GENETICS OF THRIPS (*Megalurothrips sjostedti*) RESISTANCE IN COWPEA (*Vigna unguiculata* (L.) WALP.)

BY

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DECLARATION

I hereby declare that this thesis embodies the results of my own research work. No part of this thesis has previously been submitted for a degree or any other qualification. Any portions of the thesis for which the author is indebted to other sources are vividly mentioned and explicit references are given.

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CERTIFICATION

This thesis entitled ‘‘GENETICS OF THRIPS (*Megalurothrips sjostedti*) RESISTANCE IN COWPEA (*Vigna unguiculata* (L.) WALP.)’’ by DORMATEY RICHARD meets the regulations governing the award of the degree of Masters of Science of Ahmadu Bello University, Zaria and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

Affectionately dedicated to Juliet, Selassie, Selorm and Selikem.

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ABSTRACT

Genetics of resistance of *Megalurothrips sjostedti* in cowpea was studied, field trial was conducted at Savannah Agricultural Research Institute (SARI), Nyankpala, Ghana, involving F_1, F_2, backcross populations and the five parental materials: four improved varieties; Sampea 8, Ife brown, Sampea 7, Padi-tuya and one local landrace, Sanzi obtained by bi-parental mating design at the Institute for Agricultural Research (IAR), Samaru, Nigeria. Nyankpala is located on ($9^0\ 25^1$ N: $0^0\ 58^1$ W). The study was undertaken to validate the resistance status of the parental materials, to elucidate the mode of inheritance of flower bud thrips resistance in these genotypes and to establish the genetic relationships between the resistance genes. The results showed Sanzi to be resistant and Sampea 8, moderately resistant whilst Ife Brown, Sampea 7 and Padi-tuya were classified as susceptible. Maternal effect was implicated while frequency distributions of the F_2 and backcross generations revealed quantitative inheritance. Additive, dominance and epistatic gene effects made major contributions. The effective factors of 3 to 4 indicated an oligogenic inheritance of resistance genes for flower bud thrips. The study suggested that some of the resistant genes in Sampea 8 and Sanzi are non-allelic. Broad sense heritability estimates ranged from 53.00 % to 58.00 % and 85.00 % to 94.00 % in Number of flower bud thrips per plant and pods per peduncle. Narrow sense heritability ranged from 13.00 % to 28.00 % and 18.00 % to 41.00 % coupled with genetic advance of 3.64 to 4.78 respectively. The estimates of broad and narrow sense heritability with genetic advance showed the possibility to increase and diversify resistance of cowpea to flower bud thrips by using these two resistant genotypes as viable sources for resistant to *Megalurothrips sjostedti* in high yielding commercial cultivars.

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ABBREVIATIONS

CGIAR:	Consultative Group on International Agricultural Research
CRI:	Crop Research Institute
FTh:	Flower bud thrips
GLM:	General Lineal Model
GMA:	Generation Mean Analysis
IAR:	Institute for Agriculture Research
IITA:	International Institute of Tropical Agriculture
PSBs:	Pod sucking bugs
QTL:	Quantitative Trait Loci
SAS:	Statistical Analysis System
SARI:	Savannah Agricultural Research Institute
F_1:	Hybrid (First filial generation)
F_2:	Second filial generation
BCP_1:	F_1 x Parent 1
BCP_2:	F_1 x Parent 2
σ^2**:**	Variance
DR:	Damage rating
NFTh:	Number of flower bud thrips
PPR	Pods per peduncle
NS	Number of seeds
NP	Number of pods per plant

CHAPTER ONE

INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is one of the world’s most important food legume crops. In Africa, particularly, the Western and Central regions, cowpea is the main source of plant protein (IITA, 1994). The tender leaves, immature pods, soft stem and fresh seeds are eaten as vegetables and the dry grains serve as staple food (Prah, 1993; Okigbo, 1978). The protein content ranges from 23-38 % in the grain and 29-43 % in the leaves (Bressani, 1985; Walker, 1982). For this reason, cowpea has been referred to as “the poor man’s meat” (Aykroyd and Doughty, 1982). In addition, cowpea contributes to the sustainability of cropping systems and soil fertility improvements in marginal lands by providing ground cover and plant residues, fixing atmospheric nitrogen and suppressing weeds (Inaizumi *et al*., 1999). Golop *et al*. (1996) reported that, cowpea production helps to maintain yield of other agricultural crops in areas where fertilisers are difficult to obtain or not affordable.

Cowpea is a hardy crop that can produce reasonably well under conditions that may render other crops unproductive, however, its production is still constrained by several stresses (Hall *et al.,* 1997). Among these yield reducing factors, damage by thrips species (Thysanoptera: Thripidae) is the most important biotic stress that has devastating effects on cowpea in West Africa and other parts of the world (Hall *et al.,* 1997). The most destructive thrips species include the Florida flower thrips *(Frankliniella tritici),* the western flower thrips *(Frankliniella occidentalis*), *Bispinosa, Thrips palmi, Thrips tabaci* and the flower bud thrips (*Megalurothrips sjostedti)* (Bottenberg *et al.,* 1997; Jackai and Adalla, 1997). *Thrips palmi* causes significant yield losses in Asia and *Thrips tabaci* is widely spread in Asia and South

America. *Megalurothrips sjostedti* appears more destructive in West Africa, causing 20-70 % yield losses (Ngakou *et al.,* 2008; Bottenberg *et al*., 1997 and Jackai and Adalla, 1997). Thrips also serve as vectors transmitting over 20 plants infecting viruses such as Tospoviruses (Nault, 1997).

Despite the considerable work done on various control methods of thrips species, *Megalurothrips sjostedti* has received relatively little attention. Cultural practices recommended to limit thrips infestation include irrigation, tillage operation, planting date, crop rotation and intercropping (Parella and Lewis, 1997). However, the incidence of multiple infestations to cereals, vegetables, and cowpea, thrips species coupled with their biology and wide host range (Morse and Hoddle, 2006) preclude effective control through these methods. According to Omo-Ikerodah *et al*. (2009) flower bud thrips constitutes the first major pest of cowpea at the reproductive stage and if not controlled is capable of reducing grain yield significantly. Lewis (1997) reported that, reflective mulches such as aluminium surfaced mulch has considerably decreased thrips in tomato, pepper and tobacco, meanwhile, the effectiveness of the mulch decreased with increased shading of lower leaves and the results have not been known with respect to cowpea flower bud thrips. Other chemicals that have been recommended for thrips management include garlic, rotenone, ryania, pyrethrum and sabadilia. Home made garlic and pepper has been recommended for botanical growers in USA (ATTRA, 2004). Adoption of a broad range of strategies that include repeat applications of expensive insecticides has also been recommended (ATTRA, 2004). However, these synthetic and non-synthetic insecticides have some major draw backs; these often lead to rapid development of insecticide resistance in thrips populations rendering the chemical treatments ineffective (Morse and Hoddle, 2006). In addition, they are expensive and sometimes need to be applied with special equipment that put them out of reach of the majority of resource-poor farmers who grow the crop. The technical know how of the correct usage of these chemicals to ensure effective control is another limitation.

In order to minimize yield losses associated with thrips damage in cowpea, a major component of long lasting and affordable control package would be genetic control via host plant resistance. In that, identification and deployment of natural host-plant resistance in elite cultivars to manage thrips minimizes or eradicates dependence on environmentally toxic chemicals that resource poor subsistence farmers cannot afford and are not well equipped to handle (Jackai and Adalla, 1997). Host-plant resistance can also be integrated with other control methods as a basis of integrated pest management. Results from independent field and screen house evaluations revealed the cowpea variety, Sanzi showing resistance to flower bud thrips (Omo-Ikerodah *et al*., 2009; Abudulai *et al.,* 2006; Alabi *et al.,* 2003). However, studies in other insects systems suggest that genetic resistance mechanisms may be highly specific to the insect species or even the developmental stages of the insect pest (Walling, 2000; Hilder and Boulter, 1999).

Better understanding the resistance mechanisms and mode of gene action determining inheritance of the different mechanisms of resistance can improve methods of screening and enhance development and identification of resistant or tolerant varieties. The individual value of different sources of resistance in a breeding programme cannot be assessed until the genetic relationships among them are better understood. This knowledge moreover, is useful in determining selection criteria, appropriate breeding methods for durable resistance and sustainable yield in cowpea. The study was therefore designed to achieve the following objectives:

(i) to validate the resistance status of the parental materials used for the experiment,

(ii) to elucidate the mode of inheritance of resistance to flower bud thrips (*Megalurothrips sjostedti*),

(iii) to determine the allelic relationship between the resistance sources.

CHAPTER TWO

LITERATURE REVIEW

2.1 IMPORTANCE OF COWPEA

Cowpea which is indigenous to south-eastern Africa, has spread world wide and is extensively cultivated and consumed in regions around the globe, including the tropical savannah zones of Africa (Cisse and Hall, 2010). It is an important source of quality nourishment to the urban and rural poor of West Africa who cannot afford meat and milk products (Omo-Ikerodah *et al.,* 2009; Kamara *et al.*, 2008). Cowpea is consumed as a dry grain, fresh shelled 'peas', fresh pods (snap beans) and fresh and dried leaves (Jackai and Daoust, 1986). The foliage and stems are also a good source of fodder for livestock (Ajeibe *et al.*, 2008; Tarawali *et al.,* 2007 and Abudulai *et al.,* 2006). It forms a major component of the tropical farming systems because of its ability to improve marginal lands through nitrogen fixation and as a cover crop (Abayomi, *et al*., 2008; Sanginga *et al*., 2003 and Carsky *et al.,* 2002). The crop can fix about 240 kg ha^{-1} of atmospheric nitrogen and make available about 60-70 kg ha^{-1} nitrogen for succeeding crops grown in rotation with it (Aikins and Afuakwa, 2008; CRI, 2006; Bakayoko *et al.,* 1998). The crop is also a source of income especially for women who prepare and sell several food products from the crop (Ishiyaku, 2001).

Although, indigenous to south-eastern Africa, cowpea has spread worldwide and is extensively cultivated and consumed in regions of Asia, south and central America, the Caribbean, the United States, the middle East and southern Europe (Cisse and Hall, 2010). Cowpea is a preferred staple food in many regions of Africa because of the fact that the leaves, immature pods, fresh seeds (southern peas) or "green pods" and dry grain can be eaten or marketed (Cisse and Hall, 2010). Cisse and Hall (2010) reported that, some cowpea varieties have short cycle and mature early, thus are able to provide food during the ‘hungry period’ when food can become extremely scarce in semi-arid regions of Sub-Sahara Africa. The dry grain is also commonly milled and consumed in numerous traditional main dishes of Africa as porridge and breads, fed to young children as weaning foods and as processed snack foods (Cisse and Hall, 2010). Cowpea grains also contain the following nutrients, 50-67 % starch, B vitamins such as folic acid which is important in preventing birth defects, amino acids (lysine and tryptophan), essential micronutrients such as iron, calcium and zinc (Cisse and Hall, 2010). From a perspective, cowpea is well suited to the agro-climatic–adaphic, technological and socio- economic situations in sub-Sahara Africa. The traits that distinguish cowpea from many other crops currently grown in Africa include (1) substantial adaptation to drought; (2) high potential to biologically fix atmospheric nitrogen in marginal soils with low organic matter (<0.2 %), high sand content (>85 %) and a broad range of pH (4.5-9.0), (3) tolerance to shade, (5) rapid vegetative growth and (6) tri-purpose utilization, producing vegetable leaves and pods, dry grain and foliage (Cisse and Hall, 2010). According to Islam *et al*. (2006), the adaptation to drought is especially important for the dry Sahelian and other Savannah zones of Western and Eastern Africa. Cowpea due to its high adaptability to drought-prone conditions, relative to other crops, is the crop of choice in these harsh environments.

2.2 COWPEA PRODUCTION

The total worldwide production of cowpea for 2010 is estimated at 5.5 million tones (FAO, 2012) of grain. Cowpea is grown in 45 countries across the world (Abate *et al*., 2012). An estimated 14.5 million ha of land is planted to cowpea each year worldwide (Abate *et al*., 2012). The South-Sahara Africa region accounts for about 84 % of area as well as production. The world average yield is estimated at about 450 kg per ha, the lowest for all tropical grain legumes (Abate *et al*., 2012). Cowpea productivity has not seen sustained growth over the last two decades (Abate *et al*., 2012). Total area, yield, and production in South-Sahara Africa grew at the rate of about 4.3 %, 1.5 %, and 5.8 %, respectively (Abate *et al*., 2012). An estimated 38 million households (194 million people) grow cowpea in South Sahara Africa. Nigeria and Niger each cultivate well over 4 million ha and account for more than 45 % and nearly 15 % of the world's total production, respectively. Other major producers include Burkina Faso, Cameroon, Mali, Uganda, Kenya, Senegal, Tanzania, and Democratic Republic of Congo (Abate *et al*., 2012). Cowpea production in South-Sahara Africa is projected to grow at the rate of 2.6 % per annum, which is from about 6.2 million MT in 2010 to nearly 8.4 million MT by 2020. The overall demand for cowpea grain in South-Sahara Africa is projected to grow at the rate of 2.7 % per year.

Cowpea occupies the largest proportion of land planted to tropical legumes (ca. 43 %) in South Sahara Africa, followed by groundnut (34 %), common bean (19 %), soybean (<5 %), pigeon pea (<2 %), and chickpea (<2 %) (Abate *et al*., 2012). But within Africa, average cowpea yields vary dramatically depending upon the varieties planted, the extent of inputs (fertilizer and pesticides), the cropping system (intercropping versus sole cropping) and the agro-climatic-adaphic conditions (CGIAR, 2001).

Improved cultivars, however, yield an average of 1,500 kg/ha when grown as sole crop with improved production practices (CRI, 2006). In Nigeria, the production trend of cowpea experienced about 441 % increase in area planted and 410 % increase in yield from 1961-1995 (Qrtiz, 1998). This impressive increase was due to significant advances made by the International Institute of Tropical Agriculture (IITA) (Inaizumi *et al*., 1999).

In Ghana, cowpea is one of the widely cultivated legumes, mainly in the savannah and transitional zones (CRI, 2006). In recent time, the yield of the crop in Ghana, is among the lowest in the world, averaging 310 kg/ha (Ofosu-Budu *et al*., 2007; IITA, 1993). Hence, efforts have been made to improve cowpea production in Ghana through various means including the introduction of new varieties and breeding of resistant varieties to various diseases and pests such as those used in this study.

2.3 BIOLOGY, TRANSMISSION AND ECONOMIC IMPORTANCE OF FLOWER BUD THRIPS

The life history of thrips involves an egg, two larval stages and the non-feeding stages of pre-pupa and pupa (Africa. ICIPE, 2010). The eggs are very tiny; a single egg is 0.25 mm long and 0.1 mm wide. They are white when freshly laid and turn pale yellow toward maturation (www.infonet-biovison.org, 2010). According to Tamo' *et al*. (1993a) flower bud thrips are involved in rapid breeding, with eggs laid on leaf petioles, peduncles, inflorescences and pods. Some flower thrips and leaf-feeding species insert their eggs into plant tissue by means of a serrated ovipositor (a specialized egg-laying structure). Salifu (1992) reported that the development of thrips from egg to adult takes about 19 days at 29 ^{0}C and 58 % RH and adult thrips live for about 23 days or less. The eggs laid are therefore not visible (Africa. ICIPE, 2010).

