EVALUATION OF SELECTED COWPEA CULTIVARS FOR RESISTANCE TO COWPEA APHID, APHIS CRACCIVORA KOCH (HOMOPTERA: APHIDIDAE) IN KENYA.

BY

CHARLES NEWTON MWANIKI MBOGO

A THESIS SUBMITTED IN PART FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE (AGRICULTURAL ENTOMOLOGY) IN THE UNIVERSITY OF NAIROBI.

FACULTY OF SCIENCE

1985

D E C L A R A T I O N

This is my original work and has not been presented for a degree in any other University.

Signature ..... Date 27/11/85

Charles N.M. Mbogo

This thesis has been submitted for examination with our approval as University supervisors.

Signature ..... Date 27.11.85

Dr. Battan M. Khaemba

Signature ..... Date 27/11/85

Prof. Canute P.M. Khamala

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

A C K N O W L E D G E M E N T S

I am extremely grateful to my supervisors, Dr. B.M. Khaemba and Prof. C.P.M. Khamala for their guidance, encouragement and dedication throughout the course of this investigation.

I am grateful to the Senior Pathologist at National Agricultural Laboratories (NAL), Mr. Ramos for allowing me to use greenhouses where investigations were carried out. Also I cannot forget to thank Mr. Peter Kipruto of the Biometrics Section (NAL) for his invaluable assistance in the data analysis on computer.

I very much appreciate the technical assistance I received from Mr. J. Moilo and Mr. A.G. Luvembe. My sincere thanks are also due to Mrs. R.N. Watulo and Mrs. M.O. Ombete who typed this thesis.

I am also very grateful to the Kenyatta University College for sponsoring this project and to the University of Nairobi for offering me the course.

Finally, I thank my parents, brothers and sisters for giving me support and encouragement throughout the course.

ABSTRACT

The cowpea aphid, Aphis craccivora koch (Homoptera: Aphididae) is one of the major common pests of cowpea, Vigna unguiculata (L.) walp in Kenya. The biological performance of the cowpea aphid on different cowpea varieties, and its exact pest status has not been studied before. Greenhouse and field studies were conducted to assess the effects of cowpea cultivars on the biology of A. craccivora, and varietal reaction to feeding of A. craccivora as a means to measure cowpea resistance to this notorious pest.

Greenhouse studies showed that the mean fecundity of the aphids on Tvu 310 was significantly (P=0.05) smaller (15.3 nymphs) than on the other cowpea cultivars tested indicating that this cultivar adversely affected aphid reproduction. The fecundity was highest on the cultivars Machakos 66 (65.8 nymphs) and Ex-Luanda (63.8 nymphs) suggesting that these two cultivars were suitable hosts and therefore susceptible.

Apterous aphids reared on Tvu 310 were smaller in size (body length =1.62 mm), and had significantly (P=0.05) shorter lifespan (13.5 days) and longer pre-reproductive period (7.76 days) as compared to aphids reared on Ex-Luanda which were larger in size (body length =2.07 mm), and had significantly longer lifespan (19.2 days) and shorter pre-reproductive period (6.50 days) at P=0.05 level. This suggested that the latter cultivar was more susceptible. The aphids reared on Katuli 107 did not differ significantly (P=0.05) from those reared on Ex-Luanda, but had a longer pre-reproductive period (7.41 days) and lifespan of 18.1 days.

Additionally, aphids reared on Tvu 310 and Katumani 4 had higher nymphal mortality rates being 47.65% and 36.83% respectively, in comparison to the corresponding mortalities recorded on the other four cultivars tested.

Greenhouse studies also showed that A. craccivora populations developed significantly (P=0.05) more rapidly from initial higher population intensities of aphids than from lower ones. As expected high aphid population intensities caused significantly (P=0.05) higher damage to plant growth and seed yield in all the cultivars than low aphid population intensities.

Field studies revealed that yield losses were significant (P=0.05) between infested and uninfested cultivars when the data collected was put to t-test. Field incidence of A. craccivora showed significant (P=0.05) variation among the cultivars tested. Ex-Luanda, Katuli 107 and Machakos 66 were highly preferred for aphid colonization. On these cultivars except Katuli 107, plant height and sizes of leaf area were greatly reduced.

In view of the adverse effects that Tvu 310 ER-1 and Katumani 4 had on aphid performance, it was concluded that these cultivars possessed varying levels of antibiosis. On the other hand, Katuli 107 which supported large population of aphids but with minimal yield losses were regarded as being tolerant to the pest. Finally, Ex-Luanda and Machakos 66 favoured the development of large aphid populations thereby sustaining heavy yield losses. These cultivars were thus regarded as being susceptible.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1. INTRODUCTION.

1.1.1. The cowpea plant and its uses.

Cowpea, Vigna unguiculata (L.) Walp (Leguminosae) is an important grain legume in tropical Africa (Cobley and Steele, 1976). It is either erect, prostrate or climbing annual plant depending on the variety and season (Purseglove, 1968; Hutchinson, 1969; Rachie and Roberts, 1974; Smartt, 1976). Cowpea stems are glabrous or glabrate with alternate, trifoliate and dark green leaves.

The crop can be grown under a wide range of conditions (Purseglove, 1968). It is either grown as a monocrop or together with other stables such as maize, sorghum, beans and millet as one of the principal food crop of subsistence farmers. Okigbo (1978) reported that the crop is important because of being relatively cheap and locally available source of dietary protein, energy, minerals, vitamins and roughage for man and livestock. Its protein content ranges from 20 to 40% with an average of 23% (FAO, 1970). It therefore has the potential for alleviating protein deficiency where human malnutrition is chronic.

Cowpeas has several advantages over other grain legumes. These include the following: wide agronomic and environmental adaptability; draught resistance; soil erosion control; ability to supplement soil nitrogen through atmospheric fixation and to grow rapidly thereby smothering weeds; and, finally, it is widely accepted as a

food being used in many forms (Rachie and Roberts, 1974: Williams, 1975; ICRISAT, 1977a; Moody and Shetty, 1979; Suh and Simbi 1983).

Cowpea seeds are generally an important crop for human consumption in the drier areas of Kenya (Muruli et al 1980; Malinga 1978). The green tender leaves are used as a "spinach crop", the immature pods as vegetable, and the seeds as a pulse crop (Khamala, 1978; Khaemba, 1980).

1.1.2. Distribution and production of cowpeas

Cowpea is believed to have originated in West Africa (Faris, 1965; Taylor, 1971; Nwanze, 1971; Rachie and Roberts, 1974; Smart, 1976), which is still its major production area (Singh and van Emden, 1979). Commercial production of the crop is found in West Africa. Elsewhere in Africa the crop is commercially grown in Sudan, Uganda, Tanzania, Kenya, Zimbabwe and South Africa. Singh and van Emden (1979) estimated that cowpea production (in millions of hectares) is over 4.8 in West Africa, close to 1 in East Africa, 0.85 in India and 0.6 scatterred over south-east Asia.

Khamala (1978) and Khaemba (1980) reported that cowpea was among the most important leguminous crops in Kenya, taking second position to common beans, Phaseolus vulgaris (L.). They further stated that cowpea was grown as a major crop in Eastern, Coast, Nyanza and Western provinces, and occupied about 67,000 hectares of crop land. About 85% of the cowpea crop is produced in the marginal areas of Eastern province, while 8% is grown in coast province and the remaining in Nyanza, western and central provinces (Anon., 1978).

1.1.3. Cowpea yield constraints and losses.

It has been reported in Nigeria that insect pests are the main limiting factor of cowpea yields (Booker, 1963; 1965a, b; Taylor, 1968, 1971; Williams, 1975; Raheja, 1976; Singh, 1976, 1977, 1978; Singh and Taylor, 1978; Singh and Allen, 1978). In that country yield losses attributable to field insect pests range from 20 to 90% (Booker, 1965b; Singh and Allen, 1980; Raheja, 1976).

It has been reported that cowpea yield losses in Kenya are significantly low ranging from 80 kg/ha (Khamala, 1978) to 135 kg/ha (Anon. 1974). Although research in cowpea entomology in Kenya is of comparatively recent origin, evidence from available literature strongly implicate insect pests including Aphis craccivora koch as being one of the major limiting factors to achieving high yields (Khamala 1978; Khaemba, 1980; Muruli et al, 1980; Khaemba and Khamala, 1981; Mabonga, 1983).

In other East African countries (Uganda and Tanzania) insect pests are reported to constitute the major constraint to cowpea production (Nyiira, 1971, 1973, 1978; Koehler and Mehta, 1972, Le Pelley, 1959; de Pury, 1968; Bohlen 1973; Mehta and Nyiira, 1973; Hill, 1975; Kayumbo 1975, 1978). Insect pests attack all parts of cowpea plants at every stage of growth as well as seeds in storage. A detailed review of field pests of cowpea including A. craccivora on which studies reported here were based is given in section 1.2.1 of this thesis.

Of the many insect pests attacking cowpea crops in the field, A. craccivora infests foliage parts, flowers and pods during both the pre-flowering and post-flowering stages of plant development (Singh and van Emden, 1979; Singh, 1979; Mabonga, 1983; Muruli et al, 1980). Crop losses due to this pest are estimated at 40% in Nigeria (Singh, 1979, Singh and Allen, 1978). In Iran the damage caused ranges from 13-87% as a result of its feeding activities as well as transmitting viruses (COPR, 1981). In Kenya, the magnitude of the damage this pest causes to cowpea has not be quantified. Part of the studies reported here were aimed at generating information which could be useful in establishing or estimating the extent of damage caused by the pest to cowpea.

Chemical control of phytophagous insects including A. craccivora resulted in increased yields in Nigeria (Taylor 1964, Booker 1965b). Taylor (1964) demonstrated that such control doubled or even trembled the yields. Similarly in Uganda, Mehta and Nyiira (1973) recorded increased yields of upto ten-fold as a result of using insecticides to control cowpea pests. In Kenya, despite the fact that A. craccivora has been recorded on cowpea wherever the crop is grown (Le Pelley, 1959; de Pury, 1968), studies on how the pest could be controlled using insecticides have not been undertaken. However, the control aspect of the pest involving insecticides was not considered in the course of the studies reported here.

Recently, Mabonga (1983) working in Machakos district of Kenya reported a high incidence of A. craccivora in her experimental plots. She was of the opinion that chemical control of A. craccivora in Machakos district was not necessary especially if the cowpea varieties grown were indeterminate in growth habit. In her studies

she did not evaluate the varieties for possible resistance against this pest. In part of the current studies reported here, selected promising cowpea cultivars being bred for commercial cultivation by Kenyan farmers were evaluated for qualities of resistance against A. craccivora.

The studies on cowpea resistance to cowpea aphid were undertaken in view of Singh's (1978) observations that many farmers did not spray cowpea crops in Africa because of the low value of the crop. He also cited several other related problems, notably, the high costs of insecticides and their application equipments and shortage of water, all of which prevent farmers from using insecticides to control A. craccivora and other cowpea insect pests.

Besides Singh's (1978) observations, insecticides have certain well known serious disadvantages which include environmental pollution, food contamination, effects to non-target organisms and pest resistance to them (way, 1961; Singh, 1978; Metcalf, 1980) which limit their use. On the other hand, the use of resistant plant varieties to control insect pests is an ideal method and its advantages over insecticides are documented in a number of publications (Horber, 1972; Metcalf, 1980; Metcalf and Lackman, 1975; Pathak and Saxena, 1976; Singh, 1978). The principles and concepts of host plant resistance to insects are reviewed later (section 1.2.3) in this thesis.

There are recent reports which indicate that there is a possibility of there being resistant cultivars to A. craccivora in the available world cowpea germplasm assembled at the International

Institute of Tropical Agriculture (IITA), Ibadan, Nigeria (Singh 1978, 1979; IITA, 1978, 1981, 1982, 1983, 1984). Several resistant cultivars have been identified but none of them has been adopted for widespread cultivation by farmers in the entire African content. Cowpea as a plant is very sensitive to photoperiodism (Purseglove, 1968; summerfield and Bunting, 1980) such that a variety performing well in the region may do very poorly in a slightly different region. There is therefore an urgent need in Kenya to undertake similar studies using local promising cultivars in the hope that if any are identified with reasonable levels of resistance against A.craccivora they could be immediately recommended for commercial cultivation by farmers.

1.2. LITERATURE REVIEW

1.2.1. Field insect pests of cowpea.

Cowpea is an example of a crop with multiple, often overlapping pests (Jackai, 1982). Large numbers of insect pests covering the main phytophagous taxa, between them attack all parts of the plant at all stages from seedling to harvest and beyond (Le Pelley, 1959; Booker, 1965b; Kayumbo, 1975; Singh, 1977; Nyiira, 1978; Agyen-Sampong, 1978; Singh et al 1978; Singh and Allen, 1980; Singh and van Emden, 1979). Moreover all other leguminous plants are alternative host plants to the same pests that attack cowpea (Taylor 1971; Singh et al, 1978).

The biology, ecology and distribution of field pests of cowpea in Asia and Africa have been comprehensively reviewed and documented (Singh, 1977; Singh and Taylor, 1978; Singh et al, 1978; Singh and van Emden, 1979; Singh, 1979). In Kenya, field insect

pests of cowpea have recently been documented by Khamala (1978), Khaemba and Khamala (1978, 1979, 1981), Karel and Mueke (1978), Karel (1979), Khaemba (1980, 1985), Muruli et al (1980) and Okeyo-Owuor (1979). The immediate two subsections based on the phenology of cowpea are therefore devoted to a review of the major insect species of the crop in Africa with special reference to Kenya.

1.2.1.1. Pre-flowering insect pest species.

Pests regarded as pre-flowering species include all those that attack plants from seedling to flowering. These include many beetles, lepidopterous larvae and aphids.

Several authors have reported Ootheca mutabilis Sahlb as being the most important pre-flowering pests in West Africa (Booker, 1963, 1965a,b; Singh and Taylor, 1978; Singh and van Emden, 1979). Taylor (1971) showed that its importance was due to the heavy degree of defoliation it causes to young plants. Whitney and Gilmer (1974), Chant (1959, 1960) and Booker (1965b) reported that the beetle was a vector of cowpea yellow mosaic virus. Moreover, Taylor (1971) and Ochieng (1978) reported that the larvae of the beetle attacked roots of cowpea in Nigeria.

In Kenya, Muruli et al (1980), Okeyo-Owuor (1979) and Khaemba (1980) reported the occurrence of O. mutabilis, while a closely related species O. bennigseni Weise has been reported by Bohlen (1973) and Kayumbo (1978) as occurring in Tanzania. Additionally Le Pelley (1959), Hill (1975), Khamala (1978) and Okeyo-Owuor (1979) recorded several larvae of lepidopterous species feeding on the stem,, leaves and roots of cowpea in Kenya. They included Agrotis segetum F.,

A. ipsilon and spodoptera spp.

Cowpea or groundnut aphid, A. craccivora has been reported as being the commonest pre-flowering pest of cowpea in West Africa (Singh, 1979; IITA, 1978, 1981, 1982, 1983, 1984) and in East Africa including Kenya (Nyiira, 1971, 1978; Bohlen, 1973; Kayumbo, 1978; Okeyo-Owuor 1979; Muruli et al, 1980; Mabonga, 1983). The biology ecology and control of this pest species is reviewed in section 1.2.2 of this thesis.

1.2.1.2. Post-flowering pest species.

Several workers have shown that the most economic damage is caused by insect pests during flowering and early stages of pod production (Taylor, 1968; Ayoade, 1976; Singh 1977; Khamala, 1978; Singh and van Emden, 1979; Okeyo-Owuor and Ochieng, 1981; Khaemba, 1980, 1985; Khaemba and Khamala,1981). These workers reported that the major post-flowering pests consisted of mainly lepidopterous flower feeders, notably, the legume pod-borer, Maruca testulalis (Geyer) the African bollworm, Heliothis armigera Hubner, and the flower thrips, Megalurothrips sjostedti Trybom, and a complex of the hemipteran sucking bugs represented by members from the genera Clavigralla, Riptortus, Anaplocnemis and Nezara.

M. testulalis has been established as being a major pest of cowpea in Nigeria and causes yield losses to the crop estimated between 20 and 60% (Taylor 1964, 1968; Jerath, 1968; Ayoade, 1969; Singh and Taylor, 1978; Singh, 1979). The pest is widely distributed in Africa wherever grain legumes especially cowpea are grown. The larvae feed on terminal shoots, flower buds and

green pods. In Kenya, Okeyo-Owuor 1979 reported that this pest occurred in the lower parts of Eastern and Western provinces. Later, Khaemba (1980) reported that M. testulalis was the main species present on cowpea in the hot and humid areas of coast and Nyanza provinces of Kenya. Okeyo-Owuor and Ochieng (1981) reported that crop losses in Kenya due to damage by this pest ranged between 10 and 80%.

H. armigera has been reported as being an important leguminous pest of cowpea in Kenya (Khamala, 1978). The larvae feed on flower buds, flowers and green pods. Hill (1975) reported that H. armigera attacks a wide range of leguminous plants including cowpea.

M. sjostedti is recognised as being a serious pest of cowpea in Nigeria (IITA, 1978, 1981, 1982; Singh, 1979; Jackai, 1982). Taylor (1969) and Nyiira (1971) showed that damage to cowpea by flower thrips is characterised by malformation and discoloration of floral parts. Severe thrips infestation causes abscission of flower buds which is sufficient to prevent flowering of the crop (IITA, 1978).

Other post-flowering pests include hemipteran bugs from the genera clavigralla, Riptortus, Anoplocnemis and Nezara. In Nigeria these pests are recognized as being major pests of cowpea (Singh, 1979). They suck sap from the developing pods and cause pods to shrivel, dry prematurely, inhibit seed development thereby resulting in serious yield losses. Khaemba (1980) reported that these pests occurred in Kenya causing serious damage to developing pods. In field observations he showed that R. dentipes (F.) infested

the cowpea fields early and attacked mainly young pods, while A. curvipes (F.) infested cowpea field late and attacked older pods.

Finally, mature cowpea pods while still in the field are attacked by several species of coleopterans, of which the major pest is cowpea bruchid, Callosobruchus maculatus F. Although infestation starts in the field, development is completed in storage. However, storage pests fall outside the scope of this review and hence are not dealt with in details here.

1.2.2. Aphid pests of cowpea and their control.

Reported aphid pests of cowpea belong to the sub-order Homoptera (Schmutterer, 1969). However, most important aphid pest species belong to the family aphididae (Schmutterer, 1969; Kennedy and stroyan, 1959). These include the following species: Aphis fabae scop., Aphis gossypii Glov., Acyrthosiphum pisum Harris and A. craccivora.

In Kenya, all the aforementioned aphid species have been recorded on grain legumes including cowpeas (Eastop, 1952, 1957; Okeyo-Owuor 1979; Muruli et al 1980). A fabae is widespread in East Africa and is the main pest of the common bean (Eastop, 1953, 1957; Le Pelley, 1959; de Pury, 1968; Ingram, 1969; Hill, 1975). Ingram (1969) reported that the pest causes severe damage to the bean crop resulting into total loss of the crop. In his survey for cowpea pests in Kenya, Okeyo-Owuor (1979) reported that A. fabae attacked cowpea crop wherever beans are absent in the field.

