SOME ASPECTS OF CULTURAL PRACTICES AND USE OF BOTANICALS IN FIELD MANAGEMENT OF PIGEONPEA BRUCHIDS, *CALLOSOBRUCHUS* SPP. AND OTHER FLOWER AND POD PESTS OF PIGEONPEA.

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August, 2001

DECLARATION

I declare that this thesis is my original work and has not been presented for a degree award in any other University.

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DEDICATION

This work is dedicated to my family.

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SUMMARY

The influence of cultural practices (intercropping, time of planting, spacing, time of harvesting) and use of botanicals and synthetic insecticide in field management of the major flower, pod and seed pests of pigeonpea were investigated during the first and second rains of 1998 and the first rains of 1999 at Kawanda Agricultural Research Institute (KARI).

The effects of intercropping on the incidence and/or severity and damage of flower beetles (*Mylabris* spp.), thrips (*Megalurothrips* spp.), pod borers (*Helicoverpa armigera)*, pod bugs (*Clavigralla* spp.), pod fly (*Melanagromyza* spp.) and bruchids (*Callosobruchus* spp.) on pigeonpea were studied. Six treatments Viz.(short duration pigeonpea intercropped with finger millet, medium duration pigeonpea intercropped with finger millet, short duration pigeonpea intercropped with cowpea, medium duration pigeonpea intercropped with cowpea, short duration pigeonpea sole crop and medium duration pigeonpea sole crop) were imposed. The experiment was laid out in a randomised complete block design (RCBD) on 6x4m plots and replicated four times.

Similarly, the effects of time of planting and spacing on the above parameters and pests was studied, being laid out in a split plot design, arranged in a RCBD. Three planting dates at on-set of rains, 2 and 4 weeks after on-set of rains were in the main plots (14x11m) and three spacing treatments as 50x20cm (recommended), 25x10cm and 100x40cm) in the sub plots (4x3m), and replicated four times. Effects of time of harvest on pigeonpea seed damage in storage was also evaluated, with three treatments (at physiological maturity (PM), 2 and 4 weeks after PM), replicated four times in a RCBD.

Additionally, the effects of selected botanicals and a synthetic insecticide on pigeonpea seed damage in storage was investigated using nine treatment applications (4 fresh formulations of crude water extracts of ash, tobacco, tephrosia and melia seed(MS); 2 fermented formulations of tephrosia and MS;

1 compound extract of tephrosia and MS; 1 treatment of cypermethrin (synthetic) and the control). The experiment was arranged in a RCBD, on 4x3m plots, replicated four times. Data were analysed by M-STATC statistical package except for time of planting and spacing which was by SAS system for mixed models.

Results indicated that *Mylabris pastulata*, *H. armigera* and *C. chinensis* infestations were significantly lower ($p<0.05$) in pigeonpea intercropped with millet than in either pigeonpea intercropped with cowpea or pigeonpea sole crops. But infestations of *Megalurothrips sjostedti*, *Aphis* spp and *Clavigralla* spp were significantly lower ($p<0.05$) in pigeonpea intercropped with cowpea than in either pigeonpea intercropped with millet or pigeonpea sole crops. Seed damage by *Clavigralla* spp and *H. armigera* were significantly lower in pigeonpea intercropped with cowpea than in pigeonpea intercropped with millet or pigeonpea sole crops. Intercropping did not significantly influence pigeonpea seed damage by *Melanagromyza* spp. Seed damage by pod bugs was highest (17.0%-19.1%) followed by pod borer damage (4.3%-7.1%) and pod fly damage was the lowest (0.9%-1.6%).

Planting date but not spacing significantly ($p<0.05$) influenced damage by *H. armigera*, *Clavigralla* spp, *Melanagromyza* spp and *C. chinensis*. Planting at on-set and 2 weeks after on-set of rains significantly reduced damage on pigeonpea seed. The interaction of planting date and spacing were significant only for *Clavigralla* spp in the first rains of 1999 and *C. chinensis* in both rains.

Seeds harvested at physiological maturity and 2 weeks after physiological maturity, had significantly lower damage in storage than those harvested at 4 weeks after physiological maturity. The adult *C. chinensis* emergence from seeds after one and two months of storage and the seed damage were highest from treatments with ash and the control, while the lowest were in seeds from plots treated with cypermethrin and tobacco. The performance of tephrosia and melia seed extract (MSE) followed those of cypermethrin and tobacco. However, the fermented extracts of tephrosia and MSE were more effective in reducing adult emergence and seed damage compared to their fresh formulations.

In conclusion this study has shown that intercropping pigeonpea with cowpea can significantly reduce pigeonpea seed damage in the field due to *Clavigralla* spp and *H. armigera*. Planting pigeonpea at on-set of rains up to 2 weeks after on set of rains, significantly reduces pigeonpea seed damage by *H. armigera*, *Clavigralla* spp, *Melanagromyza* spp and *C. chinensis*. Harvesting pigeonpea at physiological maturity and 2 weeks after, significantly reduces pigeonpea seed damage in storage due to *C. chinensis*.