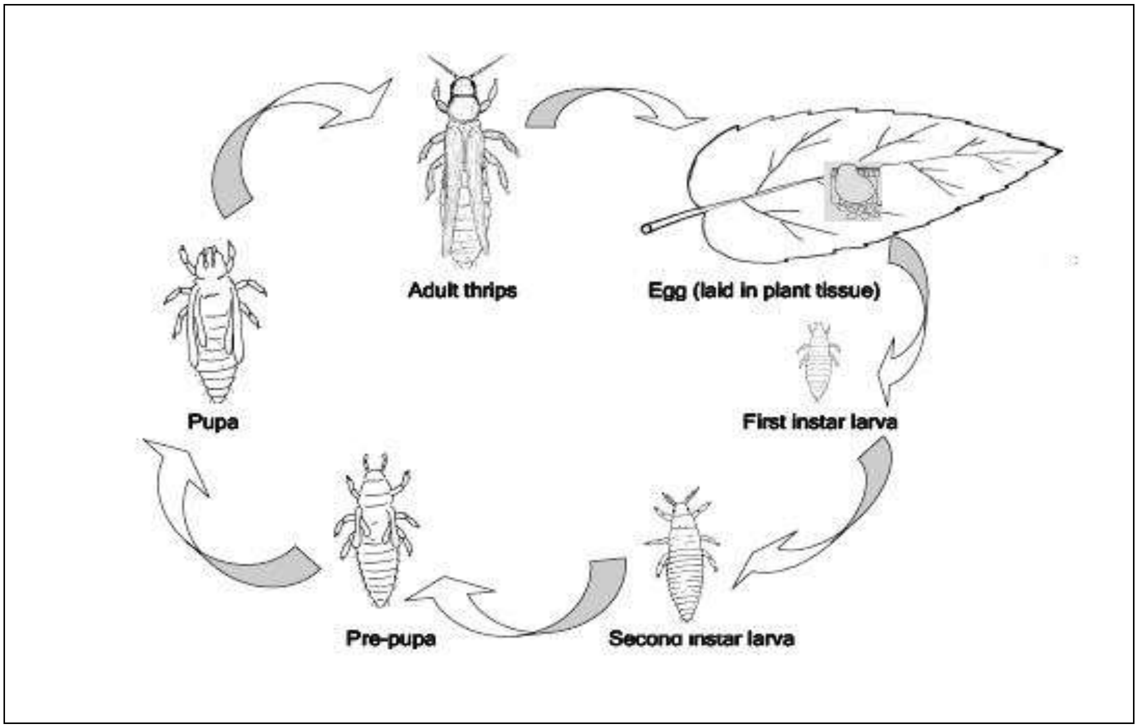

Figure 1. Life cycle of flower bud thrips (Africa. ICIPE, 2010)

Thrips are described as haploidiploid, thus males have half the number of chromosomes and the other half (haploid number) is found in females (Crespi, 1993). The males are developed from unfertilized eggs and are usually smaller than females. The first and second instar larvae are very small (0.5 to 1.2 mm), elongated, slender and vary in colour from pale-yellow, orange or red according to the species (Africa. ICIPE, 2010). They have piecing-sucking mouth part as miniature version of the adult but do not have wings (Africa. ICIPE, 2010). Pre-pupa and pupa instars are intermediate forms between the nymph and the adults. They have short wing buds with no functional wings. During these stages, thrips are inactive and so do not feed, therefore they do not cause any significant damage to the host. Pupation may occur on a plant or in the soil beneath, depending on species (Africa. ICIPE, 2010). Adult thrips are small usually 1.5 mm, slender and winged. The wings are long, narrow and fringed with long hairs and at rest, which are tied on the back along the body. Their colour varies in accordance with the species. Most species are black, brown or yellow, *Megalurothrips sjostedti* is black whilst *Frankliniella species* is yellow (Africa. ICIPE, 2010).

However, long-distance dispersal has been recorded for few species of thrips (Mound and Marullo, 1996) but this possibility occurs only under unusual circumstances as small organisms dehydrate rapidly and must drink plant fluids often to survive. Most species of flower thrips disperse over a series of short flight. The frequency and duration of flight varies with the species and gender which is influenced by the weather, the suitability of food and possibly by crowding (Mound and Marullo, 1996). Taylor (1969) reported that the infestation of cowpea plants to flower bud thrips begins just before flowering, with the peak activity occurring between noon and 1pm at a temperature of 23-24 ^{o}C. Both temperature and light intensity influenced flight, as observed by Taylor (1969).

The report of Ramachandran *et al*. (2001), showed that the eastern flower thrips (*Frankliniella tritici*) and the Florida flower thrips (*Frankliniella bispinosa*) are highly dispersing, moving rapidly between flowers. According to Ramachandran *et al*. (2001) adult of these species can rapidly recolonise a crop treated with an insecticide resulting in an ‘apparent’ rather than ‘real’ lack of control. Mass flights of flower thrips are typical following their rapid population build up on the abundant spring flowers (Ramachandran *et al*., 2001). According to Heming (1993) the feeding apparatus of thrips uniquely involved only one mandible and a stylet or tube through which food is drawn and also used to punch a hole in the plant surface for inserting the stylet.

There are about 5,000 described species of thrips (insects in the order *Thysanoptera*) (Mortiz *et al*., 2001; Mound, 1997). Most of these species feed on fungi and live in leaf litter or on dead wood. The species that feed on higher plants occur mostly in the family *Thripidae* (Moritz *et al*., 2001). This family includes the important pest species. Some flower thrips reproduce in flowers and feed on the cells of the flower tissue, on pollen grains and on small developing fruits (Mortiz *et al*., 2001). Many of the flower-living species are partly predatory on small insect whilst other species primarily feed on leaves. Tamoʽ *et al*. (1993b) reported that legumes are the main host of flower bud thrips (*Megalurothrips sjostedti*) which include *Vigna unguiculata* (cowpea), *Cajanus cajan* (pigeon pea), *Phaseolus vulgaris* (common beans). They also attack some other plants considered as minor host such as *Arachis hypogaea* (groundnut) and some wild host, whilst some other species feed on vegetables.

Tamoʽ *et al*. (1993b) reported that, flower bud thrips are found throughout Sub-Sahara Africa, from the high rainfall areas of the west to the semi-arid area of Kenya and Sudan. However, in Nigeria, it is associated with dry Savannah regions in which cowpea are produced (Tamoʽ *et al*., 1993b). According to Abudulai *et al.* (2006) flower bud trips infestation is found both in the southern and northern sectors of Ghana, causing significant effect on cowpea production.

Serious infestation causing loss of flowers resulting in complete loss of yield was reported by Childers and Achor (1995). Alghali (1992) found out that, in Nigeria, yield loss of cowpea was up to 75% when insects attacked during the flower bud formation and flowering stage. Omo-Ikerodah *et al*. (2009) also reported that flower bud thrips is a major pest of cowpea that caused considerable grain yield losses ranging from 20 to 80 % under severe infestation. Grain yield may be almost nil, according to (Singh and Allen, 1980).

A considerable damage is inflicted on food and fodder plants by occurrence of large population of thrips. Several insect pests attack the crops in the field but it is believed that the flower bud thrips is presently, the greatest biological constraint to cowpea production (Jackai and Daoust, 1986; Jackai *et al*., 1992). The species of thrips identified to cause the greatest damage in West Africa and other parts of the world, include the foliar-feeding *Frankliniella sp* which are mainly found on blossom or cotton bud (Bottenberg *et al*., 1997). It is also reported that *Frankliniella sp* are vectors of plant diseases such as tospoviruses in vegetables production (Gillot, 2005; Childers and Achor, 1989). *Thrips palmi* cause significant yield losses in vegetables in Asia and South America (Jackai and Adalla, 1997). In West Africa, the flower bud thrips, *Megalurothrips sjostedti* is the most economically important insect pest of cowpea causing yield losses between 20 and 70 % depending on the severity of infestation (Ngakou *et al.,* 2008).

The economic impact of foliar thrips on cowpea yield varies across the different parts of the world. Singh and Allen (1980) reported that damage caused by foliar thrips feeding at the seedlings stages resulted in yield losses up to 15 % in West Africa. More recently, damage by

T. tabaci has been reported to cause significant yield loss of cowpea in some parts of India (Muchero *et al*., 2009). Moreover, since leaves are a major source of nutrition in Eastern and Southern Africa (Saidi *et al*., 2007), damage caused by thrips feedings on the leaves of cowpea bring about significant reduction of market and aesthetic value of the crop. Cisse and Hall (2010) reported in Senegal that flower bud thrips have caused major losses to cowpea production in Eastern and Southern regions discouraging farmers from growing cowpea.

2.4 SYMPTOMS OF THRIPS INFESTATION IN HOST PLANT

The physiological disorder caused by the flower bud thrips (*Megalurothrips sjostedti*) begins at the terminal leaf bud stage of the cowpea plant and spreads to flower buds and subsequently leading to necrosis (Ezuah, 1981). More details of symptoms of flower bud thrips infestation on cowpea have been described by Omo-Ikerodah *et al*. (2009). The commonest symptoms observed on cowpea infestation by flower bud thrips in the field comprise a combination of varying intensities of browning of the stipules and flower buds, non-elongation of peduncles and flower bud abscission. Abudulai *et al.* (2006) also reported that, thrips attack terminal leaf buds, racemes or flower buds which result in browning, distortion and abscission of floral parts. On a severely infested plant, important symptoms include inflorescence distortion and discolouration, abortion, reduced pollen production and flower loss, leaves defoliation leading to death of the whole plant and drastic reduction in yield (Childers and Achor, 1995). However, Muchero *et al*. (2010) worked on QTL analysis for resistance to *Thrips tabacci* and *Frankliniella species* and reported that feeding by the thrips on susceptible plants caused the characteristics scaring along the mid-rib of affected leaves resulting in curled and distorted leaflets.

Similar to legumes, Varela *et al*. (2003) observed in vegetables that, the characteristics symptoms of attack are a silvery sheen of the attacked plant tissue, white patches coupled with streaks on leaves, fruits and pods. In addition, desiccation later spread on the affected tissue when damage is severe (Varela *et al.*, 2003). However, a small black spot of faecal material on the affected parts of the plant is symptomatic of even higher infestation (Varela *et al.*, 2003). According to Varela *et al*. (2003) damaged leaves may become papery and distorted, infested terminals lose their colour, roll, and drop leaves prematurely. Feeding on fruits leaves a roughened silvery texture on the skin.

2.5 CONTROL PRACTICES OF THRIPS INFESTATION

Several yield losses of cowpea in tropical Africa are caused by the interplay of abiotic and biotic constraints. Ranked first among the latter group, a wide array of pests can cause total yield failure in cases of severe attack (Jackai and Daoust, 1986). Thrips control has become paramount in cowpea production due to its devastating effect recorded from various parts of the world. These have necessitated the pragmatic approaches to managing flower bud thrips so as to guarantee increased and sustainable production of this vital crop. Grainge and Ahmed (1988), Jacobson (1989) and Schmutterer (1990) recommended plant extracts (aqueous or oil) for pest management worldwide. Oparaeke (2006) evaluated West African black pepper (*Piper guineense*) (WABP) extract for efficacy against flower bud thrips on cowpea flowers in two years. The results indicated that 20 and 10 % extracts of WABP at six and four weekly applications, respectively caused significant reduction of flower bud thrips in flowers and increased pod carrying capacity of the cowpea cultivar, Sampea 7. He noted that, the extract was not inferior to the synthetic insecticide treatment. This result was consistent with the reports of Ogunlana *et al*. (2002), Ekesi (2000), Tanzubil (1991) and Jackai and Oyediran (1991) who worked on different plant materials at various concentrations against different species of crop pests. In Nigeria, there is more literature on the application of naturally growing plants as insecticides for pest control on the field (Olaifa *et al.,* 1987). These include extracts of *Nicotiana tabacum* L., *Lonchocarpus species* (Matsumura, 1975), *Melia azaderach, Argemone medicinal* L. (Pandey *et al.,* 1981), *Chrysanthemum cinerariaefolium* L. (Stoll, 1986), *Azadirachta indica* (Jackai and Oyediran 1991; Jackai *et al.*, 1992; Olaifa and Adenuga, 1988; Tanzubil, 1991), *Syzigium aromaticum* (L) Merr and Perr (Oparaeke *et al*., 2002), *Allium sativum* L. *and Monodora myristica* (Gaertn) Dunal and many others have been reported to possess insecticidal properties against a number of insect species (Oparaeke *et al*., 2000). According to them, the effectiveness of the extract for thrips control has shown a great potential of a bio-pesticide due to the chemical constituents of WABP. Oparaeke *et al*. (2000) mentioned however that, botanical extracts are slow-acting mortality agents; therefore, frequent and adequate applications are required to protect flowers from thrips damage. Another drawback of WABP is that the pods of WABP are currently expensive in markets in Nigeria since a substantial quantity is imported from the Republic of Cameroon.

Intercropping has been reported to reduce thrips infestation. The effects are probably caused through shedding of the lower crop by the taller intercrop, which influences the abundance and activity of the thrips (Parella and Lewis, 1997). However, thrips reduction is not necessarily translated in yield increase. Parella and Lewis (1997) reported that populations of the onion thrips increased on potatoes when intercropped with shallot and garlic. They added that, intercropping onion and garlic with tomato reduced thrips infestations by almost 80 %. Similar results were reported in Kenya, were populations of the African bean flower thrips (*M. sjostedti* and *Hydatothrips adolfifriderici)* on cowpea buds were drastically reduced by intercropping cowpea with sorghum and maize (Parella and Lewis, 1997). In Eastern Uganda, Nampala *et al.* (2002) observed that thrips population were significantly reduced in cowpea and sorghum intercrops than the sole crop. However, a major limitation of intercropping is reduction in yield. According to Atokple (1992), yield of cowpea on average is high when grown as sole crop compared to cowpea grown in mixture with maize, sorghum or millet.

In search for sustainable control measures in thrips infested field Ezuah (1981) recommended biological control which aimed at presenting the available natural enemies to reduce thrips populations. In the literature concerning pest control in cowpea, the term biological control was usually used to indicate the naturally occurring interactions between pests and their antagonist (Ezuah, 1981; Singh *et al.*, 1990; Jackai and Daoust, 1986). Natural enemies in particular predators were often found feeding on thrips causing drastic reduction in thrips population in infested field (Varela *et al.*, 2003). These important predators include predatory mites (*Amblyseius spp*), anthocorid bugs or minute pirate bugs (*Ovius spp*), ground beetles, lace wings, hoverflies and spider. Ramachandran *et al.* (2001) reported that, natural enemies found to reduce flower bud thrips in vegetables include minute pirate bugs (true bugs of the order Hemiptera, family Anthocoride) and entomogenous nematodes that are specialized parasites of thrips (Loomans *et al*., 1997).

However, in 1992, an indigenous larva parasitoid of *Megalurothrips sjostedti* was recorded for the first time in Republic of Benin in the flowers of an exotic shrub, *Tephrosia candida* (Ezuah, 1981). The solitary endoparasitoid was tentatively identified as *Ceranisus menes* (Tamo' *el al*., 1993b). According to Tamo' *et al*. (1993b) further studies on *Megalurothrips sjostedti* larva collected from cowpea revealed very low parasitism rates. After having reared over 12,000 thrips larvae sampled from different ecological zones in Republic of Benin, caused a total parasitism rate of < 1%. They concluded that *Ceranisus menes* could not effectively recolonize cowpea as a host plant for *M. sjostidti*. Tamo *et al*. (1993b) observed that, parasitism rates recorded on naturally occurring alternative host plant which represent a much more stable ecosystem than the cowpea field indicated that *Ceranisus menes* was not an efficient natural enemy of *Megalurothrips sjostedti*. Abudulai *et al*. (2001) also reported that, important natural enemies of insect pests are highly susceptible to many of the insecticides for control of cowpea pests.

However, adoption of a broad range of strategies that include repeated applications of expensive insecticides has been recommended in many regions around the globe. Chemical control has been the principal recourse for control of insect pests on cowpea (Abudulai *et al*., 2006). According to Omo-Ikerodah *et al*. (2009) chemical control measures have been used and are the most widely known form of control of flower bud thrips in cowpea to obtain reasonable yield. Afun *et al*. (1991) reported that, a 10-fold increase in grain yield of cowpea has been demonstrated with the use of insecticides. To minimize losses, farmers in eastern Uganda regularly apply insecticide (Omongo *et al.,* 1997). According to Morse and Hoddle (2006) adoption of a broad range of strategies that include repeated applications of expensive insecticides has been recommended which shown reduction of about 80 % of flower bud thrips population in cowpea production. Tanzubil *et al.* (2008) also observed that, chemical control via the use of synthetic insecticides thus remains the most popular control tactic of managing flower bud thrips in cowpea production in Northern Ghana. But the chemical control technology is however seldom very effective and efficient among the largely peasant farming communities of Northern Ghana (Tanzubil *et al*., 2008). However, poor timing of spray application, inappropriate sprayer calibration and the use of sub-optimal doses of toxicants are common constraints to the realization of effective chemical control of cowpea insect pests on most farms (Tanzubil, 1991). Apart from these, insecticides and their applications equipments are generally beyond the economic means of the majority of resource-poor farmers who grow the crop (Tanzubil *et al*., 2008; Morse and Hoddle, 2006). In addition, frequent usage of insecticides could often lead to rapid development of insecticides resistance in thrips populations rendering the chemical treatments ineffective (Morse and Hoddle, 2006). Furthermore, there are health and environmental hazards associated with the use of insecticides (Abudulai *et al*., 2006). According to Omo-Ikerodah *et al*. (2009), economic realities and public sensitivity to environmental degradation have rendered expensive insecticides use unacceptable, unproductive and hazardous.

Therefore, concerted efforts are being made to develop varieties of cowpea that are resistant to insect pests to minimize the need for chemical use (Omo-Ikerodah *et al*., 2009). According to Tanzubil *et al*. (2008) one promising integrated approach to mitigate flower bud thrips infestation would be the use of host-plant resistance alongside reduced insecticide application. Although, there is evidence that low levels of resistance to flower bud thrips exists in some cowpea varieties, but the desired levels of resistance have not been identified or obtained among available cowpea landraces and improved varieties (Omo-Ikerodah *et al*., 2009).

The cultivation of varieties resistant to thrips is perhaps the most economical method of thrips control (Atokple, 1992). Good progress has been made in identifying sources of resistance to thrips (*Megalurothrips sjostedti*) in cowpea genotypes, Sanzi, ITH 98-45 and ITH 98-47 (Abudulai *et al*., 2006). In Nigeria, the cowpea genotype TVu 1509 was identified as possessing some level of resistance to thrips (Omo-Ikerodah *et al*., 2009; Singh, 1977). The cowpea variety, cowpea Sampea 8 has also been found to have some level of resistance to flower bud thrips (Ishiyaku, personal communication). In IITA, cowpea varieties such as IT90 K-277-2, KVx 404 8-1, Moussa Local, Sewe, TVu 1509, TVx 3236 and IT9I K-180 had been reported to show resistance against the cowpea flower bud thrips in West Africa (IITA,1994).