A. gossypii is an important pest of cotton in Africa (Schmutterer, 1969; Hill, 1975). It is an extremely polyphagous pest infesting cotton, tomato, groundnut, cowpea, pumpkin, citrus and robusta coffee (Hill, 1975). The pest attacks tender shoots and lower surfaces of young leaves of the host plants. A heavy infestation leads to leafcurl and stunting in growth (Le Pelley, 1959; de Pury, 1968; Schmutterer, 1969; Schaefers and Judge, 1972)

The genus, Acyrthosiphum has been recorded on wild legumes in Kenya by Eastop (1958) and de Pury (1963). Some species of this genus have also been found to attack cowpea leaves (Malinga, 1978). He (Malinga 1978), for example, reported that A. pisum attacks cowpea in Kenya and causes stunting in the growth of the plant.

An economically important aphid pest of cowpea is the cowpea or groundnut aphid, A. craccivora. It has been reported as being a major pest of cowpea in Asia and a minor species in Africa (Booker, 1963). However, more recently, Singh (1979) reported that heavy aphid populations have become more than ever before frequent and widespread in Africa. Mabonga (1983) reported that A. craccivora was an important pest of cowpea in Kenya. It infests the crop at seedling stage and the direct damage caused to the host is typical as that inflicted by other aphids: depletion of assimilates and vital plant hormones by removal of sap, and transmission of the cowpea aphid-borne mosaic virus. Dixon (1973) and Singh (1979) reported that aphids generally occurred in large numbers in a relatively short time thereby sucking large amounts of plant sap, and causing interference with the normal plant physiology and sometimes resulting in severe reduction in growth.

The degree of damage done by A. craccivora feeding on cowpea crop in Kenya has not been fully investigated. Part of the studies reported here were aimed at estimating the amount of damage done by the pest to different cowpea cultivars starting with different levels of initial infestation of the aphid. The response of different cowpea cultivars to aphid infestation would be an important indication of the varietal resistance to aphid feeding by the cultivars tested.

Singh and van Emden (1979) reported that fecundity and developmental rate of A. craccivora varied with the host plant, soil moisture and temperature. A. craccivora is known to have four nymphal instars in both alatiform and apteriform nymphs (Johnson, 1953). He (Johnson, 1953) further reported that on healthy plants at 20°C the durations of the successive nymphal instars in apteriform were about 1.5, 1.5, 2.0 and 2.0 days, while in alatiform nymphs the last stadium was one day longer than all the others which were 2.0 days. Singh (1979) reported that adult longevity of A. craccivora varied from 6 to 15 days with a fecundity rate of about 100.

Adult A. craccivora are either apterae (wingless adults) or alatae (winged adults) and reproduction in these two forms is exclusively parthenogenetic (Johnson, 1953). Adult aphids differ from nymphs principally in that they are reproductively mature. The apterae are easily distinguished from other black aphids by their shinning black dorsum with pronounced reticulation. Farrel (1976) reported that there were no sexual forms of this species in Africa.

The adult alatae form infesting many species of host plants, mainly leguminosae migrate to invade crops of cowpea (Evans, 1954; Booker, 1963, Davies, 1972). The first generation, initiated by winged migrants would be apterous, and the progeny, in response to a declining favourability of the food supply, would form large alatae second generation (Hughes, 1963). Large aphid colonies of A. craccivora have been reported by Jones (1967) on groundnut plants and these declined with deterioration of the host plant. Kennedy and Stroyan (1959) reported that density dependent factors including overcrowding often played a part in behaviour and form determination of aphids.

Using parameters such as fecundity, sizes, population development and mortality of the pest many different cowpea cultivars have been tested for their resistance or susceptibility to A. craccivora at IITA (Singh 1978; 1979; IITA, 1978, 1982, 1983). In Kenya, similar studies have not been conducted to identify cowpea cultivars with appreciable levels of resistance to the pest. It was with this aim in mind that studies reported here were conducted to find out whether there are any differences in the fecundity, mortality, size and population development when A. craccivora were bred on a few selected promising cowpea cultivars currently being bred for cultivation by farmers in Kenya. The information obtained would be useful in determining whether some of the cultivars studied possessed appreciable levels of resitance against A. craccivora. A resistant cultivar (Tvu 310) to the pest (IITA, 1982; Singh 1979) was used as a standard resistance check to determine the levels of resistance or susceptibility to the pest.

Aphids are primarily controlled using insecticides such as dimethoate (300 ml a.i/ha), Menazon (1000 g ai/ha), Bromophos (500 ml ai/ha) and Demeton-s-methyl (250 g ai/ha) (Davies, 1972; Mehta and Nyiira, 1973; COPR, 1981; IITA, 1983). The development of resistance to insecticides by aphids is likely to increase virus transmission and especially the non-persistent type, which is acquired by the aphid during brief probes (Eastop 1977). Since the aim of chemical control is 100% kill, such complete destruction is almost impossible (Maramorosch, 1980).

In view of this, one viable and environmentally sound method to control aphid vectors is the growing of resistant varieties. Several researchers have reported that the use of aphid resistant cultivars and genotypes have decreased the incidence and spread of non-persistent viruses (Wilcoxon and Peterson, 1960; Muller, 1964) and semi-persistent viruses (Jones, 1976; 1979; Schwartze and Huber, 1937). However, the aspect of virus control was not considered in the studies reported here which dealt a great deal with host plant resistance against A. craccivora.

1.2.3. Plant resistance to insects.

Painter (1951, 1958) defined host-plant resistance (HPR) as the consequence of heritable plant qualities that results in the plants being relatively less damaged than susceptible plants without these qualities. Earlier, Snelling (1941) defined HPR as including those characteristics which enable a plant to avoid, tolerate or recover from attacks of insects under conditions that would cause greater injury to other plants of the same species. Beck (1965) employed a slightly different defination to mean the collective

heritable characteristics by which a plant species, race or clone or individual may reduce the probability of successful utilization of that plant as a host by an insect species, race, biotype or individual. The effects of HPR on the development of insect pests have been well documented in a number of reports (Painter, 1951, 1958; Beck, 1965; Horber, 1972, 1980; Maxwell 1972; Maxwell and Jennings, 1980).

Painter (1951, 1958) classified HPR into three major types: Preference and non-preference, antibiosis and tolerance. Non-preference is the insects' response to plants that lack the characteristic to serve as hosts, resulting from negative reactions or total avoidance during search for food, oviposition sites or shelter. Dethier (1954, 1970) reviewed that successful utilization of any host by an insect usually followed a chain of conditional responses. Any break in the chain results in a reduction of successful utilization of the host.

Many insects such as aphids, are known to be attracted to host plants by colour (Cody, 1941). For instance, Searls (1935) and Cody (1941) demonstrated that yellow green varieties of peas are more resistant to pea aphid than blue green varieties. They attributed this as due to non-preference type of mechanism. In the present studies this mechanism of resistance was not observed in cowpea cultivars that were tested.

A plant has antibiosis when it adversely affects the bionomics of the insect, for example, A. craccivora feeding on it. Antibiosis, according to Painter (1951) is manifested by the following features: death during the first instar; abnormal longevity; smaller size;

decreased fecundity; and other abnormalities of the insect feeding on it.

Beck (1965) divided antibiosis into two components: biophysical and biochemical. He stated that biophysical resistance results from physical factors such as hard woody stems, tissue thickness and arrangement, trichomes or pubescence. On the other hand, biochemical resistance is antibiosis resulting from the presence of toxins and lack or imbalance of some essential nutritional materials in resistant plants. Beck (1965) emphasized that this type of antibiosis adversely influence physiological processes pertaining to growth, metamorphosis and reproduction.

Plant tolerance was described by Painter (1951) as being the ability of a plant to grow and reproduce itself or repair injury to a marked degree in spite of supporting a population about equal to that damaging a susceptible host.

Painter (1951) reported that the expression of plant resistance to insects is dependent upon the insect pests, the host and the environment. He further reported that insect factors included insect abundance, activity, disease transmission or biotypes, whereas, plant factors included hydrid vigour, mechanical structure, chemical composition, sensitivity to insect feeding and secretion. On the other hand, he stated that factors such as temperature, light, relative humidity, soil fertility and soil moisture affected the ability of the plant to resist pest attack.

1.2.4 Objectives

The main objectives of the studies reported here were as summarised here-under.

(i) To evaluate cowpea varietal effects on the biology of A. craccivora.

. determine fecundity, longevity, size, mortality and developmental period.

. determine population development and abudance of forms of A. craccivora.

(ii) To elucidate cowpea varietal reaction to feeding of A. craccivora.

. determine effects of aphid feeding on plant growth (plant height and leaf area)

. determine effects of aphid feeding on yield loss.

(iii) To evaluate field incidence of A. craccivora on several selected promising cowpea cultivars.

CHAPTER 2.

GREENHOUSE STUDIES ON THE BIOLOGICAL PERFORMANCE OF A. CRACCIVORA ON SELECTED PROMISING COWPEA CULTIVARS.

2.1. Introduction.

van Emden (1972) pointed out that an important preliminary step in the evaluation of the relationship between the pest and its host plants is the study of the biological performance. Bond and Lowe (1975) conducted studies on the resistance of field beans vicia faba L. to the bean aphid, A. fabae and found that resistance or susceptibility of beans was partially indicated by the relative differences in the biological performance of A. fabae on the varieties tested.

Resistance to the cowpea aphid, A. craccivora in various cowpea cultivars was first reported in the early 1970's (IITA, 1974) and was recently shown to be heritable (IITA, 1982). As part of the present studies specific parameters were studied to determine the performance of A. craccivora when reared on six different cowpea cultivars. The parameters studied were: reproductive rate or fecundity, developmental period, longevity, mortality, population development and abundance of aphid forms.

2.2. Materials and methods.

2.2.1. General procedure.

Experiments were conducted in the greenhouse at National Agricultural Laboratories (NAL), Kabete, to study some aspects of the

CHAPTER 2.

GREENHOUSE STUDIES ON THE BIOLOGICAL PERFORMANCE OF A. CRACCIVORA ON SELECTED PROMISING COWPEA CULTIVARS.

2.1. Introduction.

van Emden (1972) pointed out that an important preliminary step in the evaluation of the relationship between the pest and its host plants is the study of the biological performance. Bond and Lowe (1975) conducted studies on the resistance of field beans vicia faba L. to the bean aphid, A. fabae and found that resistance or susceptibility of beans was partially indicated by the relative differences in the biological performance of A. fabae on the varieties tested.

Resistance to the cowpea aphid, A. craccivora in various cowpea cultivars was first reported in the early 1970's (IITA, 1974) and was recently shown to be heritable (IITA, 1982). As part of the present studies specific parameters were studied to determine the performance of A. craccivora when reared on six different cowpea cultivars. The parameters studied were: reproductive rate or fecundity, developmental period, longevity, mortality, population development and abundance of aphid forms.

2.2. Materials and methods.

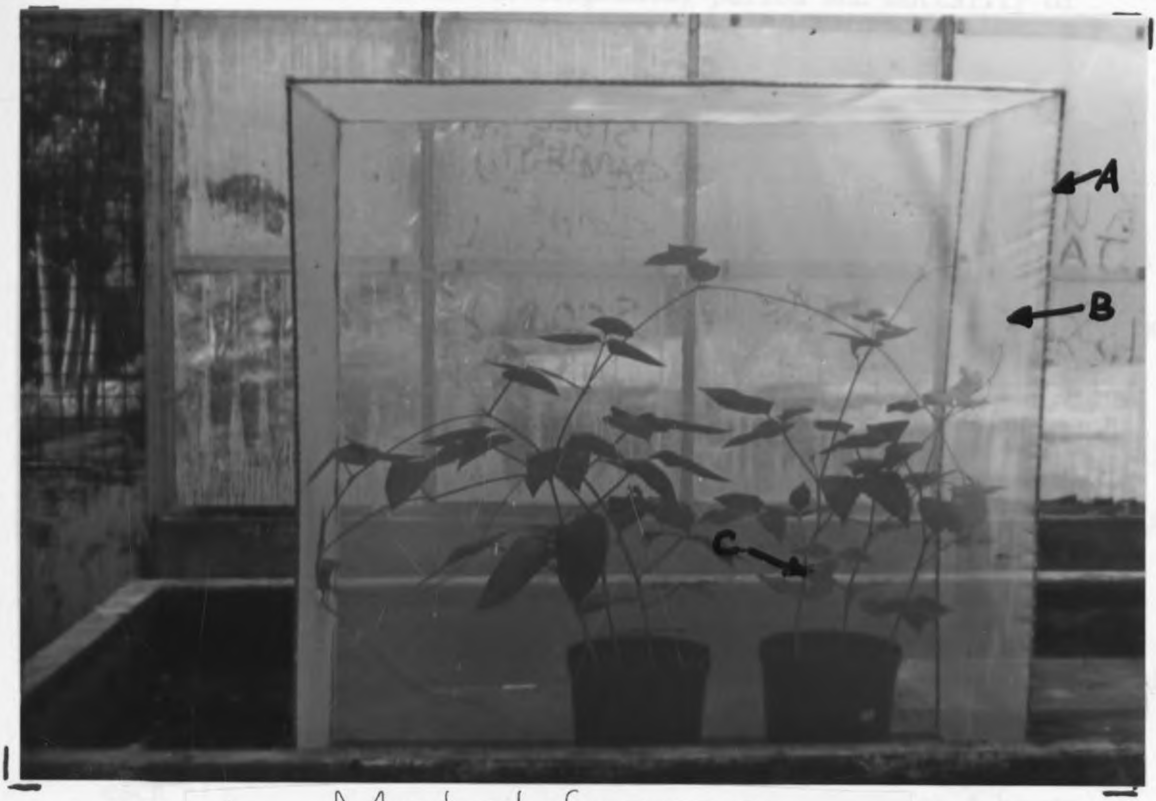
2.2.1. General procedure.

Experiments were conducted in the greenhouse at National Agricultural Laboratories (NAL), Kabete, to study some aspects of the

biology of A. craccivora on the cowpea plants. The cowpea cultivars used in these studies were: Katuli 107, Machakos 66, Katumani 4, Ex-Luanda, ER-1 and Tvu 310. Seeds for all these cultivars were obtained from Coast Agricultural Research Station (CARS), Mtwapa. These cultivars were selected because they are of agronomic interest and of considerable potential on the basis of seed yield for cultivation by farmers (Anon, 1974). Seedlings of these cultivars were raised in plastic pots (top diameter =22 cm). Six seeds were planted in each pot and the seedlings thinned to three per pot two weeks after planting. All the plants used in the experiments reported here were of uniform growth. The potting soil used consisted of virgin soil obtained from fallow land at NAL. No fertilizers were added as this would perhaps affect the expression of resistance.

Test insects used in these experiments were reared using whole plant cages similar to those described by van Emden (1972). The cages (Plate 1) consisted of iron frames (1x0.5x1 M) covered with fine nylon net mesh. Adults of A. craccivora were initially obtained from field populations breeding on cowpea. They were then reared on cowpea seedlings of cultivar Ex-Luanda in the greenhouse from which parasites and predators were excluded. Four days after larviposition, the mother aphids were removed and their progenies left to develop and multiply. This method allowed for large numbers of individual A. craccivora to be raised which were healthy and unparasitised. Freshly moulted A. craccivora adults obtained from the greenhouse colonies were used to infest experimental plants by transferring them with a wet camel's hair brush following the procedure described by van Emden (1972). Plant materials for

Plate 1. A photograph of the whole plant cage used for rearing A fraccivora.



A = Metal frame

B = Netting material

C = Potted plant

rearing aphids were watered every three days and changed every two weeks. Greenhouse temperatures were recorded throughout the experimental period and ranged between 20 and 30°C (Mean=27°C).

2.2.2. Studies on the developmental period and mortality of A. craccivora on six different cowpea cultivars under greenhouse conditions.

The purpose of the experiment reported here was to assess the influence of cowpea cultivars on the mean developmental period and nymphal mortality of the cowpea aphid, A. craccivora. Comparison of the developmental rates of the aphid and its nymphal mortality would serve to indicate the suitability of the cultivars as hosts of A. craccivora.

For each of the six cultivars tested three pots were used. One freshly moulted A. craccivora aptera adult was infested onto each plant. The aphids were allowed to reproduce for 4 hours after which only 5 of the nymphs born were left on each plant. The rest of the excess nymphs produced and their mother aphids were removed. This ensured that the nymphs remaining on the seedlings were of a fairly uniform age. The aphids were then left to grow and develop on the plants until larviposition.

Everyday the nymphs on each plant were inspected at intervals of 4 hours starting from 07.00 hours, to 18.00 hours, to assess the length of life cycle from one nymphal instar to the next. This observation was continued until the nymphs started producing young ones. Each aphid that started larvipositing was was removed from the plants and the appropriate time of first

larviposition recorded. From this, the period taken from birth to larviposition, being the developmental period was calculated. Additionally, data obtained also permitted estimation of each instar duration.

To ascertain mortality during developmental period, the proportion of the nymphs dying before reproducing were recorded.

2.2.3. Studies on the fecundity and longevity of A. craccivora on six different cowpea cultivars under greenhouse conditions.

Experiments were conducted to obtain information on the fecundity and longevity of A. craccivora when reared on six different cowpea cultivars under greenhouse conditions. This was necessary as the information obtained would be useful in indicating the potential reproductivity and lifespan of the aphids when fed on different cultivars. In addition data obtained would be useful in giving indication of the comparative resistance of the test cowpea cultivars to the aphids.

For this purpose, seedlings of each cowpea cultivar were infested with a single reproducing aphid. After 4 hours of larviposition, the mother aphid and all but one of its progeny were removed. Plants on which no young nymphs were produced during this short period were infested with one of the excess nymphs removed from other plants. The aphids were then allowed to develop for a period of one week after which they were inspected daily in the mornings at 08.00 hours. Any nymphs produced over a period of 24 hours were counted and then removed from the plant. The young aphids were removed to prevent overcrowding on test plants

and to avoid development of the second generation which would result if the progenies are allowed to grow to maturity.

To estimate longevity of the aphids, observations were began and continued at 12-hour intervals, when emaciation and reduced reproductivity indicated that the parent aphids were growing weaker. This interval of 12-hours was chosen in order to record the actual day on which each parent aphid died. This experiment was concluded upon the death of the last parent aphid in each cowpea cultivar.

2.2.4. Studies on the effect of cowpea cultivars on the size of apterae adults of A. craccivora under greenhouse conditions.

Experiments were conducted so as to ascertain, if there were any effects caused by cowpea cultivars, on the size of apterae adults of A. craccivora when reared on six different cowpea cultivars. The information yielded from the study would be useful in indicating the nature, if any, of resistance existing in the test cultivars.

Two newly emerged nymphs produced by the apterae mothers were transferred to leaves of the test cultivars. They were then allowed to grow and develop on the plants. Shortly after the final moult the adult apterae aphids were removed from the plants with a wet camel's hair brush and immobilised with 70% Ether, before being transferred onto a slide. The length of the adult, from the

vertex to the base of cauda, was measured using a compound stereoscopic microscope fitted with an occular micrometer.

