore' x 'Ml-2'	30.1	11	67.4
'BElCx 'Legon 18'	27.4	11	65.7
'BEK1 x 'Ml-2'	26.8	9	66.1
'AA/05/008'x'Legon 18'	37.7	10	67.2
'AA/05/008'x'Ml-2'	31.6	9	64.2
'AA/05/016'x'Legon 18'	32.2	9	64.6
'AA/05/016'x'MI-2'	34.0	8	61.93
LSDfo.osi	**4.4**	**1**	**5.59**

4.2.2 Reproductive traits in parental lines and Fi generations.

Days to first flower opening, fruit set and fruit ripening were significantly different among the parental lines and the Fis (Table 7). The differences observed among the parents were not significant for days to first flower opening and fruit set.

The cross between 'BEK' and 'Legon 18' flowered earliest at 27 days after transplanting while it took 'Legon 18' 39 days after transplanting to flower (Table 8). The cross between 'BEK' and 'Legon 18' was first to set fruits at 31 days after transplanting while 'Legon 18' was the last to set fruit. Fruits of'BEK', 'BEK' x 'Legon 18' and 'BEK' x 'MI-2' ripened significantly earlier than other entries. Fruit of 'Long red cayenne' x 'Legon 18' ripened last, 78 days after transplanting.

Table 7: Mean squares for number of days to first flower opening, fruit set and fruit ripening of the breeding populations of pepper

Source of variation	Degrees of freedom	Mean squares		
		Days to first flower opening	Days to fruit set	Days to fruit ripening
Replication	2	16.976NS	14.078	18.978
Genotypes	17	34.508***	35.900***	48.473***
Parents	7	36.68 NS	37.72NS	32.651**
Parents vs Crosses	1	67.45*	67.76*	14.99NS
Crosses	9	27.965***	28.48***	64.61***
Lines	5	33.15*	36.67*	14.74NS
Testers	1	88.17NS	88.17NS	4.17NS
Lines x testers	5	29.90***	31.63***	81.53***
Error	34	6.09	6.45	3.822

*, **, **: Significant at 5%, 1% and 0.1% respectively.
NS: Not significant at 5%

Table 8: Number of days to flowering, fruit set and fruit maturity of parental and hybrid generations In pepper.

Parents/Crosses	Days to first flower open	Days to first fruit set	Days to first fruit ripening
Lines			
'Marconi hot'	30	34	67
'Singapore'	37	41	70
'BEK'	29	33	63
Long Red Cayenne	37	41	67
'AA/05/008'	33	37	68
'AA/05/016'	33.	37	68
Testers			
'Legon 18'	38	43	74
'MI-2'	31	35	72
Crosses			
'Marconi hot' x 'Legon 18'	30	37	69
'Long red cayenne' x 'Legon 18*	38	42	78
'Singapore' x 'Legon 18'	34	38	68
'Singapore' x 'MI-2'	31	35	66
'BEK'x'Legon 18'	27	31	63
'BEK* x'MI-2*	30	33	63
'AA/05/008'x'Legon 18'	33	37	72
'AA/05/008'x'MI-2'	30	34	66
'AA/05/016'x'Legon 18'	29	33	66
'AA/05/016'x 'Ml-2'	31	35	65
LSDo.os	**4**	**4**	3

4.2.3 Yield and Yield Characteristics

42.3a Fruit Number per plant, fruit weight (g) and Fruit yield (g).

The genotypes differed significantly from each other in terms of fruit number per plant, fruit weight (g) and fruit yield (g) (Table 9). The cross 'BEK' x 'Legon 18' gave 270 fruits per plant which was the highest among all the entries. 'Marconi hot' recorded the lowest fruit number per plant with 36 fruits. On the other hand, the average fruit weight of 'Marconi hof was 9.8 g which was significantly higher than the other genotypes. Fruits of'BEK weighed the least, 0.7 g per fruit.

Fruit yield per plant (g) was significantly different among parents and Fis with the highest being 421 g per plant produced by 'AA/05/016' and the lowest, 92 g per plant given by 'BEK' (Table 10).

4.2.3b Fruit Length, Fruit diameter and Number of seeds per fruit

There were significant differences among the genotypes for fruit length, diameter and number of seeds per fruit (Table 10). 'AA/05/008' had the longest fruits with average length of 10.9 cm and the shortest fruits averaged 4.3 cm from 'BEK' (Table 11).

Fruits of 'Marconi hot' on the other hand had the widest diameter of 2.3 cm while fruits of'BEK* had the narrowest of 0.7 cm. Seed number was also significant among the genotypes. The highest number of seeds per fruit was 112 in 'AA/05/008' and the lowest was 32 seeds per fruit produced by 'BEK' (Table 11).

Table 9: Mean squares for fruit number per plant, fruit weight and fruit yield per plant of the breeding populations of pepper

Source of variation	Degrees of freedom	Mean squares		
		Fruit number per plant	Fruit weight (g)	Fruit yield per plant
Replication	2	1699	0.02	3031
Genotypes	17	9374***	15.82***	2667.20**
Parents	7	4660.1***	30.54***	39882***
Parents vs crosses	1	13438NS	4.61NS	88721**
Crosses	9	12175***	5.05***	10574NS
Lines	5	5375.60***	34.18***	42906**
Testers	1	4428.20NS	0.45NS	2473NS
Line x testers	5	10926.40***	5.61***	10000NS
Error	34	1098.00	0.18	7916

*, **, **: Significant at 5%, 1% and 0.1% respectively.
NS: Not significant at 5%

Table 10: Mean squares for fruit length, diameter and seed number per fruit of breeding nonulations of DeDDer

Source of Variation	Degrees of freedom	Moan Snnares		
		Fruit length fcrnl	**Fruit diameter (cm)**	**Seed number Der fruit**
Replication	2	0.2458	0.0017	54.43
Genotypes	17	9.1710***	0.4735***	1535.40***
Parents	7	14.62***	1.01***	2448.24***
Parents vs crosses	1	0.65NS	0.21NS	1066.9NS
Crosses	9	5.90***	0.06***	916.58***
Lines	5	17.54***	1.26***	2924.02***
Testers	1	2.94***	0.004NS	73.50NS
Line x testers	5	5.08***	0.06***	831.81***
Error	34	0.29	0.007	54.43