2.6 SOURCES OF RESISTANCE TO THRIPS SPECIES IN COWPEA

The importance of sources of resistance to stresses in breeding programme cannot be over emphasised. Although there is evidence that some levels of resistance to flower bud thrips exists in some cowpea varieties, the desired levels of resistance have not been identified or obtained among available cowpea landraces and improved varieties (Omo-Ikerodah *et al*., 2009).

Field screening of seventeen varieties at the Savannah Agricultural Research Institute (SARI), Nyankpala, Ghana in 2003 and 2004 indicated three varieties, Sanzi, ITH 98-45 and ITH 98-47 to be resistant to flower bud thrips (Abudulai *et al*., 2006). These varieties showed a lower yield loss and a fewer number of thrips population counted in their flowers compared to a greater yield loss and large number of thrips counted in flowers of the susceptible check variety, Vita 7. An independent screening at the Crop Research Institute at Fumesua, Ghana also confirmed Sanzi to be resistant to thrips (Abudulai *et al*., 2006). The cowpea genotypes, TVu 1509 had also been reported to show some level of resistance against the cowpea flower bud thrips in Nigeria (Omo-Ikerodah *et al*., 2009; Singh, 1977). In addition to these sources of resistance to flower bud thrips, a number of moderately resistant lines had been identified in IITA. These include improved breeding lines and landraces such as KVx 404 8-1, Moussa Local, Sewe, TVu 1509, TVx 3436, TVx 3236 and IT9IK-180 (IITA, 1994; Alabi *et al*., 2003). At Institute for Agricultural Research, Samaru, a released cowpea variety Sampea 8, had also been identified with some moderately low level of resistance to flower thrips (Ishiyaku, Personal communication). Genetic studies conducted in IITA, Nigeria under humic condition involving the resistant varieties, Sanzi and TVu 1509 had maintained their high levels of resistance (Omo-Ikerodah *et al*., 2009). Contrary to the findings of Alabi *et al*., (2003), the screening result by Abudulai *et al*., (2006) showed the cowpea genotype TVx 3236 to be susceptible to flower bud thrips at SARI, Ghana.

The search for additional sources of resistance identified two landraces, such as Omondaw and Bengsogla to have supported relatively fewer thrips and pod sucking bug populations, thus suffered significantly lower damage and produced better yields under no insecticide protection at Manga in the Sudan Savannah Zone of Ghana (Tanzubil *et al*., 2008).

Host plant resistance has been deployed successfully against other insect pests in other crops of economic importance via conventional breeding or genetic engineering (Hilder and Boulter, 1999; Christou *et al*., 2006). Germplasm with other thrips species genes for elite cultivar development had been identified in different crops. For instance, resistance varieties have been described in cotton (Stanton *et al*., 1992), common bean (Cardona *et al*., 2002), Pepper (Maris *et al.*, 2003) and cabbage (Stoner *et al*., 1989).

2.7 INDICES OF THRIPS RESISTANCE IN HOST PLANT

A combination of the knowledge of greenhouse and field techniques for thrips infestation provides most effective results in evaluating resistance. Measurements of resistance and the criteria for its selection can become complicated by the existence of different mechanism of resistance.

In cowpea, flower bud thrips count per flower or raceme with per cent of plant infested has been used in selecting and confirmation of resistant cowpea varieties in the field (Abudulai *et al*., 2006 and Ta'ama *et al,* 1981). Based on the thrips populations counted in each sampled flowers, a scale of 1-5 was developed in assessing the resistance and susceptibility in the field (Ta'ama *et al,* 1981).

1 = 0 – 10 % damage
2 = 11 – 20 % damage
3 = 21 – 30 % damage
4 = 31 – 40 % damage
5 = 41 – 100 % damage

They observed that the more the number of thrips found in a flower the higher the damage caused to the host plant and more susceptible the plant. In addition, visual ratings for flower bud thrips damage on cowpea plants recorded on five consecutive plants based on the scale 1-5 was used to successfully describe resistant and susceptible cowpea cultivars (Abudulai *et al.*, 2006).

Omo–Ikerodah *et al.* (2009) rated flower bud thrips damage based on the scale of 1–9, using the susceptible material as a check. Rating was however based on a combination of varying intensities of browning of the stipules and flower buds, non–elongation of peduncles and flower bud abscission as described by Jackai and Singh (1988).

1 = very low susceptibility
2 = very low to low susceptibility
3 = low susceptibility
4 = low to intermediate susceptibility
5 = intermediate susceptibility
6 = intermediate to high susceptibility
7 = high susceptibility
8 = high to very high susceptibility
9 = very high susceptibility

The above scale was successfully used to classify cowpea genotypes as resistant, moderately resistant and susceptible in the field (Omo-Ikerodah *et al.*, 2009).

In different species of thrips (*Thrips tabaci and Franklinella schultzei*) the most commonly used selection criterion is the phenotypic symptoms of damage, scarring along the mid-rib and leaf deformation in response to foliar feeding by a complex thrips. The phenotypic symptoms, scarring was described using a scale of 1- 10 by Cardona *et al*. (2002). Feeding by these thrips on susceptible plants caused the characteristics scarring along the mid-rib of affected leaves resulting in curled and distorted leaflets.

1 = No scarring
2 = Mild scarring on most leaves or definite scarring few lower leaves
4 = Definite scarring on 20 – 50 % of the leaves
6 = Definite scarring on 50 – 75 % of the leaves
8 = Definite scarring on 75 – 100 % of the leaves
10 = Definite scarring on 75 – 100 % of the leaves followed by completely curled and distorted leaflets.

Although, the intensity of the external symptoms was generally related to the number of successful foliar thrips infestation in cowpea susceptible genotypes, the symptoms expression could be related to environmental conditions. Nevertheless, damage ratings were taken on 5-week–old cowpea plants using the rating scale 1-10 to classify cowpea recombinant inbred population derived from a cross between susceptible cowpea genotypes and resistant genotypes into resistance and susceptible groups (Muchero *et al.*, 2009).

2.8 MECHANISMS OF HOST RESPONSES TO THRIPS INFESTATIONS

The defense mechanisms of host plants against their potential insect pests may be due to either avoidance or resistance. Avoidance reduces the opportunity of contact between the prospective host tissue and the pest, whereas resistance operates when host tissue and the pest come into contact (Atokple, 1992).

Early maturity or tolerance of conditions which adversely affect pest development such as extremes of temperature or humidity are examples of avoidance mechanisms. They are genetically determined and may be very useful in breeding for disease and pest control (Atokple, 1992). However, the influence of host plant resistance on various thrips species have been studied (De Jagar *et al*., 1995; Mollema *et al*., 1995 and Stoner and Shelton, 1988). The mechanism of cowpea resistance to *Megalurothrips sjostedti* as a matter of fact, received little attention therefore further detailed studies on different varieties of cowpea are required. According to Ekesi (2000) host-plant resistance is often the result of a combination of resistance categories. Salifu *et al*. (1980a, b) in their studies of mechanism of resistance in cowpea genotype TVx 3236 to flower bud thrips reported that resistance was due to antibiotic and antixenotic mechanisms.

Antibiosis has been used to describe resistance to successful establishment of the prospective pest flower bud thrips (Ekesi *et al*., 2000). Differences in total developmental times were, therefore, due to prolonged developmental period of larva II on the resistant varieties (Ekesi *et al*., 2000). Salifu *et al*. (1988 b) and Soria and Mollema (1995) have reported similar observation on *Megalurothrips sjostedti* and *Frankliniella occidentals* (Pergande) when reared on resistant lines of cowpea and cucumber, respectively. Prolonged developmental period on resistant varieties could be due to reduce food intake due to toxins, malnutrition or deterrents (Bakkar, 1961). These factors adversely affect thrips larva stages as reported by Trichilo and Leigh (1988). Extension of immature period could reduce the number of generations, increasing the effects of predation, parasitism and disease (Painter, 1951). Soria and Mollema (1995) suggested that exposure of female thrips to toxins, deterrents or antifeedants on resistant cultivars may reduce food intake and subsequently affect egg production. Moreover, poor oviposition as a result of inadequate nutrition was also well established for thrips (Kirk, 1995; Murai and Ishii, 1982 and Laughline, 1971).

Expression of antixenosis through host plant odour has also been reported for many insects. Rymal *et al*. (1981) observed that, extracts from different cultivars of cowpea had been shown to either attract or repel cowpea curcuilio in an alfactometer. The resistance of IT84S-2246 appeared to be antixenotic (Ekesi *et al*., 2000); the lack of statistically significant difference in developmental period between this variety and the susceptible variety showed that antixenosion rather than antibiosis is involved in the resistance. The high ‘repellency’ observed by Ekesi *et al*. (2000) in the laboratory test with flowers of IT84S-2246 and in the alfactometer provided additional evidence of antixenosion in the variety.

According to Ejeta *et al*. (1991) tolerance is operative when the host plant supports as many pests as susceptible varieties without showing a concomitant reduction in grain yield or overall plant productivity. In order words, it is the ability of the host plant to grow and reproduce normally in spite of supporting thrips infestation equal or more than that required to damage a susceptible host. In contrast, Robinson and Dowler (1966) observed that a host plant that is able to restrict the infestation of insect pest attack is resistant variety. Resistance levels vary from low to almost total immunity. Further studies should concentrate on identification of factors which affect development and behaviour of the pest in these varieties. This will provide valuable and dependable information for the development of varieties of cowpea resistant to *Megalurothrips sjostedti.*

2.9 GENETICS OF RESISTANCE TO FLOWER BUD THRIPS

There are not many reports on the genetic nature of resistance in different crops attacked by flower bud thrips (*Megalurothrips sjostedti*). Little information is available on the mode of gene action conditioning resistance in cowpea to flower bud thrips. In Nigeria, IITA, 1994; Omo–Ikerodah *et al.,* (2009) working on genetic analysis of resistance to flower bud thrips in cowpea in the field reported that maternal effect was implicated while frequency distributions of the F_2 and backcross generations suggest quantitative inheritance. The studies from the crosses involving cowpea varieties, Sanzi and TVu 1509 (resistant) and two susceptible varieties, Ife brown and VITA 7 using complete dialel, indicated more than one mode of gene action. They reported that dominance gene effect was highly significant for the crosses between Sanzi and TVu 1509. Results also showed that, though, the mean damage ratings of the two resistant parents were different, coupled with the highly significant dominance towards the better of the two parents, Sanzi, further showed that some of the genes in the two parents are non-allelic. The six parameters estimated for the various gene effects showed that both additive and dominance gene effects, contributed significantly to the inheritance of the traits studied. However, dominance gene effects were larger than the additive gene effects in the two resistance parents (Omo-Ikerodah *et al.*, 2009). According to them, additive x additive and dominance x dominance gene effects made major contributions to resistance to flower bud thrips. In addition, the occurrence of reciprocal differences between the F_1 means indicated the presence of cytoplasmic factors Omo-Ikerodah *et al.* 2009, Fatunla and Badaru, 1983, Rusoke and Fatunla 1987; Sigh and Hadley, 1972.

CHAPTER THREE

MATERIALS AND METHODS

3.1 EXPERIMENTAL SITES

The development of genetic populations was carried out in the screen house at Institute for Agricultural Research (IAR) Samaru, Ahmadu Bello University, Zaria in Nigeria. The field trial was conducted at Savannah Agricultural Research Institute (SARI), Nyankpala in the Northern Region of Ghana. Samaru is located on (11^0 11′ N: 7^0 38′ E) at altitude 686 m above sea level. The average annual rainfall of Samaru is about 1128.5 mm. The mean annual temperature is about 33.92 ^oC. The relative humidity varies greatly, falling during the dry season and rising during the rainy season with average figure of 53.33 %. Nyankpala is located on (9^o 25′ 41′ N: O^o 58′ 42′W) at altitude 183 m above sea level. The average annual rainfall of the area is about 1000 mm. The temperature distribution is fairly uniform with a mean annual temperature of 28.3 ^oC. The relative humidity varies greatly, falling during the dry season and rising during the rainy season with an annual relative humidity of 54 %.

3.2 EXPERIMENTAL MATERIALS

The experimental materials used in the study included cowpea genotypes: Sanzi, Sampea 8 (IT93K-452-1), Sampea 7 (IAR-48), Ife Brown and Padi-tuya (SARC 3-122-2). The origin, pedigree descriptions and reactions to *Megalurothrips sjostedti* of these materials are presented in Table 3.1.

Table 3.1 The Pedigree and description of the parental materials used in the experiment

Genotype	**Pedigree**	**Descriptions**
Sanzi	Unknown	Sanzi has prostrate plant type with indeterminate and twining tendency growth habit. The variety is photoperiod insensitive. It is extra-early (60 to 65 days) in maturity. The matured pods measure between 5 to 6 cm in length and average number of pods per plant is between 18 and 20. A pod contains between 15 and 18 seeds. The seeds are rather small, creamy in colour with smooth testa. Sanzi is resistant to flower bud thrips (*Megalurothrips sjostedti*) Omo-Ikerodah *et al*. (2009) and Abudulai *et al*. (2006).
Sampea 8 IT93K-452-1	(IT860-782 x IT90-76) F_6	Sampea 8 has semi-erect plant type with semi-determinate growth habit. The variety is not sensitive to photoperiod. The variety is extra-early (60 to 65 days) in maturity. The pods measure between 6 and 7 cm in length with average of 10 to 15 pods per plant. The pods do not shatter and contain between 12 and 16 seeds. The grain contains 23- 25 % protein. Sampea 8 is resistant to pod scattering and weathering, diseases such as anthracnose and Cercospora leaf spot. It is also resistant to insect pests like aphids and moderately resistant to flower bud thrips (Ishiyaku, personal communication).

Table 3.1 Continued

Genotype	**Pedigree**	**Descriptions**
Ife Brown	Unknown	This variety is semi-erect type with indeterminate growth habit. It is photoperiod insensitive with medium maturity (70 to 75 days). Matured pod measures between 6-7 cm in length and an average number of pods per plant is between 12 to 18. The pods contain between 14 to 20 seeds, medium size with brown and rough seed coat. The variety is susceptible to several insect pests and diseases which attack the leaves, stems and pods in the field and dry seeds in storage. It is susceptible to flower thrips Omo-Ikerodah *et al*. (2009).
Sampea 7 IAR-48	Ife Brown x Yalla	Sampea 7 was developed at IAR, Samaru. The variety is medium (70 to 80 days) in maturity. Matured pod measures between 5 and 6 cm in length. The average number of pods per plant is between 12 and 16. The seeds are large, light brown to dark brown colour with rough seed coat texture. The plant architecture is semi-upright growth habit. The variety is susceptible to insect pests such as thrips (Alabi *et al*., 2003), maruca pod borer, pod sucking bugs and bruchids.
Padi-tuya SARC 3-122-2	Unknown	Padi-tuya has erect plant type with few vines growth habit. The variety has (64 - 67 days) to maturity. Matured pod measures 9 to 10 cm in length with average number of pods per plant between 10 to12. A pod contains 10-12 seeds. The seeds are white, large size with round to kidney shape with black helium. The variety is moderately resistant to aphids but susceptible to flower bud thrips (Atokple, personal communication)

3.3 DEVELOPMENT OF GENETIC POPULATIONS AND CROSSES

In order to study cowpea resistance to *Megalurothrips sjostedti* three flower bud thrips-susceptible (Ife brown, Sampea 7, Padi-tuya) and two flower bud thrips-resistant genotypes (Sanzi and Sampea 8) were crossed following the hybridisation procedure, using bi-parental mating design 1:1 procedure to generate six sets of F_1 populations. The F_1 populations were advanced to F_2 and at the same time backcrossed to their respective parents to produce BCP_1 and BCP_2 populations, respectively. For each cross, six generations, P_1, P_2, F_1, F_2, BCP_1, and BCP_2, were produced in the screen house. Sufficient parental, F_1, F_2, and the backcrosses seeds were produced using sequential plantings from March to September, 2010 in the screen house at the IAR, Ahmadu Bello University, Nigeria.

Emasculation procedure involved grasping the bud selected for the emasculation firmly but gently to avoid any stress at the fragile attachment of the bud and raceme. A cut was made two-thirds the width of the unopened bud in the centre of the bud starting from its straight edge, opposite the hooked edge enclosing the style and stamens with forceps. The upper portion of the folded petals was grasped by the thumb and index finger and gently tore off at the cut segment to expose the style (stigma and stamens). The ten immature anther sacs were then removed with forceps, leaving the stigma. The emasculation was carried out in the evening, between 5-6.00 pm local time.