Cypermethrin and crude extracts of tobacco, tephrosia and melia seed significantly reduced field infestations and pigeonpea seed damage in storage due to *C. chinensis*. Tobacco extract had the highest efficacy followed by tephrosia and melia seed extract.

CHAPTER ONE

INTRODUCTION

1.1.0 The Pigeonpea Crop

The pigeonpea (*Cajanus cajan* (L) Millsp.) belongs to the sub-tribe Cajanae and tribe Phaseoleae which contains many bean species consumed by man. Out of the eleven genera within the sub-tribe, *C. cajan* is the only cultivated food crop (Van der Maesen, 1990). Pigeonpea is widely thought to have originated from Peninsular India where several of its wild relatives are still found, (Van der Maesen, 1990), although some authors consider East Africa, where pigeonpea seems to occur wild as the possible centre of origin (Purseglove, 1968). Endowed with several unique characteristics, it finds an important place in the farming systems adopted by smallholder farmers in a large number of developing countries. Water logging, frost in winters and highly acidic soils adversely affect pigeonpea crops.

1.1.1 Importance of the crop

The pigeonpea is an important food crop for both humans and livestock. Nutritionally, pigeonpea is very rich, having a protein content of about 20.5% and a starch content of about 64.2% (Faris and Singh, 1990). It also contains important minerals, vitamins and fibre. It ranks fifth in importance among the true pulse crops grown for human consumption in the world (Khan and Rachie, 1972), and fourth in Uganda after Phaseolus beans, groundnuts and soybeans (Table

1). Apart from its food value pigeonpea is widely grown in the tropics and Sub-tropics for its role in the farming systems adopted by the small holder farmers in a number of developing countries. It is a hardy crop growing in marginal soils and fitting extremely well into diverse intercropping systems (Natarajan *et al*, 1985). The plant is also an important source of bio-fuel (Nene *et al*, 1990) and has many medicinal attributes (Morton, 1976). The crop is also useful in agro-forestry for soil fertility improvement (Mulila,1993), it adds humus, and in symbiosis with Rhizobia fixes additional nitrogen to the soil, while through its deep and wide root penetration offers improved soil structure (Nene and Sheila, 1990).

1.1.2 Production and Utilisation

Pigeonpea is ranked as one of the major grain legume crops of the tropics (Nene and Sheila, 1990). The Indian sub-continent accounts for nearly 90% of the area cropped and most of the remaining percentage of production comes from South East Asia, East Africa and Central America (Van der Maesen, 1990). In East Africa pigeonpea is the second most important grain legume after beans (*P. vulgaris* L.) where approximately 133,000t is produced from more than 249,000ha (Nene *et al.*, 1990).

Production in Uganda was estimated at 54,600t from 78,000ha in 1993 compared to 22,000t from 63,000ha in 1987 (Nalyango and Emeetai-Areke, 1987). From 1990 to 1992 an estimated 50,000-53,000t were produced from

59,000-63,000Ha (Esele, 1994). However, its production in the last decade portrays its competition among other grain legumes grown in the country (Table 1).

Table 1 Area planted and production of selected legumes in Uganda from the year 1987 to 1997

Year	Fieldpea	Cowpea	Pigeon-pea	Soybean	Fieldpea	Cowpea	Pigeon-pea	Soybean
	Area ('000Ha)				Production ('000t)			
1987	22	42	60	10	11	37	27	8
1988	23	46	64	17	12	38	42	14
1989	24	47	68	18	12	38	46	16
1990	24	49	62	37	12	39	51	37
1991	25	48	60	54	15	40	50	59
1992	26	49	62	59	15	41	51	53
1993	27	51	64	65	16	43	53	67
1994	28	53	67	68	17	45	55	75
1995	28	54	70	72	16	45	58	79
1996	29	56	71	76	17	47	58	87
1997	30	58	72	76	18	48	59	87

Note: Estimates are of economic production after making allowance for post harvest losses.
(Source: MAAIF and Statistics Dept. MPED)

Most of the crop is grown in the drier areas of the North and North east covering the traditional Lango, Acholi and Teso areas, where the crop is best adapted (Jameson, 1970; Silim *et al,* 1993). It is mainly grown as an intercrop with cereals like finger millet and sorghum, root crops like cassava and also with other legumes notably groundnuts and cowpeas or other intercrops like sesame. Most production, if not all come from small-holder farms (Nalyango and Emeetai-Areke, 1987; Nene and Sheila, 1990).

The average yield on subsistence farms is very low, less than 1t/ha compared to 2-4t/ha from experimental plots (Musaana, 1978; Silim-Nahdy, 1995). The main use of pigeonpea is for human food in the form of dried seeds or green seeds and to a small extent pods as a vegetable (e.g. in Indonesia). In India dry seeds are dehulled and split to make ‘dhal’, a popular Indian dish, which is also practiced in Lango and Acholi areas of Uganda (syn. ‘Agira’- Luo).