*, **, **: Significant at 5%, 1% and 0.1% respectively.
NS: Not significant at 5%

Table 11: Fruit yield and yield characteristics of parental and Fi generations in pepper

Parents/Crosses	Fruit Number per plant	Fruit weight (g)	Fruit yield per plant (g)	Fruit length (cm)	Fruit Diameter (cm)	Seed Number per fruit
Lines						
'Marconi hot'	36	9.8	368	9.0	2.4	97
‘Singapore’	57	3.2	189	9.1	0.9	48
'BEK'	142	0.7	92	4.3	0.7	32
Long red cayenne	119	2.4	279	6.6	0.9	49
‘AA/05/008’	40	7.2	289	10.9	1.9	112
‘AA/05/016’	74	5.7	421	9.8	1.2	79
Testers						
‘Legon 18’	63	2.06	136	7.4	0.9	42
‘MI-2’	118	1.5	177	6.0	0.9	49
Crosses						
‘Marconi hot* x ‘Legon 18’	56	5.209	305	9.0	1.2	69
‘Long red cayenne'x ’Legon 18’	81	2.521	224	7.8	1.0	52
‘Singapore’x’Legon 18'	95	2.628	247	9.5	0.9	57
'Singapore'x'MI-2'	108	2.9	315	8.1	1.0	72
’BEK’x‘Legon 18’	270	1.4	381	5.2	0.8	57
'BEK’x‘MI-2'	183	1.7	304	6.4	0.9	57
'AA/05/008'x'Legon 18¹	74	5.1	370	9.6	1.3	107
‘AA/05/008’ x 'MI-2'	101	4.2	419	9.3	1.2	91
‘AA/05/016’x'Legon 18'	100	3.14	310	7.6	1.0	68
'AA/05/016'x'MI-2'	94	3.7	346	8.1	1.0	79
LSDfo.o5i:	**55**	**0.7**	**148**	**0.9**	**0.1**	**12**

4.3 Heterosis in the Fi hybrids

4.3.1 Heterosis in Vegetative crharacters

Heterosis estimates over better-parent and mid-parent were found to be significant in some of the crosses for plant height at flowering (cm), canopy diameter (cm) and number of primary branches (Table 12). Better -parent heterosis was negative in all crosses for plant height at flowering except 'Singapore' x 'Legon 18' and 'BEK' x 'MI-

2'. However the positive heterosis values realised in 'Singapore' x 'Legon 18' and 'BEK' x 'MI-2' were not significant The lowest significant better-parent heterosis was recorded in 'AA/05/008' x 'Legon 18' at -30.9% while the highest was -9.4% in 'Marconi hot' x 'Legon 18'. Mid-parent heterosis for plant height at flowering ranged from -11.8% to 22.4% in 'BEK' x 'Legon 18' and 'Singapore' x 'Legon 18' respectively. 'AA/05/016' x 'MI-2' expressed the best significant heterosis over mid-parent **(20.6%).**

Apart from 'Singapore' x 'Legon 18' (11.9%) and 'AA/05/008' x 'MI-2' (18.5%), none of the crosses exhibited significant better-parent heterosis for canopy diameter. Heterosis over mid-parent was positive in all crosses for canopy diameter from 5.5% in 'Long red cayenne' x 'Legon 18' to 39.0% in 'BEK' x'MI-2'.

Better- and mid-parent heterosis values for number of primary branches ranged from -25.0% to 16.7% and -18.2% to 21.7% respectively. Only 'Singapore' x 'MI-2' and 'Long red cayenne' x 'Legon 18' exhibited positive better-parent heterosis but these were not significant 'AA/05/008' x 'MI-2' and 'BEK' x 'MI-2' showed no heterosis over better and mid-parent (0%) and the rest were all negative. Mid-parent heterosis was highest and significant in AA/05/016 x 'MI-2' (15.79%) and the lowest significant heterosis was recorded in 'Singapore' x 'Legon 18' at -9.09% for number of primary branches.

Table 12: Heterosis (%) over better-parent (BP) and mid-parent (MP) for some vegetative characters in pepper

Crosses	Plant height at flowering (cm)		canopy diameter (cm)		No.of prim. Branches	
	BP	MP	BP	MP	BP	MP
'Marconi hot' x 'Legon 18'	-9.4*	-7.6	3.1	21.2*	-25.0*	-10.0
'Long red cayenne'x 'Legon 18'	-9.5	-5.3	1.4	5.5	16.7	21.7
'Singapore' x 'Legon 18'	16.4	22.4	11.9*	24.8*	-16.7*	-9.1*
'Singapore' x 'MI-2'	-6.4	10.4	1.6	25.7*	10.0	15.8
'BEK" x 'Legon 18'	-23.3*	-11.8*	-1.1	23.4*	-8.3*	4.6
'BEK'x'MI-2'	1.4	9.9*	20.8	39.7*	0.0	0.0
'AA/05/008' x 'Legon 18'	-17.5*	-7.3	1.2	17.2*	-16.7*	-4.7
'AA/05/008'x 'MI-2'	-30.9*	-7.2	18.5*	27.7*	0.0	0.0
'AA/05/016'x 'Legon 18*	-9.7	-7.6	-2.6	6.5	-25.0*	-18.2
'AA/05/016'x 'MI-2'	-0.1	20.6*	12.7	13.1	-20.0*	15.8*

•Significant at p=0.05

4.3.2 Heterosis in Reproductive Characters

All crosses except 'AA/05/016' x 'Legon 18' expressed negative better- and mid-parent heterosis for days to first flower opening. Heterosis ranged from -30.93% to -3.42% and -21.24% to 19.30% over better- and mid-parent respectively (Table 13). Heterosis over better-parent was negative in all the crosses for days to first fruit set 'BEK' x 'Legon 18' expressed the highest significant mid- parent heterosis at 19.0% while that of'Singapore' x 'Ml-2' was -9.62%. 'Long red cayenne' x 'Legon 18' was the only cross to exhibit significant heterosis over better- and mid-parent in days to first fruit ripening. 'AA/05/008' x 'Legon 18' also showed positive mid-parent heterosis but this was not significant at P = 0.05(Table 13).