Pollination: The emasculated flowers were crossed or pollinated immediately after emasculation. The pollination procedure involved the removal of the mature flowers of the male parent. Slip downwards the innermost petals of the mature opened flower. The mass of pollen on the hairy-necked style was then used as a brush to deposit pollen grains on and immediately under the green circular disc-shaped stigma. One flower was used to pollinate 4 to 5 emasculated flower buds. This pollination procedure was carried out when there are few mature flowers from the male plant. If more flowers were available for pollination, one flower was used to pollinate one emasculated flower bud by capping, which recorded higher percentage success of nicking. A small tag listing the cross and the date was affixed to the raceme or the peduncle beneath the pollinated bud. Unfertilised flowers dropped off 24 hours after anthesis, while fertilised ovary remained attached and developed into pods and seeds. At maturity, the pods were harvested into clearly labelled paper bag and subsequently, hand threshed and seeds were collected into another clearly labelled paper bag. F_1 seeds from each of the bi-parental crosses were divided into two parts; one part was sown in 12 pots made up of 2 pots per cross. The 12 pots of the F_1 were further divided into two groups each group was made up of a complete set of the F_1 cross. Each of the F_1 in the two groups was backcrossed to the respective parents to generate BCP_1 and BCP_2 populations, following the same emasculation and pollination procedures. The F_2 Generation: The F_2 population for each of the six different crosses was obtained by allowing its corresponding F_1 plants (group two) to self fertilised. The F_2 populations were developed along with the backcrosses in the screen house at IAR, Samaru.

Based on the reactions of the parents to flower bud thrips, the following pairs of crosses were grouped for determination of mode of inheritance of resistance to thrips and allelic relationships of resistance genes against flower bud thrips.

A, Mode of Inheritance of Thrips Resistance

(i)	Sanzi x Ife Brown	(R x S)
(ii)	Sanzi x Sampea 7	(R x S)
(iii)	Sampea 8 x Padi-tuya	(R x S)

B, Allelic Test for Thrips Resistance

(i)	Sanzi	x	Sampea 8	(R x R)
(ii)	Sampea 8	x	Sanzi	(R x R)
(iii)	Ife brown	x	Padi-tuya	(S x S)

3.4 FIELD SCREENING

3.4.1 Resistance of Cowpea Parental Materials to Flower Bud Thrips (FTh)

The five cowpea parental materials: Ife brown, Sampea 7, Sanzi, Sampea 8 and Padi-tuya were planted in a randomized complete block design with three replications in the experimental field at SARI, in October, 2010 when natural infestation of flower bud thrips was high. Each genotype was planted on a 3-row plot. Each row was 3m long with inter row spacing of 0.60m and intra-row spacing of 0.20m within a row, with one plant per hill. Plant growth was boosted by the application of NPK 15:15:15 at the rate of 2 g per plant at three weeks after sowing. Hand weeding was carried out at the initial stage, and hoeing at 4 and 7 weeks, respectively. The experiment was given protection by spraying with the insecticide λ-cyhalothrin (as Karate 2.5 EC) applied at the rate 2.5 g (a.i.) ha^{-1} using a CP-15 knapsack sprayer at 50 % podding (50-55 days after sowing (DAS)) against pod sucking bugs (PSBs) to eliminate their confounding effects. At maturity, all plants were harvested, hand threshed and the seeds were put into a clearly labelled paper bags. The following data were collected:

Number of days to 50 % flowering: number of days after seedlings emergence taken by half of the total plant population in a plot to flower.

Number of days to 50 % maturity: number of days after seedlings emergence taken by half of the total plant population in a plot to reach physiological maturity.

Number of pods per plant: the number of dried pods harvested from each plant.

Number of peduncles per plant: the number of peduncles was counted on each plant.

Number of seeds per plant: at maturity, pods from each plant were harvested, hand-threshed and seeds were counted. Harvesting was done twice.

Dried pod weight (g): harvested pods from each plant were weighed after sun drying using electronic scale balance in the laboratory.

Grain weight per plant (g): at maturity, pods from all plants were harvested, hand-threshed and seeds were weighed using electronic scale balance in the laboratory.

Thrips damage rating: The test materials were rated for damage on a scale of 1-9 at about 36 days after planting and subsequently at weekly intervals until pods were formed (Jackai and Singh, 1988). Where 1-3 = resistant, 4-6 = moderately resistant and 7-9 = susceptible. Rating was based on a combination of varying intensities of browning of the stipules and flower buds, non-elongation of peduncles and flower bud abscission.

Number of thrips per plant was measured:

Populations of flower bud thrips (FTh) were estimated by randomly picking 5 flowers per plant for all generations, depending on the stage of growth. The samples were taken early in the morning, between 7–9.00 am local time during the peak of flowering, thus about 40 days after sowing and the subsequent two weeks. The flowers were placed in glass vials or petri-dish containing 40 % ethanol and subsequently dissected to count number of thrips (Abudulai *et al*., 2006). The infestation was assessed twice during the crop phenology.

3.4.2. Resistance of Cowpea Genetic Populations to Flower Bud Thrips (FTh)

In order to study the mode of inheritance of resistance to FTh in cowpea, all the populations (F_1, F_2, BCP_1 and BCP_2) generated with their respective parents: P_1 and P_2 were planted in the experimental field at SARI on 14 October, 2010 when natural infestation of flower bud thrips was high. All genetic populations were grown in a randomized complete block design with three replications. Each replication contained two rows of each of the parents and $F_{1,}$ three rows of each backcross and four rows of each F_2 generations. Each row was 2.5 m long with 0.60 m between rows and intra-row distance of 0.20 m with one plant per hill, thus accommodating 9 plants per row. 60 plant each per non-segregating populations (P_1, P_2 and F_1), backcross, 90 plants each and 105 plants for each of the F_2 populations.

3.4.3 Data Collection

Flower bud thrips damage rating was recorded on all plants on a scale of 1-9 as described earlier.

Number of flower bud thrips per plant was estimated as described earlier.

Number of Pods per plant: number of dried pods harvested from each plant was counted.

Number of peduncles per plant: the number of peduncles was counted from each plant.

Number of pods per peduncle = (Number of pods per plant, divided by number of peduncles per plant)

3.4.4. Screening of Cowpea for Resistance to Flower Bud Thrips

To ensure high populations of thrips, the cowpea genotypes were planted in a plot located near an established field of pigeon pea and cowpea, which was served as sources of inoculum of thrips at the research field of SARI. Spreader row of susceptible genotype, Ife Brown was also planted around the plot and between the rows two weeks prior to planting of the test materials. Thirty-five days after planting, the spreader row plants were uprooted and laid down between rows of test materials. The test materials were rated for damage on a scale 1-9 at 35 days after planting as described by Jackai and Singh, (1988). Rating was based on a combination of varying intensities of browning of the stipules and flower buds, non-elongation of peduncles and flower bud abscission. The plants were sprayed at 50 % podding {50-55 days after sowing (DAS) } against pod sucking bugs (PSBs) to eliminate their confounding effects in identifying thrips resistant genotypes. All insecticide protection was accomplished using λ-cyhalothrin (as Karate 2.5 EC) applied at the rate 2.5 g (a.i.) ha^{-1} using a CP-15 knapsack sprayer.

3.4.5. Test of Allelism

In order to study the allelic relationship between the resistance and susceptible sources, the two cowpea resistant genotypes: Sampea 8 and Sanzi were reciprocally crossed as well as two susceptible genotypes: Ife Brown and Padi-tuya to generate genetic populations in the screen house at IAR, Ahmadu Bello University, Zaria in March to September, 2010. The F_1 plants obtained were grown, advanced to F_2 and at the same time backcrossed to their respective parents to generate BCP_1 and BCP_2. All the genetic populations generated with their respective parents were grown in the field at SARI under natural infestation of flower bud thrips.

3.5. STATISTICAL ANALYSES

3.5.1. Validation of Resistance Status of Parental Materials

The data pertaining to FTh resistance, number of FTh per plant, thrips damage rating, number of pods per peduncle and some agronomic traits such as days to 50 % flowering, days to 50 % maturity, number of pods per plant and number of seeds per plant were subjected to analysis of variance using the general linear model (GLM) procedure of the Statistical analysis System (SAS) programme. Duncan Multiple Range Test was used to separate the means where there was significant difference.

3.5.2. Mode of Inheritance of Resistance to FTh

The data collected on the different genetic populations were subjected to:

3.5.2.1 Paired t-test Analysis

To determine the possible maternal effects by comparing the reciprocals in the respective F_1 hybrids involving Sampea 8 x Sanzi verses Sanzi x Sampea 8, paired t-test analysis was carried out on some key parameters such as number of FTh per plant, thrips damage rating and number of pods per peduncle, using the formula by (Little and Hill, 1978)

$$t = \frac{\overline{x}_1 - \overline{x}_2}{SE}$$

T= paired t-test, $\overline{x_1}$ = mean of population 1, $\overline{x_2}$ = mean of population 2, SE= standard error

3.5.3 Generation Mean Analysis (GMA)

To estimate mode of gene interaction, the generation mean analysis (GMA) was used to measure genetic parameters following the procedure described by Kang (1994). Generation mean was calculated for six generations on an individual plant basis. To determine the mode of inheritance of resistance to flower bud thrips, Gamble's (1962) notation was used as:

$Y = m + \alpha a + \beta d + \alpha 2aa + 2\alpha\beta ad + \beta 2dd.$

Where Y, the observed generation mean; m, mean; a = additive gene effects; d, dominance gene effects; aa, additive x additive epistatic gene effects; ad, additive x dominance epistatic gene effects; dd, dominance x dominance epistatic gene effects. α and β represent the coefficients for the genetic effects for the particular generation being estimated (Hayman, 1958; Mather and Jinks, 1982).

3.5.3.1 Chi-square Test

A chi-square test was conducted to test the goodness of fit of the data to the additive dominance model by (Little and Hill, 1978)

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

O = Observed value, E = Expected value and $\sum$ = summation

The model described by Cavalli (1952) was used to estimate the expected values

$$\overline{P}_1 = m - a$$

$$\overline{P_2} = m + a$$

$$\overline{F_1} = m + d$$

$$\overline{F_2} = m + \tfrac{1}{2}(d)$$

$$\overline{BCP_1} = m - \left(\tfrac{1}{2}\right)a + \left(\tfrac{1}{2}\right)d$$

$$\overline{BCP_2} = m + \left(\tfrac{1}{2}\right)a + \left(\tfrac{1}{2}\right)d$$

Where; m = mean

a = value of additive gene effects

d = value of dominance gene effects

3.5.4 Number of Effective Factors

The following formula proposed by Lawrence and Frey (1976) was used to estimate the minimum number of effective factors (N).

$$N = R^2 / 8(\sigma^2{}_g)$$

Where R is range of F_2 segregates in the cross.

$\sigma^2{}_g$ = genetic variance of the F_2 population of a cross.

3.5.5 Heritability

Broad sense and narrow sense heritability estimates were obtained using the variance component methods. The F_2 variances were used to compute the broad sense heritability according to Mahmud and Kramer (1951) as given below:

$$H_{(B)} = \frac{\sigma^2 F_2 - \sqrt{\sigma^2 P_1 x \sigma^2 P_2}}{\sigma^2 F_2} x100$$

Where $\sigma^2 F_2 = \sigma^2 G + \sigma^2 E$, $\sigma^2 P = \sigma^2 E$, $\sigma^2 P_1 = \sigma^2 E_1$, $\sigma^2 P_2 = \sigma^2 E_2$

In these relationships

$H_{(B)}$ = broad sense heritability

$\sigma^2 F_2 =$ phenotypic variance of F_2 population of a cross

$\sigma^2 G =$ genetic variance of the F_2 population of a cross

σ^2E = environmental variance of F_2 population of a cross

The narrow sense heritability estimates were computed using the formulae described by Warner (1952).

$$H_{(N)} = \frac{2\sigma^2 F_2 - (\sigma^2 B_1 + \sigma^2 B_2)}{\sigma^2 F_2}$$

Where $H_{(N)}$ = narrow sense heritability

$$\sigma^2 F_2 = \tfrac{1}{2} A + \tfrac{1}{4} D + E$$

$$\sigma^2 B_1 + \sigma^2 B_2 = \tfrac{1}{2} A + \tfrac{1}{2} D + E$$

$$2\sigma^2F_2 - \sigma^2B_1 - \sigma^2B_2 = A + \tfrac{1}{2}D + 2E - (\tfrac{1}{2}A + \tfrac{1}{2}D + 2E) = \tfrac{1}{2}A$$

A = additive variance

D = dominance variance

E = environmental variance

B_1 = backcross to parent P_1

B_2 = backcross to parent P_2

F_2 = second filial generation

Assumptions are:

(i) independence of genotypic and environmental variances

(ii) additivity of genetic effects over the various loci.

(iii) the F_2 and the two backcross variances are of comparable magnitude.

3.5.6 Genetic Advance (GA)

Genetic Advance (GA) was calculated in accordance with the method illustrated by Allard (1960) as: GA or $G_s = K * \sigma^2_A * h^2_{(n)}$

Where, K is the standardized selection differential, at 10 % selection intensity, K = 1.755

σ^2_A is additive variance and h^2 is narrow sense heritability estimate

3.5.7 Correlation

Genotypic and phenotypic correlation were used to investigate the association between flower bud thrips damage rating and number of thrips per plant and other agronomic characters measured in the parental genotypes and their progenies. Correlation coefficients were calculated from component of variance and covariance according to Shivaji and Gritton (1975). The genotypic components were computed by equating the genotypic variances and covariance to the expected mean square and cross products, and hence genotypic correlations were computed by the formula:

$$rg = \frac{\text{cov}_{g12}}{\sqrt{(\sigma^2{}_{g1})(\sigma^2{}_{g2})}}$$ Where

$rg =$ genotypic correlation coefficient

$\text{cov}_{g1.2} =$ the estimates of the genotypic covariance for traits 1 and 2

$\sigma^2{}_{g1} =$ estimate of the genotypic variance of trait 1

$\sigma^2{}_{\text{g2}}$ = estimate of the genotypic variance of 2.

Phenotypic correlation was computed using the following formula:

$$rp = \frac{Cov_{ph1}}{\sqrt{(\sigma^3{}_{ph1})(\sigma^2{}_{ph_2})}}$$ where:

$rp =$ phenotypic correlation coefficient

$\text{cov}_{ph1.2} =$ estimate of the phenotypic covariance for traits 1 and 2

$\sigma^2{}_{ph1}$ =estimate of the phenotypic variance for trait 1, $\sigma^2{}_{ph2}$ = estimate of phenotypic variance for trait 2.

CHAPTER FOUR

RESULTS

4.1 VALIDATION OF RESISTANCE STATUS OF PARENTAL MATERIALS EVALUATED UNDER NATURAL THRIPS INFESTATION IN THE FIELD AT SARI, NYANKPALA, 2010

The result of the validation of resistance of the parental materials used in this study is presented in Table 4.1 and 4.2. The result shows the performance of the parental materials in the traits measured: The mean number of days to 50 % flowering, 50 % maturity and average number of pods produced per plant under flower bud thrips natural infestation (Table 4.1). The mean number of pods produced per plant showed highly significant differences ($P > 0.01$) among the parental materials. The average number of pods per plant ranged from the lowest value, 3.41 to the highest value, 8.35 for Ife Brown and Sanzi, respectively. The average number of pods produced per plant was drastically reduced by flower bud thrips infestation in cowpea genotypes, Ife Brown, Sampea 7 and Padi-tuya while considerable number of pods was sustained in the parental genotypes Sampea 8 and Sanzi (Table 4.2). These values did however take into consideration the eliminating of confounding effects of other cowpea insect pests. Though there were no significant differences among the parental materials with regards to days to 50 % flowering, the materials showed significant differences with regards to days to 50 % maturity Table 4.1.

The result of the average number of seeds per plant, pods per peduncle per plant, number of flower bud thrips (FTh) per plant and the thrips damage rating are presented in Table 4.2. The parental genotype, Sampea 7 had a mean of 8.30 FTh per plant, the parental genotype, Sanzi and Sampea 8 had mean of 3.43 and 5.80 FTh per plant, respectively (Table 4.2). The parental genotype, Ife Brown had a mean of 7.67 thrips damage rating, Sampea 7 and Padi-tuya had mean of 7.70 and 7.66 thrips damage rating respectively, Table 4.2. While Sanzi and Sampea 8 had mean of 3.00 and 5.00 thrips damage rating, respectively. The parental genotypes, Ife brown, Sampea 7 and Padi-tuya had mean of 0.51, 0.58 and 0.59 pods per peduncle per plant, respectively, while Sanzi and Sampea 8 had mean of 0.85 and 0.75 pods per peduncle. The parental genotypes, Ife Brown, Sampea 7 and Padi-tuya; susceptible genotypes had mean of 12.12, 11.92 and 11.89 number of seeds per plant while Sanzi and Sampea 8, resistant genotypes had mean of 21.78 and 17.80 number of seeds per plant Table 4.2.

Table 4.1 Mean number of days to 50 % flowering, days to 50 % maturity and average number of pods per plant of the parental materials evaluated under natural infestation of thrips in the field at SARI, Nyankpala, 2010

Genotype	Days to 50 %* Flowering	Days to 50 %* Maturity	Number of Pods* per Plant
Ife brown	42.33	71.33^{b}	3.41^{c}
Sampea 7	42.47	72.64^{a}	3.57^{c}
Sanzi	41. 33	61.67^{d}	8.35^{a}
Sampea 8	41.33	62.23^{d}	5.60^{b}
Padi-tuya	42.33	67.00^{c}	3.61^{c}
Grand Mean	42.2	67.2	4.91
C.V (%)	1.53	0.99	9.35
S. E±	0.28	0.42	0.22

* Means with the same alphabet in a column are not significantly different according to Duncan multiple range text (DMRT).