2.2.5. Studies on the effect of cowpea cultivars on the abudance of the forms of A. craccivora under greenhouse conditions.

This experiment was conducted in order to determine the quantity of each aphid form (nymphs, apterae and alatae) that developed on each of the six different cowpea cultivars studied under the same conditions. This was done in order to obtain preliminary information on the relative productivity of aphid forms. Data obtained would be useful in indicating the nature of resistance existing in the test cultivars.

Single apterae adult aphids were transferred from the greenhouse aphid colonies to leaves of the test cultivars. They were left to reproduce for 24 hours. After that period, only 5 nymphs per plant were retained, while the adults and excess nymphs produced were removed. This ensured that all the nymphs left on the seedlings were of a nearly uniform age. The aphids were allowed to grow and develop for 14 days, which is the average generation time for A. craccivora. At the end of 14 days, all the aphids were brushed off onto a plain white sheet of paper, and the number of each form determined. The aphids were recorded either as nymphs, apterae (wingless adults) or alatae (winged adults).

2.2.6. Studies on the population development of A. craccivora on six different cowpea cultivars under greenhouse conditions.

The purpose of the experiment reported here was to study the build up of A. craccivora population on cowpea cultivars from three contrasting levels of initial aphid infestations over a period of 14 days. Data obtained would serve to indicate the influence of different cowpea cultivars on the build up of A. craccivora populations. This knowledge would give an indication on how this pest performs on different test cultivars.

Newly moulted A. craccivora adults were placed onto the cowpea seedlings at three infestation levels as follows: One aphid per plant; three aphids per plant; and five aphids per plant. Pots containing cowpea seedlings were arranged in a complete randomised design, replicated three times. The aphids were counted at intervals of two days starting two days after initial infestation. On each day of counting, all the aphids on three plants chosen at random for each level of initial aphid population were counted.

2.3. Results.

2.3.1. Developmental period and mortality of A. craccivora when reared on six different cowpea cultivars.

Table 1 shows the mean development period (DP) of

A. craccivora when reared on different cowpea cultivars. Analysis of variance (Appendix 1a) showed that the overall developmental period of A. craccivora significantly (P=0.05) differed among all the cultivars on which the aphids were bred. Data presented in Table 1 shows that A. craccivora nymphal instars fed on Ex-Luanda (DP=6.50 days) and Machakos 66 (DP=6.74 days) took significantly (P=0.05) shorter period to complete development than when they were fed on Katuli 107 (DP=7.41 days), ER-1 (DP=7.20 days) and Tvu 310 (DP=7.76 days). The duration of development of A. craccivora nymphs fed on Tvu 310 took significantly (P=0.05) longer period than when they were reared on Katuli 107 and ER-1. The developmental period of nymphs reared on Katumani 4 (DP=6.96 days) and Machakos 66 (DP=6.74 days) did not significantly (P=0.05) differ from each other.

Table 1 also shows data on durations of different nymphal instars of A. craccivora when reared on different cowpea cultivars. Analysis of variance (Appendices 1b, 1c, 1d,1e) showed that the nymphal durations for each of the instars (1st, 2nd, 3rd and 4th) significantly (P=0.05) differed on all the cultivars. For example the first nymphal instars reared on Katuli 107, Machakos 66, Katumani 4, Ex-Luanda, ER-1 and Tvu 310 had nymphal durations of 2.40, 1.90, 1.80, 2.59, 2.37 and 3.01 days, respectively, before moulting. The corresponding nymphal durations for fourth instars were 1.94, 1.26, 1.84, 1.36, 1.08 and 1.49 days when reared on the same cultivars.

Table 1. Developmental period (in days) of A. craccivora on different cowpea cultivars.

Cowpea cultivars	developmental period (in days)				
	length of nymphal instars				total developmental period (in days)
	1st nymphal Instar	2nd nymphal Instar	3rd nymphal Instar	4th nymphal Instar	
Tvu 310	3.01a	1.81b	1.45c	1.49b	7.76a
Katuli 107	2.40b	1.02e	2.05a	1.94a	7.41b
ER-1	2.37b	2.07a	1.68b	1.08a	7.20bc
Katumani 4	1.80c	1.46d	1.86ab	1.84a	6.96cd
Machakos 66	1.90c	1.72bc	1.86ab	1.26cd	6.74de
Ex-Luanda	2.59b	1.58cd	1.01d	1.36bc	6.50e
Overall mean	2.35	1.48	1.64	1.50	7.09
C.V.	21.11%	19.99%	21.86%	24.10%	14.33%

a, b, c, d, e: means in columns followed by the same letter are not significantly different from each other at P=0.05, according to Duncan's (1955) New multiple range test.

Considering the overall means of each nymphal instar presented in Table 1 regardless of cultivars used it was evident that the first nymphal instar took significantly (P=0.05) longer periods (2.35 days) to moult into second nymphal instars in comparison to the other stages of nymphal instars studied. On the other hand, it was observed (Table 1) that nymphal durations for the second third and fourth were almost identical (1.50 days) in that they did not differ significantly at the level of P=0.05.

These results (Table 1) further revealed that A. craccivora nymphs took a shorter time to complete their development when reared on Ex-Luanda, Machakos 66 and Katumani 4 than when they were bred on ER-1, Katuli 107 and Tvu 310 on which they took a considerably longer period of development. This indicated that the latter three cultivars were not suitable as hosts for nymphal development suggesting that they could have qualities of resistance against A. craccivora.

The percentage mortality of A. craccivora analysed after transformation using arc sin $\sqrt{(\text{proportion})}$ is given in Table 2. Analysis of variance showed that nymphal instar mortality significantly (P=0.05) differed among the test cowpea cultivars. The percentage number of nymphs dying before reaching reproductive maturity on Katuli 107, Machakos 66, Katumani 4, Ex-Luanda ER-1 and Tvu 310 was 22.13, 18.41, 36.83, 19.07, 16.89 and 47.65%, respectively. These results show that when A. craccivora nymphs were reared on ER-1, Ex-Luanda and Machakos 66 significantly (P=0.05) fewer nymphs died before completing their development than when the nymphs were reared on Tvu 310 and Katumani 4. However, mortality of nymphs reared on Katuli 107 was significantly lower

Table 2a. Percentage mortality of nymphs dying when A. craccivora nymphs were reared to maturity on six different cowpea cultivars under greenhouse conditions.

Cowpea cultivars	Percentage mortality
Katuli 107	22.13bc
Machakos 66	18.41c
Katumani 4	36.83ab
Ex-Luanda	19.07c
ER-1	16.89c
Tvu 310	47.65a
C.V.	31.77%
S.E. of treatment mean	4.92

a, b, c means followed by the same letter are not significantly different from each other at P=0.05, according to Duncan's (1955) New multiple range test.

b) Analysis of variance for mortality of A. craccivora on six cowpea cultivars during developmental period. Based on transformation arc sin (√proportion)

Sources of variance	df	SS	MSS	F
Blocks	2	978,3745	489.1873	6.730**
Treatments	5	2355.6155	471.1231	6.482**
Error	10	726.8244	72.6824	
Total	17	4060.8144		

than when the nymphs were reared on Tvu 310 and Katumani 4.

These results (Table 2) confirmed earlier observations on durations of nymphal development which indicated that Katumani 4 and Tvu 310 possessed some levels of resistance to the pest. The results (Table 2) also further showed that Ex-Luanda and Machakos 66 were the most susceptible cultivars to the pests since very low nymphal mortalities were recorded on them.

2.3.2. Fecundity and longevity of A. craccivora when reared on six different cowpea cultivars under greenhouse conditions.

Table 3 presents a summary of the mean number of nymphs produced by each mother aphid when bred on different cowpea cultivars. Analysis of variance (Table 3) showed that the variation in nymphal production experienced on different cowpea cultivars was significant at P=0.05 level. Data collected (Table 3) showed that significantly (P=0.05) fewer nymphs were produced when aphids were reared on Tvu 310 than on any other cowpea cultivar tested. Approximately twice as many nymphs were larviposited when the aphids were reared on ER-1 (30.17 nymphs) and Katumani 4 (32.83 nymphs) as compared to the number of nymphs produced when the aphids were bred on Tvu 310 (15.25 nymphs). Katuli 107, Machakos 66 and Ex-Luanda favoured the production of a higher number of nymphs per mother aphid reared on them, this being 46.75, 65.83 and 63.75 nymphs respectively.

It was evident from the data presented (Table 3) that varietal differences in terms of their influences on aphid fecundity existed among the cultivars tested. The cultivars Ex-Luanda and Machakos 66 which favoured the production of high population of nymphs on them

Table 3a. Fecundity of A. craccivora when bred on six different cowpea cultivars.

Cowpea cultivars	mean fecundity (nymphs/mother aphid)
Katuli 107	46.75b
Machakos 66	65.83a
Katumani 4	32.83c
Ex-Luanda	63.75a
ER-1	30.17c
Tvu 310	15.25d
C.V.	14.61%
S.E. (treatment mean)	1.79

a, b, c means in columns followed by the same letter are not significantly different from each other at P=0.05, according Duncan(s (1955) New multiple range test.

b) Analysis of variance of fecundity of A. craccivora on six different cowpea cultivars.

Sources of variation	df	SS	MS	F
Total	71	26563.65		
Treatments	5	24025.90	4805.18	124.97***
Error	66	2537.75	38.45	

*** significant at P=0.01

were regarded as being suitable hosts for the pest and therefore susceptible to it. On the other hand, it was concluded that Tvu 310 was the most resistant cowpea cultivar followed by ER-1 and Katumain 4 since aphids bred on them produced comparatively fewer nymphs than on the aforementioned two cultivars. These findings are also in agreement with earlier observations which indicated that these cultivars possessed some levels of resistance to A. craccivora when nymphal developmental periods and mortality were considered.

Data on longevity of A. craccivora adults when reared on the six different cowpea cultivars are presented in Table 4. These results (Table 4) showed that the longevity of the aphid significantly (P=0.05) differed among the test cultivars. The mean longevity of A. craccivora was 18.08, 18.58, 16.33, 19.17, 14.83 and 13.50 days when they were reared on Katuli 107, Machakos 66, Katumani 4, Ex-Luanda, ER-1 and Tvu 310, respectively. The longevity of A. craccivora on Tvu 310 was significantly (P=0.05) shorter than on the aphids reared on Ex-Luanda, Katuli 107, Machakos 66 and Katumani 4. Except for the longevity of aphids reared on Katumani 4, the lifespan of aphids reared on Katuli 107, Machakos 66 and Ex-Luanda did not differ significantly (P=0.05) from each other.

These results (Table 4) demonstrated further that the cultivars Tvu 310, ER-1 and Katumani 4 on which aphid survival was very short were resistant to the pest than cultivars Machakos 66 and Ex-Luanda on which the survival of the aphids appeared to be of normal duration.

Table 4a. Longevity of A. craccivora when bred on six different cowpea cultivars.

Cowpea cultivars	mean longevity (in days)
Katuli 107	18.08a
Machakos 66	18.58a
Katumani 4	16.33b
Ex-Luanda	19.17a
ER-1	14.83bc
Tvu 310	13.50c
C.V.	11.12%
S.E. (treatment mean)	0.54

a, b, c, means followed by the same letter are not significantly different from each other at P=0.05, according to Duncan's (1955) New multiple range test.

b) Analysis of variance on longevity of A. craccivora on six cowpea cultivars.

Sources of variation	df	SS	MS	F
Total	71	533.50		
Treatments	5	304.67	60.93	17.57***
Error	66	228.83	3.47	

*** significant at P=0.01.

Table 4a. Longevity of A. craccivora when bred on six different cowpea cultivars.

Cowpea cultivars	mean longevity (in days)
Katuli 107	18.08a
Machakos 66	18.58a
Katumani 4	16.33b
Ex-Luanda	19.17a
ER-1	14.83bc
Tvu 310	13.50c
C.V.	11.12%
S.E. (treatment mean)	0.54

a, b, c, means followed by the same letter are not significantly different from each other at P=0.05, according to Duncan's (1955) New multiple range test.

b) Analysis of variance on longevity of A. craccivora on six cowpea cultivars.

Sources of variation	df	SS	MS	F
Total	71	533.50		
Treatments	5	304.67	60.93	17.57***
Error	66	228.83	3.47	

*** significant at P=0.01.

2.3.3. Effect of different cowpea cultivars on size of apterous adult A. craccivora under greenhouse conditions.

Data on the mean size of adult apterous A. craccivora bred on different cowpea cultivars is presented in Table 5. These data (Table 5) showed that the size of aphids was affected significantly at P=0.05 level, when the pests were reared on different cowpea cultivars. Aphids reared on Katuli 107 and Ex-Luanda were significantly (P=0.05) larger than those which were reared on Machakos 66, Katumani 4, Tvu 310 and ER-1. However, aphids reared on Tvu 310 (body length =1.62 mm) were significantly (P=0.05) smaller than any of their counterparts reared on the other five cultivars (Table 5).

The sizes of the aphids reared on Machakos 66 (body length = 1.93 mm), Katumani 4 (body length =1.92 mm) and ER-1) (body length =1.88 mm) were not significantly (P=0.05) different when compared to each other. From these observations (Table 5) it was confirmed that Tvu 310 (resistant check) followed by ER-1 and Katumani 4 on which the aphids attained small sizes possessed some levels of resistance to the pest. On the other hand, Katuli 107 and Ex-Luanda were the most least resistant in that, aphid bred on them developed to attain large body sizes.

2.3.4. Effect of different cowpea cultivars on the abudance of the forms of A. craccivora under greenhouse conditions.

Three aphid forms observed were: alatae, apterae and nymphs (Table 6). Data assembled and analysed after transformation based on $\sqrt{(n+0.5)}$ showed that there were significant (P=0.05) differences

Table 5a. Size of adult apterous A. craccivora bred on six different cowpea cultivars.

Cowpea cultivars	mean length (mm) from vertex to base of cauda
Katuli 107	2.09a
Machakos 66	1.93b
Katumani 4	1.92b
Ex-Luanda	2.07a
ER-1	1.88b
Tvu 310	1.62c
C.V.	7.44%
S.E. (treatment mean	0.04

a, b, c, means followed by the same letter are not significantly different from each other at P=0.05, according to Duncan's (1955) New multiple range test.

b) Analysis of variance on the size of adult apterous A. craccivora bred on six different cowpea cultivars.

Sources of variation	df	SS	MS	F
Total	71	3.03		
cultivars	5	1.69	0.34	16.66***
Error	66	1.34	0.02	

*** significant at P=0.001.

in the numbers of alate aphids that developed on Katuli 107 (2.49 aphids), Machakos 66 (2.09 aphids), Ex-Luanda (1.83 aphids) and ER-1 (1.86 aphids) (Table 6; Appendix 2a). The number of alatae aphids that developed on Katumani 4 (0.61 aphids) and Tvu 310 (0.68 aphids) were significantly (P=0.05) fewer than their counterparts that were developed on the other four cultivars that were tested. This further demonstrated that the latter two cultivars were resistant to the pest.

It was further indicated that, with the exception of apterae aphids that developed on Tvu 310 (3.07 aphids), there were no significant (P=0.05) differences in the populations of this type of aphids that developed on Katuli 107 (4.06 aphids), ER-1 (3.97 aphids), Machakos 66 (3.83 aphids), Katumani 4 (3.76 aphids) and Ex-Luanda (4.01 aphids) (Appendix 2b). It was concluded from the foregoing observation that Tvu 310 was less suitable as host and therefore resistant cultivar to A. craccivora. This was further evidenced by the data collected (Table 5) on the number of nymphs produced by mother aphids when they were reared on different cowpea cultivars.

Nymphs that were produced by adult aphids reared on Katuli 107 and Ex-Luanda were 13.13 and 11.13 respectively, indicating that these cultivars favoured the development of large quantity of nymphs on them. It was also evident from the data collected (Table 6, Appendix 2c) that Katumani 4 (11.81 nymphs), ER-1 (11.27 nymphs) and Machakos 66 (11.04 nymphs) favoured the high nymphal development suggesting they are also suitable hosts for the pest. On Tvu 310 which is the resistant check only a small quantity (4.35 nymphs) of the nymphs were produced. These findings are not in conformity with

Table 6. Effect of cowpea cultivars on abundance of forms of A. craccivora under greenhouse conditions.

cowpea cultivars	mean number of aphid forms		
	alate	apterae	nymphs
Katuli 107	2.49a	4.06a	13.13a
Machakos 66	2.09a	3.83a	11.04b
Katumani 4	0.61b	3.76a	11.81b
Ex-Luanda	1.83a	4.01a	11.13b
ER-1	1.86a	3.97a	11.27b
Tvu 310	0.68b	3.07b	4.35c
C.V.	36.89%	8.59%	6.51%
S.E.(treatment mean)	0.34	0.188	0.393

a, b, c, means in columns followed by the same letter are not significantly different from each other at P=0.05, according to Duncan's (1955) New multiple range test.

Table 6. Effect of cowpea cultivars on abundance of forms of A. craccivora under greenhouse conditions.

cowpea cultivars	mean number of aphid forms		
	alate	apterae	nymphs
Katuli 107	2.49a	4.06a	13.13a
Machakos 66	2.09a	3.83a	11.04b
Katumani 4	0.61b	3.76a	11.81b
Ex-Luanda	1.83a	4.01a	11.13b
ER-1	1.86a	3.97a	11.27b
Tvu 310	0.68b	3.07b	4.35c
C.V.	36.89%	8.59%	6.51%
S.E.(treatment mean)	0.34	0.188	0.393

a, b, c, means in columns followed by the same letter are not significantly different from each other at P=0.05, according to Duncan's (1955) New multiple range test.

regard to Katumani 4 which in earlier observations was shown as being resistant to the pest.

2.3.5. Population development of A. craccivora on six different cowpea cultivars under greenhouse conditions.

The population build up of aphid numbers on six different cowpea cultivars is presented in Table 7. The data (Table 7) showed that the aphid numbers were greatest on Ex-Luanda among all the other five cultivars studied, for all the levels of initial aphid infestation applied.

It was found that the number of aphids per plant after 14 days of reproduction on Katuli 107, Machakos 66, Katumani 4, Ex-Luanda, ER-1 and Tvu 310 were 67.8, 86.0, 82.0, 197.0, 33.3 and 24.2 aphids, respectively, when initially one aphid was infested per plant (Table 7). Table 7 also shows that at the initial infestation level of three aphids per plant their numbers on cultivars Katuli 107, Machakos 66 Katumani 4, ER-1, Ex-Luanda and Tvu 310 were 124.5, 144.0, 174.4, 250.5, 79.2 and 39.8 aphids respectively, at the end of 14 days. The corresponding numbers of aphids starting from the initial infestation level of 5 aphids per plant were 157.6, 199.0, 251.0, 363.3, 119.7 and 60.3 aphids when reared on the same cultivars.