In Africa and Central America whole seeds with or without testa is more popular. Quite often sprouted seeds which are consumed whole, split or ground sprouted seeds are also used for soups (Nene and Sheila, 1990). It is also used as animal feed in the form of leaves, cast off pods and husks. Recent work indicates that pigeonpea starch can be used to make noodles that compare well with those presently made from mung bean starch. Likewise fermented foods such as tempe, normally made from soybean, can be successfully made from pigeonpea. Another possible product is instant dhal made from pre-cooked split pigeonpea seed, which could prove very popular in both traditional and non-traditional pigeonpea consuming areas.

In Venezuela a local soft drink/ mild liquor called ‘chicha’ which is usually prepared from rice, can be prepared from pigeonpea and is considered very tasty, this could be one more possibility of using pigeonpea (Reed and Lateef, 1990). Some recent studies in Bangaladesh indicate the possibility of using pigeonpea to produce paper pulp (Razzaque *et al.,* 1986; Akhtaruzzaman *et al.*, 1986) and such use is thought to certainly increase the demand for pigeonpea in non-traditional areas.

1.1.3 Production Constraints

There are a number of varied constraints encountered in pigeonpea production and post-production systems. The nature and magnitude of these constraints differ among the various production areas. However, one of the constraints in Uganda is the low yields which is mainly attributed to the use of unimproved land races, damage by disease and insect pests (Silim *et al*, 1993; Silim-Nahdy, 1995). The most serious damage to pigeonpea is caused by insect pests that attack the flowers, pods, and seeds (Lateef and Reed, 1990).

1.2 Problem statement

Cultural practices such as intercropping, time of planting and growing different cultivars are common in pigeonpea farming systems (Osiru and Kibira, 1981; Reed and Lateef, 1990). However, the benefit of these practices seem to have been studied with respect to land productivity values rather than pest control values. There is evidence that some cultural practices are of pest management values and many reports point that pod borer infestation in pigeonpea remains at a sub economic level if pigeonpea is intercropped with other compatible crops (Singh and Singh, 1978; Giri *et al*, 1980; Bhatnagar and Davies, 1980). Lateef (1991), noted that the manipulation of sowing dates and maturity periods of pigeonpea are likely to have profound effects on *Helicoverpa* attacks. Such aspects as these have not been given due research considerations in Uganda and yet they could be equally useful once proven to be effective strategies.

Bruchid infestation starts in the field and is characterised by its insidious nature of damage to seeds in storage (Silim-Nahdy, 1995). Although infestation and damage in the field have been reported to be generally low, such infestations nevertheless, have serious implications. This is because once infested seeds are stored, the insects multiply very rapidly within a short time with very high consequent damage (Silim-Nahdy, 1995). Although some pest control methods are available, the more modern pest control options (insecticides and fumigants), have several drawbacks including lack of sustainability in usage by resource poor farmers in developing countries and their hazardous nature in the stored food grains, if not properly applied (Kitch *et al.*, 1992),.

As an alternative to chemical control, farmers adopt various methods to prevent losses. These include; use of botanicals, such as vegetable oils and other plant parts or products (Sangappa, 1977; Nazan, 1983), applied in stored produce. Therefore the problem is lack of field management strategies for the bruchids to break the field to store infestation cycle. Furthermore the effect of various cultural practices on field infestations of pigeonpea by bruchids, other flower and pod pests, is not known.

1.3 Justification of the study

The production and marketing of pigeonpea is mainly hampered by bruchids which attack the crop and cause extensive damage resulting in enormous losses of up to 40% or more, (Silim-Nahdy, 1995; Minja, 1997) during storage. The most predominant and important bruchid causing damage to pigeonpea is *Callosobruchus chinensis* (Silim-Nahdy, 1995). This species attacks pigeonpea seeds while still in the field and the damage continues during storage (Taylor, 1981). Although it is known that infestation and damage starts in the field, the most common control methods target the crop in storage rather than in the field.

Preliminary studies have shown that synthetic insecticide applications are effective in the control of bruchids in the field (Silim-Nahdy, 1995). However, the use of synthetic insecticides has not been encouraged due to concern of agrochemical pollution of the environment, (Lateef, 1991; Armes *et al*, 1992). This therefore calls for adoption of control strategies that are eco-friendly, like botanicals, which have also been used in control of this pest in storage (Van Huis, 1991; Silim-Nahdy, 1995).

Thus, a study of field management of *C. chinensis* using botanicals and the manipulation of cultural practices is considered important and worth undertaking. The relationship between some cultural practices associated with the production of pigeonpea and pest infestation is also not well known. These are necessary for better understanding and for determination of their potential in checking the transfer of infestation from field to storage. In addition they would be an important tool in developing an integrated pest management approach.

1.4 Objectives of the Study.

The broad objectives of this study were to identify some cultural practices that could be used in the management of pigeonpea field and seed storage pests notably the bruchid (*Callosobruchus sp.)*, some other flower and pod pests, while the crop is still in the field. In addition, the efficacy of botanical pesticides needed to be understood in the management of pigeonpea pests in the field condition.

Thus the specific objectives of this study were to:

1) Investigate some cultural practices that may influence field infestation of pigeonpea by *C. chinensis,* other flower and pod pests of pigeonpea.

2) Establish the level of damage of pigeonpea seed in storage by *C. chinensis* due to field infestation.