Table 4.2 Mean number of flower bud thrips per plant, number of pods per peduncle, average number of seeds per plant and thrips damage rating of the parental materials evaluated under natural infestation of thrips in the field at SARI, Nyankpala, 2010

Genotype	Number* Thrips/plant	Pods/peduncle* per Plant	Number of* Seeds	Damage* Rating
Ife Brown	8.50^{a}	0.51^{d}	12.12^{c}	7.67^{a}
Sampea 7	8.30^{b}	0.58^{c}	11.92^{c}	7.70^{a}
Sanzi	3.43^{d}	0.85^{a}	21.78^{a}	3.00^{c}
Sampea 8	5.80^{d}	0.75^{b}	17.80^{b}	5.00^{b}
Padi-tuya	8.32^{c}	0.59^{c}	11.89^{c}	7.66^{a}
Grand Mean	6.88	0.66	15.16	6.17
C.V (%)	6.93	2.54	4.66	3.08
S.E±	0.0021	0.00093	0.17	0.013

* Means with the same alphabet in a column are not significantly different from each other according to DMRT

4.2 MODE OF INHERITANCE

4.2.1 Evaluation

The results of the field evaluation of different populations derived from the various crosses involving parents with varying reaction to flower bud thrips (FTh) is presented in Table 4.3. The reactions of the parental genotypes and the F_1s to FTh infestation and the segregation patterns of the F_2 and the backcross progenies in relation to resistance were used to determine the mode of inheritance of resistance in each cross. Result of the thrips damage rating (DR) of all the populations evaluated under natural and inoculation infestation of flower bud thrips in the field is presented in Table 4.3. The parental genotype, Sanzi (parent 1) in the cross Sanzi x Ife Brown scored a mean of 3.00 thrips damage rating and a range between 2 and 5. The mean value of thrips damage rating for Ife Brown (parent 2) was 7.67 with a range between 6 and 8 (Table 4.3). The variation between the mean damage ratings scored by the two parental genotypes confirms the earlier findings of Sanzi being resistant, while Ife Brown being susceptible genotype as observed in the validation of parental status of resistance. The F_1 hybrid scored an average damage rating of 2.80 with a rage between 2 and 4. The F_1 mean was lower than the mid-parental mean (5.34 DR), indicating better performance than both parents. Mean damage rating for the backcross involving Sanzi and Ife brown, BCP_1 and BCP_2 had mean values (3.77 and 4.67) lower than the mid-parental mean (5.34 DR). In addition, there was high level of variation among the F_2 population, the range of the F_2 is outside the parental range (1-9), with mean scored and coefficient of variation of 5.53 and 25.33 %, respectively (Table 4.3). The means of the six populations (P_1, P_2, F_1, F_2, BCP_1 and BCP_2) emanated from the cross Sanzi x Ife Brown were significantly different from each other ($P < 0.01$) Table 4.3.

The crosses Sanzi x Sampea 7 and Sampea 8 x Sanzi, resistant x susceptible and resistant x resistant cowpea genotypes produced similar result to that of Sanzi x Ife Brown. The F_1 means were lower than the mid-parental means (Table 4.3). The F_2 range is outside the parental range in both crosses stated above. However, the F_1 generation that emanated from Sampea 8 x Padi-tuya had mean value of 5.96 damage rating with a range between 1 and 6 (Table 4.3). This mean value is similar to the mid-parent (6.35 DR). The $BCP_1$and BCP_2 had mean values of 4.63 and 5.53 damage rating coupled with range between 2 and 9. F_2 population had a range between 1 and 9 with a mean of 5.00 DR Table 4.3.

The range, mean and coefficient of variation (CV %) of number of thrips per plant for the different generations of different crosses evaluated in the field under natural infestation is presented in Table 4.3. The parents, Sanzi (P_1) and Ife Brown (P_2) in the cross Sanzi x Ife Brown had mean of 3.43 and 8.50 with range between 0 and 6 as well as 3 and 13, respectively (Table 4.3). The F_1 had average number of thrips per plant of 4.10, range of 0-8 and CV of 8.24 %. BCP_1 and BCP_2 had mean number of thrips per plant of 3.80 and 4.47 with CV % of 13.61 and 12.74, respectively. The genotype, Sampea 7, had mean number of thrips of 8.30, range of 5-11 and CV of 4.90 %. F_1 (Sanzi x Sampea 7) recorded mean number of thrips of 4.47, range of 0-9 and CV of 10.89 %, respectively. The F_2 (Sanzi x Sampea7) had mean number of thrips of 5.80, range of 0-15 and CV of 28.57 %. The BCP_1 and BCP_2 population recorded mean number of thrips of 3.88 and 5.80, had range of 1-10 and 2-12, with CV of 17.56 and 18.25 %, respectively Table 4.3. Sampea 8 x Sanzi and Sampea 8 x Padi-tuya. The F_1 generations from these crosses had mean values of (3.10 and 5.75), lower than that of their respective mid-parental means (4.62 and 7.05) for number of thrips per plant. The backcross generations had mean number of thrips similar to their recurrent parents. F_2 populations had range (0-15 and 1-16) outside the range of their respective parents (0-9). The means of the six populations (P_1, P_2, F_1, F_2, BCP_1 and $BCP_{2)}$ that emanated from each cross were significantly different from each other ($P < 0.01$) Table 4.3.

Result of the number of pods per peduncle (NPP) of all the populations evaluated under natural infestation of flower bud thrips in the field is presented in Table 4.3. The parental genotype, Sanzi had a mean of 0.85 pods per peduncle and a range between 0.5 and 1.3. Ife Brown, the susceptible parent had a mean of 0.51with a range between 0.1 and 0.9, respectively (Table 4.3). The F_1 hybrid had a mean of 0.70 with a range between 0.1 and 1.2. The F_1 mean was higher than the mid-parental mean (0.68 NPP). Mean of pods per peduncle per plant for the backcrosses, BCP_1 and BCP_2 were (0.66 and 0.58) higher than that of P_2 (Ife Brown) but similar to mid-parental mean (0.68 NPP). In addition, there was high level of variation among the F_2 population, with the range of the F_2 being outside the parental range couple with high CV of (22.19) (Table 4.3).

The parents from the crosses Sanzi x Sampea 7 and Sampea 8 x Sanzi had mean number of pods per peduncle of 0.85 and 0.58 as well as 0.75 and 0.85, respectively, (Table 4.3). The F_1 generations from these crosses had mean number of pods per peduncle (0.74 and 0.86) higher than mid-parental man of 0.72 and 0.80, respectively. However, the F_1 generation that emanated from Sampea 8 x Padi-tuya had mean of 0.66 pods per peduncle with a range between 0.1and 1.3 (Table 4.3). This mean value is similar to the mid-parent (0.68 NPP). The $BCP_1$and BCP_2 had mean values of 0.62 and 0.55 pods per peduncle per plant coupled with range between 0.4 and 1.2 and 0.3 and 1.2, respectively. F_2 population had a range between 0.1 and 1.3 with a mean of 0.62 and CV of 27.39 % NPP, respectively. The means of the six populations (P_1, P_2, F_1, F_2, BCP_1 and BCP_2) that emanated from the cross Sampea 8 x Padituya were significantly different from each other ($P < 0.05$) Table 4.3.

Table 4.3 Range, mean and coefficient of variation (CV %) of thrips damage rating (DR), number of thrips per plant (NFTh) and number of pods per peduncle (NPP) for the parents, F_1, F_2 and backcross populations evaluated under natural infestation of thrips in the field at SARI, Nyankpala, 2010

		Thrips Damage Rating			**Number of Thrips per Plant**			**Number of Pods per Plant**		
Cross	**Generation**	**Range**	**Mean**	**CV (%)**	**Range**	**Mean**	**C V (%)**	**Range**	**Mean**	**CV (%)**
Sanzi x Ife Brown	Sanzi	2-5	3.00	4.99	0-6	3.43	4.64	0.5-1.3	0.85	6.16
	Ife Brown	6-8	7.67	4.34	3-13	8.50	5.13	0.1-0.9	0.51	5.81
	F_1	2-4	2.80	8.89	0-8	4.10	8.24	0.1-1.2	0.70	10.24
	F_2	1-9	5.53	25.37	0-14	8.00	33.70	0.1-1.5	0.70	22.19
	BCP_1	1-9	4.67	12.06	0-12	3.80	13.61	0.2-2	0.66	18.67
	BCP_2	2-9	3.77	10.74	1-12	4.47	12.74	0.5-1.4	0.58	14.45
Sanzi x Sampea 7	Sanzi	2-5	3.00	6.30	0-6	3.43	5.00	0.5-1.3	0.85	7.81
	Sampea 7	7-9	7.70	4.68	5-11	8.30	4.92	0.1-0.9	0.58	5.67
	F_1	1-4	2.47	9.98	0-9	4.47	10.89	0.2-1.3	0.74	12.46
	F_2	1-9	5.27	26.20	0-15	5.80	28.57	0-1.4.5	0.64	23.01
	BCP_1	2-9	4.33	15.97	1-10	3.88	17.56	0.2-1.2	0.68	15.68
	BCP_2	1-9	3.73	11.30	2-12	5.80	18.25	0.1-3	0.63	13.12
Sampea 8x Sanzi	Sampea 8	2-6	5.00	4.92	0-9	5.80	4.80	0.4-1.3	0.75	6.41
	Sanzi	2-5	3.00	4.04	0-6	3.43	4.12	0.5-1.3	0.85	6.04
	F_1	1-3	2.40	9.62	0-5	3.10	6.73	0.1-1.3	0.86	9.14
	F_2	1-9	5.20	25.22	0-15	6.00	34.51	0.3-1.5	0.72	19.64
	BCP_1	1-9	3.37	17.25	0-9	4.95	10.05	0.3-1.4	0.75	13.11
	BCP_2	1-8	3.20	12.19	0-9	3.43	8.89	0.4-1.4	0.81	11.81
Sampea 8 x Padi-t	Sampea 8	2-6	5.00	4.12	0-9	5.80	7.73	0.4-1.3	0.75	7.09
	Padi-tuya	6-9	7.66	3.82	5-13	8.30	6.10	0.1-0.9	0.60	6.37
	F_1	1-6	5.96	6.14	0-12	5.75	10.57	0.1-1.3	0.66	11.47
	F_2	1-9	5.00	30.28	0-15	7.60	21.98	0-1.4	0.62	27.39
	BCP_1	2-9	4.63	12.73	2-9	5.48	13.69	0.4-1.3	0.62	18.06
	BCP_2	2-9	5.53	10.47	2-12	5.95	14.15	0.3-1.5	0.55	19.84

4.2.2 Test of Allelism for Resistance to *Megalurothrips sjostedti* in Cowpea

The reactions of Sampea 8 x Sanzi, their F_1, F_2, BCP_1 and BCP_2 generations to flower bud thrips are shown in Table 4.4. The means of the number of flower bud thrips per plant from the two resistant genotypes Sampea 8 (5.83) and Sanzi (3.43) were significantly different ($P > 0.05$) Table 4.4. The reciprocal backcross population BCP_1 and BCP_2 were all resistant (Table 4.4). Most of the F_2 progenies were resistant while some were susceptible in spite of the fact that the two parents are resistant. There were some F_2 segregants that were more resistant than the parents, they recorded few number of flower bud thrips than both parents, which could be categorised into resistant, moderately resistant and susceptible. However, the ratio of F_2 to F_1 (3.71) variance was significant ($P > 0.05$) for flower thrips damage rating, confirms that F_2 segregation observed was significant. The result from generation mean analysis revealed that dominance gene effects was significant for the cross Sampea 8 x Sanzi.

However, the reaction of Ife brown x Padi-tuya and Padi-tuya x Ife brown (susceptible x susceptible) parents showed no significance difference. The mean of flower bud thrips was 8.52 for Ife brown and 8.34 for Padi-tuya. Their progenies had similar performances which were not significantly different from each other ($P < 0.05$). No apparent segregation pattern was evident in backcross and the F_2 populations (Table 4.4).

Comparing F_1 hybrids indicated reciprocal differences in the cross between Sampea 8 x Sanzi ($P < 0.01$ and $P < 0.05$) in thrips damage rating, number of thrips per plant and number of pods per peduncle. The number of thrips per plant however, was not significant but the performance of the RF_1 was slightly above the F_1 (Table 4.5).

Table 4.4. Mean performance of the two resistant and the two susceptible cowpea genotypes and their progenies for allelic test

	DR	**NFTh**	**NPP**	σ^2**DR**		**DR**	**NFTh**	**NPP**
Generation	**Mean***	**Mean***	**Mean***		**Generation**	**Mean***	**Mean***	**Mean***
Samp.8 (R)	5.00^{b}	5.83^{a}	0.71^{f}		Ife brown (S)	7.67	8.51	0.53
Sanzi (R)	3.00^{e}	3.43^{d}	0.85^{b}		Padi-tuya (S)	7.63	8.32	0.55
F_1	2.40^{f}	3.10^{e}	0.86^{a}	3.4	F_1	7.70	8.33	0.56
F_2	5.20^{a}	5.76^{b}	0.72^{e}	12.6	F_2	7.71	8.57	0.59
F_1x Samp.8	3.37^{c}	4.95^{c}	0.81^{c}		F_1 x Ife brown	7.72	8.40	0.56
F_1 x Sanzi	3.00^{d}	3.43^{d}	0.75^{d}		F_1 x Pad-tuya	7.72	8.40	0.58

*Means with the same alphabets in a column are not significantly different according to Duncan Multiple Range Test. DR = Thrips damage rating

NFTh = Number of Flower bud thrips per plant

NPP = Number of pods per peduncle per plant

σ^2DR = Variance of F_2 and F_1 for thrips damage rating

Table 4.5 Comparison of F_1 hybrids with their respective reciprocals for mean thrips damage rating, number of thrips per plant and number of pods per peduncle under natural infestation of thrips in the field

Cross[a]	Mean Thrips damage rating	Mean number of thrips per plant	Mean number of pods per peduncle
Sampea 8 x Sanzi	3.72±0.4	5.9±0.28	0.70±0.03
Sanzi x Sampea 8	3.10±0.4	7.8±0.31	0.86±0.04
t-test[b]	ns	**	*

[a] First named parent = ♀, second named parent = ♂

[b] F_1 means compared with Reciprocal F_1 (RF_1) means

*, ** and ns Significant at 0.05; 0.01 probability levels and non significant by t-test

4.2.3 Progenies of Crosses

Frequency distributions for number of thrips per plant in the parental, F_1, F_2, and backcross generations are presented in Figure 2. The parents used in this study did not represent genotypic extremes for resistance and susceptibility to flower bud thrips as the mean for number of thrips per plant was 3.43 for Sanzi, 8.50 for Ife brown, 8.30 for Sampea 7, 8.27 for Padi-tuya and 5.80 for Sampea 8, respectively. The observed frequency distributions of the two parents overlap for number of thrips per plant for all the crosses (Figure 2). The frequency distributions for average number of pods per peduncle are presented in Figure 6. The average number of pods per peduncle for Sanzi was 0.85, Ife brown was 0.51, Sampea 7 was 0.58, Padi-tuya was 0.59 and Sampea 8 was 0.75, respectively.

The number of flower bud thrips per plant and pods per peduncle for the F_1 hybrids of all the crosses involving resistance x susceptible, were lower than that of the susceptible parents (P_2s). BCP_1 and BCP_2 plants were partially distributed across the range of both parents but were skewed towards the recurrent parents for both number of thrips per plant and number of pods per peduncle. On the other hand, in the resistant x resistant crosses Sampea 8 x Sanzi, number of flower bud thrips per plant and that of pods per peduncle had frequency distributions of the two parents overlap (Figure 5 and 9). P_1 mean (5.83) was higher than P_2 mean (3.43) for number of thrips per plant. But for number of pods per peduncle, P_1 mean (0.71) was lower than P_2 mean (0.85). The Reciprocal F_1 (RF_1 hybrids) in the resistant x resistant crosses had mean values of 1.9 and 3.10 for thrips damage rating and number of thrips per plant which were lower than both parents. The average number of pods per peduncle was 0.86, which was higher than both parents. BCP_1 and BCP_2 plants were distributed partially across the range of both parents but skewed towards the recurrent parent.

The phenotypic classes intermediate of the parents were also observed, the F_2 distributions occurred over the range of both parents for number of thrips per plant and pods per peduncle among the 105 plants studied. However, F_2 means of thrips damage rating, number of flower bud thrips per plant and number of pods per peduncle was similar to the mid-parental means (Figure 2-9).

The F_2 generations from both resistant x susceptible crosses and resistant x resistant crosses had continuous distributions (Figure 2-8). The F_2 distributions had coefficient of variation (CV) ranged from 25.37 % to 30.28 % for thrips damage rating, 21.84 % to 28.57 % for number of thrips per plant and 22.19 % to 27.39 % for number of pods per peduncle in resistant x susceptible crosses, respectively (Table 4.3). In resistant x resistant crosses, coefficients of variation (CV) for the three parameters were 25.22 %, 34.51 % and 19.64 % (Table 4.3).