The pattern of population increase of A. craccivora on six different cowpea cultivars when infested at initial levels of one, three and five adults per plant is shown in Figs 1, 2, and 3. The pattern of population development differed according to each of the cultivars used. It is further shown that the patterns of population increase of A. craccivora were similar for

Table 7. Mean number of A. craccivora under three infestation levels on six different cowpea cultivars.

Cowpea cultivars	level of infestation	mean no. of aphids/plant						
		Days after initial infestation						
		2	4	6	8	10	12	14
Katuli 107	1	18.67	30.33	35.89	42.55	55.67	60.78	67.78
	3	26.8	38.6	43.2	55.1	84.7	91.4	124.5
	5	28.0	50.2	62.3	91.8	122.7	141.1	157.6
Machakos 66	1	9.56	25.33	30.56	39.89	55.5	65.22	86.0
	3	14.9	26.9	30.4	48.7	86.3	98.6	144.0
	5	31.5	69.4	74.2	74.6	150.1	168.2	199.0
Katumani 4	1	7.2	19.78	25.67	31.56	46.33	62.11	101.3
	3	9.8	19.6	43.1	55.0	85.3	89.6	174.4
	5	31.8	44.7	96.2	109.2	142.4	160.1	251.0
Ex-Luanda	1.	6.54	18.78	36.4	53.1	79.6	119.8	197.0
	3	19.3	76.2	84.0	93.7	182.3	200.4	250.5
	5	37.7	79.9	94.5	119.9	250.0	289.6	363.3
ER-1	1	5.38	14.9	19.1	21.1	22.9	30.1	33.3
	3	16.6	19.7	28.1	31.7	60.4	64.5	79.2
	5	31.1	32.3	40.0	50.0	79.8	109.5	119.7
Tvu	1	4.6	7.9	14.0	16.2	19.8	21.9	24.2
	3	8.4	11.9	16.6	19.1	32.6	35.5	39.8
	5	11.9	24.8	36.0	41.1	47.7	52.3	60.3

Fig 1 POPULATION INCREASE OF A CRACCIVORA ON SIX COWPEA VARIETIES FROM INITIAL INFESTATION OF ONE APHID PER PLANT.

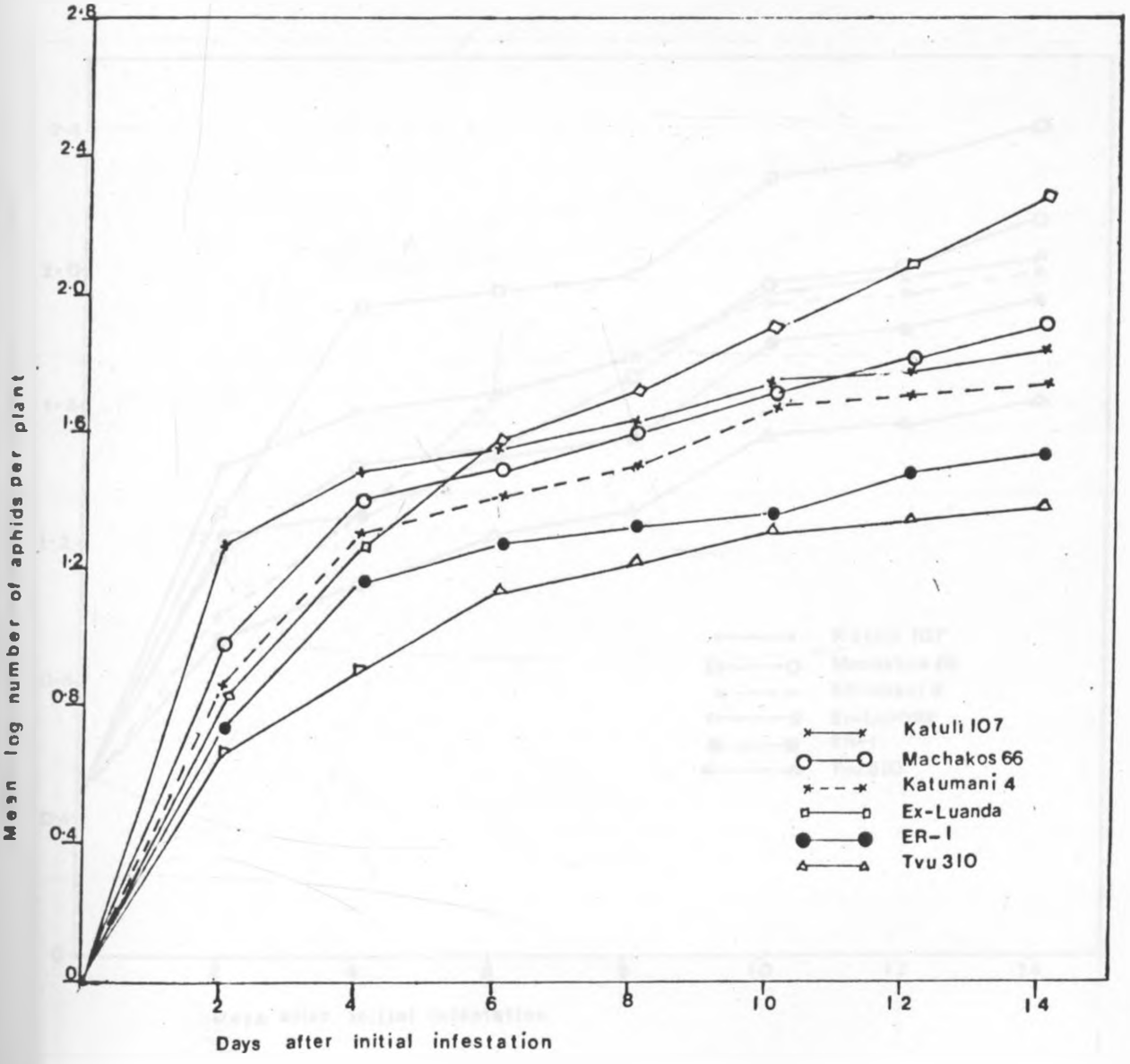


Fig 2 POPULATION INCREASE OF A CRACCIVORA ON SIX COWPEA VARIETIES FROM INITIAL INFESTATION OF THREE APHIDS PER PLANT

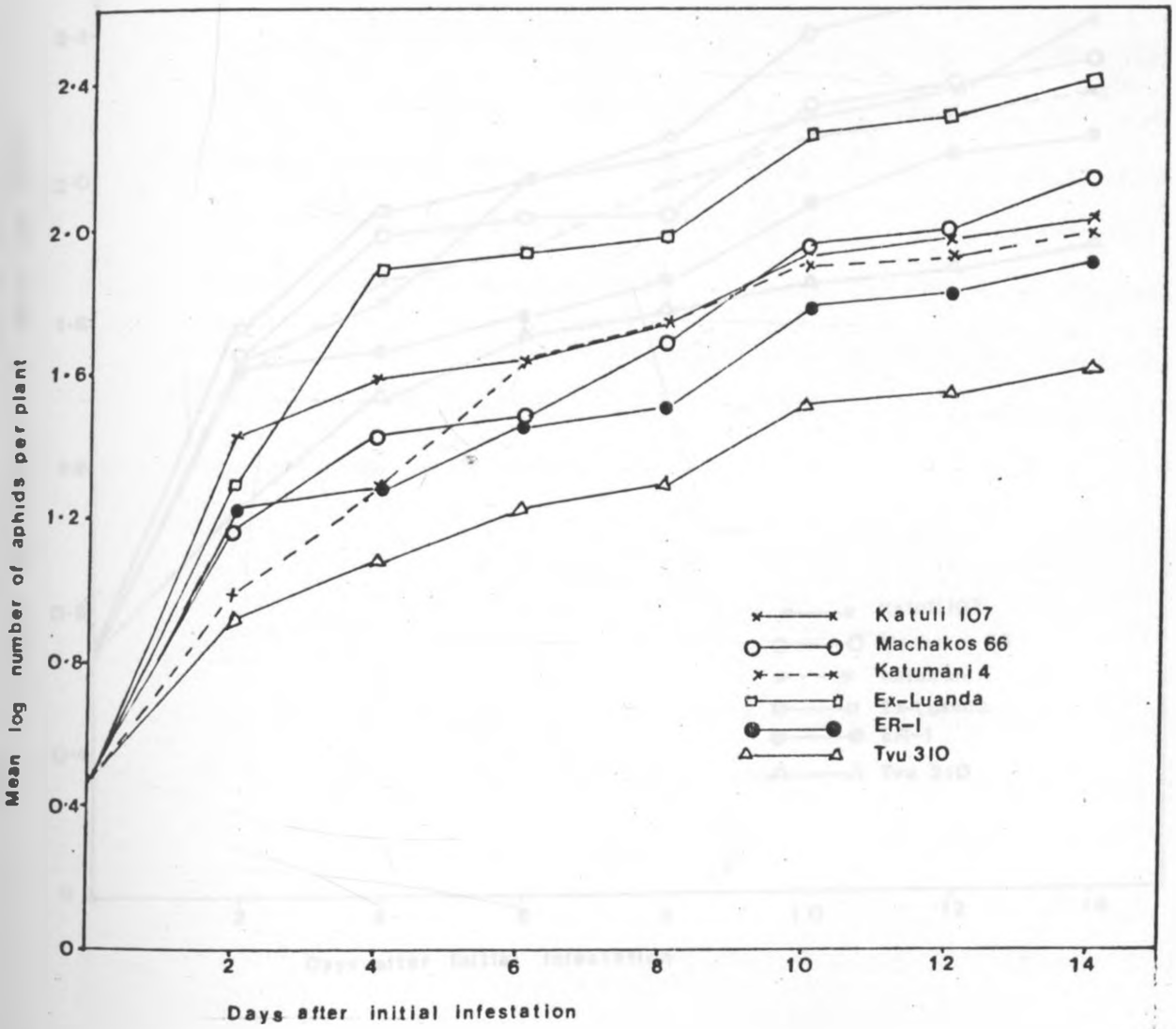
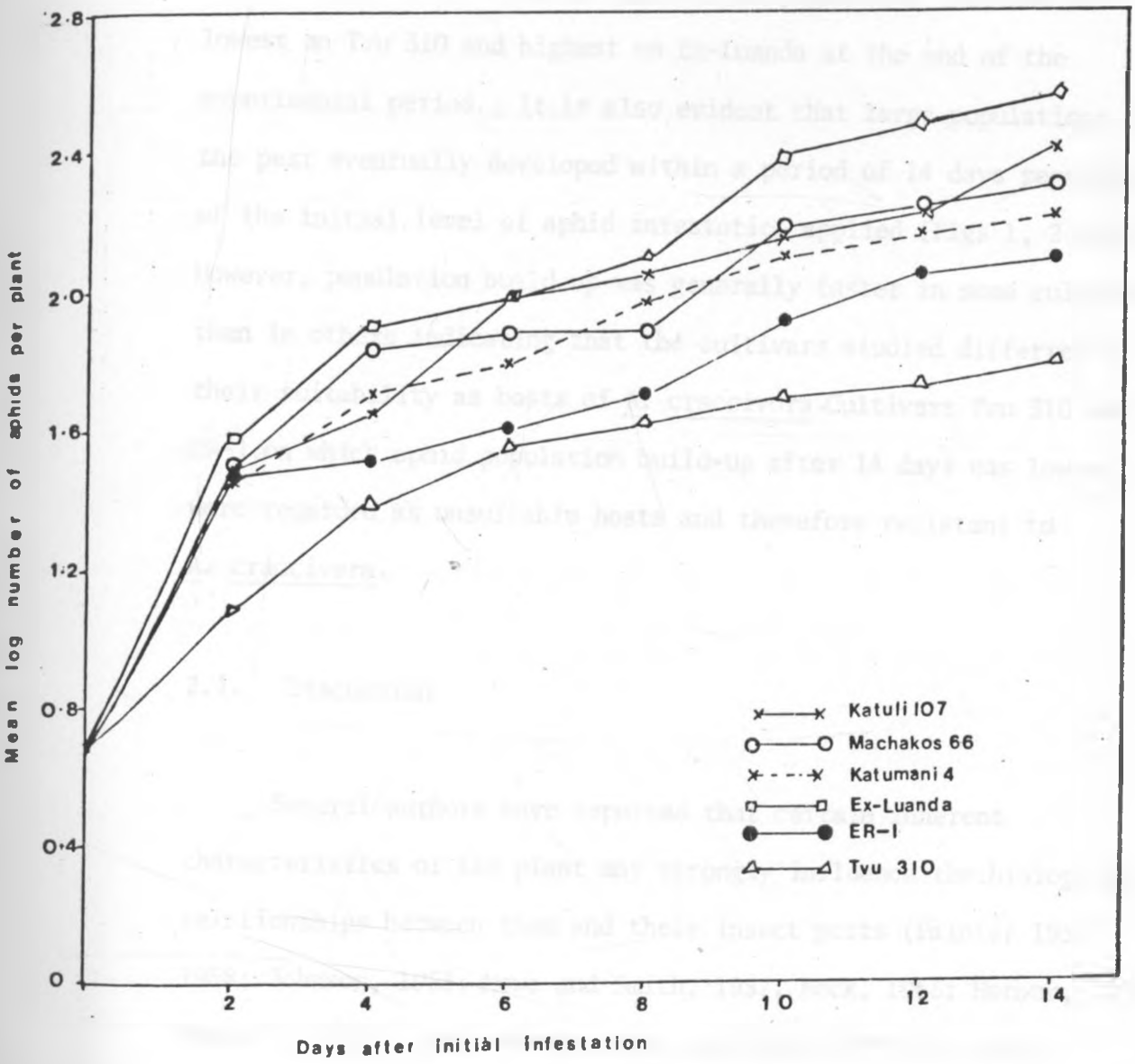


Fig 3 : POPULATION INCREASE OF A CRACCIVORA ON SIX COWPEA VARIETIES FROM INITIAL INFESTATION OF FIVE APHIDS PER PLANT.



all the three levels of initial infestation applied on the cowpea cultivars that were tested (Figs 1, 2, and 3).

When one, three and five aphids per plant were initially used to start aphid colonies, the pattern of population increase was lowest on Tvu 310 and highest on Ex-Luanda at the end of the experimental period. It is also evident that large populations of the pest eventually developed within a period of 14 days regardless of the initial level of aphid infestation applied (Figs 1, 2 and 3). However, population build up was generally faster in some cultivars than in others indicating that the cultivars studied differred in their suitability as hosts of A. craccivora. Cultivars Tvu 310 and ER-1 on which aphid population build-up after 14 days was lowest were regarded as unsuitable hosts and therefore resistant to A. craccivora.

2.4. Discussion

Several authors have reported that certain inherent characteristics of the plant may strongly influence the biological relationships between them and their insect pests (Painter 1951, 1958; Johnson, 1953; Howe and Smith, 1957; Beck, 1965; Horber, 1972; Maxwell, 1972). For example, Howe and Smith (1957) in their studies reported that the biology of the spotted alfalfa aphid was adversely affected when aphids were reared on resistant plants. They further reported that a 100% mortality of introduced spotted alfalfa aphids occurred within 72 hours on highly resistant plants.

From the data assembled in these investigations it was apparent that there were variations in the duration of nymphal development, mortality rates, size of individual aphids, fecundity rates and build up of populations when A. craccivora were reared on different cowpea cultivars. The cowpea aphid, A. craccivora performed poorly on Tvu 310, Katumani 4 and ER-1 indicating that these cultivars were resistant to the pest. Indeed, the cultivar Tvu 310 had already been identified as being resistant to the aphid (Singh 1979; ICIPE, 1981, 1982; IITA 1978, 1982) and was used in these investigation as resistant check cultivar. The other two cultivars had not been identified as specifically being resistant to A. craccivora. Anyhow ER-1 developed at IITA is reported to have multiple resistance to pests and diseases, and this is the first time it has been demonstrated that the cultivar possesses resistance against cowpea aphid.(IITA, 1982).

The mechanism of resistance in Katumani 4 and ER-1 against A. craccivora was thought to be essentially the same as that which has been reported for Tvu 310 by Singh (1979). In his studies, Singh (1979) reported that A. craccivora reared on Tvu 310 had lower fecundity rates and higher mortality rates. He attributed this as being due to antibiosis mechanism of resistance. Singh's (1979) observations were recently confirmed by studies conducted locally in Kenya (ICIPE, 1981, 1982).

It was also observed in these studies that the developmental periods of nymphs in Katumani 4 and ER-1 took longer time to reach maturity and subsequently aphid population development was affected. When A. craccivora were reared on ER-1 and Katumani 4 they affected

the aphid in the same manner as described for cultivar Tvu 310. It is for this reason that it was considered that Katumani 4 and ER-1 possessed the same mechanism of resistance as Tvu 310 which is known to have antibiosis.

Howe and Smith (1957) found that adult spotted alfalfa aphids produced fewer nymphs on resistant than on susceptible plants. In these studies this did not happen in the case of Katumani 4 which was regarded as being resistant. The reasons for Katumani 4 favouring the development of large quantities of nymphs were not immediately known.

It was also observed in these studies that only a small proportion of the aphid colonies developed on resistant cultivars were alatae. The reason for this was also not immediately known although the involvement of nutritional factors and crowding effects which have been suggested by earlier researchers conducting similar studies were suspected (Johnson, 1965, 1966; Lees, 1967; Gutierrez et al 1971; Raccah et al, 1971). Whatever the mechanism operating in plants, the reduction of production of the alatae form of resistant plants is of considerable significance since it is the alatae form that migrate and colonize other suitable host plants. From this observation it can be argued therefore that planting of resistant varieties leading to production of smaller proportions of alatae forms is advantageous in that there would now be fewer aphids that can perform migration to spread the disease.

Unfortunately, however, there is an indication that cowpea cultivars identified as being resistant to A. craccivora are susceptible to serious virus infection transmitted by the aphid (Atiri et al, 1984). In this case it means that only a few winged adults performing migration could cause untold damage to cowpea crops. This observation would mean that the advantage of resistant varieties leading to production of smaller proportions of the alatae form is of negligible significance. It was therefore concluded that it would be more advantageous from the point of view of aphid infestation and virus disease transmission to breed varieties which incorporate resistance qualities for both and more especially against viruses. The reason for this apparently is that the cultivars tested influenced aphid population development differently. This was supported by observations which showed that, for example, aphids bred on Tvu 310 (resistant check) did not multiply at the same rate as those that were bred on Ex-Luanda which was regarded as being susceptible to the pest.

It was further observed in these studies that aphid populations developed more rapidly from initial higher population levels than from lower ones. It was evident from these investigations that because of the shorter nymphal developmental periods, low mortality rates coupled with the high fecundity rates of the cowpea aphid when bred on Ex-Luanda and Machakos 66, this led to rapid increase in the population of the aphid even from very low initial infestation levels (1aphid/plant) on these cultivars. On the other cultivars that were tested the opposite was the case. This clearly showed that Ex-Luanda and Machakos 66 were suitable

hosts of the pest and therefore susceptible to it. This demonstrated that harmful proportions of the aphid could develop within a very short time on susceptible plants causing considerable damage to them. Ogenga-Latigo (1983) was of the same opinion after he conducted similar studies with regard to initial infestation levels of A. fabae when reared on the common bean. Other relevant studies have been reported by Davidson (1925) and Barlow (1977).