Table 13: Heterosis (%) over better-parent (BP) and mid-parent (MP) for some reproductive characters in pepper

Crosses	Days to 1st flower open		Days to fruit set		Days to first fruit ripening	
	BP	MP	BP	MP	BP	MP
'Marconi hot' x 'Legon 18'	-10.8*	-4.5	-13.5*	-3.0	-6.3*	-1.8
'Long red cayenne'x 'Legon 18'	-3.4	-1.1	-3.1	-1.0	5.9*	10.6*
'Singapore' x 'Legon 18*	-11.4	-9.7	-10.7	-9.2	-7.7	-5.2
'Singapore' x 'MI-2'	-18.2*	-10.7*	-16.4*	-9.6*	-8.3*	-6.9
'BEK'x'Legon 18'	-30.9*	-21.2*	-28.0*	19.0*	-14.9*	-8.3*
'BEK' x 'MI-2'	-5.3	-2.3	-6.6	-4.0	-13.0*	-7.2*
'AA/05/008'x 'Legon 18*	-14.7*	-7.9	-13.9	7.8	-2.3	2.4
'AA/05/008'x'MI-2'	-8.8	-6.0	-7.9	-5.4	-8.8*	-6.0
'AA/05/016'x 'Legon 18'	-25.1	19.3	-22.8	17.4	-10.5	-6.4
'AA/05/016'x'MI-2'	-6.3	-3.3	-5.6	-2.9	-9.7	-0.1

•Significant at p=0.05

4.3.3 Heterosis in yield and yield traits

4.3.3a Heterosis in fruit length (cm), diameter (cm) and seed content per plant

All the FIs recorded positive significant heterosis over mid-parent for seed number per fruit except 'Marconi hot' x 'Legon 18' which recorded -28.9% and -2.2% respectively (Table 14). The crosses 'AA/05/008' x 'Ml-2' and 'AA/05/016' x 'Legon 18' had negative better-parent heterosis of -18.8% and -13.9% respectively. The highest significant mid-parent heterosis for seed number was 54.1% in 'BEK' x 'Legon 18'.

The Fis exhibited negative significant heterosis over better-parent in fruit length (cm). 'BEK' x 'Legon 18' showed the highest better-parent heterosis value at 6.7% (not significant) while the least was -28.5% in AA/05/016 x 'Legon 18'. Mid-parent heterosis was positive for fruit length in all crosses except 'AA/05/016' x 'Legon 18' which showed -11.1%. 'Marconi hot[1] x 'Legon 18' recorded the highest significant mid-parent heterosis for fruit length (9.6%) among the crosses.

Better-parent and mid-parent heterosis in fruit diameter (cm) ranged from -32.3% to 35.1% and -12.0% to 15.7% respectively. 'Singapore' x 'Legon 18' recorded 0.0% heterosis over better-parent for fruit diameter (cm).

Table 14: Heterosis (%) over better-parent (BP) and mid-parent (MP) for number of seeds per fruit, fruit length and fruit diameter in pepper

Crosses	No. of seeds per fruit		Fruit length (cm)		Fruit Diameter(cm)	
	BP	MP	BP	MP	BP	MP
'Marconi hot' x 'Legon 18*	-28.9*	-2.2	-0.4	9.6*	-50.2*	-28.9*
'Long red cayenne' x 'Legon 18'	6.1	14.3*	5.2	10.9	6.1	8.4*
'Singapore' x 'Legon Iff	18.8	26.7	3.2	14.3	0.0	1.8
'Singapore' x 'MI-2'	46.9*	48.5*	-11.4*	7.1*	11.4	15.9
'BEK' x 'Legon 18'	35.7*	54.1*	-28.5*	9.6	-10.7*	3.3
'BEK'x MI 2	16.3	40.7	6.7	24.1	-5.2	7.1
'AA/05/008'x'Legon 18[1]	0.9	39.0*	-11.9*	5.1*	-32.3*	9.8*
'AA/05/008'x'MI-2'	-18.8	13.0	-14.9*	9.9	-12.0*	35.1*
'AA/05/016'x'Legon 18'	-14.0*	12.4*	-21.9*	-11.1*	-10.3*	-0.3
'AA/05/016'x'MI-2'	0.0	23.4	-16.9*	3.0	-14.3	-2.4

•Significant at p=0.05

4.3.3b Heterosis in fruit weight (g), fruit yield per plant (g) and number of fruits per plant

None of the crosses recorded positive significant heterosis over better-parent for fruit weight (Table 15). Better-parent heterosis was between -47.0% in 'Marconi hot' x 'Legon 18' and 10.9% (not significant) in 'BEK' x 'MI-2'. 'Singapore' x 'MI-2' expressed the highest significant heterosis over mid-parent (22.1%) for fruit weight Better-parent heterosis was as low as -41.6% in AA/05/016 x 'MI-2' and as high as 180.2% in 'BEK' x 'Legon 18'. 'AA/05/008' x 'MI-2' recorded the highest significant heterosis over better-parent (45.0%) in fruit yield per plant (g). Mid-parent heterosis values in fruit yield per plant (g) were positive and significant at 79.0%, 52.0% and 15.7% in 'AA/05/008' x 'MI-2', 'Singapore' x 'Legon 18' and AA/05/016 x 'MI-2' respectively. All the other crosses had positive but not significant mid-parent heterosis values.