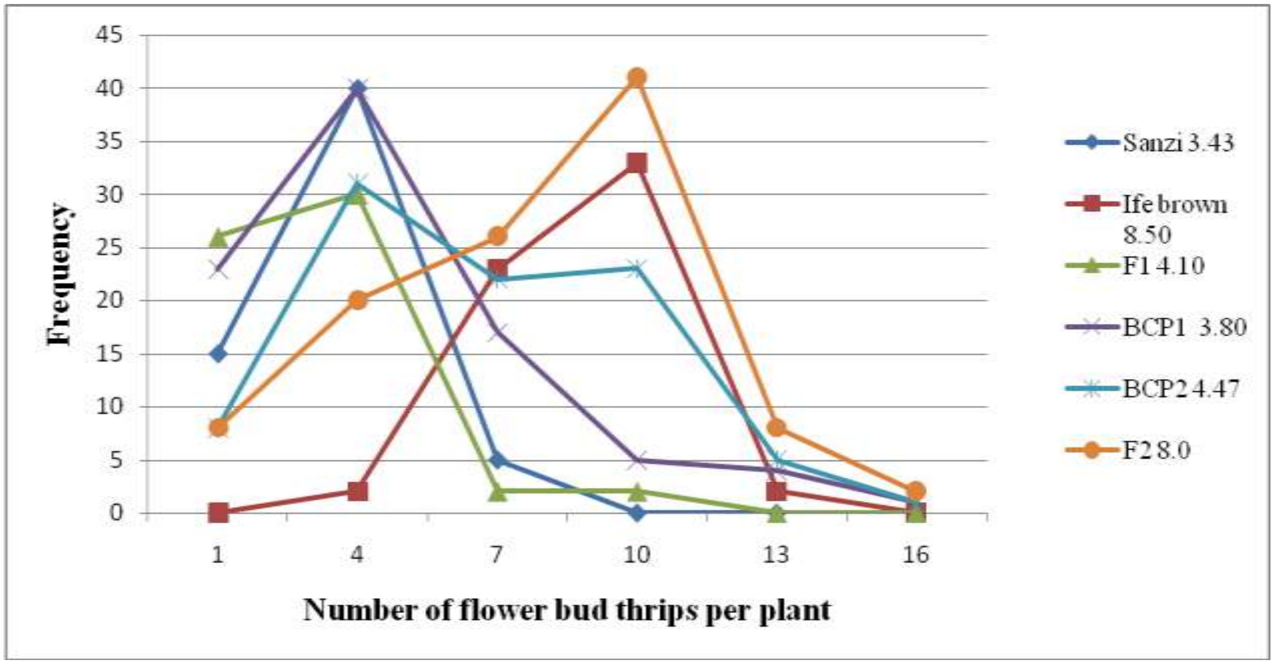

Figure 2 Frequency distribution of number of flower bud thrips per plant for parents, F_1, backcrosses and F_2 populations for the cross Sanzi x Ife brown evaluated in the field at SARI, Nyankpala, 2010

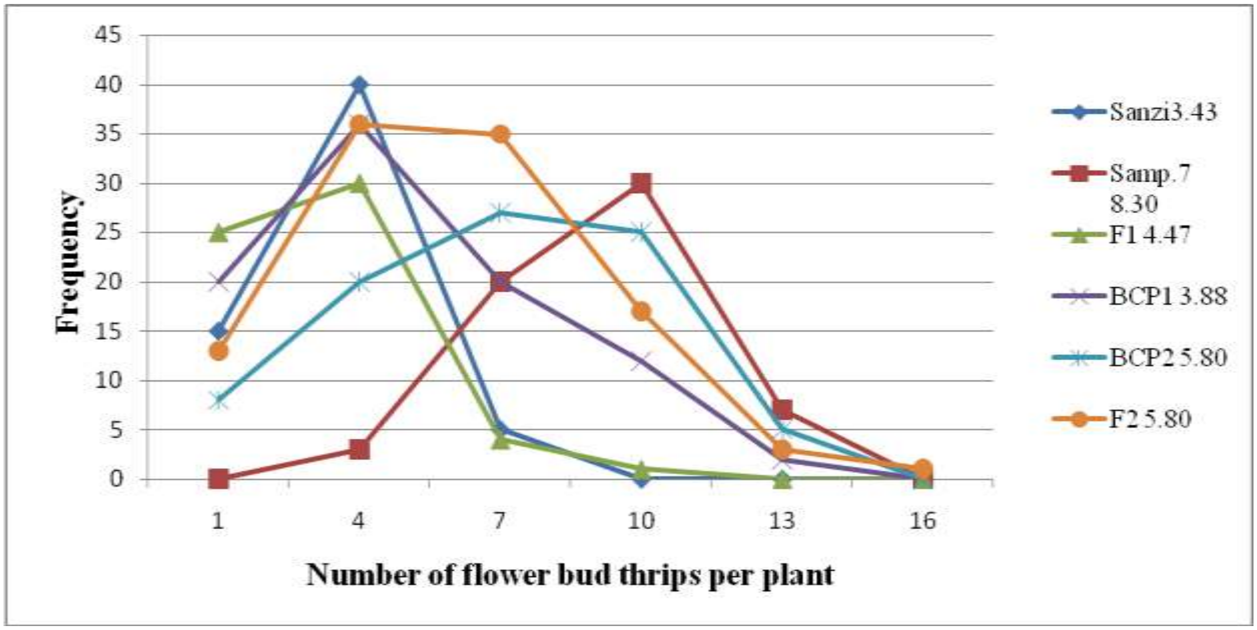

Figure 3 Frequency distribution of number of flower bud thrips per plant for parents, F_1, backcrosses and F_2 populations for the cross Sanzi x Sampea 7 evaluated in the field at SARI, Nyankpala, 2010

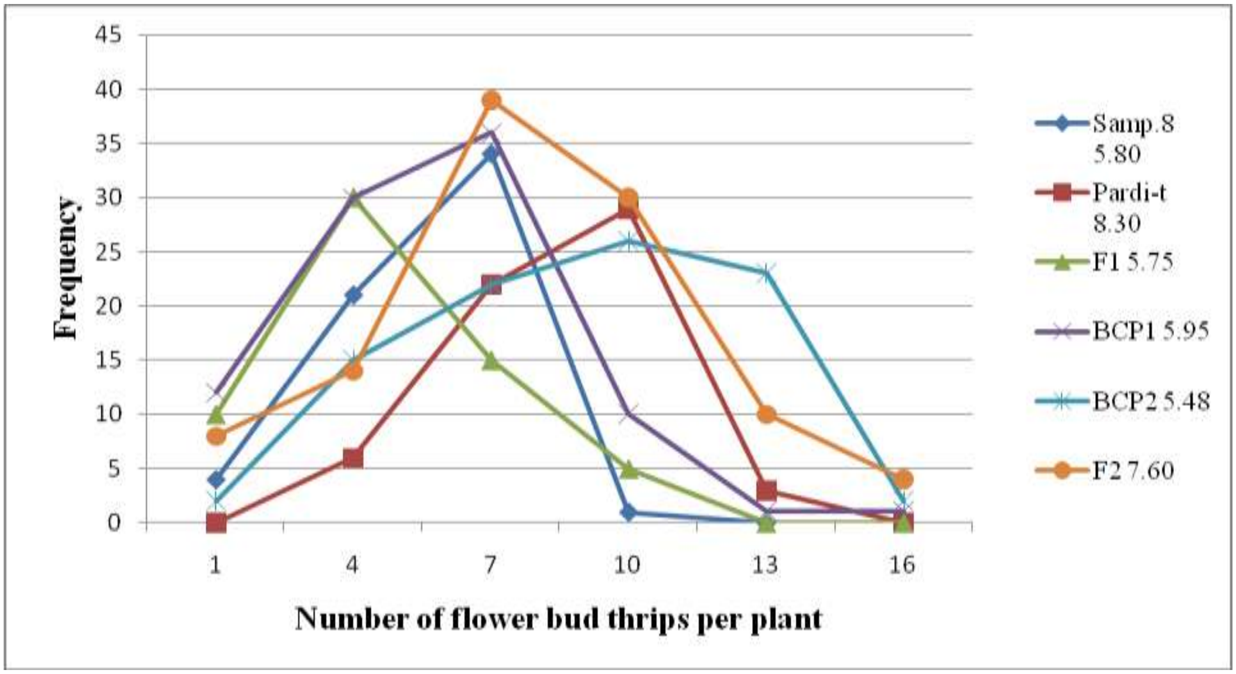

Figure 4 Frequency distribution of number of flower bud thrips per plant for parents, F_1, backcrosses and F_2 populations for the cross Sampea 8 x Pardi-tuya evaluated in the field at SARI, Nyankpala, 2010

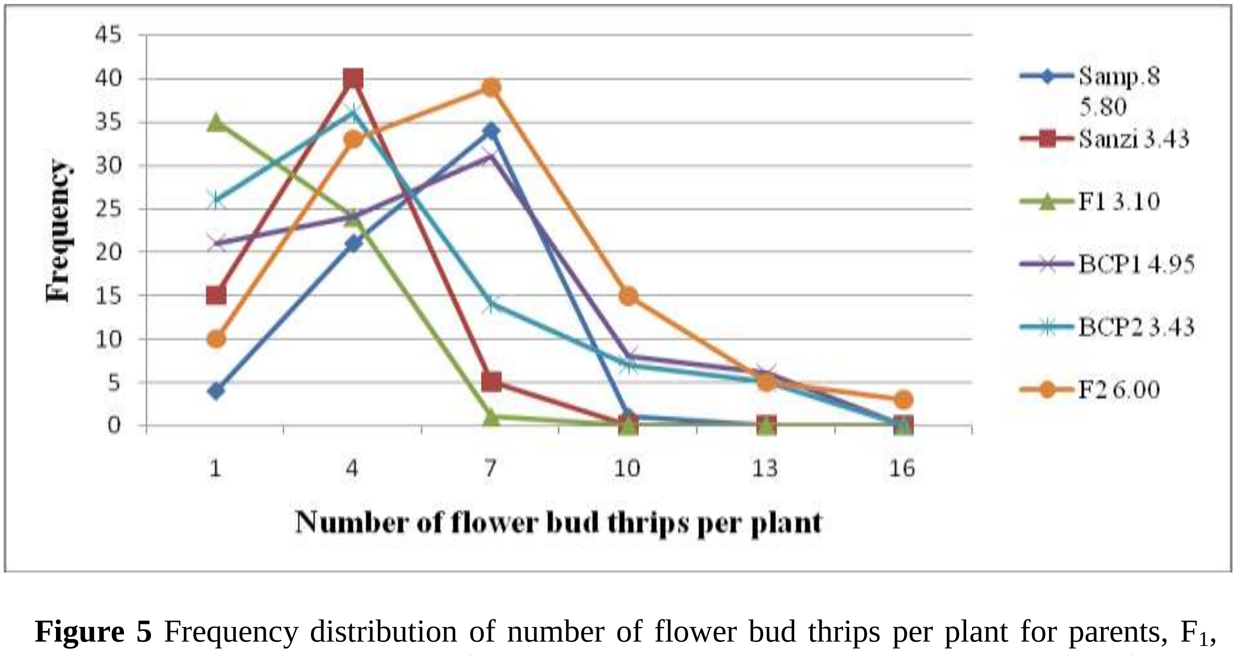

Figure 5 Frequency distribution of number of flower bud thrips per plant for parents, F_1, backcrosses and F_2 populations for the cross Sampea 8 x Sanzi evaluated in the field at SARI, Nyankpala, 2010

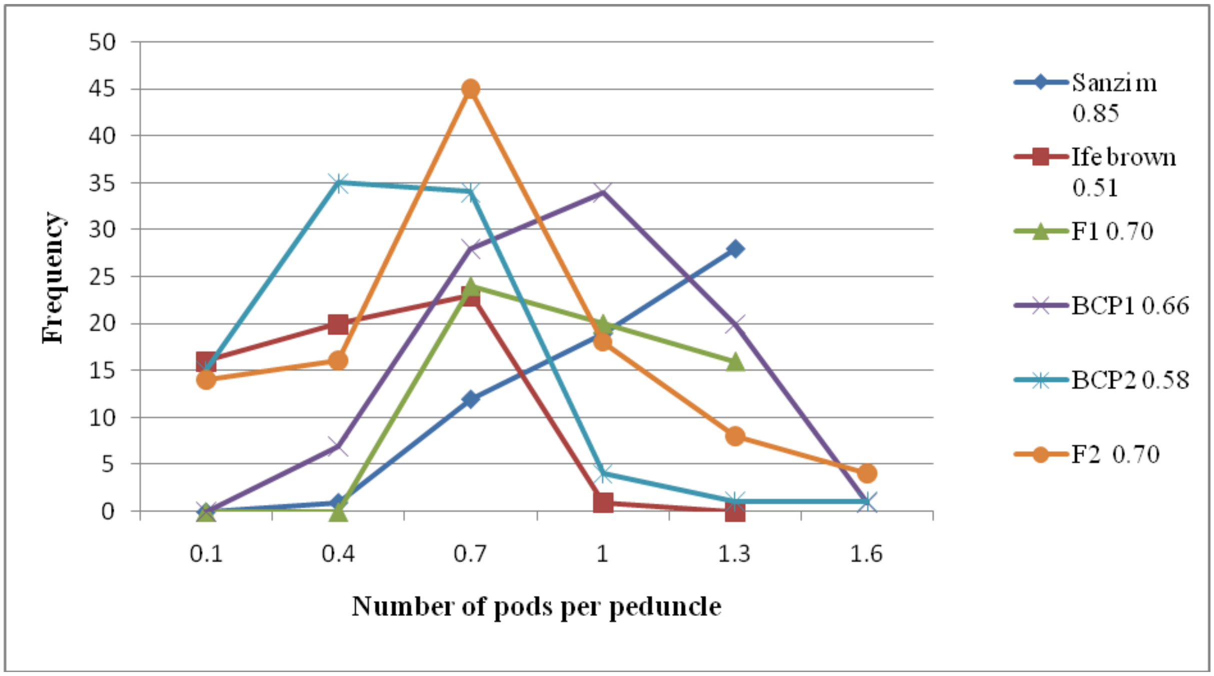

Figure 6 Frequency distribution of number of pods per peduncle per plant for parents, F_1, back crosses and F_2 populations for the cross Sanzi x Ife brown evaluated in the field at SARI, Nyankpala, 2010

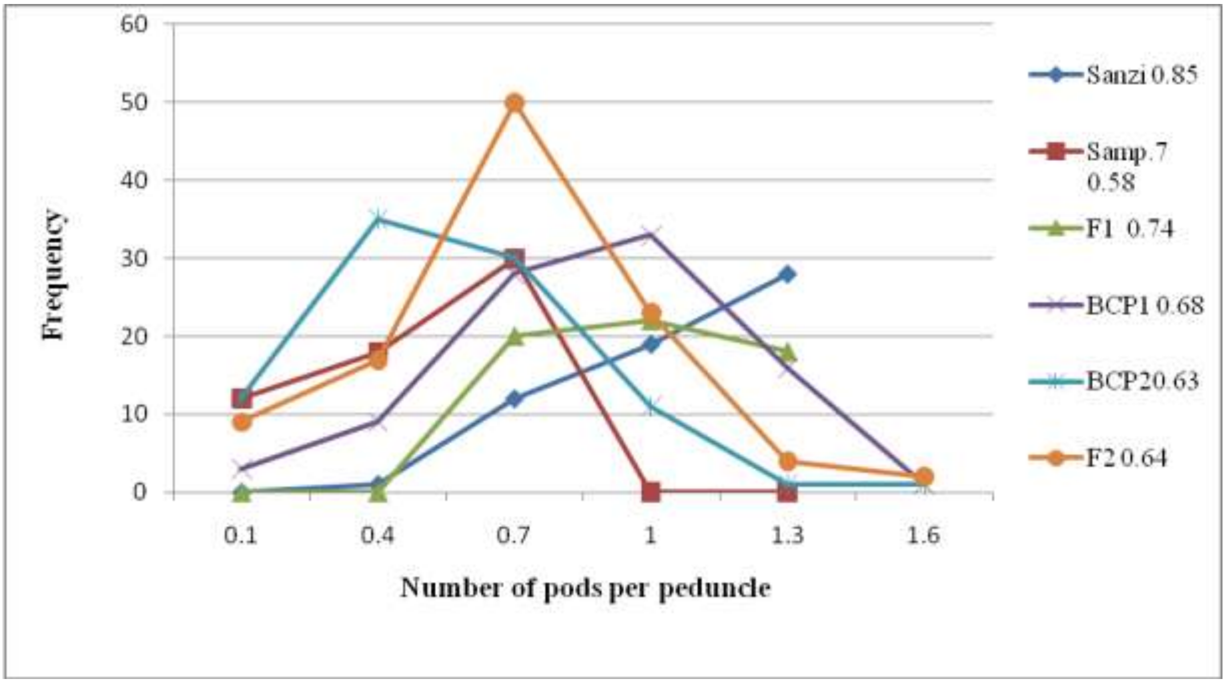

Figure 7 Frequency distribution of number of pods per peduncle for parents, F_1, backcrosses and F_2 populations for the cross Sanzi x Sampea 7 evaluated in the field at SARI, Nyankpala, 2010