3) Evaluate the efficacy of selected botanicals and a synthetic insecticide in controlling *C. chinensis* , other flower and pod pests of pigeonpea in the field.

CHAPTER TWO

LITERATURE REVIEW

2.1 Insect Pests of Pigeonpea.

Pigeonpea is one of the grain legumes with the greatest range and incidence of pests both in the field and in storage, with more than 200 insect species in India alone (Singh and Van Emden, 1978; Lateef and Reed, 1990). Pigeonpea has consequently been described as a very accomodative crop because out of the over 200 insect pest species that attack the crop only a few cause economic damage. Moreover, pigeonpea produces ample amount of flowers which compensate those lost due to insects (Reed and Lateef, 1990). In storage, the commonest and most damaging insect pests that cause considerable crop losses belong to the family Bruchidae and Order Coleoptera (Singh and Jambunathan, 1990).

2.2 Flower and Pod Pests of pigeonpea

The most damaging pests of pigeonpea are those that attack the flowers and pods (Reed and Lateef, 1990). The most frequent flower and pod pests of pigeonpea include insects of the families; Meloidae (*Mylabris* spp.), Scarabaeidae (*Pachnoda* sp. cordata), Coreidae (*Clavigralla* spp.),Noctuidae (*Helicoverpa* spp.), Pyralidae (*Maruca* sp. M. *vitrata* (formerly, *testulalis*). The pod pests are not exclusive to pods but may also attack flowers as well as dry seed e.g. families Bruchidae (*Callosobruchus* spp.). Others may attack both pods and seeds e.g. family Agromyzidae (*Melanagromyza* spp.), and also *Clavigralla* spp., and *Helicoverpa* spp in other families.

Among the pod pests, the most important by far is the lepidopteran pod borer, *H. armigera* (Hub.). The adult moths fly during the night and lay their eggs on a large range of plants. They are strongly attracted to pigeonpea when flowers appear, and the small white eggs are laid singly on leaves, flowers and pods. The tiny larva first feeds by scraping the surface tissue then bores into buds and flowers and the large larvae bore into the pods, eating the developing seeds and leaving characteristic large round holes along each locule (Reed and Lateef, 1990). A large larva can destroy many flowers and several pods each day. The life cycle can be completed in a little more than a month. The female can lay more than 1000 eggs, resulting in rapid increase in infestation (Reed and Lateef, 1990).

Other important lepidopterran larvae attacking flowers and pods include those of *Maruca vitrata* which is common in many areas in Africa and Asia; the larvae of *Lampides boeticus*, *Catochrysops strabo* and *Exelastis atomosa* (plume moth), are common in several parts of Asia and can cause substantial losses in some years (Bhalani and Parsana ,1987). Larvae of *Etiella zinckenella*, a pest of several grain legumes, are often found in mature pods (Reed and Lateef, 1990; Night and Ogenga-Latigo, 1994).

Many species of thrips including *Megalurothrips usilatus* and *M. sjostetdi* are found in the flowers. These have been reported to cause yield losses in some areas (Rawat *et al.*, 1969; Pollard and Guiseppi-Elie, 1981), although at ICRISAT centre flowers infested with 200 or more thrips have been observed to develop into healthy pods (Reed and Lateef, 1990). In Uganda flower thrips infestation in pigeonpea, however, have not been investigated.

Several species of large blister beetles including *Mylabris pastulata* (Thunberg) in India invade pigeonpea and feed on the flowers. These can be very damaging in areas where only a few small plots are in flower, but where large areas are in flower the pests are diluted across the crop, and the damage is insignificant (Reed and Lateef, 1990). In Uganda, blister beetles has been recorded as a new pest on pigeonpea (Night and Ogenga-Latigo, 1994) which may be important considering that pigeonpea in this country is grown in small fields (Nalyango and Emeetai-Areke, 1987) and may be difficult to synchronise sowing.

Pod fly (*Melanagromyza obtusa)* is a very damaging pest in Asia. The small black fly lays its eggs through the wall of the young pod and its larva feeds in a seed. Reed and Lateef (1990), reported that the most likely species in Africa is *M. chalcosoma* (spencer). However, in Uganda the incidence and damage levels of pod fly on pigeonpea has not been studied. Several pod sucking bugs, particularly *Clavigralla* sp. and *Nizara viridula* feed on pigeonpea pods. These pests are very common in Africa and Asia, particularly in dry seasons (Reed and Lateef, 1990). Ayyar, (1940), noted that the adults and nymphs of the bugs infest pods and suck the juice. The seeds in the attacked pods become shrivelled and are useless. They are underestimated pests and the seed damage that they cause is often attributed to drought.

The bugs mate end to end and such pairs are easily seen in the fields. The female lays eggs in clusters ranging from 3 to 14 in the field and pods are preferred for egg laying. The egg is brown to deep brown and shows a depression dorsally after one or two days of its deposition, which becomes well marked as the egg nears hatching. The incubation period varies from 8 to 15 days. A newly transformed nymph is reddish brown and is gregarious in nature. It moults five times and the duration of the life cycle varies from 36 to 56 days (Gangrade, 1961). The activity of the bugs starts with the pod formation in the field and continues till harvest of the crop. Both nymphs and adults feed on stems and pods though a large number of them feed on pods. As a result, the pods show pale yellow patches and the seeds are shrivelled (Gangrade, 1961).