Table 15: Heterosis (%) over better-parent (BP) and mid-parent (MP) for fruit wt (g), fruit yield per plant (g) and number of fruits per plant in pepper

Cross	Fruit wt(g)		Fruit yield per plant (g)		Numberof Fruits per plant	
	BP	MP	BP	MP	BP	MP
'Marconi hot[1] x 'Legon 18'	-47.0*	-12.4	-17.1	21.0	-11.1	13.1
'Long red cayenne'x 'Legon 18'	5.3	13.1	-19.7	8.0	-31.9	-11.0
'Singapore' x 'Legon 18'	-19.0	-1.0	30.7	52.0*	50.8*	57.0*
'Singapore'x 'MI-2'	-10.4	22.1*	66.7	72.1	-8.5	23.4
'BEK* x'Legon 18'	-31.5*	4.1	180.2	234.2	90.1	163.4*
'BEK x MI 2	10.9	55.0	71.6	126.0	28.9*	40.8*
'AA/05/008'x 'Legon 18'	-29.5*	9.6	28.0	74.1	17.5	43.7
'AA/05/008'x'MI-2'	-42.2*	-4.7	45.0*	79.0*	-14.4*	27.9*
'AA/05/016' x 'Legon 18'	-45.4*	19.7*	-26.4*	11.3	35.1	46.0*
'AA/05/016' x'MI-r	-34.5*	3.6	-41.6*	15.7*	-20.6	-28.2

•Significant at p=0.05

4.4. Combining Ability in Pepper

4.4.1 General (GCA) and Specific (SCA) Combining Abilities in Vegetative Characters

General and specific combing abilities of parents and hybrids for vegetative traits were significant for vegetative traits. 'Singapore' showed the highest GCA estimates for all vegetative parameters measured, plant height at flowering (cm), canopy diameter (cm) and number of primary branches. All the lines were significantly better general combiners for plant height at flowering than 'BEK' (Table 16).

There were significant differences among the SCA values of the hybrids. 'Singapore' x 'Legon 18' had the highest SCA values for plant height at flowering (cm) and canopy second highest diameter (cm). The SCA value of 'Singapore' x 'Ml-2' for number of primaiy branches was significantly higher than that of 'Singapore' x 'Legon 18' but did not differ from any of the other entries.

Table 16: General (GCA) and Specific (SCA) combining ability estimates in pepper (C. *annuum*) for Vegetative characters

Parent/Cross	Plant height at flowering (cm)	Canopy diameter (cm)	No. of prim. Branches
	GCA of Lines(Females)		
'Singapore'	1.06	1.47	0.22
'BEK'	-1.86	-0.12	0.17
'AA/05/008'	0.66	-0.25	-0.06
'AA/05/016'	0.15	-1.04	-0.34
LSD fp=0.05)	**1.32**	**1.90**	**0.26**
	GCA of Testers (Males)		
'Legon 18'	0.68	0.50	0.14
'MI-2'	-0.68	-0.50	-0.14
LSD fp=0.05)	**1.10**	**0.45**	**0.32**
	SCA of Hybrid		
'Singapore' x 'Legon 18'	1.23	0.64	-0.31
'Singapore' x 'MI-2'	-1.23	-0.65	0.31
'BEK'x'Legon 18'	-0.59	-0.65	0.08
'BEK x'MI-2'	0.59	0.65	-0.08
•AA/05/008'**x'Legon** 18'	0.34	0.00	0.08
'AA/05/008'**x'MI-2'**	-0.34	0.00	-0.08
'AA/05/016'**x'Legon** 18'	-0.98	-0.05	-0.08
'AA/05/016'**x'MI-2'**	0.98	0.05	0.08
LSD (p=0.05)	**0.96**	**1.63**	**0.42**

***4.42,* Combining ability of reproductive traits.**

GCA estimates for plant reproductive characters showed significant differences at P=0.05 (Table 17). Values ranged from -0.82 in 'BEK' to 0.63 in 'Singapore' for days to first flower opening. 'Singapore' exhibited the highest GCA for all three characters measured. On the other hand, 'BEK had the lowest GCA values for all traits.

The testers were significantly different from each other in terms of GCA for all the reproductive characters with 'Legon 18' showing tonsistently higher GCA values than 'Ml-2'.

From the SCA estimates for days to first flower opening, fruit set and fruit ripening were all significantly different (Table 17). 'AA/05/016' x Ml-2 had the highest SCA value for days to first flower opening while 'AA/05/016' x 'Legon 18' had the least 'Singapore' x 'Legon 18' had an SCA of 0.52 for days to first fruit set which was significantly higher than that of'Singapore' x 'MI-2' for the same trait

Table 17: General (GCA) and Specific (SCA) combining ability estimates in pepper (C. *annuum)* for some Reproductive characters in pepper

Parent/Cross	Days to first flower open	Days to first fruit set	Days to first fruit ripening
	GCA Lines(Females)		
'Singapore'	0.63	0.66	0.34
'BEK*	-0.82	-0.88	-1.11
'AA/05/008'	0.35	0.36	0.95
'AA/05/016'	-0.17	-0.12	-0.17
LSDfo.osi	1.06	0.94	0.90
	GCA Testers (Males)		
'Legon 18'	0.08	0.09	0.39
'Ml-2'	-0.08	-0.09	-0.39
LSDfo.osi	0.54	0.66	0.90
	SCA Crosses		
'Singapore' x 'Legon 18'	0.55	0.52	-0.03
'Singapore' x 'MI-2'	-0.55	-0.52	0.03
'BEK'x'Legon 18'	-0.54	-0.43	-0.39
'BEK" x 'Ml-2'	0.54	0.43	0.39
'AA/05/008'x'Legon 18'	0.41	0.35	0.67
'AA/05/008'x'MI-2'	-0.41	-0.35	-0.67
'AA/05/016'x'Legon 18'	-0.66	-0.44	-0.22
'AA/05/016'x'MI-2'	0.66	0.44	0.22
LSD fo.os>	1.07	0.93	0.53

4.4.3 Combining ability of fruit yield and fruit characteristics

Yield and yield components of the lines had significantly different GCA values for all yield and yield component characters measured. The GCA of 'Singapore' was the lowest among the lines (females) for fruit diameter, fruit weight and fruit yield per plant (Table 19).

GCA of the two testers (males) were not different for fruit number per plant, fruit weight (g), fruit yield per plant (g), number of seeds per fruit, diameter and length (Table 19).

The hybrids had significantly different SCA values for fruit traits except for fruit yield per plant (Table 19). 'BEK' x 'Legon 18' had the highest SCA for number of fruits per plant (12.2) and fruit yield per plant (though not significant). 'AA/05/008' x 'Legon 18' had the highest SCA value for seed number per fruit while 'Singapore' x 'Ml-2' was highest for fruit diameter (cm).