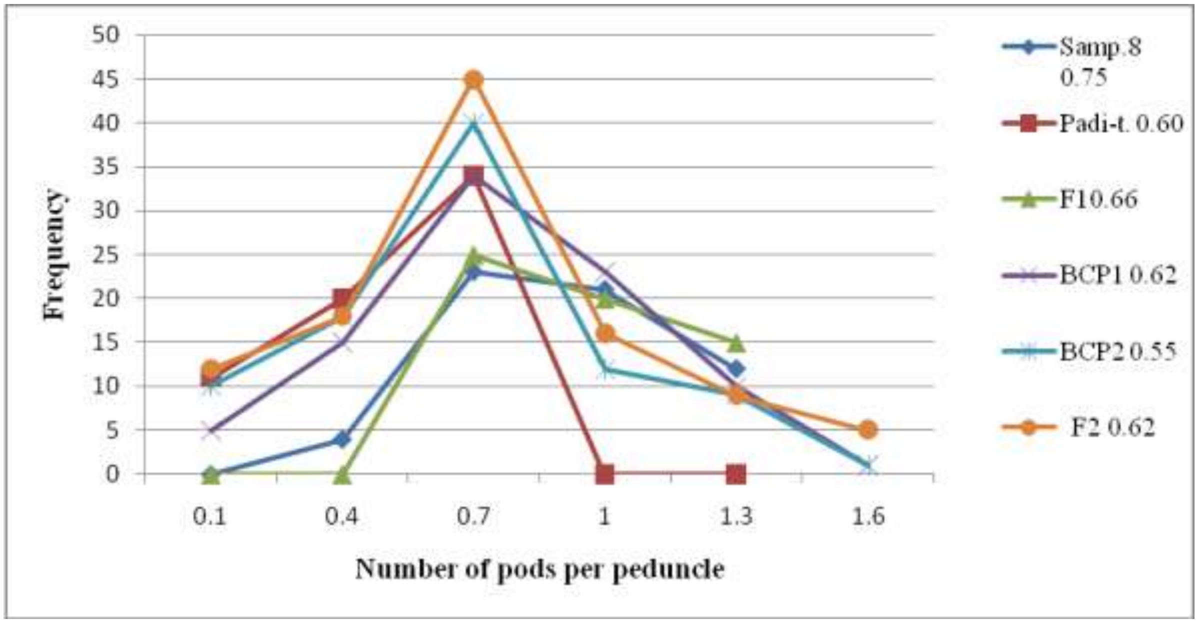

Figure 8 Frequency distribution of number of pods per peduncle for parents, F_1, backcrosses and F_2 populations for the cross Sampea 8 x Padi-tuya evaluated in the field at SARI, Nyankpala, 2010

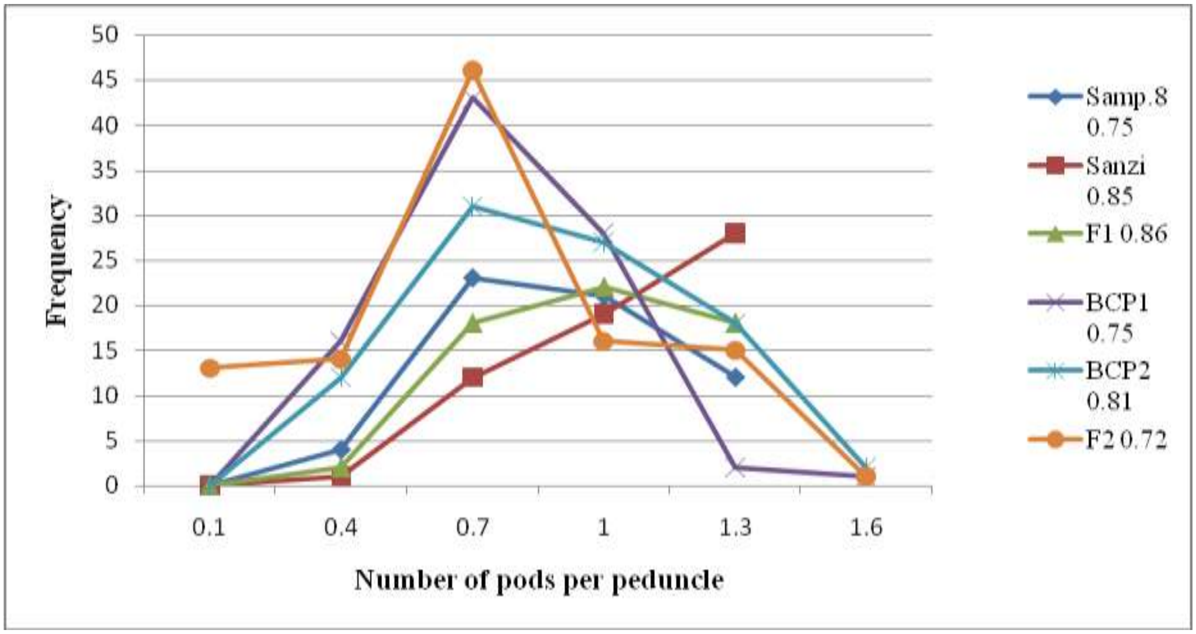

Figure 9 Frequency distribution of number of pods per peduncle per plant for parents, F_1, backcrosses and F_2 populations for the cross Sampea 8 x Sanzi evaluated in the field at SARI, Nyankpala, 2010

4.2.4 Estimates of Gene Effects for Thrips Damage Rating, Flower Bud Thrips and Number of Pods per Peduncle

The generation mean analyses of the thrips damage rating, number of flower bud thrips per plant and number of pods per peduncle showed the presence of epistatic gene action in all the crosses involving resistant and susceptible and resistant and resistant (Table 4.6 – 4.8). A test of goodness of fit to the additive-dominance model (Table 4.9-4.10) were not significant ($P < 0.05$, χ^2 1.67, 7.4, 5.61 and 5.11, respectively) involving crosses of Sanzi x Ife brown and Sampea 8 x Padi-tuya for number of thrips per plant as well as Sanzi x Ife Brown and Sampea 8 x Sanzi for thrips damage rating and number of pods per peduncle. The nature of gene action involved in the resistance of cowpea to flower bud thrips confirmed the inadequacy of additive-dominance model to explain the gene action governing the inheritance of resistance to flower bud thrips. The estimation of the six parameters for the various gene effects revealed that additive (a) gene effect was significant for resistance to flower bud thrips in number of FTh per plant, thrips damage rating, as well as number of pods per peduncle in all the five families including the resistant x resistant and the resistant x susceptible crosses (Table 4.6, 4.7 and 4.8). The dominance (d) gene effect was also significant in three crosses except the crosses between Sanzi x Ife brown and Sampea 8 x Sanzi for thrips damage rating, number of thrips per plant and number of pods per peduncle. In the resistant x susceptible crosses, dominance gene effects were greater than the additive gene effects with all the three important traits studied. The dominance gene effects ranged from 2.84 to 7. 05, whilst additive gene effects ranged from 1.00 to 2.35 in thrips damage rating for resistance to *Megalurothrips sjostedti* (Tables 4.6, 4.7 and 4.8).

In resistant and resistant crosses, dominance gene effects made the greater contribution than additive gene effects with 6.80 to 7.29 and 0.63 to 1.85 against 1.22 to 2.60 and 0.06 to 0.17 in number of thrips per plant and number of pods per peduncle, respectively. However, both dominance and additive gene effects were in negative directions in only number of pods per peduncle. In addition, the epistatic component, additive x additive (aa), additive x dominance (ad) and dominance x dominance (dd) gene interaction effects were also vital in at least two of the five crosses involving the three traits studied (Table 4.6, 4.7 and 4.8). The additive x additive (aa) interaction gene effects were generally important in all the traits studied among resistant x susceptible crosses except in the case of the cross Sampea 8 x Padi-tuya. This ranged from 3.48 to 6.14 for thrips damage rating, 4.47 to 5.46 for number of thrips per plant and 0.21 to 0.81 for number of pods per peduncle, respectively (Table 4.6, 4.7 and 4.8).

Additive x dominance (ad) gene interaction effects were significant in three of the crosses except that of Sampea 8 x Padi-tuya in thrips damage rating and number of thrips per plant, but for pods per peduncle, it was significant in only one cross (Sanzi x Ife brown). Dominance x dominance interaction gene effects was significant ($P > 0.05$ and $P > 0.01$) for thrips damage rating for two crosses (Sampea 8 x Sanzi and Sampea 8 x Padi-tuya) and in number of thrips per plant for Sanzi x Ife brown and Sampea 8 x Padi-tuya. But in pods per peduncle, dominance x dominance interaction gene effects was significant in three crosses, except Sampea 8 x Sanzi. In the resistant x resistant cross (Sampea 8 x Sanzi), additive, dominance, additive x additive, additive x dominance and dominance x dominance gene effects were significant ($P > 0.01$ and $P > 0.05$, respectively). But additive, dominance and additive x additive gene effects were more vital than the rest in thrips damage rating. On the other hand, all the five types of gene effects were observed to be important in two or all the characters (number of flower bud thrips per plant and number of pods per peduncle) in the crosses (Table 4.6, 4.7 and 4.8).

Table 4.6 Estimates of gene effects for flower bud thrips damage rating for five cowpea crosses evaluated under natural infestation of thrips in the field at SARI, Nyankpala, 2010

Crosses	m	a	d	aa	ad	dd
Sanzi x Ife brown	5.53 **	2.33**	3.07	4.41**	-4.07**	1.06
	±0.18	±0.03	±1.48	±0.33	±0.39	±0.91
Sanzi x Sampea 7	5.27*	2.35**	7.05*	6.14**	-3.42*	-0.98
	±0.19	±0.08	±2.73	±0.97	±0.84	±1.9
Sampea 8 x Sanzi	5.20**	1.00**	2.84**	3.48**	-1.62**	1.84**
	±0.24	±0.01	±0.43	±0.15	± 0.1	±0.32
Sampea 8 x Pardi-tuya	5.03*	1.30**	-6.57*	0.53	-0.83	5.82*
	±0.21	±0.04	±1.57	±0.61	±0.44	±1.07
Ife brown x Padi-tuya	7.73*	-0.02	1.38	-0.07	0.10	-0.51
	±0.14	± 0.05	±0.83	±0.34	±0.22	±0.51

Table 4.7 Estimates of gene effects for number of flower bud thrips per plant for five cowpea crosses evaluated under natural infestation of thrips in the field at SARI, Nyankpala, 2010

Crosses	m	a	d	aa	ad	dd
Sanzi x Ife brown	7.75*	2.60**	-0.29	4.47*	-6.29**	6.50*
	±0.25	±0.12	±2.71	±1.18	± 0.59	±1.68
Sanzi x Sampea 7	5.80**	2.45**	7.29**	5.46**	-1.20*	-1.89
	±0.22	±0.09	±2.04	±0.88	±0.47	±1.19
Sampea 8 x Sanzi	5.61**	1.22**	6.80*	4.98*	-5.08**	-0.91
	±0.25	±0.16	±3.01	±1.28	± 0.73	±1.91
Sampea 8 x Padi-tuya	7.59**	1.33**	-6.18	0.16	-1.44	6.76*
	±0.19	±0.17	±4.82	±2.13	±1.01	±2.89
Ife brown x Padi-tuya	8.57**	0.11	-0.29	-0.03	0.27	0.43
	±0.067	±0.06	±0.18	±0.34	±0.29	± 0.54

The upper values and their standard errors

*, ** Significant at 0.05 and 0.01 probability levels, respectively

Table 4.8 Estimates of gene effects for number of pods per peduncle per plant for five cowpea crosses evaluated under natural infestation of thrips in the field at SARI, Nyankpala, 2010

Crosses	**m**	**a**	**d**	**aa**	**ad**	**dd**
Sanzi x Ife brown	0.67 **	-0.17**	-1.85**	-0.81**	0.19**	1.03**
	±0.06	±0.01	±0.22	±0.09	±0.06	±0.14
Sanzi x Sampea 7	0.63**	-0.14**	-1.89**	-0.38*	0.14	0.44*
	±0.06	±0.01	±0.29	±0.12	±0.08	±0.18
Sampea 8 x Sanzi	0.73*	-0.07*	-0.12	-0.54*	-0.08	0.41
	±0.05	±0.02	±0.40	±0.18	±0.09	±0.25
Sampea 8 x Pardi-tuya	0.60*	-0.06*	-0.96*	-0.38*	-0.04	0.54 *
	±0.20	±0.02	±0.30	±0.13	±0.04	±0.19
Ife brown x Padi-tuya	0.59**	0.04*	-0.40	-0.15	-0.23	0.23
	±0.12	± 0.02	±0.27	±0.06	±0.12	±0.10

The upper values and their standard errors

*, ** Significant at 0.05 and 0.01 probability levels, respectively

Table 4.9 Test of goodness of fit to the additive-dominance genetic model for the crosses Sanzi x Ife brown and Sampea 8 x Padi-tuya for number of thrips per plant

Sanzi (R) x Ife Brown (S)				Sampea 8 (R) x Padi-tuya (S)			
Generation	Observed	Expected	χ^2	Generation	Observed	Expected	χ^2
Sanzi	3.43	2.76	0.16	Sanzi	5.83	5.49	0.03
Ife brown	8.5	7.95	0.09	Ife brown	8.3	8.14	0.009
F_1	4.08	4.27	0.0028	F_1	5.75	0.63	2.48
F_2	7.83	4.81	0.70	F_2	7.59	3.72	1.39
BCP_1	3.79	6.11	0.14	BCP_1	5.33	9.23	2.82
BCP_2	4.47	4.59	0.58	BCP_2	5.92	4.38	0.67
Total			**1.67**	Total			**7.4**
Significance			$P < 0.05$	Significance			$P < 0.05$

Table 4.10 Test of goodness of fit to the additive-dominance genetic model for the crosses Sanzi x Ife Brown for thrips damage rating and Sampea 8 x Sanzi for number of pods per peduncle

Sanzi (R) x Ife Brown (S)				**Sampea 8 (R) x Sanzi (R)**			
Generation	Observed	Expected	χ^2	Generation	Observed	Expected	χ^2
Sanzi	3.00	2.24	0.12	Sampea 8	0.75	0.86	0.25
Ife Brown	7.67	6.90	0.14	Sanzi	0.85	0.72	0.33
F_1	2.80	7.64	1.64	F_1	0.86	0.67	0.43
F_2	5.53	4.73	1.60	F_2	0.72	0.73	0.002
BCP_1	4.67	4.52	0.03	BCP_1	0.75	0.45	2.25
BCP_2	3.77	4.95	2.08	BCP_2	0.81	0.59	1.85
Total			**5.61**	Total			**5.11**
Significance			$P < 0.05$	Significance			$P < 0.05$

4.2.5. Heritability, Genetic Advance and Number of Effective Factors

The minimum number of effective factors segregating in the F_2 generation of the resistant x susceptible crosses for number of flower bud thrips per plant, ranged from 3 to 5, while 3 to 4 was estimated from thrips damage rating and number of pods per peduncle. The estimation minimum number of effective factors from resistant x resistant cross ranged from 3 to 4 (Table 4.11-4.13).

Broad sense heritability ranged from 53.00 % to 58.00 while narrow sense heritability ranged from 13.04 % to 28.02 % Table 4.11, respectively for number of thrips per plant. Thrips damage rating had broad sense heritability ranged from 49.70 % to 58.312.69 % and 12.69 % to 20.86 % Table 4.12. Broad and narrow sense heritability estimated for number of pods per peduncle ranged from 85.00 % to 94.00 % and 18.00 % to 41 .00 %, respectively Table 4.13.

Estimation of genetic advance (G A) from all the crosses ranged from 4 to 6 was predicted from number of thrips per plant in the future generation Table 4.11.