CHAPTER 3

GREENHOUSE STUDIES ON THE INFLUENCE OF A. CRACCIVORA INFESTATION ON GROWTH AND YIELD COMPONENT OF COWPEA

3.1 Introduction

It has been reported that high aphid populations cause damage to host plants and the degree of such damage varies with varying aphid population levels (Judenko et al, 1952; Barlow, 1977, Singh and van Emden, 1979; Ogenga-Latigo, 1983). In their study of field beans, Judenko et al (1952) found that the attack of A. fabae on Vicia faba (L.) in the field resulted in significant reduction in mean stem length. They further observed that reduced seed yield was due to fewer pods which also were smaller in size and contained fewer and light seeds as a result of the feeding activities of aphids. In a recent study conducted by Ogenga-Latigo (1983) similar damage effects were observed when different levels of A. fabae were reared on P. vulgaris.

Similar information is lacking for cowpea when infested by its aphid, A. craccivora at varying levels of population intensities. In view of the fact that cowpea has become an important food crop in Kenya (Muruli et al, 1980) and that the crop is usually infested by A. craccivora wherever it is grown in the country (Karel, 1979) it became necessary to conduct studies reported here to ascertain whether aphid infestation affected, in any way, the performance of the crop. The other objective was to find out whether any of the cowpea cultivars tested possessed qualities for aphid resistance that could be tapped for its control.

3.2 Materials and Methods

Cowpea cultivars listed in section 2.2.1 were grown in pots at the rate of six seeds per pot. The seedlings were thinned to three plants per pot 14 days after planting. Newly moulted A. craccivora apterous adults were placed onto cowpea seedlings at the following infestation levels:

(i) 0 aphid per plant (control)

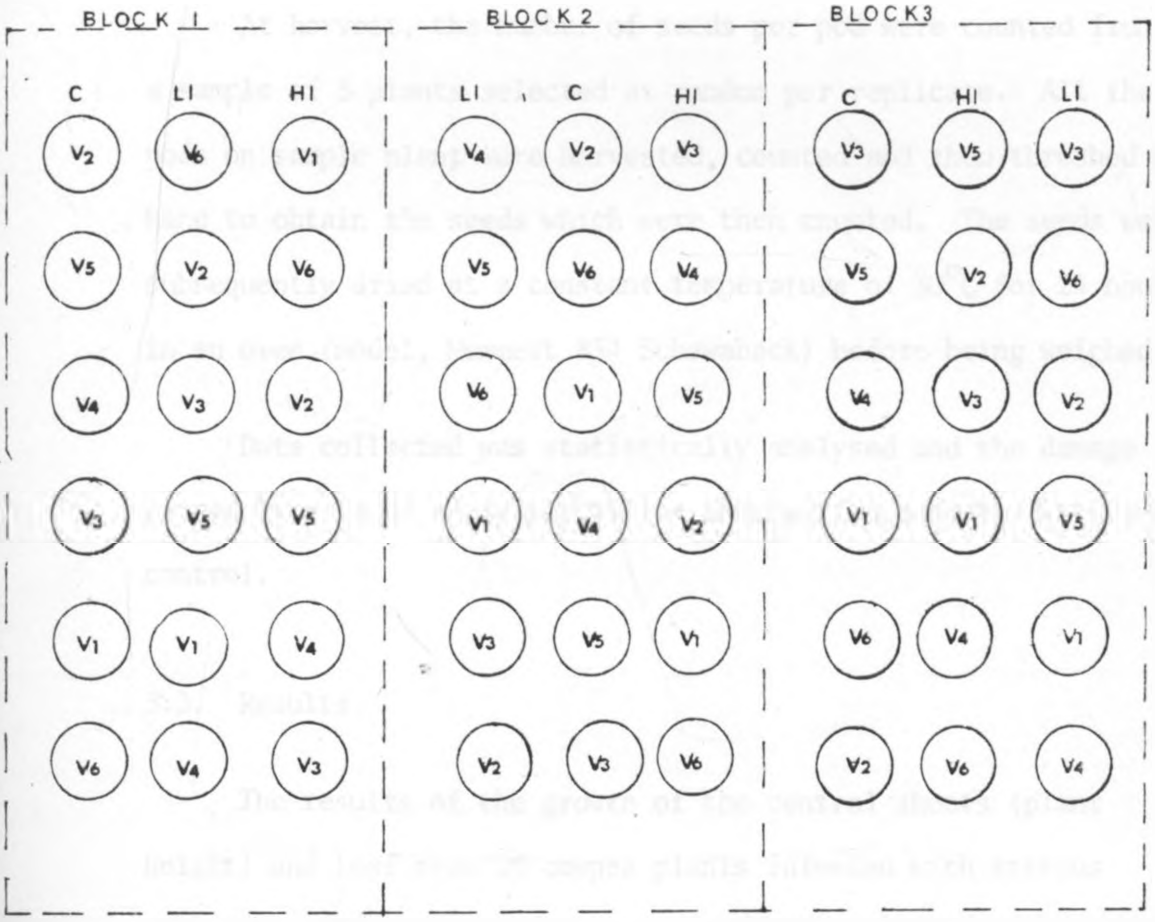
(ii) 2 aphids per plant

(iii) 4 aphids per plant

Pots containing test plants were arranged in complete randomised blocks, replicated 3 times. The greenhouse layout of the experiment was as shown in Fig. 4. The different population intensities were allowed to develop and multiply on the cowpea cultivars for 50 days up to the late vegetative phase (8 weeks old seedlings). During this period aphids were counted at intervals of two days starting two days after the initial infestation to ensure that none of the aphids placed onto the plants was lost or died. Any aphid found to have died or lost was replaced with aphids of about the same age. Aphid population counts were also done at the end of the experimental period.

Plant height and leaf area were determined 50 days after infestation. Plant height was determined by measuring the central shoots. This was taken as being the length of the shoots from the base of the stems above the soil surface to the tip of the vegetative bud of shoots. Leaf area was measured from samples of nine leaves per cultivar selected at random on the third node

Fig 4 Greenhouse layout of the experiment on the effect of various aphid population intensities on growth and yield in cowpea



KEY

V_1 – Katumani 4
V_2 – Katuli 107
V_3 – Machakos 66
V_4 – ER – 1
V_5 – Ex – Luanda
V_6 – Tvu 310

C – Control 0 aphid/ plant
LI – low infestation 2 aphids/plant
HI – High infestation 4 aphids/plant

– Pots contain 3 uniformly growing plant

of each plant. Leaves were harvested, placed in polythene bags and taken to the laboratory for leaf area determination using Delta-T leaf area metre (Model, AM T/2).

At harvest, the number of seeds per pod were counted from a sample of 3 plants selected at random per replicate. All the pods on sample plant were harvested, counted and then threshed by hand to obtain the seeds which were then counted. The seeds were subsequently dried at a constant temperature of 30°C for 24 hours in an oven (model, Memmert 854 Schawaback) before being weighed.

Data collected was statistically analysed and the damage caused by various aphid population intensities compared with the control.

3.3. Results

The results of the growth of the central shoots (plant height) and leaf area of cowpea plants infested with various aphid population intensities are presented in Table 8. The table shows that the reduction in growth of the central shoots was significantly (P=0.05) greater on cowpea cultivars infested with four aphids per plant than on those that were infested with two aphids per plant.

Analysis of variance of the data collected (Appendix 3a, Table 8) showed that there were significant (P=0.01) differences in the reduction of the height of the central shoots caused by different aphid population intensities. The percentage reductions of the central shoots of plants infested at the population intensity of 4 aphids per plant were by 59.14, 64.80, 29.95,

Table 8: Mean plant height and leaf area of different cowpea cultivars infested at three population intensities of A. craccivora under greenhouse conditions.

Cowpea cultivars	Initial no. of aphids per plant	No. of aphids per plant at end of 50 days	Mean plant height (cm)	Mean leaf area (cm^2)	% reduction of plant height as compared with control	% reduction of leaf area as compared with control
	0	-	130.13a	96.0	-	-
Katuli 107	2	655.87	54.87b	90.33	57.83	5.91
	4	975.94	53.17c	86.50	59.14	9.89
	0	-	68.67a	156.43	-	-
Machakos 66	2	754.45	26.576	122.73	61.31	21.54
	4	997.30	24.17c	76.83	64.80	50.89
	0	-	107.70a	162.00	-	-
Katumani 4	2	357.21	87.33b	158.77	18.91	1.99
	4	629.51	78.67c	154.00	26.95	4.94
	0	-	127.33a	82.23	-	-
Ex-Luanda	2	855.56	56.30b	54.60	55.78	33.60
	4	975.31	37.90c	52.07	70.23	36.68
	0	-	103.40a	119.07	-	-
LR-1	2	575.52	51.90b	101.33	49.81	14.89
	4	748.57	27.97c	96.10	72.95	19.29
	0	-	142.47a	213.80	-	-
TVu 310	2	142.80	112.87b	206.27	20.78	3.52
	4	259.85	104.70c	204.67	26.50	4.27

a,b,c, means followed by the same letter are not significantly different from each other at P=0.05, according to Duncan's (1955) New Multiple range test.

70.23, 72.95 and 26.5 on Katuli 107, Machakos 66, Katumani 4, Ex-Luanda, ER-1 and Tvu 310, respectively, as compared with the control at the end of the experimental period which was 50 days. However, when cowpea cultivars were infested with two aphids per plant, the percentage reductions in the growth of the central shoots on Katuli 107, Machakos 66, Katumani 4, Ex-Luanda, ER-1 and Tvu 310 were by 57.83, 61.31, 18.91, 55.78, 49.81 and 20.78, respectively.

These results indicated that significantly (P=0.05) less damage was caused on the shoots of Tvu 310 and Katumani 4 at both high and low population levels. However, significantly (P=0.05) greater damage was caused on ER-1, Machakos 66 and Ex-Luanda at both high and low aphid population levels. This, therefore, confirmed findings reported in Chapter 2 that Katumani 4 and Tvu 310 possessed some levels of resistance to A. craccivora, whereas Ex-Luanda and Machakos 66 did not.

Table 8 also shows data obtained when leaf area of different cowpea cultivars infested with varying aphid population intensities was measured. High aphid population intensities caused significant (P=0.05) reduction in leaf area as compared to the control.

Analysis of variance (Appendix 3b) showed that the leaf area of the cowpea cultivars tested was significantly influenced by the level of the aphid populations that were applied. For cultivars infested with high aphid population intensities per plant, the reductions of leaf area were by 9.89%, 50.89%, 4.94%, 36.68%, 19.29% and 4.27% for Katuli 107, Machakos 66, Katumani 4,

Ex-Luanda, ER-1 and Tvu 310, respectively, as compared with the control. The corresponding data of leaf area reduction when a low level of aphid population was applied on Katuli 107, Machakos 66, Katumani 4, Ex-Luanda, ER-1 and Tvu 310 were by 5.91%, 21.54%, 1.99%, 33.60%, 14.89% and 3.52%, respectively, as compared with the control.

These results (Table 8) revealed that like for the other parameters already studied, Tvu 310 (resistant check) and Katumani 4 suffered the least damage at both high and low aphid population levels in comparison to the other cultivars studied. This was further confirmation that Tvu 310 and Katumani 4 possessed some degree of resistance to cowpea aphids.

The mean number of seeds produced per pod by cowpea cultivars when infested by different levels of aphid population intensities are presented in Table 9. These data (Table 9) shows that at each level of aphid population intensity, the feeding effects of A.craccivora reduced the number of seeds produced per pod. However, the number of seeds produced varied from cultivars to cultivar at P=0.01 level (Appendix 4a). Table 9 shows further that seed reduction was severest on the crop when a high aphid population intensity was used. This high aphid population intensity caused reductions of 2.3, 5.1, 1.2, 2.3, 1.6 and 1.4 seeds per pod in Katuli 107, Machakos 66, Katumani 4, Ex-Luanda, ER-1 and Tvu 310, respectively, as compared to the control.

At low population intensity a significant (P=0.05) reduction to the seeds produced per pod in Machakos 66 was caused as compared to the control (Appendix 4a).

Table 9. Mean seed number per pod of different cowpea cultivars infested at different initial levels of A. craccivora

Cowpea cultivars	Level of aphid infestation			Overal mean seed no. per pod due to infestation
	0	2	4	
	mean seed number per pod			
Katuli 107	9.5	8.5	7.2	8.4
Machakos 66	13.2	10.9	8.1	10.7
Katumani 4	9.9	9.5	8.7	9.7
Ex-Luanda	7.9	6.3	5.6	6.6
ER-1	7.5	7.2	5.9	6.9
Tvu 310	13.7	12.8	12.3	12.9
Overall mean seed number due to cowpea cultivars	10.3	9.2	7.9	9.13

LSD 0.05: (i) For differences among cultivars means = 1.66 seeds,

(ii) For differences among infestation means = 4.73

(iii) For differences among infestation means same level of cultivar = 11.57

This was not the case with all the other cultivars tested at the same level of aphid infestation. This indicated that the cultivar Machakos 66 was highly susceptible to the pest.

The average weight of seeds produced per pod were also reduced as a result of the feeding activities of aphids (Table 10). Data obtained for the feeding effects of aphids when an initial infestation level of 2 aphids per plant was applied indicates that there was a general reduction in seed weight from the control. The main effects of the cultivars, infestation and their interraction were significant at P=0.05 level (Appendix 4b). There was a steady decrease in seed weight which could be as a result of the interaction between the cultivars and the aphid population intensities. Further, the significant main effects of cultivars was as a result of the average variental yields over all the infestation of aphid population intensities, and not to the yields with a particular aphid infestation level.

3.4 Discussion

It was shown in these studies that A.craccivora attack on cowpeas caused serious reduction in the growth of shoots, leaf area and seed yield. This reduction generally became greater with the increase in number of aphids. Evidence of this exists in

Table 10. Mean seed weight per pod of different cowpea cultivars infested with different initial levels of A. craccivora.

Cowpea cultivars	Level of aphid infestation			Overall mean seed weight due to infestation
	0	2	4	
	Mean seed weight/pod			
Katuli 107	0.92	0.78	0.66	0.79
Machakos 66	1.75	1.12	0.55	1.14
Katumani 4	1.06	0.92	0.78	0.92
Ex-Luanda	0.89	0.37	0.24	0.49
ER-1	0.91	0.72	0.47	0.69
Tvu 310	2.19	1.89	1.73	1.94
Overall mean seed weight/pod due to cultivars	1.29	0.96	0.74	0.99

LSD: 0.05 (i) For differences among cultivar means = 0.25g

(ii) For differences among infestation means = 0.09g

(iii) For differences among infestation level means same level of cultivar = 0.22g.

literature showing that insects which feed exclusively on sap cause damage to plants which is not immediately obvious but subsequently leads to poor performance of the affected plants (Hackerott, et al 1963; Dixon, 1971a,b; Barlow, 1977). For instance Dixon (1971b) showed that the feeding of the sycamore aphid could reduce development of sycamore stem wood by as much as 280%. In their studies Hackerott et al (1963) also reported that estimated losses of alfalfa hay production due to pea aphid infestation was 4.1% representing an annual loss of over 30 million dollars. In the case of A. craccivora feeding on cowpeas it was on the overall found that it reduced shoot height, leaf area and seed yield of test cultivars considered together by 48.75%, 17.22% and 35.9%, respectively.

Dixon (1971a,b) suggested that substances injected by aphids during feeding could inhibit growth. The saliva of aphids is known to contain phenolic substances which generally act as plant growth inhibitors (Thomaszewski and Thimman, 1966). Judging from the foregoing observations it was suggested that A. craccivora investigated in the studies reported here secreted similar salivary substances which had adverse effects on the general performance of cowpea.

CHAPTER 4

DETERMINATION OF COWPEA RESISTANCE IN THE FIELD TO A. CRACCIVORA

4.1 Introduction

It has long been recognised that host plant resistance is a variable tool in pest management and is considered as being an ideal way of reducing damage to crops by pests (Painter, 1951, 1958; Beck, 1965; Grison, 1965; Horber, 1972; Brader, 1973; Singh, 1979; IITA, 1982). Singh (1979) emphasized the need to establish in grain legumes meaningful control strategies in relation to host plant resistance and pest management. Lack of basic knowledge of host plant resistance to A. craccivora and its significance to pest management is still unexploited in cowpea in Kenya.

Cowpea is a crop in which the value of insect resistance is immense since it is a low value crop (Singh, 1978). It is generally known that genes for resistance to pests and diseases exist in crop germplasm and could be identified in field screening trials (Painter, 1951). It is not known whether plant characters for resistance to A. craccivora exist in cowpea cultivars currently being developed for commercial cultivation by farmers in Kenya. Therefore the purpose of the investigations reported in this Chapter was to identify in the field if any of the selected cowpea cultivars were resistant to cowpea aphids. Other studies reported here involved the quantification of the effects of aphid infestation on plant growth and the eventual yield realised.

4.2 Materials and Methods

4.2.1 Field incidence of A. craccivora on six different cowpea cultivars.

This experiment was aimed at assessing the incidence and development of A. craccivora on different cowpea cultivars when grown under field conditions. Knowledge gained from these studies would be useful in indicating the level of susceptibility of the test cultivars to the cowpea aphid.

The experiment was conducted at Chiromo and University farm, Kabete. The field trials consisted of the six cowpea cultivars previously used in all the other experiments reported in this thesis except Ex-Luanda which due to insufficient quantity of planting seeds, was not tested. Vita 4 was therefore used in its place. The field layout consisted of a randomised design of three blocks of 4x5M each. The cowpea cultivars were randomly planted in each block spaced at 75 cm between rows and 20 cm between plants.

Sampling of infested and uninfested plants for aphids was started 4 days after the plants had been thinned two weeks after planting. This was conducted at intervals of one week for four weeks. This was intended to assess primary migration only, since after this period of infestation winged aphid migrants from the colonies on the plants would usually cause secondary infestation on plants. During sampling all the plants in each row for each cultivar were counted and examined to record the number of plants infested and those that were not infested. The percentage of plants infested was then calculated. The data collected was statistically analysed after transformation based on arc sin $\sqrt{(\text{proportion})}$.

4.2.2 Cowpea varietal response to A. craccivora feeding under field conditions

The purpose of this experiment was to determine whether aphid infestation in the field like in the greenhouse influenced plant growth and seed yield. This was intended to verify whether the nature of damage caused by the aphid infestation in the field was similar to the one they cause to the crop in the greenhouse. This would reveal whether the cultivars identified in the greenhouse as being resistant to A. craccivora were also resistant to the pest under field conditions. To evaluate these factors six cowpea cultivars were grown in single rows of 5 m long spaced at 75 cm and 20 cm between rows and plants, respectively. The field layout consisted of a randomised design consisting of three blocks of 9x5 m each. Each block contained two subplots each measuring 4x5 m. Spacing between blocks and plots was 1.5 m and 1.0 m, respectively.