Table 18: Combining ability estimates of fruit length, fruit diameter and seed content per fruit in pepper

Parent/ Cross	Fruit length (cm)	Fruit Diameter (cm)	Seed Number per fruit
GCA Lines (Females)			
'Singapore'	0.27	-0.01	-3.10
'BEK*	-0.71	0.04	-5.54
'AA/05/008'	0.49	0.07	8.57
'AA/05/016'	-0.04	0.00	0.07
LSD f5%1	0.23	0.37	7.20
GCA Testers (Males)			
'Legon 18'	0.003	-0.0002	-0.40
'Ml-2'	-0.003	0.0002	0.40
LSD (5%)	0.15	0.17	7.20
SCA Crosses			
'Singapore'x'Legon 18'	0.21	-0.24	2.05
'SingaporeYMI^'	-0.21	0.24	-2.05
'BEKY Legon 18'	-0.24	-0.002	0.40
'BEK'x'MI-2'	0.24	0.002	-0.40
'AA/05/008'x'Legon 18'	0.05	0.008	3.07
'AA/05/008'x'MI-2'	-0.05	-0.008	-3.07
'AA/05/016'x'Legon 18'	-0.09	0.007	-0.4
'AA/05/016'x'MI-2'	0.09	-0.007	0.4
LSD (5%)	0.23	0.37	2.38

Table 19: Combining ability of number of fruits per plant, fruit weight and fruit yield per plant in pepper

Genotypes	Fruit Number per plant	Fruit weight (g)	Fruit yield per plant (g)
	GCA Lines(Females)		
Singapore'	-8.90	.0.11	-18.40
'BEK'	33.00	-0.52	2.00
'AA/05/008'	-5.50	0.51	19.30
'AA/05/016[1]	-10.50	0.11	-2.90
LSDfo.osi	**39.92**	**0.33**	**16.20**
	GCA Testers (Males)		
'Legon 18'	2.20	-0.01	-3.20
'MI-2'	-2.20	-0.02	3.20
LSDjaosi	**20.66**	**0.06**	**16.20**
	SCA Crosses		
'Singapore' x 'Legon 18'	-4.30	-0.04	-8.10
'Singapore' x 'MI-2'	4.30	0.04	8.10
'BEK'x'Legon 18'	12.20	0.14	16.00
•BEK[1] x'MI-2'	-12.20	-014	-16.00
•AA/05/008' x 'Legon 18'	-5.00	0.16	-5.10
•AA/05/008' x 'MI-2'	5.00	-0.16	5.10
'AA/05/016'x'Legon 18'	-1.20	-0.09	-2.90
•AA/05/016'x'MI-2'	1.20	0.09	2.90
LSD(aosi	**15.34**	**0.32**	**39.92**

4.43 Breeding values for lines which crossed with only one tester.

The average combining ability (breeding value) of 'Marconi hot* and 'Long red cayenne' for all traits measure were calculated (Table 20). The breeding value was positive in both crosses for plant height at flowering, fruit yield per plant and number of fruits per plant For the other characters, when the breeding value for 'Marconi hot' is positive the reverse is true for 'Long red cayenne'. Fruit yield per plant and fruit number per plant gave the greatest breeding values at 81.87 in 'Long red cayenne' and 56.28 in 'Marconi hot' respectively.

Table 20: Average combining ability values of 'Marconi hot* and 'Long red cayenne* measured by the performance of their progeny

Trait	Line 'Marconi hot'	'Long red cayenne'
Plant height at flowering (cm)	1.58	1.62
No. of seeds per fruit	0.78	-16.22
Fruit length (cm)	0.88	-0.35
Fruit Diameter (cm)	0.13	-0.05
Days to first flower open	0.68	5.18
Days to first fruit set	-0.77	-5.25
canopy diameter (cm)	-0.47	0.60
Days to first fruit ripening	0.28	-8.72
No. of primary branches	1.17	-3.50
Fruit weight (g)	-1.88	0.81
Fruit yield per plant (g)	1.33	81.87

4.5 Heritability and Correlation of characters.

Heritability of the characters measured among the parents and their Fi generation were generally high except for fruit yield per plant (g) which was 0.08 and canopy diameter (cm) with a value of 0.26 (Table 21). Heritability of fruit characteristics was high except for fruit diameter. Heritability of fruit seed content was highest (0.96).

Genetic correlations between fruit yield per plant (g) and other traits were generally low (Table 21). The correlation between fruit yield per plant (g) and vegetative characters, days to first flower open, first fruit set and days to fruit ripening were negative, it was positive for fruit yield traits; number of fruits, fruit length (cm), fruit diameter (cm) and number of seeds per fruit. Number of fruits per plant showed the highest positive correlation with fruit yield per plant.

Table 21: Heritability of fruit characters and correlation between fruit yield and other characters in pepper

Character	Heritability	Correlation
Plant height at flowering (cm)	0.57	-0.29
Canopy diameter (cm)	0.26	-0.32
No. of primary branches	0.87	-0.29
Days to first flower opening	0.76	-0.26
Days to first fruit set	0.78	-0.23
Days to first fruit ripening	0.71	-0.28
Fruit Number per plant	0.70	0.44
Fruit weight (g)	0.81	0.27
Fruit yield per plant (g)	0.08	--
Fruit length (cm)	0.95	0.10
Fruit Diameter (cm)	0.42	0.18
Seed Number per fruit	0.96	0.37

CHAPTER FIVE

5.0 DISCUSSION

5.1 Variability in Qualitative and Quantitative Traits in the Parent and Fi Generations

The pepper varieties used in the experiment showed variability in morphological and qualitative characteristics, such as growth and branching habits and inflorescence and fruit characteristics in line with reports by Zogli (2006), who worked with forty accessions of pepper collected in Ghana. According to Manju and Sreelathakumary (2002) this presence of high variability in the crop offers much scope for its improvement The differences between the FI generations and their respective parents were as a result of recombination of genes during hybridization.

Canopy diameter and number of primary branches were generally higher in the FI population than among the parents and one would have expected that the number of primary branches will correspond with the canopy diameter. This was not the case in this study. 'Long red cayenne' with the highest number of primary branches did not have the widest canopy. Rather the canopy of 'Singapore' x 'Legon 18' was the widest among all the genotypes. These differences were as a result of the different branching habits such as the angle between the branch and the stem as well as number of secondary and tertiary branches which were not measured in this study.