2.3.0 Storage pests of Pigeonpea

The common pests that attack pigeonpea in storage and cause considerable crop losses belong to the insect family Bruchidae (Coleoptera)(Singh and Jambunathan, 1990). Different bruchid species have been reported according to their origin e.g. *Callosobruchus analis* from India (Nair, 1975), *C. chinensis* from India and the Caribbean, (Srivastava, 1964, Bridwell, 1918), *C. maculatus* from India and the Caribbean (Davies and Lateef, 1975, Bridwell, 1918), *C. theobromae* from India (Davies and Lateef, 1975). In East Africa, *C. analis* (F.) which is of Asian origin has been reported in Tanzania (Mphuru, 1978). In Uganda the occurrence of *C. maculatus* on pigeonpea has been associated with cross infestation in stored pigeonpea and cowpea (Silim-Nahdy, 1995). Apart from bruchids the other but minor secondary insect pest attacking pigeonpea in storage is the red flour beetle, *Tribolium castaneum.*

2.3.1 Pigeonpea Bruchids *Callosobruchus* spp.

The pigeonpea bruchid *Callosobruchus* spp and especially *C. chinensis (L.)* referred to as the Adzuki bean weevil (Southgate, 1978), belongs to the Order Coleoptera and family Bruchidae. The Bruchidae comprises nearly 1,300 species grouped into 56 genera of which three tribes constitute genera of economic importance (Southgate, 1979).

Some species belonging to at least six genera attack grain legumes grown, stored and eaten by man (Southgate, 1979). *C. chinensis* together with other species such as *C. maculatus, C. analis, C. rhodesianus* and *C. atrolineatus*, infest common legumes either in the field or in storage (Utida, 1972; Messina and Renwick, 1985). In Uganda, *C. maculatus* and *C. chinensis* have been observed to feed on pigeonpea (Davies, 1960). Silim and Odong (1993), Silim-Nahdy, (1995) found *C. chinensis* to be the most predominant species in Uganda. Bruchid damage starts in the field and continues in storage where it intensifies (Taylor, 1981).

2.3.2 Origin and Distribution of *Callosobruchus spp.*

Callosobruchus chinensis is believed to have originated from tropical Asia where it is still a dominant species of the genus *Callosbruchus*. It is now distributed throughout the tropics and Sub-tropics. For example, in India, *C. chinensis* and *C. maculatus* are the most important species responsible for storage damage (Singh and Jambunathan, 1990). In Jamaica, *C. chinensis* and *C. maculatus* have also been recorded (Nwanze and Horber, 1976; Schotman, 1986). In Tanzania, *C. chinensis* is the most widespread among the other species like *C. maculatus, C. analis* and *C. rhodesianus* (Mphuru, 1978). Past records in Uganda show that C. *chinensis, C. maculatus* and *C. atrolineatus* do commonly infest pigeonpea (Davies, 1960). Recent survey results , however, have shown that three bruchids; *C. chinensis, C. maculatus* and *A. obtectus* actually infest pigeonpea in Uganda (Silim and Odong, 1993; Silim-Nahdy, 1995). The most widespread and serious species by far was *C. chinensis* (Silim-Nahdy, 1995). Their relative incidence and distribution are however, not indicated. And all the above records seem to suggest a similar cue for both field and storage distribution pattern.

2.3.3 Biology and Ecology of the Pest

Haines (1991), studied the biology and ecology of *C. chinensis.* The mottled brown beetle about 3mm long, lays eggs singly glued on pods or seeds and can be easily seen. Eggs hatch into white larvae in 4-6 days and burrow into the pod or seed through the base of the egg where they feed and moult four times within a period of about 21 days before developing into pupae. The pupae takes about 10 days inside the seed from which adults emerge through a neat cylindrical hole. Sometimes after emergence, the adult may remain in the pupal cell for a few days before chewing and pushing the `window' prepared by the last instar larva to facilitate emergence (Haines, 1991).

One generation takes four or more weeks depending on temperature and Relative Humidity, for example in the Caribbean, development period ranged from 32 to 37 days (Schotman, 1986). *C. chinensis* develops within a temperature range of 17.5-37.5°C with an optimum of 32.5°C and 22.5 days as the shortest mean development period (Howe and Currie, 1964). Adult beetles in storage live for not more than 12 days under optimum conditions (32°C and 90% R.H) and do not feed during this time but the female lays up to 70 eggs. Oviposition, however, may be depressed in the presence of previously infested seeds (Haines, 1991).

Adults are sexually mature at emergence and under field conditions feed on nectar and fungi (Yoshida, 1990). *C. chinensis* appear to develop dimorphic forms of flight/active and flightless/sedentary stages (Silim-Nahdy, 1995), just like in the case *of C. maculatus* and *A. obtectus* (Utida, 1972; Nwanze and Horber, 1976; Messina *et al.*, 1987; Gopal, 1986). The dimorphic forms are due to the ecological niches they occupy, that is, flight forms adapted to the field and normal forms to storage conditions (Messina, 1990). It is therefore important to target this flight forms in the field in order to reduce infestations carried from the field to the store.