One half of each block received protection from aphids by spraying with dimethoate, while the other half was not sprayed and was left to be naturally infested by aphids. Attempts were made to control predators by spraying the infested subplots with cabaryl which is not harmful to aphids (Singh, 1979). Natural infestation of A. craccivora was reinforced by placing heavily infested cowpea leaves and stems on the experimental plants. Several weedings were made during the growth period of the crop to ensure a good performance of the crop.

To determine cowpea varietal response to A. craccivora feeding, the parameters, namely, plant growth (plant height and

size of leaf area) and final seed yield, were used. Measurements of plant height and size of leaf area were done 50 days after planting using similar procedure as those described in section 3.2.1. Samples of 15 unprooted plants were chosen at random for each cowpea cultivar. Plant height was taken and leaves on nodes 3, 5, and 7 in all these plants were harvested and taken to the laboratory for leaf area determination.

At harvesting, three types of data were collected: total number of pods per plant, total number of seeds per plant and seed weight per plant. Eight plants in each subplot for each cultivar were randomly selected and harvested for the foregoing assessments. All the pods on each sample plant were harvested, counted and then threshed by hand to obtain the seeds which were then counted. The seeds were then dried in an oven (Model Memmert 854 Schwabach) at $30^{o}C$ for 48 hours before being weighed.

4.3 Results

4.3.1 Field incidence of A. craccivora on six different cowpea cultivars.

Table 11 presents data on the percentage of plants infested by aphids four weeks after emergence when different cowpea cultivars were grown together under field conditions. The results (Table 11) showed that the lowest incidence of the pest occurred on Tvu 310 with only 29.22% of the plants being infested while the highest incidence was recorded on Katuli 107 with 67.36% of the plants infested. When data collected (Table 11) was put to statistical analyses, it was revealed that the proportion of plants of the cultivar Tvu 310 infested by aphids was significantly ($P=0.05$)

Table 11a. The percentage of cowpea plants infested by A. craccivora sampled four weeks after emergence for cultivars grown in the field.

Cowpea cultivars	Mean percentage infestation
Katuli 107	67.36a
Machakos 66	57.68b
Katumani 4	44.66d
Vita 4	51.30c
ER-1	52.99bc
Tvu 310	29.22e

a, b, c, d, e; means followed by the same letter are not significantly different from each other at P=0.05.

(b) Analysis of variance on field incidence four weeks after emergence based on transformation arc sin √(proportion).

Source of variation	df	SS	MS	F
Blocks	2	0.37	0.185	0.0102 NS
Cultivars	5	2489.02	497.80	27.54***
Error	10	180.75	18.08	
Total	17	2670.14		

NS = not significant *** significant at P=0.001

C.V. = 23.62%

S.E. (treatment mean) = 2.45

LSD: 5% = 5.18%

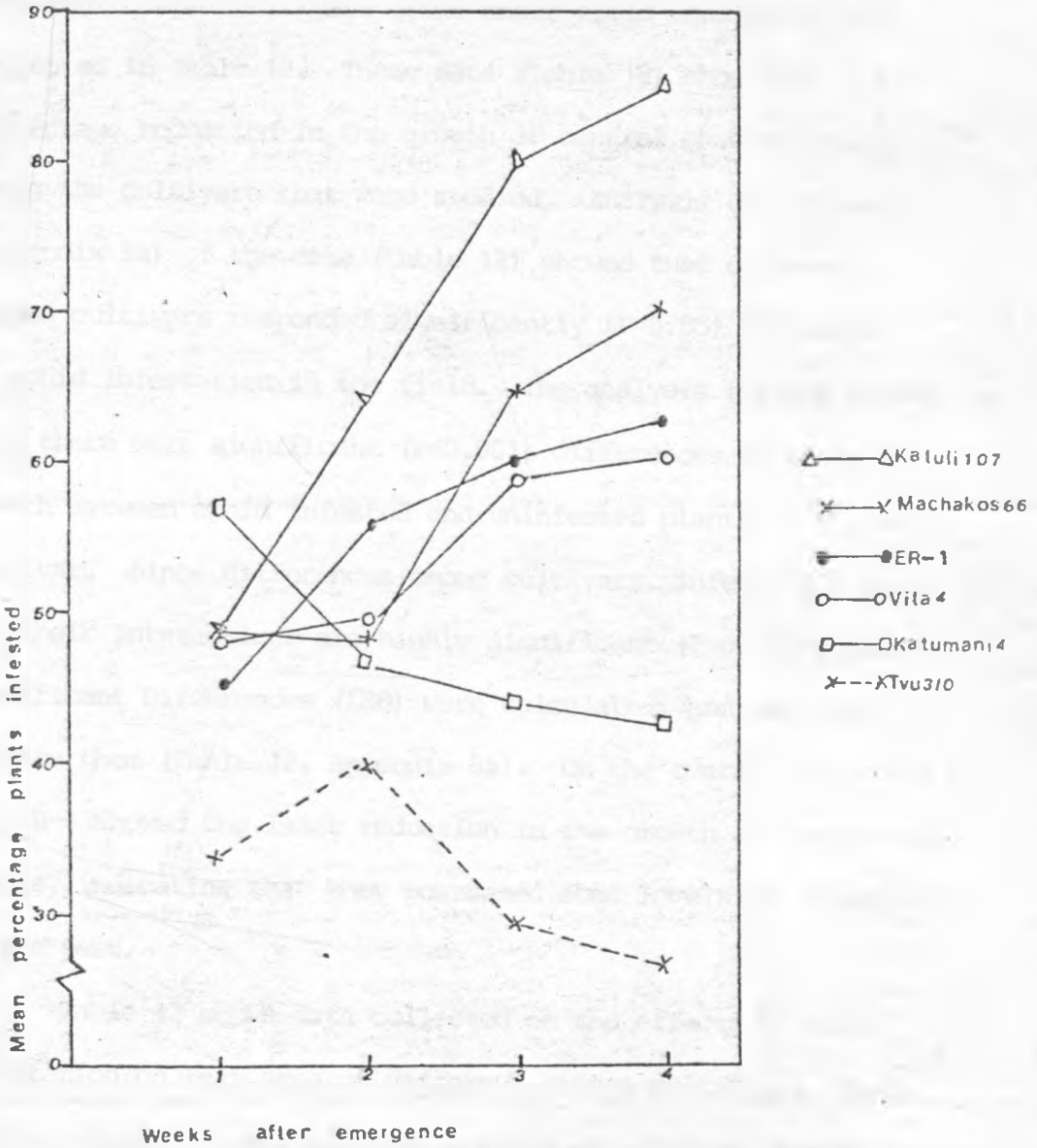
1% = 6.88

smaller than that of the other five cultivars tested. The proportions of plants infested by aphids for Katuli 107, Machakos 66, Katumani 4, ER-1 and Vita 4 were 67.36%, 57.68, 44.66%, 52.99% and 51.30%, respectively. Except for Vita 4 and ER-1 there were significant differences at the level P=0.05 for Katuli 107, Machakos 66 and Katumani 4 when compared amongst themselves. These observations indicated that in comparison to the others, Tvu 310 was highly resistant to A. craccivora while all the other cultivars possessed only minimal levels of resistance to the pest.

The development of the aphid population on cowpea crop during the first four weeks of plant growth on different cowpea cultivars is shown in Fig. 5. It is showed in Fig. 5 that the development of aphid population (colonies) on Katuli 107 was consistently higher than on any of the rest of the cultivars tested. In the greenhouse this particular cultivar promoted development of large populations of the pest. The proportion of the plants infested during the four weeks of plant growth increased. On the other hand, like in the greenhouse, the development of aphid population on Tvu 310 which is a resistant check decreased throughout the first four weeks of plant growth. However, aphid development on Katumani 4 which had the highest incidence during the first week of plant growth, decreased tremendously during the second, third and fourth weeks of plant growth.

The development of aphid population on Machakos 66, ER-1 and Vita 4 was consistently similar being high during the first four weeks of plant growth (Fig. 5). Like in greenhouse studies, Machakos greatly enhanced population development suggesting that the cultivar was susceptible to A. craccivora.

Fig 5 Population development of A. craccivora on different cowpea cultivars in the field.



4.3.2. Effects of aphid infestation on plant growth and yield in selected cowpea cultivars grown under field conditions.

Data assembled on the height of the central shoots of different cowpea cultivars grown under field conditions are presented in Table 12. These data (Table 12) show that the percentage reduction in the growth of central shoots varied among the cultivars that were studied. Analysis of variance (Appendix 5a) of the data (Table 12) showed that different cowpea cultivars responded significantly (P=0.05) different to aphid infestation in the field. The analysis further showed that there were significant (P=0.001) differences in terms of growth between aphid infested and uninfested plants of the same cultivar. Since differences among cultivars, infestation means and their interactions are highly significant (P=0.001), Least Significant Differences (LSD) were calculated, and used to compare them (Table 12, Appendix 5a). On the overall Tvu, Vita 4 and ER-1 showed the least reduction in the growth of the central shoots, indicating that they possessed some levels of resistance to the pest.

Table 13 shows data collected on the effects of aphid infestation on leaf area of different cowpea cultivars. These results (Table 13) are comparable to those obtained previously under greenhouse conditions. They showed that there was a high leaf area reduction on infested plants than on uninfested ones depending on the cultivar thus confirming earlier findings in the greenhouse that aphid infestation causes leaf area reduction.

Table 12. Mean plant height in cm of different cowpea cultivars infested with A. craccivora.

Cowpea cultivars	Mean plant height (cm)		% reduction compared with control
	Uninfested	infested	
Katuli 107	90.37a	75.00b	17.01
Machakos 66	74.73a	20.43b	72.66
Katumani 4	53.33a	21.05b	60.57
Vita 4	66.07a	61.13a	7.48
ER-1	119.53a	101.47b	15.11
Tvu 310	58.20a	56.20a	3.44

C.V. = 11.49%

S.E. (treatment mean) = 4.41

LSD: 5% = 12.94 1% = 17.59

a, b; means in rows followed by the same letter are not significantly different from each other at P=0.05.

Table 13. Leaf area of different cowpea cultivars infested with A. craccivora.

Cowpea cultivars	Mean leaf area (cm^2)		% reduction compared with control
	Uninfested	infested	
Katuli 107	68.43a	55.03b	19.58
Machakos 66	115.03a	98.40b	14.46
Katumani 4	130.90a	88.90b	32.09
Vita 4	77.97a	66.00b	15.35
ER-1	92.23a	85.93a	6.83
Tvu 310	175.97a	143.50b	18.45

C.V. = 3.84%

S.E. (treatment mean) = 2.21

LSD: 5% = 6.49 1% = 8.82

a, b, means in rows followed by the same letter are not significantly different from each other at P=0.05.

Analysis of variance (Appendix 5b) of the data in Tables 13 showed that there were significant (P=0.001) differences in the levels of aphid infestation depending on the cultivar used. The size of leaf area reductions were 19.58%, 14.46%, 32.09%, 15.35%, 6.83% and 18.45%, respectively, as compared to the control. These results (Table 13) indicated that unlike when experiments were conducted under greenhouse conditions, leaf area reduction was most severe on Katumani 4, suggesting that the cultivar could be susceptible under field conditions.

Results on the number of pods, seeds and weight of seeds produced per plant as influenced by aphid infestation in the field are presented in Table 14. The results obtained were similar to those assembled in the greenhouse since the effects of aphid infestation resulted in reduction on mean pod number, seed number and weight of seeds per plant. Analysis of variance (Appendix 5c, 5d, 5e) of the data in Table 14 showed that there were significant (P=0.05) differences among cultivars, infestations and their interactions. There were interactions between cultivars and infestation levels indicating that pod number, seed number and weight of seeds per plant would be significantly reduced. There were significant reductions for Katuli 107, Machakos 66 and Katumani 4 in number of pods and seeds produced per plant. However, there were no significant reductions on the number of

Table 14. Mean pod number, seed number and weight of seeds per plant of cowpea cultivars in the field.

Cowpea cultivars	Uninfested	Infested	Difference	% loss	LSD 0.05	LSD 0.01
a) Pod number/plant						
Katuli 107	26.30	19.83	6.47**	24.6	3.15	4.29
Machakos 66	21.87	10.20	11.67**	53.4	3.15	4.29
Katumani 4	24.73	14.60	10.13**	40.9	3.15	4.29
Vita 4	26.80	23.80	3.0 NS	11.2	3.15	4.29
ER-1	25.83	24.30	1.53NS	5.9	3.15	4.29
Tvu 310	13.57	11.80	1.77NS	13.0	3.15	4.29
C.V. = 9.17%; S.E. = 1.08						
b) Seed number/plant						
Katuli 107	254.40	182.60	71.8**	28.2	37.23	50.6
Machakos 66	310.30	144.60	165.7**	53.4	37.23	50.6
Katumani	360.60	226.40	134.2**	37.2	37.23	50.6
Vita 4	372.93	336.67	36.26NS	9.7	37.23	50.6
ER-1	331.10	309.33	21.77NS	6.6	37.23	50.6
Tvu 310	196.53	181.63	14.90NS	7.6	37.23	50.6
C.V. = 8.25%; S.E. = 12.69						
c) Seed weight/plant						
Katuli 107	26.37	20.97	5.4NS	20.5	5.78	7.85
Machakos 66	38.40	20.30	18.1**	47.1	5.78	7.85
Katumani 4	41.63	26.63	15.0**	36.0	5.78	7.85
Vita 4	37.20	33.97	3.23NS	8.7	5.78	7.85
ER-1	55.67	52.07	3.6 NS	6.5	5.78	7.85
Tvu 310	29.07	26.00	3.07NS	10.6	5.78	7.85
C.V. = 10.03%; S.E. = 1.97						

seeds per plant for Tvu 310, Vita 4 and ER-1 as compared to the control. This indicated that like in the greenhouse conditions the yield components of Tvu 310 and ER-1 were not adversely affected by aphid infestation. Except for Katumani 4, the results for Machakos 66 and Katuli 107 conformed to those obtained from greenhouse studies.

Data obtained on the effects of aphid infestation on seed weight per plant (Table 14) as compared to those obtained from greenhouse conditions also showed a similar reduction from the control for all the cultivars. The differences of seed weights per plant were 5.40, 8.10, 15.0, 3.23, 3.60 and 3.07 g for Katuli 107, Machakos 66, Katumani 4, Vita 4, ER-1 and Tvu 310, respectively, as compared with the control (Appendix 5e). Except for Vita 4, ER-1 and Tvu 310 this reduction in seed weight per plant was significant at P=0.05 level for Katuli 107, Machakos 66 and Katumani 4. This indicates that the former three cultivars were consistent both in the greenhouse and field conditions in that they were the least damaged. This further confirms earlier findings which showed that these cultivars possessed some levels of resistance. Although Katumani 4 was greatly damaged in the field, it always ranked third in terms of population development (Figs. 1,2,3) in the greenhouse and ranked second (Fig. 4) in the field. This suggested that under field conditions, the expression of resistance shown by Katumani 4 against A. craccivora in earlier investigations was affected by some factors not immediately known.

4.4 Discussion

It was observed in the studies reported here that varietal variations in the manner in which the aphids infested plants, existed among the cowpea cultivars tested. A higher number of plants were colonized by A. craccivora with regard to cultivars Katuli 107 and Machakos 66. The opposite was true for the other cultivars that were tested. Except for minor variations these observations closely conform to those which were recorded for greenhouse studies when aphid population development on the test cultivars was monitored. Apart from varietal influences causing differences in the degree of the number of plants infested, it was also suspected that other factors both abiotic and biotic in nature affected infestation. During the experimental period there were heavy showers which dislodged insects from plants thereby reducing the overall intensity of infestation on the crop. Additionally observational evidence accumulated in the course of these studies indicated that aphids were parasitized and predated upon by a large number of natural enemies. Factors such as the foregoing ones have been cited in many studies as affecting populations of insects (Southwood, 1966; Varley, et al, 1973; Price, 1975).

The fact that Katumani 4 which had been identified earlier as being resistant to A. craccivora was highly infested by the pest during its first week of growth, and thereafter the population of the pest decreasing tremendously was rather interesting. This can be explained by the fact that Katumani 4 was to be resistant through antibiosis mechanism (Chapter 2).

This kind of phenomenon whereby a resistant cultivar (antibiosis) inflicts harmful effects to its pests has been documented by many authors (Painter, 1951, 1958; Beck, 1965; Horber, 1972).

Data accumulated in field studies on yield of the cultivars studied was closely similar to data collected on the same parameter in the greenhouse. These indicated that the response of the cultivars in the field was similar to their response in the greenhouse. From this it was concluded that resistance if any expressed in the greenhouse was also expressed in the field in the same manner without much variation. This finding is important in view of the fact that resistance is not always expressed in all the environments where resistant varieties may be grown (Painter, 1951; Beck, 1965; Maxwell, 1980). It is evident therefore that in additional to greenhouse studies, field studies are necessary to identify resistant cultivars to A. craccivora in order to demonstrate consistency of resistance. A variety identified as being resistant to the pest in the greenhouse should be thoroughly screened in the field before recommending it for commercial cultivation by farmers.

An interesting observation in the field was that the cultivar Katuli 107 which was shown as being a suitable host for aphid development in the greenhouse as well as in the field survived and produced good yields. On the basis of this, Katuli 107 was regarded as being resistant through tolerance to A. craccivora. This observation was supported by the fact that many crop varieties are known to be tolerant to insect infestation particularly if the species concerned have sucking mouth-parts (Owens, 1965; Maxwell, 1980).

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

In these studies two types of mechanisms of resistance were identified: tolerance and antibiosis. Tolerance can be sub-divided into two components namely, endurance and repair of damaged tissues through compensatory growth (Painter, 1951). In the studies reported here tolerance through repair mechanism was not involved because this type of resistance is normally associated with insects with chewing mouthparts (Painter, 1958). It was then concluded that the tolerance mechanism available in Katuli 107 was endurance in which case the plant was able to withstand mechanical damage caused by the penetration of the stylets and withdraw of sap by the aphids without the significant loss in the final yield. For varieties which do not have this quality, damage by aphids through feeding wounds and withdraw of sap could lead to drastic yield losses. Evidence of this is contained in the works of Dixon (1973), De Boo et al (1964) and Mailu et al (1982) all of whom showed that removal of sap by aphids led to severe stunting in plants and subsequent heavy losses of yield.

Apart from Tvu 310, antibiosis mechanism of resistance has been reported in several other cowpea cultivars (Singh, 1979). In these studies it has already been reported that Katumani 4 and ER-1 are probably resistant through antibiosis mechanism. It is therefore apparent from the current and past investigations that the commonest type of resistance mechanism in cowpea germplasm to Aphis craccivora is antibiosis.

The most significant value of antibiosis is the effect it has on subsequent populations of the pest which are reduced from generation to generation as pointed out by Painter (1951). In this case resistant cowpea varieties would reduce aphid population from generation to generation thereby also causing a reduction in the amount of damage they may cause to cowpea crops.