Differences in plant height may be attributed to differences in growth rate. Increase in plant height could be directly attributed to increased growth due to rapid cell division at the apical meristem of a plant. Accession ‘AA/05/008’ was significantly the tallest at flowering. The same accession had very few primary branches and a short canopy diameter. This may be explained by the fact that rapid growth at the apical region of a plant, there is always exerts an inhibition on the growth of lateral buds hence lateral growth is at the minimum.

The significant differences in mean performance of lines, testers and their hybrids in reproductive growth indicated that there was genetic variability for improvement of pepper in terms of earliness, based on the number of days to first flower open, days to first fruit set and days to fruit ripening. 'BEK' was the first parent to bear opened flowers, set fruits, and ripened fruits. The hybrid 'BEK' x 'Legon 18' had fewer number of days to first flower open, fruit set and first fruit ripening indicating earliness in the hybrid, a trait that must have been inherited from 'Bek". Between the testers, number of days to first flower opening and fruit set were significantly higher in 'Legon 18' than 'Ml-2', they were however not significantly different in terms of number of days to fruit ripening. 'Legon 18' had the highest number of days to first flower opening, fruit set and fruit ripening compared with all other genotypes (that is lines, testers and FIs) though not significantly different from that of 'Singapore' and 'Long red cayenne'. It is therefore not desirable for improvement of earliness.

The varieties 'BEK', 'Long red cayenne' and 'Ml-2' had significantly more number of fruits per plant than all the other parents and would therefore be useful parents to consider when breeding for improved yields through number of fruits. 'Marconi hot' and 'AA/05/008' yielded fruits with the highest individual fruit weight but had the lowest number of fruits per plant. Low number of fruit on a plant implies that all the photosynthates produced would be distributed to very fewer fruits for growth as compared to plants that bear many fruits. When compared with the other female (lines) parents, 'AA/05/008', 'Marconi hot' and 'BEK' would be more desirable for yield improvement programmes since fruit size and fruit number per plant are mostly the two most important yield components. Seed number increased with a considerable increase in fruit size as was observed in the top three genotypes for seed number per fruit,'AA/05/008', 'AA/05/008' x 'Legon 18' and 'Marconi hot[1]. Marcelis and Hofman- eijer (1997) also found a positive relationship between seed number and individual fruit weight or size.

5.2 Combining ability of yield and its associated characters.

Significant positive and negative general combining ability (GCA) effects were found in the females (lines) for both plant height at flowering and number of primary branches. 'BEK' had a significantly low GCA for plant height The testers on the other hand showed significant GCA in canopy diameter and number of primary branches. GCA was also significantly positive for number of primary branches however this was low. Apart from 'Singapore' and 'Legon 18' which had positive GCA effects and 'Mi-2' having negative GCA for all vegetative traits studied the other genotypes each had two negative GCA values. 'Singapore' and 'Legon 18' can therefore be considered to be the best female and male combiners respectively for vegetative characters. However these would not be ideal for pepper fruit yield improvement since there was no corresponding increase in the fruit yield. 'AA/05/016' was significantly the poorest general combiner for number of primary branches. Specific combining ability (SCA) effects were significant among the Fis for plant height at flowering and number of primary branches per plant with 'Singapore' x 'Legon 18', 'BEK' x 'Ml-2' and 'AA/05/016' x 'MI-2' having positive SCA effects. The presence of significant GCA and SCA effects in vegetative characters indicated the importance of genetic variance in the inheritance of these characters within the pepper lines used. The non-significant or negative SCA values exhibited by the hybrids for these traits also imply the lack of dominant and over-dominant genic effects.

GCA values among the lines and testers were significant for days to first flower open, days to first fruit set and days to first fruit ripening. Like the GCA and SCA effects in vegetative parameters, 'Singapore' and 'Legon 18' recorded positive GCA values for all three traits. A cross between the two recorded positive SCA results in two of the same characters studied. 'AA/05/008' was the best general combiner among the females (lines) for days to first fruit ripening. Lines with low GCA for vegetative parameters as well as days to first flower opening days to first fruit set and days to first fruit ripening are more desirable when breeding for higher yields and earliness.

Significant GCA effects were found for all yield and yield components among the females (lines). 'AA/05/008' showed significant positive GCA for all the traits except number of fruits per plant Mean while only three yield traits had significant GCA effects in the males (testers) viz fruit weight, fruit length and fruit diameter. 'Singapore' was the poorest general combiner for fruit yield per plant (g) and fruit diameter while 'BEK' was the poorest general combiner for fruit weight (g), fruit length (cm) and seed number per fruit. Among the crosses SCA was significant for number of fruits per plant, fruit diameter and seed number per fruit

The breeding values found for various traits in the female parents, 'Marconi hot' and 'Long red cayenne' which crossed with only ‘Legon 18’ were variable for many of the traits considered. This variation, according to Falconer and Mackay (1989) may be due to non-additive gene effects.

The presence of both significant GCA and SCA, and variable breeding values in the germplasm suggested the involvement of additive and non-additive gene effects. This is consistent with findings reported by Ahmed *et al.,* (1999), Legesse (2000) and Zewdie (2001). Again a comparison between the mean performance of the genotypes and their GCA is in agreement with report by Legesse (2000), that many of the parents which were good combiners for various traits also possessed high means for those traits. In view of these, 'BEK' is the best parent for fruit number per plant and could be crossed with 'Marconi hot[1] and 'AA/05/008' which yielded the biggest fruits.

5.3 Heterosis estimates in the hot pepper crosses

Heterosis is the main purpose of controlled hybridization (Geleta and Labuschagne, 2004). Better- and mid- parent heterosis were both exhibited by many of the Fis evaluated for various vegetative, reproductive and yield characteristics.