2.3.4 Source of Infestation and Damage Patterns

Infestation may come from previously infested seeds at planting, nearby stores or alternative host plants like cowpeas or weeds in the field and then disperse through the flight stages adapted to field conditions. Available information indicates that *Callosobruchus spp* does infest pigeonpea in the field (Raina, 1972; ICRISAT, 1977). Silim-Nahdy (1995), showed that in pigeonpea *C. chinensis* is responsible for 100% of field infestation of all species involved and that infestation at pod stage development is highest at mature dry pod `early', and mature dry pod `late', with egg laying more on seeds than on pods.

In addition to pod stage suitability and pod texture, other factors that encourage infestation include damage to pods by other pod pests especially *H. armigera* and partially dehisced pods which provide access to seeds for egg laying and quicker reproduction in the field.

Though the major source of infestation is from the field, cross infestation within stored commodities also occurs (Caswell, 1968; Singh and Jambunathan, 1990). In storage infestation builds up rapidly with corresponding high levels of damage (Southgate, 1979; Alzouma, 1981) and most often an apparently undamaged sample of seeds at harvest becomes heavily infested after only 4-8 weeks of storage (Taylor, 1981). Though none of the available estimates of the actual quality of legume seeds lost due to bruchid attack have been obtained using acceptable and reliable loss assessment techniques (Harris and Lindbland, 1978), the existing estimates , variable as they are, indicate very high figures. Caswell (1959), observed that 1% field infestation of seeds at harvest time results in 80% damage after only `a few months' of storage.

In some parts of Eastern and Southern Africa, weight loss of 30% has been reported for stored legumes in Kenya (Delima, 1973), 40% on cowpeas in Zambia, and 21% reported on grain legumes in Uganda after six months of storage (Silim *et al*, 1993). Using the above estimates as indicators of general losses in legumes it would appear that storage losses in pigeonpea may be equally high (Silim-Nahdy, 1995).

2.4.0 Control of Pigeonpea Bruchids (Pest Management)

In view of the fact that bruchid infestation starts in the field , many authors have recommended early harvest of mature pods, followed by sun-drying of seeds before storage in beetle proof containers which include metals, plastic, or earthware. However, storage of grain legumes over long periods is usually difficult in many countries of the tropics because of their high susceptibility to bruchid attack (Jakai and Daoust, 1986). Various pest management strategies available have targeted `in storage' seed treatment and offering no `in field' management which could help break the field to storage infestation cycle.

Cultural practices observed or recommended for reducing field infestation mostly refer to harvest time and intercropping patterns (Prevett, 1961; Caswell, 1968). The use of resistant varieties and chemical insecticides have been recommended to control field infestation of *C. chinensis* (Silim-Nahdy, 1995), in addition to other cultural practices like rotation and crop hygiene.
But the use of resistance in crop plants is a long term strategy, while synthetic chemicals are a threat to the environment and very expensive for the resource poor farmers. Considering that insect pests often develop

resistance to them, it becomes very difficult to use them in a sustainable small-holder, poor-resource base farming system.

2.4.1 Cultural Control methods

Over the generations pigeonpea farmers have evolved traditional practical means of pest management that allow them to grow the crop profitably in most years (Reed and Lateef, 1990). Perhaps the most obvious factor in traditional pigeonpea growing is that it is most frequently grown as an intercrop (Acland,1971; Osiru and Kibira, 1981). Most of the pigeonpea grown in the traditional intercrop systems is of medium to long-duration cultivars, with much of the crop's growth and flowering occurring after the harvest of the companion crops (Reed and Lateef, 1990). There is some evidence to suggest that cultivar duration has been unconsciously selected to avoid the potential peak pest attacks in an area. For example, in northern India most farmers grow long duration varieties that flower soon after the winter, when insect populations are at a relatively low level (Reed and Lateef, 1990).

One of the most important factors in traditional agricultural pest management is the strict adherence to well defined crop seasons. When all farmers in an area synchronously sow crops of similar duration, there is a reduced opportunity for pests to build up on early sown crops and then disperse onto the later sown (Lateef, 1991). Where all the pigeonpea in an area is simultaneously attractive to a pest the available population is diluted across the area and pest-caused losses are minimised (Reed and Lateef, 1990). Lateef (1991), suggested that the manipulation of sowing dates and maturity of pods in pigeonpea are likely to have profound effects on Helicoverpa attacks, but there is lack of detailed information on such aspects as these.

A few cultural practices have been observed to reduce bruchid damage in storage. These include time of harvest, pod storage, crop hygiene, intercropping pattern. For example, regular weekly harvest of cowpea (Prevett, 1961; Caswell, 1968), intercropping of beans and maize (De-Lima, 1973) have shown reduced bruchid infestations on cowpeas and beans, respectively. Early harvest and `whole plant' harvest have been considered as one of the cultural control strategies. From the biology of the pest, it has been found that harvesting early as soon as pods mature can reduce infestation in subsequent storage (Silim-Nahdy, 1995). Pod storage, as a measure of bruchid control has been reported in several countries (Booker, 1967; Silim *et. al.* 1990). In pigeonpea however, pod storage is only recorded in Uganda (Acholi area) and is shown to be effective against *C. chinensis* during storage (Silim-Nahdy, 1995).