One shortcoming which may arise as a result of using varieties with high levels of antibiosis is the development or creation of insect biotypes. A biotype is an insect which by way of mutation and selection of its physiology has the ability to utilize resistant plants as food (Painter, 1951). Biotypes develop most easily with insects having a high and short generation time such as the aphids (Horber, 1972, 1980). In view of this phenomenon (biotype) it would be undesirable to use cowpea varieties which have high levels of antibiosis against A. craccivora lest biotypes develop and lead to problems in their control.

The other type of resistance mechanism not identified in the cultivars tested here is non-preference to feeding, oviposition and shelter. From the point of view of A. craccivora which does not only damage the plant but also through transmission of viruses, non-preference mechanism of resistance would be ideal in suppressing damage since the pest will not in the first place bite resistant plants, later on preferring them for shelter and oviposition. In this type of mechanism also there is no risk of insect biotypes.

In conclusion, a large number of cowpea cultivars available in Kenya should be tested with a view to identifying if there are any, which are resistant to A. craccivora through non-preference

type of mechanism. In the meantime the cultivar Katuli 107 which was found to be resistant to the cowpea aphid through tolerance should be screened further in the field before being recommended for commercial cultivation by farmers.

A P P E N D I C E S

Appendix 1a. Summary of Analysis of variance and the results of the mean developmental period (in days) of A. craccivora on six different cowpea cultivars.

Sources of variation	df	SS	MSS	F
Total	128	50.3329		
Cultivars	5	19.1065	3.8213	15.052***
Error	123	31.2264	0.2539	

*** significant at P=0.001

Summary of results

Cultivars	Treatment means	S.E.
Katuli 107	7.41	0.11
Machakos 66	6.74	0.13
Katumani 4	6.96	0.10
Ex-Luanda	6.50	0.10
ER-1	7.20	0.10
Tvu 310	7.76	0.12

Appendix 1b. Summary of Analysis of variance and the results of mean developmental period of first nymphal instar of A. craccivora on six different cowpea cultivars.

Sources of variation	df	SS	MSS	F
Total	128	44.881		
Cultivars	5	15.765	3.153	13.321***
Error	123	29.116	0.237	

*** Significant at P=0.001

C.V. = 21.11%

Summary of results

Cultivars	Treatment mean	S.E.
Katuli 107	2.40	0.11
Machakos 66	1.90	0.13
Katumani 4	1.80	0.095
Ex-Luanda	2.59	0.10
ER-1	2.37	0.095
Tvu 310	2.81	0.12

Appendix 1c. Analysis of variance on developmental period of second nymphal instar of A. craccivora on six different cowpea cultivars.

Sources of variation	df	SS	MSS	F
Total	128	28.308		
Cultivars	5	15.357	3.071	29.168***
Error	123	12.952	0.105	

*** Significant at P=0.001

C.V. = 19.99%

Summary of results

Cultivars	Treatment means	S.E.
Katuli 107	1.02	0.07
Machakos 66	1.72	0.08
Katumani 4	1.46	0.06
Ex-Luanda	1.58	0.07
ER-1	2.07	0.06
Tvu 310	1.81	0.08

Appendix 1d. Analysis of variance on the developmental period of third nymphal instar of A. craccivora on six different cowpea cultivars.

Sources of variation	df	SS	MSS	F
Total	128	31.456		
Cultivars	5	15.574	3.115	24.122***
Error	123	15.882	0.129	

*** Significant at P=0.001

C.V. = 21.5%

Summary of results

Cultivar	Treatment mean	S.E..
Katuli 107	2.05	0.08
Machakos 66	1.86	0.09
Katumani 4	1.86	0.07
Ex-Luanda	1.01	0.07
ER-1	1.68	0.07
Tvu 310	1.45	0.09

Appendix 1e. Analysis of variance on the developmental period of fourth nymphal instar of A. craccivora on six different cowpea cultivars.

Sources of variation	df	SS	MSS	F
Total	128	29.332		
Cultivars	5	13.171	2.634	20.047***
Error	123	16.161	0.131	

*** Significant at P=0.001

C.V. = 24.10%

Summary of results

Cultivar	Treatment mean	S.E.
Katuli 107	1.94	0.08
Machakos 66	1.26	0.09
Katumani 4	1.84	0.07
Ex-Luanda	1.56	0.07
ER-1	1.08	0.07
Tvu 310	1.49	0.09

Appendix 2a. Summary of Analysis of variance and the results of the mean numberof alatae of A. craccivora on six different cowpea cultivars.

Sources of variation	df	SS	MSS	F
Total	17	12.413		
Replicate	2	0.022	0.011	0.032 NS
Cultivars	5	8.932	1.786	5.163**
Error	10	3.459	0.346	

NS = not significant ** significant at P=0.01

C.V. = 36.88%

S.E. (treatment mean) = 0.34

Summary of results

Cultivar	Mean number of alatae/cultivar
Katuli 107	2.49
Machakos 66	2.09
Katumani 4	0.61
Ex-Luanda	1.83
ER-1	1.86
Tvu 310	0.68
LSD: 5%	1.07
1%	1.52

Appendix 2b. Summary of Analysis of variance and the results of the mean number of apterae of A. craccivora on six different cowpea cultivars.

Sources of variation	df	SS	MSS	F
Total	17	3.055		
Replicate	2	0.002	0.001	0.0082 NS
Cultivar	5	1.995	0.399	3.774*
Error	10	1.058	0.106	

NS = not significant * significant at P=0.05

C.V. = 8.59%

S.E. (treatment mean) = 0.19

Summary of results

Cultivar	Mean number of apterae/cultivar
Katuli 107	4.06
Machakos 66	3.83
Katumani 4	3.76
Ex-Luanda	4.01
ER-1	3.97
Tvu 310	3.07
LSD: 5%	0.59

Appendix 2c. Summary of Analysis of variance and the results of the mean number of nymphs of A. craccivora on six different cowpea cultivars.

Sources of variation	df	SS	MSS	F
Total	17	152.653		
Replicate	2	4.779	2.389	5.158*
Cultivar	5	143.241	28.648	61.835***
Error	10	4.633	0.463	

* significant at P=0.05

*** significant at P=0.001

C.V. = 6.51%

S.E. (treatment mean) = 0.39

Summary of results

Cultivar	Mean number of nymphs
Katuli 107	13.13
Machakos 66	11.04
Katumani 4	11.81
Ex-Luanda	11.13
ER-1	11.27
TVx 310	4.35
LSD: 5%	1.24
1%	1.76

Appendix 3a. Summary of Analysis of variance and the results of the mean plant height (cm) of six different cowpea cultivars infested with different levels of A. craccivora.

Sources of variation	df	SS	MSS	F
Total	53	74689.87		
Replicates	2	0.25	0.125	
Cultivar (C)	5	33329.89	6665.979	23633.28***
Infestation level (I)	2	35454.75	17727.376	62849.89***
C x I	10	5895.38	589.538	2090.123***
Error	34	9.59	0.282	

NS = not significant *** significant at P=0.001

C.V. = 0.68%

Since the differences among cultivars and infestation means and their interaction are highly significant (P=0.001) LSD can be used to compare them.

(i) for differences among cultivars means

LSD: 5% = 0.684 cm 1% = 0.903 cm

(ii) for differences among infestation means

LSD: 5% = 0.36 cm 1% = 0.484 cm

(iii) for differences among any interaction means

LSD: 5% = 0.882 cm 1% = 1.185 cm

Appendix 3b. Summary of Analysis of variance and the results of the mean leaf (cm^2) of six different cowpea cultivars infested with different levels of A. craccivora

Sources of variation	df	SS	MSS	F
Total	53	133683.459		
Replicates	2	6.366	3.183	2.602 NS
Cultivar (C)	5	121130.513	24226.103	19806.17***
Infestation level (I)	2	6115.335	3057.667	2499.81***
C x I	10	6389.659	638.966	522.389***
Error	34	41.587	1.223	

NS = not significant *** significant at P=0.001

C.V. = 0.89%

Since the difference among cultivar andinfestation means and their interaction are highly significant (P=0.001) LSD can be used to compare them.

(i) for differences among cultivars means

LSD: 5% = 1.42 cm^2 1% = 1.88 cm^2

(ii) for differences among infestation means

LSD: 5% = 0.75 cm^2 1% = 1.01 cm^2

(iii) for differences among either interaction means

LSD: 5% = 1.84 cm^2 1% = 2.47 cm^2

Appendix 4a. Summary of Analysis of variance of the mean seed number per pod of six different cowpea cultivars infested with different initial levels of A. craccivora.

Sources of variation	df	SS	MSS	F
Total	53	374.16		
Replicates	2	4.12	2.06	0.82 NS
Cultivars (C)	5	261.55	52.31	20.86***
Error (a)	10	25.08	2.51	-
Infestation level (I)	2	48.91	24.46	32.56***
C x I	10	16.47	1.65	2.19 NS
Error (b)	24	18.03	0.75	

NS = not significant *** significant at P=0.001

C.V. (a) = 17.28% C.V. (b) = 9.46

Since differences among cultivars and infestation means are highly significant (P=0.001) LSD can be used to compare them.

(i) for differences among cultivar means (main plot treatments)

LSD: 5% = 1.66 1% = 3.42

(ii) for differences among infestation means (sub-plot treatments)

LSD: 5% = 0.92 1% = 0.59

Appendix 4b. Summary of Analysis of variance of mean seed weight per pod of six different cowpea cultivars infested with different initial levels of A. craccivora.

Sources of variation	df	SS	MSS	F
Total	53	16.17		
Replicates	2	0.13	0.07	1.17 NS
Cultivars (C)	5	11.59	2.32	41.05***
Error (a)	10	0.56	0.06	-
Infestation level (I)	2	2.73	1.36	186.56***
C x I	10	0.97	0.09	13.21***
Error (b)	24	0.18	0.01	-

NS = not significant *** significant at P=0.001

C.V. (a) = 23.85% C.V. (b) = 8.58

Since differences among cultivars and infestation means and their interaction are highly significant (P=0.001) LSD can be used to compare them.

(i) for differences among cultivar means (main plot treatments).

LSD: 5% = 0.25 1% = 0.51

(ii) for differences among infestation means (subplot treatments)

LSD: 5% = 0.09 1% = 0.06

(iii) for differences among infestation for the same cultivar.

LSD: 5% = 0.22 1% = 0.14

Appendix 5a. Analysis of variance of mean plant height (cm) of different cowpea cultivars infested with A. craccivora in the field.

Sources of variation	df	SS	MSS	F
Total	35	29250.15		
Replicates	2	31.12	15.56	0.27 NS
Infestation (I)	1	3197.90	3197.90	54.77***
Cultivars (C)	5	21060.58	4212.12	72.14***
C x I	5	3676.08	735.22	12.59***
Error	22	1284.47	58.39	

NS = not significant *** significant at P=0.001

C.V. = 11.49%

Since differences among cultivars and infestation means and their interactions are highly significant (P=0.001) LSD can be used to compare them.

(i) for differences among cultivar means.

LSD: 5% = 9.15 1% = 12.44

(ii) for differences between infestation means

LSD: 5% = 7.18 1% = 9.66

(iii) for differences among either interaction means

LSD: 5% = 12.94 1% = 17.59

Appendix 5b. Analysis of variance of mean leaf area (cm^2) of different cowpea cultivars infested with A. craccivora in the field.

Sources of variation	df	SS	MS	F
Total	35	42037.96		
Replicates	2	34.55	17.27	1.18 NS
Infestation (I)	1	3763.82	3763.82	256.34***
Cultivar (C)	5	36501.07	7300.21	497.19***
C x I	5	1415.49	283.09	19.28***
Error	22	323.02	14.68	

NS = not significant *** significant at P=0.001

C.V. = 5.84%

Since differences among cultivars and infestation means and their interaction are highly significant (P=0.001) LSD can be used to compare them.

(i) for differences among cultivar means

LSD: 5% = 4.59 1% = 6.24

(ii) for differences between infestation means

LSD: 5% = 3.60 1% = 4.84

(iii) for differences among either interaction means

LSD: 5% = 6.49 1% = 8.82

Appendix 5c. Analysis of variance of pod number per plant of different cowpea cultivars infested with A. craccivora in the field.

Sources of variation	df	SS	MS	F
Total	35	1318.43		
Replicates	2	9.94	4.97	1.43 NS
Infestation (I)	1	247.01	247.01	71.25***
Cultivar (C)	5	790.87	158.17	45.62***
C x I	5	194.33	38.87	11.21***
Error	22	76.28	3.47	

NS = not significant *** significant at P=0.001

C.V. = 9.17%

Since differences among cultivars and infestation means and their interaction are highly significant (P=0.001) LSD can be used to compare them.

(i) for differences among cultivar means

LSD: 0.001 = 4.08 pods *** (P>0.001)

(ii) for differences between infestation means

LSD: 0.05 = 1.75 pods; 0.01 = 2.35 pods

(iii) for differences among either interaction means

LSD: 0.05 = 3.15; 0.01 = 4.29 pods.

Appendix 5d. Analysis of variance of mean seed number per plant of different cowpea cultivars infested with A. craccivora in the field.

Sources of variation	df	SS	MS	F
Total	35	217803.85		
Replicates	2	2943.75	1471.88	3.05 NS
Infestation (I)	1	38435.60	38435.60	79.53***
Cultivar (C)	5	129631.88	25926.38	53.65***
C x I	5	36160.66	7232.13	14.97***
Error	22	10631.96	483.27	

NS = not significant *** significant at P=0.001

C.V. = 8.25%

Since differences among cultivars and infestation means and their interaction are highly significant (P=0.001) LSD can be used to compare them.

(i) for differences among cultivar means.

LSD: 5% = 26.32 seeds; 1% = 35.78 seeds

0.1% = 48.13 seeds.

(ii) for differences among infestation means

LSD: 5% = 20.66 seeds; 1% = 27.79 seeds

0.1% = 27.79 seeds

(iii) for differences among either interaction means

LSD: 5% = 37.23 seeds; 1% = 50.60 seeds

0.1% = 68.06

Appendix 5e. Analysis of variance of mean seed weight per plant of different cowpea cultivars infested with A. craccivora in the field.

Sources of variation	df	SS	MS	F
Total	35	4660.80		
Replicates	2	78.18	39.09	3.36 NS
Infestation (I)	1	424.36	424.36	36.44***
Cultivar (C)	5	3404.55	680.91	58.47***
C x I	5	497.52	99.50	8.54***
Error	22	256.22	11.65	

NS = not significant *** significant at P=0.001

C.V. = 10.05%

Since differences among cultivars and infestation means and their interactions are highly significant (P=0.001) LSD can be used to compare them.

(i) for differences among cultivar means

LSD: 5% = 4.09 1% = 5.55

(ii) for differences between infestation means

LSD: 5% = 3.21 1% = 4.31

0.1% = 4.31

(iii) for differences among either interaction means

LSD: 5% = 5.78 1% = 7.85

0.1% = 10.57

REFERENCES

Agyen-Sampong, M. (1978). Pests of cowpea and their control in Ghana. In Pests of Grain Legumes: Ecology and control. Eds. Singh, S.R., van Emden, H.F., and Taylor, T.A. London, Academic Press, 454pp.

Anon. (1974). Annual report of Ministry of Agriculture, Coast Province, Kenya government.

Anon (1978). Annual report of Ministry of Agriculture, Eastern Province, Kenya Government.

Atiri, G.J., Ekpo, E.J.A., and Thottapilly, G. (1984). The effect of aphid-resistance in cowpea on infestation and development of Aphis craccivora and the transmission of cowpea aphid-borne mosaic virus. Ann. appl. Biol. 104: 339-346.

Ayoade, K.A. (1969). Insecticide control of the pod borer Maruca testulalis (Geyer) (Lepidoptera: pyralidae) on Westbred cowpea (vigna sp) Bull. Entomol. Soc. Nigeria 2:23-33.

Ayoade, K.A. (1976). Minimum use of insecticide and insect pest control in cowpea, vigna unguiculata (L.) walp in Southern Nigeria (unpublished).

Barlow, C.A. (1977). Effects of pea aphid, Acyrthosiphum pisum (Homoptera; Aphididae) on growth and productivity of pea plants, Pisum sativum Can. Ent. 109: 1491-1502.

Beck, S.D. (1965). Resistance of insects. Ann. Rev. Entomol. 10: 207-232.

Bohlen, E. (1973). Crop pests in Tanzania and their control. Verlag Paul parey. Berlin and Bumburg 142pp.

Booker, R.H. (1963). The effect of sowing date and spacing on rosette disease of groundnuts in Northern Nigeria, with observations on the vector, Aphis craccivora. Ann. appl. Biol. 52: 125-131.

Booker, R.H. (1965 a). List of insect pests found in association with cowpeas at Samaru (Northern Nigeria). Samaru Misc. Paper No. 9, 4p.

Booker, R.H. (1965b). Pests of cowpea and their control in Northern Nigeria. Bull ent. Res. 55(4): 663-672.

Bond, D.A. and Lowe H.J.B. (1975). Tests for resistance to Aphis fabae in field beans (vicia faba). Ann. appl. Biol. 81: 21-32.

Brader, L. (1973). Ecological basis for insect pest control Host plant resistance. Proc. FAO Conference Ecol. in relation to plant pest control. Rome 1973. pp.54-64.

Chant, S.R. (1959), Viruses of cowpea, Vigna unguiculata (L) Walp in Nigeria. Ann. appl. Biol. 47: 565-572.

Chant, S.R. (1960). The effect of infestation with tobacco mosaic virus on the growth rate and yield of cowpea in Nigeria. Emp. J. Exp. Agriculture, 28: 114-120.

Cobley, L.S. and Steele W.M. (1976). An introduction to the Botany of Tropical crops (2nd edition)pp.91-95. Longmans, London.

Cody, C.E. (1941). Colour preferences of pea aphid in Western Oregon. J. Econ. Entomol. 34: 584.

COPR. (1981). Centre for Overseas Pest Research. Pest Control in Tropical Grain Legumes, London, (1981) 206pp.

Davidson, J. (1925). Biological studies of A. rumicis Linn. Factors affecting the infestation of Vicia faba with A rumicis. Ann. appl. Biol. 12: 472-507.

Davies, J.C. (1972). Studies on the ecology of Aphis craccivora koch (Hemiptera: Aphididae), the vector of rosette disease of groundnuts in Uganda. Bull. ent. Res. 62: 169-181.

DeBoo, R.F., Diamond, J.B, and Lowe, J.H (1964). Impact of the pine leaf aphis, Pineus pinifoliae (Chermidae) on its secondary host, eastern white pine. Can. Ent. 96: 764-772.

de Pury, J.M.S. (1968). Crop pests of East Africa. Oxford University Press, Nairobi, Lusaka, Addis Ababa 227pp.

Dethier B.G. (1954). Evolution of feeding preferences in phytophagous insects. Evol. 8: 33-54.

Dethier, B.G. (1970). Chemical interactions between plants and insects. In Chemical Ecology. Ed. Soudheimer, E. and Simeone, J.B., Academic Press pp. 83-102.

Dixon, A.F.G. (1971a). The role of aphids in wood formation -II: The effect of the lime aphid, Eucallipterus tiliae L. (Aphididae) on the growth of lime, Tilia X vulgaris Hayne. J. appl. Ecol. 8: 393-399.