Most of the hybrids could not outperform their parents in vegetative. Plant height at flowering and number of primary branches were generally negative and significant both over the better-parent and mid-parent. Only 'Singapore' x ‘Legon 18' and 'BEK' x 'Ml-2' recorded positive heterosis over better- and mid-parent in plant height at flowering. These results are similar to that obtained by Senevirathne and Kannangara (2004) but part contradicts Mulge and Anand (1997), and Doshi *et al,* (2001). Senevirathne and Kannangara (2004) reported the presence of both positive and negative heterosis in hybrids for plant height while Mulge and Anand (2001) and Doshi *et al.,* (2001) reported only positive heterosis in the same trait. During the domestication process, extensive vegetative growth was found to be undesirable. Breeders therefore selected against vegetative growth and for that matter the low and negative heterosis recorded in the Fi populations in this research is beneficial. Confirming report by Senevirathne and Kannangara (2004), canopy diameter (cm) had generally positive significant heterosis among the Fis. Canopy diameter is usually associated with photosynthesis. The wider the canopy diameter of a plant the bigger the photosynthetic area available for the formation of photosynthates for use by the plant 'AA/05/008' x 'MI-2' exhibited the highest positive significant heterosis over better-parent and mid-parent for canopy width which was translated into highest positive significant heterosis in fruit yield per plant

Days to first flower opening, first fruit set and first fruit ripening all exhibited negative heterosis over both better-parent and mid-parent Hundal and Singh (2001b), Mulge and Anand (1997), Sousa and Maluf (2003), Geleta and Labuschagne (2004), and Senevirathne and Kannangara (2004) reported similar results. Heterosis over better- and mid-parent for these three characteristics implies that hybrids flowered, set fruits and the fruits ripened earlier than their parents. Since earliness in fruit maturity is a desirable character the recorded heterosis in this experiment is a trait worthy of exploitation in the germplasm. 'BEK' X ’Legon 18' expressed the highest negative significant better-parent and mid-parent heterosis. This makes it a very good choice for pepper improvement in terms of earliness.

The Fi hybrids exhibited significant positive and negative heterosis over better- and mid-parent values for seed content, fruit length and diameter. Heterosis values were generally higher for seed content than fruit length and diameter. Many cross combinations gave positive heterosis both over better- and mid-parent Positive and significant better-parent and mid-parent heterosis in seed content were expressed by the crosses between 'Singapore' and 'MI-2' and, 'BEK' and 'MI-2'. It was observed that crosses with high heterosis for seed number per fruit had at least one of the parents giving very high number of fruits per plant This could be due to the relation drawn between seed number and fruit formation by Marcelis and Hofman-eijer (1997). They reported that when seed numbers were low, there was a corresponding low probability of fruit setting. In this study high fruit number may have resulted from corresponding high number of seeds formed at the onset of fruit formation which made the high fruiting parents to give high heterosis in seed number in the hybrids.

Heterosis in fruit length and diameter were generally low in the crosses. Majority of the crosses recorded negative significant heterosis over better-parent and low but positive heterosis over mid-parent for the two characters. Only three crosses, ‘Marconi hot* x 'Legon 18', 'Singapore' x 'MI-2' and ‘AA/05/008’ x 'Legon 18' recorded significant positive heterosis over mid-parent for fruit length. The female (lines) parents in these crosses showed very high means for fruit length. The negative significant heterosis over better parent recorded for most of the crosses was contradictory to results obtained by workers such as Hundal and Singh (2001) and, Mamedove and Pyshnaja (2001). They reported positive and high heterosis over better parent in the same traits.

Many of the Fis did not perform better than their parents in terms of fruit weight fruit yield per plant and number of fruits per plant. Better- and mid-parent heterosis were generally low for fruit weight and number of fruits per plant, but high and positive for yield per plant (g). However the high heterosis values in yield was not significant in any of the crosses except 'AA/05/008' x 'Ml-2'.

The results obtained for these three characters apart from that of fruit yield per plant were in contrast with that reported by Geleta and Labuschagne (2004) who found positive heterosis exhibited by hybrids in all three parameters. Senevirathne and Kannangara (2004) also reported that the highest positive heterosis in yield was recorded by crosses with the highest heterosis in canopy diameter. Their results were confirmed by 'AA/05/008' x 'Ml-2' and 'Singapore' x 'Legon 18' which recorded the highest heterosis in canopy diameter.

The negative significant heterosis for various vegetative characters and positive heterosis in most yield characters found in these hybrids is a good basis for employing heterosis breeding to improve yield of pepper.

5.4 Heritability of yield and associated characters

High heritability was observed for most plant characters, in particular number of seeds per fruit, fruit length (cm), number of primary branches, fruit weight and number of fruits per plant This was consistent with reports by Manju and Sreelathakumary (2002) and, Sreelathakumary and Rajamony (2004). Jabeen *et al.*, (1996) also recorded high heritability for fruit weight and fruit length. The high heritability observed for the various characteristics may be attributed to additive gene action in the hybrids. Low heritability values were however recorded for canopy diameter and fruit yield per plant which is contrary to results obtained by the same workers.

Heritability is one of the parameters that influence the effectiveness of selection of a character (Manju and Sreelathakumary, 2002). High heritability estimates indicate the presence of large number of fixable additive factors. Pepper yield improvement using the germplasm considered in this research could be achieved through selection using all the characters measured except canopy diameter and fruit yield per plant since they were not highly heritable.

5.5 Correlation between yield and yield traits.

Correlation between yield and associated characters was generally low. Fruit number recorded the highest correlation with yield.

Vegetative parameters were negatively correlated with fruit yield per plant Negative genetic correlation between yield and vegetative growth is desirable since the main interest was higher yields. There was negative correlation between pepper yield per plant and, days to first flower opening, days to fruit set and days to fruit ripening (all of which are usually associated with earliness). This presupposes that selecting against these parameters will lead to improved fruit yield per plant

On the other hand, fruit characteristics like fruit number per plant seed number per fruit fruit diameter, fruit weight and fruit length were all positively correlated with fruit yield per plant and this is in line with results reported by Singh *et al.,* (2009) and Sood *et al.,* (2009). Singh *et al.,* (2009) and Sood *et al.,* (2009) reported positive correlation between average fruit weight, number of fruits per plant and fruit length, and fruit yield per plant. P6rez *et al*., (2009) also recorded positive correlation between seed number per fruit and fruit yield per plant The positive correlation between these characters and yield suggests that, in selecting for fruit yield, fruit length, average fruit weight, fruit number per plant and seeds per fruit are some of the selection criteria to be adopted. It is also important to have sufficient pollen when crossing parents used in this investigation in order to ensure pollination and subsequent seed pollination. According to P6rez *et al*., (2009), high correlation between yield and seed number suggests the necessity to secure ovule pollination when growing *Capsicum* species, where populations of pollinating insects are not sufficient