Table 4.11 Estimates of heritability, genetic advance at 10 % selection intensity and number of effective factors controlling flower bud thrips resistance for number of thrips per plant evaluated in the field at SARI under natural infestation

Crosses	% Broad sense heritability	% Narrow sense heritability	Genetic Advance	Number of Effective Factors
Sanzi x Ife Brown	56.50	28.02	4.83	3
Sanzi x Sampea 7	58.00	20.00	3.96	5
Sampea 8 x Sanzi	53.00	19.09	4.43	4
Sampea 8 x Padi-tuya	53.00	13.04	5.73	4

Table 4.12 Estimates of heritability and number of effective factors controlling flower bud thrips resistance for thrips damage rating evaluated in the field at SARI under natural infestation

Cross	% Broad sense Heritability	% Narrow sense Heritability	Number of Effective Factors
Sanzi x Ife Brown	55.31	17.84	3
Sanzi x Sampea 7	49.70	12.69	3
Sampea 8 x Sanzi	53.78	20.86	3
Sampea 8 x Padi-tuya	58.32	18.81	4

Table 4.13 Estimates of heritability and number of effective factors controlling flower bud thrips resistance for number of pods per peduncle evaluated in the field at SARI under natural infestation

Crosses	**% Broad sense Heritability**	**% Narrow sense Heritability**	**Number of Effective Factors**
Sanzi x Ife Brown	85..00	18.00	4
Sanzi x Sampea 7	86.00	22.00	4
Sampea 8 x Sanzi	94.00	40.00	3
Sampea 8 x Pardi-tuya	91.00	41.00	3

4.2.6. Correlation

Genotypic, phenotypic and environmental correlation between flower bud thrips damage rating, number of thrips per plant and other agronomic traits is presented in Table 4.14. In genotypic correlation, thrips damage rating correlated negatively with number of pods per peduncle, (r = -0.748, $P < 0.01$), average number of pods per plant, (r = -0.554, $P < 0.01$), average number of seeds per plant (r = -0.918, $P < 0.01$), but positively correlated with number of thrips per plant (r = 0.975, $P < 0.05$). Number of flower bud thrips per plant also correlated negatively, Number of pods per plant, (r = -0.568, $P < 0.05$) and number of seeds per plant (r = -0.834, $P < 0.01$). However, number of pods per peduncle correlated positively with number of pods per plant (r = 0.878, $P < 0.01$) and number of seeds per plant (r = 0.717, $P < 0.01$) Table 4.14.

In phenotypic correlation, there was no association between thrips damage rating, number of thrips per plant and other parameters significant. Moreover, number of pods per peduncle was negatively correlated with number of pods per plant (r = -0.756, $P < 0.01$) in environmental correlation Table 4.14.

Table 4.14 Genotypic, phenotypic and environmental correlation amongst the traits used to estimate resistance to flower bud thrips in the parental genotypes and their progenies

		DR	NPP	NP	NS	NFTh
	r_g					
	r_p					
DR	r_e					
	r_g	-0.748**				
	r_p	-0.179				
NPP	r_e	0.099				
	r_g	-0.554*	0.878**			
	r_p	-0.372	0.005			
NP	r_e	-0.323	0.060			
	r_g	-0.918**	0.717**	0.646*		
	r_p	-0.394	0.013	0.029		
NS	r_e	0.151	-0.047	0.756**		
	r_g	0.975**	-0.745**	-0.568*	-0.834**	
	r_p	0.091	-0.061	-0.029	-0.125	
NFTh	r_e	0.024	0.142	0.277	-0.232	

*, ** Significant at 0.05 and at 0.01 probability levels, respectively.

DR = Flower bud thrips damage rating, NPP = Number of pods per peduncle per plant, NP = Number of pods per plant, ns = Number of seeds per plant and NFTh = Number of flower bud thrips per plant.

r_g = genotypic correlation

r_{ph} = phenotypic correlation

r_e = environmental correlation.

CHAPTER FIVE
DISCUSSION

The goal of increased food production to ensure food security in most developing countries is hindered by various environmental, biological and technological constraints, encountered by resource-poor farmers which form the majority. The lack of efficient insect pests control remains as one of the dominant constraints to boost crop yield. Due to the increased economic importance of *Megalurothrips sjostedti* and the difficulty of controlling them with insecticides and other cultural methods, incorporation of natural resistance to this insect pest in elite cowpea varieties has become a major objective of the cowpea improvement programmes at national and international research institutes. Therefore, the search for sources of flower bud thrips resistance in cowpea resulted in the identification of Sanzi and Sampea 8 cowpea genotypes among others.

In the present study, the results of the validation of resistance status of the parental materials revealed that, there was no significant difference between the numbers of days to 50 % flowering among the five cowpea genotypes, evaluated, under field conditions. Therefore, the resistance in Sanzi and Sampea 8 could not be explained by flower bud thrips (FTh) infestation escape due to early flowering. However, the average number of flower bud thrips per plant for each genotype showed significant variations among the five cowpea genotypes. The infestation resulted in the abscission of almost all flower buds in the case of the susceptible genotypes, while on the other hand, many flower buds were retained and even developed pods and grains in the resistant genotypes. The average thrips damage rating scores and mean number of pods per peduncle also showed significant differences among the cowpea genotypes. Sanzi recorded less thrips damage rating of 3.00, number of thrips per plant 3.43 and number of pods per plant, 0.85, respectively. Sanzi, which is a local landrace consistently, supported fewer thrips populations and lesser damage comparable to Sampea 8, recorded thrips damage rating of 5.00, Ife brown (7.67), Sampea 7 (7.70) and Padi-tuya (7.66); susceptible genotypes. These important parameters; thrips damage rating, number of thrips per plant and number of pods per peduncle showed Sanzi to be resistant and Sampea 8 to be moderately resistant whilst Ife Brown, Sampea 7 and Padi-tuya were rated as susceptible. In related study, Omo-Ikerodah *et al.* (2009) and Alabi *et al.* (2003) both reported that Sanzi was resistant to flower bud thrips in Nigeria. Abudulai *et al.* (2006) also reported the same resistance of Sanzi to FTh in Ghana. These findings corroborated the results of the present study.

The reciprocal differences of F_1 observed in the cross between Sampea 8 x Sanzi indicated the presence of cytoplasmic factors. This result confirmed the earlier findings of Rusoke and Fatunla, 1987; Singh and Hadley 1972; Fatunla and Badaru, 1983). The consistent results of reciprocal crosses for mean number of pods per plant, pods per peduncle and flower bud thrips per plant, showed that the use of the resistant genotypes as maternal parent conferred superior resistance on the F_1 hybrids. This suggests that in a breeding programme, to improve flower bud thrips resistance in cowpea, the resistant materials should be used as the female parents. The average number of pods per plant of the F_1 plants was significantly higher than the respective mid-parent values and was closer to the resistance parent, thus indicating dominance of resistance over susceptibility. However, the average number of pods per peduncle of the F_1 plants was significantly higher than both parents indicating an over-dominance of resistance over susceptibility.

BCP_1 and BCP_2 plants were distributed partially across the range of both but skewed towards the recurrent parents. The F_2 plants were distributed over the range of both parents with continuous distribution coupled with transgressive segregation, suggesting the involvement of more than two genes controlling the inheritance of resistance of flower bud thrips in cowpea. The observations of quantitative nature of FTh from the frequency distributions of number of thrips per plant and number of pods per peduncle in the segregating populations corroborated with the findings of Ishiyaku *et al.* (2005). Ishiyaku *et al*. (2005) working on inheritance of time to flowering in cowpea, reported that, the F_2 plants were distributed over the range of both parents, indicating that more than two genes probably control the trait.

The results of genetic analysis of generation means indicated that the additive-dominance model was inadequate to explain variations observed in the inheritance of resistance to FTh in cowpea genotypes used. Thus, this finding was an evidence of the result obtained from the chi-square analysis which showed insignificance in the crosses tested. In addition, generation mean analysis provided estimates of the relative magnitudes of additive, dominance and epistatic gene effects. The estimates for the various gene effects revealed that both the additive and dominance gene effects, contributed significantly to the inheritance of the traits studied, with the preponderance of dominance gene effects. These results confirmed the earlier reports of Omo-Ikerodah *et al.* (2009). Similar results were obtained in the number of thrips per plant as well as pods per peduncle in all the crosses. Additive x additive and dominance x dominance gene effects made major contributions to resistance to flower bud thrips.

In this study, the two types of heritability estimate broad sense and narrow sense heritability were estimated. The results obtained indicated that there were variations in the heritability among all the crosses for the three traits studied. Heritability in the broad sense was relatively high for the three important characters measured. Dabholkar (1992) classified heritability estimates as low (5 to 10 %), medium (10 to 30 %) and high (> 30 %). Accordingly, the three characters considered for analysis showed high broad sense heritability averaging 55.13 %, 54.28 % and 81 % coupled with moderately high narrow sense heritability (20.04 %, 17.55 % and 30.25 %) for number of thrips per plant, thrips damage rating and pods per peduncle, respectively. Constituting high breeding value which has more additive genetic effects which is important for crop improvement. Moreover, the high heritability values estimated in this study indicated that the traits are highly heritable and selection can be done to improve the characters. This finding agreed with the findings of (Upadhyaya *et al.*, 1997). According to Johnson and Frey (19 67), in characters with highest heritability, phenotype is a good index of genotypic merits, so that genetic gain can be made easily through selection.

Genetic advance (G A) of reduction of susceptibility by 4 to 6 number of flower bud thrips per plant was predicted in the future generation. Thus indicating that, in the F_3 generation, there will be fewer number of flower bud thrips per plant compared to the F_2 generation.

This means that, genetic advance in yield of the future generation is expected to be higher because the fewer the number of thrips, the more the resistant and the higher the yield. According to Johnson *et al*. (1955), characters with high heritability accompanied with high genetic advance also result in better genetic gain through selection as high heritability will not always be associated with genetic advance (Amin *et al*., 1992). Hanson (1963) stated that heritability has meaning only in reference to defined selection units and response units and these can vary among breeding schemes. The main purpose of estimating heritability and the genetic parameters that compose the heritability estimate is to compose the expected gains from selection based on alternative selections strategies. Heritability can also be used to predict gain from selection in breeding.

In the present studies, epitasis is more important than dominance to the breeder of self-pollinating species, in that dominance is broken by segregation following hybridization. Epistatsis, on the other hand, does not depend on heterozygosity and can therefore permit more gene combinations than dominance. In the present study, dominance and epistaisis made major contributions to the inheritance of resistance to flower bud thrips in the cowpea genotypes used. Therefore, rapid advances in breeding programme to incorporate these characteristics into commercial cowpea cultivars would best be made using a procedure, which emphasizes these gene effects.

The minimum number of effective factors segregating for resistance ranged from 3 to 5 in F_2 progenies emanating from resistant x susceptible crosses and 3 in the resistant x resistant cross. The 3 to 5 gene model being proposed here means there were three to four resistance loci each contributing equally and additively in resistance to flower bud thrips. These estimates indicated an oligogenic type of inheritance of resistance to flower bud thrips in cowpea, corroborating the earlier results of Omo-Ikerodah *et al.* (2009). On the contrary, an earlier report (highlights, 1983) at IITA, that two recessive genes controlled resistance to flower bud thrips damage in cowpea. The earlier report differs from the present findings, probably due to the different cowpea genotypes used at different ecological areas for the studies.

Improvement in one trait as a result of selection of another, largely depend on the genotypic and phenotypic correlations between them and the variances associated to them. Correlation, according to Steel and Torrie (1984) is the measure of the intensity of association between traits. Genotypic correlation provides a measure of genetic association between traits, therefore helps to identify more important traits to be selected in breeding programme. For all the associations in this study, phenotypic and environmental correlations were not significant. This means that there is strong inherent relationship between the traits measured. The result of correlation analysis in Table 4.14 reveals that thrips damage rating exhibits significant negative correlation with number of pods per plant, number of pods per peduncle and number of seeds per plant but was positively correlated with number of thrips per plant. The negative and highly significant genotypic correlation observed between thrips damage rating and other agronomic traits suggest that cowpea genotypes with high damage rating would suffer severe reduction in number of pods produced per plant, pods per peduncle as well as grain yield.

In the present study, the observation of heterosis in the F_1 and transgressive segregation in the F_2, of the resistant x resistant cross may be explained by postulating the presence of both resistance and susceptible factors in the two resistant parents and complementary action of these factors in their F_1 hybrids. These observations are in line with the finding of Wolf and Hallauer (1997). Who reported that an epistatic effect could contribute to the expression of heterosis for specific hybrids. The Generation means analysis revealed that dominance gene effect was highly significant in thrips damage rating but was significant in number of thrips per plant as well as pods per peduncle for the cross, Sampea 8 x Sanzi. The two resistant parents had different performance in the mean damage ratings, number of thrips per plant and pods per plant. Coupled with significant dominance towards the better of the two parents, Sanzi consistently shows that some of the genes in the parents are non-allelic, corroborating the findings of (Omo-Ikerodah *et al*., 2009). The two resistant genotypes were chosen based on genetic diversity because of the functions of pedigree such that, alleles contributed by the two parents with different ancestry are more likely to vary from those parents with common ancestors. Thus (Sampea 8) IT93K-452-1 is a released variety from Institute for Agricultural Research (IAR) Samaru, Nigeria, while Sanzi is a local landrace from Ghana. Therefore, there is a high possibility that they have different pedigrees. The two resistant genotypes could be incorporated into breeding programmes, not only on the basis of resistance to *Megalurothrips sjostedti*, but also on the basis of their high yielding potentials and early maturity. These genes can therefore be transferred into high yielding cultivars of cowpea to enhance their productivity by backcross method using the resistant genotypes as females. For flower bud thrips, the resistance available in cowpea should be used with appropriate complementary agronomic practices of an integrated control package.

In conclusion, the findings of this study have shown that some of the F_2 segregants were more resistant than the resistant parental genotypes which could be transferred into commercial cultivars by backcross method of breeding. Therefore, it is further recommended that collaboration among national and international research institutions to establish host-plant resistance programme on flower bud thrips should be encouraged. There is also a need to screen germplasm collections systematically, to identify new genes for resistance and to incorporate the identified genes into improved cultivars.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The genetic studies were carried out using five cowpea genotypes, Sanzi, Sampea 8, Ife Brown, Sampea 7, and Padi-tuya at Institute for Agricultural Research (IAR), Samaru, Nigeria and Savannah Agricultural Research Institute (SARI), Nyankpala, northern region of Ghana throughout 2010. Population development was carried out in the screen house at IAR using bi-parental mating design while evaluation of the genetic populations was done at the experimental field at SARI, Nyankpala under natural infestation of flower bud thrips in October, 2010. Validation of the resistance status of the parental materials, the mode of inheritance of resistance to flower bud thrips (FTh) and the allelic relationship between resistance genes were studied in five crosses involving six genetic populations such as parents, F_1s, F_2s and backcross populations. Thrips damage rating, number of thrips per plant and number of pods per peduncle were the resistance criteria used.

Analysis of variance for these parameters of the parental genotypes was conducted to validate the status of resistance to whether the genotypic variation was significant prior to conducting genetic analysis using the general linear model (GLM) procedure of the statistical analysis system (SAS) programme. These key parameters showed cowpea genotype, Sanzi to be resistant and Sampea 8 to be moderately resistant, whilst Ife Brown, Sampea 7 and Padi-tuya were classed as susceptible. Thrips damage rating correlated negatively with number of pods per plant, pods per peduncle but positively correlated with number of thrips per plant.

Reciprocal effects were investigated between the resistant genotypes using the Paired t-test. Frequency distributions of number of FTh per plant and pods per peduncle in six generations of all the crosses were used to study the segregation patterns. The observed frequency distributions of each two parental genotypes showed an over-lap. The backcross population distributed across the range of both parents but skewed towards the recurrent parent. F_2 populations were distributed over the range of both parents with continuous distribution coupled with transgressive segregation. These suggested more than two genes probably control the resistance to *Megalurothrips sjostedti* in cowpea.

The genetic analysis of generation mean indicated additive–dominance model was not adequate to explain variation observed in the inheritance of resistance to flower thrips in cowpea. Chi-square test was conducted to test the goodness of fit to additive-dominance model was not significant. Estimates of the six parameters for the various gene effect showed that both additive and dominance gene effects, contributed significantly to the inheritance of the trait studied, with the preponderance of dominance gene effects. Additive x additive and dominance x dominance gene effects made major contributions to resistance to flower bud thrips.

The minimum number of effective factors segregating for resistance ranged from 3 to 5 in F_2 progenies resulting from resistant x susceptible crosses and 3 in the resistant x resistant cross. The effective factors of 3 to 5 indicated an oligogenic inheritance of resistance genes for flower bud thrips. The broad sense and narrow sense heritability estimates for thrips damage rating, ranged from 49.70 % -58.32 %, and 12.69 % -20.86 %, number of thrips per plant ranged from 53.00-58.00 % and 13.04 to 28.02 %, respectively. Pods per peduncle, the broad sense and narrow sense heritability estimates ranged from 85.00 %-94.00 % and 22.00 %-41.00 %. The two resistance genotypes have relatively high heritability and genetic advance of reduction of susceptibility from 4-6 numbers of thrips per plant was predicted in the future generation.

Generation mean analysis showed that dominance gene effect was significant for the resistant x resistant cross. The difference in means performance, coupled with significant dominance towards the better of the two parents, Sanzi, further showed that some of genes in the two parents were non-allelic.

Resistance controlled by a few genes, oligogenic inheritance of resistance genes, to insect pests generally is assumed to be more stable than monogenic resistance. Therefore, the genetic diversity for resistance established by this study is practically significant in that it promises more stable protection against flower bud thrips. Host-plant resistance is used as a component in integrated programme for pest control in several crops. For flower bud thrips resistance available in cowpea should be used with appropriate complementary agronomic practices as ideal control package. It is further recommended that collaboration among national and international research institutions to establish host-plant resistance programme on flower bud thrips should be encouraged. The level of resistance of the two parents showed in this study and the F_2 segregants could be used as resistance sources to increase and diversify resistance of cowpea to flower bud thrips in commercial cultivars.

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