Dixon, A.F.G. (1971b). The role of aphids in wood formation- I. The effect of sycamore aphid, Drepanosiphum platanoides (Schr) (Aphididae) on the growth of Sycamore, Acer pseudoplatanus (L.). J. appl. Ecol. 8(1): 165-179.

Dixon, A.F.G. (1973). Biology of aphids. The camelot press Ltd. London and Southampton.

Duncan, D.B. (1955). Multiple range and F-tests. Biometrics; 11: 1-42.

Eastop, v. F. (1952). Notes on East African aphids II. phytophagous species. E. Afr. agric. J. 17: 184.

Eastop, v.F. (1953). A study of the aphididae (homoptera) of East Africa. Colon. Res. Publ. No. 20. 126pp.

Eastop, v.F. (1957). The periodicity of aphid flight in East Africa. Bull ent. Res. 48: 305-310.

Eastop, v.F. (1977). World wide importance of aphids as virus vectors. In Aphids as virus vectors Ed. Harris, K.F. and Maramorosch, K. Academic Press, New York, London 599pp.

Evans, A.C. (1954). Groundnut rosette in Tanganyika. I. field studies - Ann. appl. Biol. 52. 125-131.

FAO (1970). Food Agriculture and Organization. FAO, Rome.

Faris, D.G. (1965). The origin of cultivated forms of vigna sinensis Can. J. Gen. Cytol. 7: 433-452.

Farrel, J.A.K. (1976). Effects of groundnuts crop density on the population dynamics of Aphis craccivora Koch (Hemiptera: Aphididae) in Malawi. Bull ent. Res. 66: 317-329.

Grison, P. (1965). Importance d'une approche Interdisciplines. Proc. FAO Symp. Integrated Pest control, Rome 3, 87-101.

Gutierrez, A.P., Morgan, D.J., and Havenstein, D.E. (1971). The ecology of Aphis Craccivora Koch and Subterranean Clover Stunt virus. -I. The phenology of aphid populations and the epidemiology of virus in pastures in South-east Australia. J. appl. Ecol. 8:699-721.

Hackerott, H.L., Sorensen, E.L., Harvey, T.L., Ortman, E.E. and Painter, R.H. (1963). Reactions of alfalfa varieties to pea aphids in the field and greenhouse. Crop Science, 3:298-301.

Hill, D.(1975). Agricultural insect pests of the tropics and their control. Cambridge University Press, Cambridge, 516PP.

Horber, E. (1972). Plant resistance to insects. Agric. Sc. Rev. 10(2): 1-10,18.

Horber, E.(1980). Types and classification of resistance. In "Breeding plants resistant to insects". Eds. Maxwell, F.G. and Jennings, P.R. PP. 15-21. John Wiley and Sons, New York, 683pp.

Howe, W.L. and Smith, O.F. (1957). Resistance to the spotted alfalfa aphid in Lahontan alfalfa. J. Econ. Entomol. 50(3):320-4.

Hughes, R.D. (1963). Population dynamics of the Cabbage aphid, Brevicoryne brassicae L. J. Anim. Ecol. 32:393-424.

Hutchinson, J.B. (1969). The evolutionary diversity of pulses. Proc. Nutri. Soc. 29:45-55.

ICIPE (1981). International Centre of Insect Physiology and Ecology, Annual Report, Nairobi, Kenya.

ICIPE (1982). International Centre of Insect Physiology and Ecology Annual Report Nairobi, Kenya.

ICRISAT (1977). Weed Research Annual Report (1976/77 Int. Crops. Res. Inst. Semi-Arid Tropics, Hyderabad, India. 32p.

IITA (1974). Annual Report of the International Institute of Tropical Agriculture, Ibadan. Nigeria.

IITA (1981). Annual Report of the International Institute of Tropical Agriculture, Ibadan, Nigeria.

IITA (1982). International Institute of Tropical Agriculture, Annual Report, Ibadan, Nigeria.

IITA (1983). International Institute of Tropical Agriculture, Annual Report, Ibadan, Nigeria.

IITA (1984). Annual Report of the International Institute of Tropical Agriculture, Ibadan, Nigeria.

Ingram, W.R. (1969). A note on the failure to control aphid infestation on beans with Insecticides in Uganda. E. Afr. agric. For J. 34(4): 476-481.

Jackai, L.E.N. (1982). A field screening technique for resistance of cowpea (Vigna unguiculata) to the pod-borer Maruca testulatis (Geyer) (Lepidoptera; Pyralidae). Bull ent. Res. 72: 145-156.

Jerath, M.L. (1968). Insecticidal control of Maruca testulalis on on cowpea in Nigeria. J. Econ. Entomol., 61: 413-416.

Johnson, B. (1953). The injurious effect of hooked epidermal hairs of French beans, Phaseolus vulgaris L. on Aphis craccivora Bull ent. Res. 44: 779-88.

Johnson, B. (1965). Wing polymorphism in aphids - II. Interaction between aphids. Ent. exp. & appl. 8: 49-64.

Johnson, B. (1966). Wing polymorphism in aphids - IV. The effect of temperature and photoperiod. Ent. exp. and appl. 9: 301-313.

Jones, A.T. (1976). The effect of resistance to Amphorophora rubi in raspberry (Rubus idaeus). On the spread of aphid-borne virus. Ann. appl. Biol. 82: 503-510.

Jones, A.T. (1979). Further studies on the effect of resistance to Amphorophora rubi in raspberry (Rubus idaeus) on the spread of the aphid-borne viruses. Ann. appl. Biol. 92: 119-123.

Jones, M.G. (1967). Observations on two races of the groundnut aphid Aphis craccivora Ent. exp. and appl. 10: 31-38.

Judenko, E; Johnson, C.G. and Taylor L.R. (1952). The effect of Aphis fabae scop on the growth and yield of field beans in a garden plot. Plant path. 1: 60-65.

Karel, A.K. (1979). Insect pests of cowpea, Vigna unguiculata (L.) and their control in Kenya. 2nd Report (Part 3) of the plant protection programme, University of Nairobi. pp 73-94.

Karel, A.K. and Mueke, J.M. (1978). Management of insect pests in mixed cropping systems in Kiambu District. Plant Protection progress Report, University of Nairobi pp.57.

Kayumbo, H.Y. (1975). Cowpea pests in Tanzania. In Proceedings of Collaborators meeting, IITA, Ibadan, Nigeria. 79 pp.

Kayumbo, H.Y. (1978). Pests of Grain Legumes and their control in Tanzania. In Pest of Grain Legumes: Ecology and Control. Ed. S.R. Singh, H.F. Van Emden and T.A. Taylor. Academic Press, London and New York 454 pp.

Kennedy, J.S. and Stroyan, H.L.G. (1959). Biology of aphids. Ann. Rev. Entomol. 4: 139-160.

Khaemba, B.M. (1980). Resistance of cowpeas to the common pod sucking bugs. Riptortus dentipes Fabricius and Anoplecnemis curvipes Fabricius (Hemiptera: coreidae). Ph.D. Thesis, University of Nairobi, 150 pp.

Khaemba, B.M. (1985). Field resistance to the common pod sucking bugs R. dentipes (F) and Anoplecnemis curvipes (F) of cowpea (vigna unguiculata (L.). E. Afr. agric. For. J. (In press)

Khaemba, B.M. and Khamala, C.P.M. (1978). A preliminary survey of the phytophagous pests of mixed cropping system of Kiambu District. In the First Annual Report of Plant Protection Programme, ed. C.N. Karue and D.M. Mukunya. University of Nairobi, 136 pp.

Khaemba, B.M. and Khamala, C.P.M. (1979). Resistance of cowpeas to the common pod sucking coreid bugs, Anoplecnemis curvipes (F.) and Riptortus dentipes (F.) (Hemiptera: coreidae). Plant Protection Report, University of Nairobi, 2: 95-119.

Khaemba, B.M. and Khamala, C.P.M. (1981). Relation of pod age to the expression of resistance in cowpea vigna unguiculata (L.) to common pod sucking bugs, Riptortus dentipes (F) and Anoplecnemis curvipes (F.) (Hemiptera: coreidae). Kenya Journal of Science and Technology (B); 2: 47-52.

Khamala, C.P.M. (1978). Pests of grain legumes and their control in Kenya. In Pests of Grain Legumes: Ecology and Control. Ed. S.R. Singh, H.F. van Emden and T.A. Taylor. Academic Press, London and New York 454 pp.

Koehler, C.S. and Mehta, P.H. (1972). Relationship of Insect control attempts by chemicals to components of yield of cowpea in Uganda. J. Econ. Entomol. 65: 1421-1427.

Lees, A.D. (1967). The production of the apterous and alate forms in the aphid Megoura viciae Buckton, with special reference to the role of crowding. J. insect physiol. 13: 289-318.

Le Pelley, R.H. (1959). Agricultural Insects of East Africa. Nairobi, Kenya; East Africa High commission. 307 pp.

Mabonga, F.R.A. (1983). Insect pests of cowpea and studies on the cowpea yield assessment under different chemical spray regimes and minimum use of insecticide against the dominant insect species at Katumani Dry-land Research station. Msc. thesis, University of Nairobi.

Mailu, A.M., Khamala, C.P.M. and Rose D.J.W. (1982), Sampling techniques for populations of pine woodly aphid, Pineus pini (Gmelin) (Adelgidae). Kenya Journal of Science and Technology 3: 9-18.

Malinga, Y.W.K. (1978). Studies on the performance of selected cowpea cultivars for resistance to some homopteran foliar pests. Msc. thesis, University of Nairobi.

Maramorosch, K. (1980). Insects and plant pathogens. In Breeding plants resistant to insects. Ed. Maxwell, F.G. and Jennings, P.R. pp. 317-155. John Wiley and Sons, New York 683 pp.

Maxwell, F.G. (1972). Host plant resistance to insects: Nutritional and pest management relationships. In Insect and Mite nutrition: Significance and implications in Ecology and pest management. ed. J.G. Rodriguez. North-Holland, Amsterdam, London pp. 599-609.

Maxwell, F.G. and Jennings, P.R. (1980). Breeding plants resistant to insects. John Willey and sons 683 pp.

Mehta, P.N. and Nyiira, Z.M. (1975). An evaluation of five insecticides for use against pests of cowpea (vigna unguiculata (L.) walp) with special reference to green pod yield. E. Afr. agric. For. J. 39: 99-104.

Metcalf, R.L. (1980). Changing role of insecticides in crop protection. Ann. Rev. Entomol. 25: 219-256.

Metcalf, R.L. and Luckman, W.H. (1975). Introduction to insect pest management. John Willey and son. Inc. USA. pp 103-146.

Moody, K. and Shetty, S.V.R. (1979). Weed management in intercropping systems. Paper prepared for the international workshop, 10-13, Jan. 1979 ICRISAT, Hyderabad, India.

Muller, H.J. (1964). Uber die auflugdichte von aphiden auf farbige salatpflanzen. Ent. exp. and appl. 7: 85-104.

Muruli, B.I; Pathak, R.S., Mukunya, D.M., Karel, A.K; Keya, S.O. and Ssali, H. (1980). Cowpea research in Kenya. Tropical grain Legume Bull. 19: 13-16.

Nwanze, K.F. (1971). Computer aided analysis of morphological variation in wild and cultivated vigna unguiculata (L.) Walp, from Africa. Dept. Agric. Biol. Univ. Ibadan, Nigeria 68 pp.

Nyiira, Z.M. (1971). The Status of insect pests of cowpea, Vigna unguiculata (L.) Walp in Uganda and their control. PANS 17(2): 194-197.

Nyiira, Z.M. (1973). Pest status of thrips and lepidopterous species on vegetables in Uganda. E. Afr. agric. For. J. 39: 131-135.

Nyiira, Z.M. (1978). Pests of grain legumes and their control in Uganda. In Pests of Grain Legumes Ecology and control. ed. Singh, S.R., van Emden H.F., Taylor, T.A. Academic Press, London and New York 454 pp.

Ochieng, R.S. (1978). Studies on the bionomics of Ootheca mutabilis. In pest of grain legumes: Ecology and control. ed. Singh, S.R. van Emden, H.F., Taylor, T.A. Academic Press, London and New York 454 pp.

Ogenga-Latigo, M.W. (1983). Interactions between the black bean aphid, Aphis fabae Scop (Homoptera: Aphididae) and the host plant, Phaseolus vulgaris Msc thesis, University of Nairobi.

Okeyo-Owuor, J.B. (1979). The pod borer Maruca testulalis as a pest of cowpea and studies on its biology. ICIPE Annual report, 1979, Nairobi, Kenya.

Okeyo-Owuor, J.B. and Ochieng, R.S. (1981). Studies on the legume pod-borer Maruca testulalis (Geyer)-I. Life cycle and behaviour. Insect Sci. Application 1(3): 263-268.

Okigbo, B.N. (1978). Grain Legumes in the agriculture of the tropics. In Pest of Grain Legumes: Ecology and control. Eds. Singh, S.R.; van Emden H.F. and Taylor T.A. Academic Press, 454 pp.

Owens, J.C. (1975). An explanation of terms used in insect resistance to plants. Iowa state Journal of Research 4(2): 513-517.

Painter, R.H. (1951). Insect resistance in crop plants New York, MacMillan Co. 520 pp.

Painter, R.H. (1958). Resistance of plants to insects: Ann. Rev. Entomol. 3: 267-290.

Pathak, M.D. and Saxena, R.C. (1976). Insect resistance in crop plants. Current advances in plant science. pp 1233-1252, IRRI, Los Banos, Laguna, Phillippines.

Price, P.W. (1975). Insect Ecology. A wiley-Interscience publication, New York 514 pp.

Purseglove, J.W. (1968). Tropical crops: dicotyledous. 2 vols. Longman, Harlow 332 pp. 333-719 p.

Raccah, B., Tahori, A.S. and Applebaum, S.W. (1971). Effects of nutritional factors in synthetic diet on increase of alate forms in Myzus persicae J. Insect physiol. 17: 1385-1390.

Rachie, K.O. and Roberts, L.M. (1974). Grain Legumes of the lowland tropics. Adv. Agron., 26: 1-132.

Raheja, A.K. (1976). Assessment of losses caused by insect pests of cowpeas in Northern Nigeria PANS 22: 229-233.

Searls, E.M. (1936). The relation of foliage colour to aphid resistance in some varieties of canning peas. J. Agric. Res. 51: 613-619.

Schaefers, G.A. and Judge, F.D. (1972). Relationship between parent size and production of winged forms in the strawberry aphid, Chaetosiphon fragaefolii J. Insect physiol. 18: 1049-60.

Schwartze, C.D. and Huber, G.A. (1937). Aphid resistance in breeding Mosaic escaping red raspberries. Science, 86: 158-159.

Schmutter, H. (1969). Pests of crops in North-east and central Africa. Gustar. Fischer Verlag Portland, 296 pp.

Singh, S.R. (1976). Coordinated minimum insecticide trial. Yield performance of insect resistant cowpea cultivars. Tropical grain Legume Bull. 5:4.

Singh, S.R. (1977). Cowpea cultivars resistant to insect pests in world germplasm collection. Tropical grain Legume Bull. 9: 1-7.

Singh, S.R. (1978). Reistance to cowpea pests in Nigeria. In Pests of Grain Legumes: Ecology and control. ed. S.R. Singh, H.F. van Emden and T.A. Taylor. Academic press. London and New York 454 pp.

Singh, S.R. (1979). Biology of cowpea pests and potential for host plant resistance. Paper presented at the Annual Research Conference of the Int. Inst. Trop. Agric., Ibadan, Nigeria, 43 pp.

Singh, S.R. and Allen, D.J. (1978). Pests, diseases, resistance and protection in Vigna unguiculata (L.) Walp. Proc. Int. Legume Conference. London. July 23-August 4, 1978.

Singh, S.R. and Allen, D.J. (1980). Pests, diseases and Protection in cowpeas, pp 419-43. In Advances in Legumes science. Eds. R. Summerfield and H. Bunting. Kew Gardens 667 pp.

Singh, S.R.; van Emden, H.F. and Taylor, T.A. (1978). Pests of Grain Legumes: Ecology and control. Academic press. London and New York 454 pp.

Singh, S.R. and van Emden, H.F. (1979). Insect pests of grain legumes. Ann. Rev. Entomol. 24: 255-278.

Singh, S.R. and Taylor, T.A. (1978). Pests of grain legumes and their control in Nigeria. In Pests of Grain Legumes: Ecology and control. ed. S.R. Singh, H.F. van Emden and T.A. Taylor. Academic press. London and New York 454 pp.

Smart, J. (1976), Tropical pulses. London. 348 pp.

Snelling, R.O. (1941). Resistance of plants to insect attack Bot. Res. 7: 543-586.

Southwood, T.R.E. (1966). Ecology Methods with special reference to the study of insect populations, London, Methuen 391 pp.

Suh, J.B and Simbi, C.O. (1983). Studies on the legume pod-borer, Maruca testulalis (Geyer) -VIII. Cowpea phenology and Yield loss assessment; Effect of Loss of leaves, shoots, flowers and pods on cowpea yield in Western Kenya. Insect Sci. Application 4: 89-86.

Summerfield, R.J and Bunting, A.H. (1980). Advances in Legume Science, Royal Botanic Gardens, Kew, England 667 pp.

Taylor, T.A. (1964). The problem pests of cowpea, Vigna sinensis L. in Southern Nigeria. The Nigeria Grower and Producer, 3: 17-21.

Taylor, T.A. (1968). The effects of insecticide application on insect damage and performance of cowpea in Southern Nigeria. Nigerian Agric. J., 5: 29-37.

Taylor, T.A. (1969). On population dynamics and flight activity of Taeniothrips sjostedti (Tryb) (Thysanoptera: Thripidae) on cowpea. Bull. ent. Soc. Nigeria 2: 60-71.

Taylor, T.A. (1971). Insect pests of tropical grain legumes. Seminar on plant protection of tropical food crops IITA/IRAT/Food foundation, Ibadan, Nigeria, May 24-28 1971, 19 pp.

Thomaszewski, M. and Thimman, K.V. (1966). Interactions of phenolic acids, Metallic ions and Chelating agents on auxin-induced growth. Pl. physiol. (Lancaster) 41:1443-1454.

van Emden, H.F. (1972). Aphid technology. Academic Press. London and New York 344 pp.

Varley, G.C., Gradwell, G.R. and Hassel, M.P. (1973). Insect population Ecology, London, Blackwell, 212 pp.

Way, M.J. (1961): Crop Losses by insects and the problem of control. Proc. Nutr. Soc. 20: 5-11

Whitney, W.K. and Gilmer, R.M. (1974). Insect vectors of cowpea mosaic virus in Nigeria. Ann. appl. Biol., 77: 17-21.

Wilcoxon, R.D and Peterson, A.G. (1960). Resistance of dollard red clover to the pea aphid, Macrosiphum pisi. J. Econ. J. Econ. Entomol. 53:863-865.

Williams, R.J. (1975). Diseases of cowpeas, Vigna unguiculata (L.) Walp in Nigeria PANS 21(3): 253-266.