CHAPTER SIX

6.0 CONCLUSIONS

Significant general combining ability (GCA) and specific combining ability (SCA) effects were recorded for most of the characters measured implicating both additive and non additive gene effects. Breeding values calculated for lines which bore fruits after the manual pollination with only one of the testers also implied the presence of non-additive gene action. 'BEK' was the best combiner for earliness and number of fruits per plant

Heterosis over better - parent and mid-parent values were significant and, either positive or negative and sometimes zero for the characters investigated. Heterosis was generally low for all characters except fruit yield per plant 'AA/05/008' x 'MI-2' recorded the highest heterosis over mid-parent and better-parent for fruit yield per plant Heterosis breeding could be employed to improve the yield of pepper.

Heritability was high for most characters measured indicating the presence of a large number of fixable additive factors, except for fruit yield per plant and canopy diameter which had low heritability values. Fruit yield would therefore not be improved simply by direct selection for fruit yield per plant in these populations.

There was low correlation between yield and other characters. Number of fruits per plant was found to be the highest correlated trait with fruit yield. Selection for yield per plant in this germplasm may be achieved indirectly by selecting for number of fruits per plant, considering that the later had a higher a higher heritability than yield per plant

6.1 Recommendations

The main objectives of this project were accomplished. Nevertheless it is important for further investigation to be carried out in some of the areas of the study to verily the consistency of the findings obtained within this particular hot pepper germpiasm.

- In order to ascertain the possibility of obtaining fruits from crosses between 'MI-2' and 'Marconi hot', and, 'MI-2' and 'long red cayenne', the crossing procedure may be repeated. This will give the full complement of progeny seed needed for the evaluation of the set of parents used in this experiment
- The number of parents could also be increased to include the very small, yellow and very hot bird eye pepper variety to investigate the gene action on fruit colour and pungency along with all the other parameters that were considered in this study.
- The FIs together with their parents need to be evaluated in different environments to ascertain the true picture of the genetic mechanism involved in yield and yield components.
- The same parents could be evaluated in a different mating system such as diallel analysis with reciprocals. This will give many more possible combinations than was obtained in the line x tester mating system used in the study.

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Appendix

Analysis of variance

Variate: Days_to_lst_flower_open

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		33.951	16.976	2.79	
Rep.'Units* stratum						
Line	17		586.634	34.508	5.67	<.001
Residual	31	(3)	188.727	6.088		
Total	50	[3)	782.620			

Analysis of variance

Variate: Days_to_lst_flower_open

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
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Analysis of variance

Variate: Days_to_first_fruit_ripening

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	Fpr.
Rep stratum	2		37.956	18.978	4.97	
Rep.'Units* stratum						
Line	17		824.048	48.473	12.68	<.001
Residual	32	(2)	122.295	3.822		
Total	51	(2)	977.692			

Analysis ofvariance

Variate: Days_to_fruit_set

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		28.157	14.078	2.18	
Rep.*Units* stratum						
Line	17		610.308	35.900	5.56	<.001
Residual	31	(3)	200.089	6.454		
Total	50	(3)	806.529			

Analysis of variance

Variate: Fruit_Diameter_cm

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		0.003434	0.001717	0.23	
Rep *Units* stratum						
Line	17		8.050299	0.473547	64.32	<.001
Residual	33	(1)	0.242951	0.007362		
Total	52	(1)	6.774102			

Analysis of variance

Variate: Fruitjength.cm

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		0.4915	0.2458	0.84	
Rep.*Units* stratum						
Line	17		155.9071	9.1710	31.28	<.001
Residual	33	(1)	9.6740	0.2932		
Total	52	(1)	165.1762			

Analysis of variance

Variate: Fruit.wt_g

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	
Rep stratum	2		0.0406	0.0203	0.12	
Rep.*Units* stratum						
Line	17		268.9388	15.8199	90.38	<.001
Residual	31	(3)	5.4261	0.1750		
Total	50	(3)	232.0776			

Analysis of variance

Variate: Fruit_yield_plt_g

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		6062.	3031.	0.38	
Rep.'Units* stratum						
Line	17		453416.	26672.	3.37	0.002
Residual	31	(3)	245406.	7916.		
Total	50	(3)	688490.			

Analysis of variance

Variate: No_of_prim_branches

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		1.3588	0.6794	1.31	
Rep.*Units* stratum						
Line	17		122.1593	7.1858	13.80	<.001
Residual	33	(1)	17.1781	0.5205		
Total	52	(1)	133.2453			

Analysis of variance

Variate: Number_Fruits_plt

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		3397.	1699.	1.55	
Rep.*Units* stratum						
Line	17		159364.	9374.	8.54	<.001
Residual	31	(3)	34034.	1098.		
Total	50	(3)	187309.			

Analysis of variance

Variate: Plt_ht_at_flowering_cm

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		54.943	27.471	3.90	
Rep.*Units* stratum						
Line	17		1517.619	89.272	12.66	<.001
Residual	31	(3)	218.598	7.052		
Total	50	(3)	1788.404			

Analysis of variance

Variate: canopy_diameter_cm

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Rep stratum	2		18.31	9.15	0.81	
Rep.'Units* stratum						
Line	17		4214.19	247.89	22.02	<.001
Residual	31	(3)	348.93	11.26		
Total	50	(3)	4232.53			

Analysis of variance

Variate: no_of_seeds_fruit

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	
Rep stratum	2		108.85	54.43	0.94	
Rep.*Units* stratum						
Line	17		26101.87	1535.40	26.48	<.001
Residual	33	(1)	1913.45	57.98		
Total	52	(1)	27252.08			

Analysis of variance

Variate: no_Of_seeds_fruit

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
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Appendix

Analysis of variance

Variate: Days_to_lst_flower_open

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	
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Line	17		586.634	34.508	5.67	<.001
Residual	31	(3)	188.727	6.088		
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Total	52	(1)	165.1762			

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