For intercropping pattern, little work has been done on understanding the nature and magnitude of pest complex and its effect on crop losses, pesticide use and pest management practices in intercropped compared to sole cropped pigeonpea (Ali, 1990). The manipulation of time of planting and plant density or time of harvest on pest incidence and damage on pigeonpea has not been studied in Uganda.

2.4.2 Chemical Control Strategies

Chemical spraying can be used in field management of pigeonpea pests with varying degrees and levels of success. Silim-Nahdy (1995), showed that field spraying with cypermethrin reduced field infestation by both *H. armigera* and *C. chinensis*. Field spraying may, however, not be able to totally prevent transfer of infestation from field to storage due to the insidious and hidden nature of *C. chinensis* in which it could escape surface application of contact insecticide. But it can significantly reduce the population of pest transferred from the field to storage and the `seed damage' in seeds stored beyond two months (Silim-Nahdy, 1995).

Fumigation and/or use of expensive chemicals with low mammalian toxicity provides relatively good control of storage pests (Credland, 1992). But such control options could be avoided if there were alternatives that are cheap and without such toxicity problems. The problem with grain legume chemical control method is associated among others with; toxicity dangers, natural enemy destruction, and resistance to pesticides (Ware, 1989; Armes *et al.*, 1992). The most widely used storage insecticide is Pirimiphos methyl, "Actellic" and Malathion dust formulations (Rajapakse, 1990; Silim *et. al.*

1990; Giga and Biscoe, 1990), but some insect biotypes have developed resistance to them (Giga and Mazarura, 1990).

Although new and generally more expensive chemicals are being introduced, their use is expected to be equally finite leaving the battle against storage pest unresolved. Some chemicals have been rejected because of potential or real danger to human health, livestock and the environment e.g. DDT and dieldrin (Sengoba, 1991). Even if chemical insecticide applications have been recommended for some pests like the pod borer complex in pigeonpea (Gosalwald *et al.*, 1992), the increasing concern for the environment and the trend towards organic farming has driven the search for effective and eco-friendly alternatives (Sadawarte and Sarode, 1997). This therefore calls for an active, cheap and locally available alternative, viz. plant products which can be got from within the farming environment. Sengoba (1991), indicated that resource poor farmers require crop protection measures that are cheap, simple and cost effective so that production can be sustained.

2.4.3 Pest Control using Botanicals

Botanical insecticides are natural insecticides, toxicants derived from plants (Ware, 1989). Among these are vegetable oils, natural plants and plant products. A widely used example of botanical application is vegetable oils, which is usually applied to prevent build up of bruchids in stored seeds of grain legumes (ICRISAT, 1976; Sangappa, 1977). The vegetable oils tested were from African palm, maize, groundnuts, soybean, cotton seed, sunflower, coconut, sesame, neem, mint, rape, mustard and *Acornus calamus*. Regardless of the source, the oils gave adequate protection from bruchids, crude extracts being more effective than the purified ones (Schoonhoven, 1978). Oil treatment acts as an ovicide (Credland, 1992) and gives the grain a good sheen (Varma and Pandey, 1978). The oils also reduced oviposition with higher adult and larval mortality reported (Van Huis, 1991). Control of *C. chinensis* by oils has also been achieved (Cruz and Cardona, 1981; Ali *et. al.*, 1983 ; Khaire *et. al.*, 1992). However, the problem with vegetable oils is that they are so much used in human diet that there is hardly any substantial amounts to be used in grain storage. In addition vegetable oil production is still at a low level in Uganda (Otimodoch and Singh, 2000).

Many natural plants and plant products are known to have either antifeedant, repellent or insecticidal effects on bruchids and their actions are sometimes synergistic (Ware, 1989; Van Huis, 1991). The use of plant materials against storage pests have been referred in many countries (Delobel and Malonga, 1987 ; Van Huis, 1991), and of particular interest is *azadiractin,* a compound (tetra-nortriterpenoid) from neem (*Azadirachta indica* A. *Juss)* and china hemp (*Melia azedarach* mill). This compound is considered a promising alternative to synthetic insecticides and is being investigated in several countries (Ivbijaro, 1983 ; Jacobson, 1988; Jilani, 1983; Isman, 1997).

Several other useful plants have been listed but their efficacy have been found to be variable perhaps due to strain differences or time of harvest and utilisation (Lambert *et al.*, 1985). For example, in surveys in several parts of Uganda, Tanzania and Zimbabwe (Giga *et al.*, 1992) many plant and plant products were reported to be used by farmers to control the bean weevil (*A. obtectus*) in storage. These included lemon grass (*Cymbopogon* sp.), banana juice (*Musa* sp.) wood ash and pawpaw (*C. papaya*). Surveys in Uganda also showed that in addition to above products, pineapple juice, wood ash and soil were also being used to protect beans from *A. obtectus* damage (Silim *et al.*, 1990). In the laboratory, some plant species have been found to be effective against the bruchids (Table 2).

Table 2 Plant species that have been used against Bruchids in storage

Plants	Bruchid species	Reference
Azadirachtha indica A. Juss	All	van Huis (1991)
Melia azedarach Mill.	All	van Huis (1991)
Cassia nigricans	*A.obtectus*	Lermbert *et al.*,1985
Annona aquamosa L.	*C.chinensis*	Ali *et al.*, 1983
Piper nigrum	*C. maculatus* & *C. chinensis*	Su (1977); Morallo-Rejesus *et al.*, 1990
Piper guineense Scum. & Thon	*C. maculatus*	Olaifa and Erhun (1988)
Capsicum spp	*C. maculatus*	Ivbijaro & Agbaje (1986)
Tephrosia spp	*C. maculatus* *C. chinensis*	Delobel&Malonga(1987) silim-Nahdy (1995)
Citrus cematofolia L.	*C. maculatus*	Rajapakse (1990)
Eichhornia crassipes Mart. Solms	*C. chinensis*	Usha and Jamil (1990) Silim-Nahdy (1995)

Very few of the plant materials have been studied under the traditional storage conditions (Van Huis, 1991). Consequently, their practicability and effectiveness under field usage have been questioned (Taylor and Webley, 1979). Among the plants found to be with high potential for use against *C. chinensis* infestation in stored pigeonpea seeds include; Tephrosia, flue cured tobacco and wood-ash (effective at very low concentration i.e. 0.5g/200). Those that had higher doze response included burley tobacco, water hyacinth and Mexican marigold (Silim-Nahdy, 1995).

2.4.4 Physical and Mechanical Control methods

This is the application of direct or indirect measures that kill the pest, disrupt its physiology other than by chemical means, exclude it from an area, or adversely alter the pest's environment (Ware, 1989). There appears to be little use of such physical methods for pigeonpea pest. One example is where Reed and Lateef (1990), observed farmers in India picking blister beetles from pigeonpea. They however, noted that this may be done in small fields and with low infestations. Moreover care must be taken to wear protective gloves on hands as these insects cause blisters upon biting human skin.

Some of the physical control strategies in storage include among others; use of sand (Silim-Nahdy, 1995), solarisation (where seeds are always sun-dried) before storage. Solar dis-infestation of infested stored grains, though with doubtful efficacy, is routinely practised by most farmers in East and Central Africa (Giga *et al.*, 1992). This is done by spreading grains on a smooth surface in the sun for sometime depending on the weather condition prevailing. A more efficient but simple solar heater can however, be made using black and transparent polythene, but it may have a negative effect on seed germination (Silim and Agona, 1996).

Traditional seed storage "tua" or other hermetically sealed containers have been shown to reduce infestation by storage pests in grains (Vincente *et al.* 1972; Caswell, 1974; Storey, 1981; Silim-Nahdy, 1995). Previous recommendations on hermetic storage were based on use of materials which are either too expensive or using weak materials and not easily available throughout Africa, nor compatible with typical storage systems. Thus their application and effective management techniques have not met wide acceptance, if at all (Silim-Nahdy, 1995).

In Uganda sealed storage "tua" made of clay and straw has been shown to be very effective in eliminating infestation by *C. chinensis*. In addition its construction requires minimal training such that any farmer could make his own structure for the required storage needs. It is also long lasting and compatible with most storage systems in use in Sub-Saharan Africa and is already in use by some farmers in Uganda (Silim-Nahdy, 1995). Therefore physical control strategies may be useful only in stored grains but not in field pests.

2.4.5 Natural and Biological Control Strategies

A number of factors are known to affect pest population, for example, high temperatures may slow down or stop their feeding and reproduction. Rainfall may wash some insects from plants or strong winds may dislodge some insects from plants and prevent immigrating adults from landing on the crop (Night and Ogenga-Latigo, 1993). Such abiotic factors as these combine with naturally occurring predators, parasitoids and pathogens to constitute `natural pest control' (Reed and Lateef, 1990).

There has been relatively little research on the predators in pigeonpea, largely because such studies in the field require many hours of tedious observation to produce quantitative data, and cage or laboratory studies are likely to produce atypical results (Reed and Lateef, 1990). However, there is little doubt that predators may be important in the control of many pigeonpea pests. For example, Reed and Lateef (1990), observed 19 species of insects and many species of spiders and birds preying on the eggs and larvae of *Helicoverpa*. The egg parasitoid *Trichogamma spp* for the control of *Helicoverpa* has been considered. However, it became clear that *Trichogamma* spp had little potential on pigeonpea (Reed and Lateef, 1990).

There appears to have been no reported attempts to enhance predation in pigeonpea. For example, it has been suggested that posts be erected in fields to provide resting sites for mud wasps such as *Delta sp* that carry off many large *Helicoverpa* larvae to feed their young. It is also possible to rear large numbers of predators such as *Chrysopa* in the laboratory, but such measures are unlikely to be economical (King *et al.*, 1982).

Perhaps the greatest potential for biological control in pigeonpea lies in the use of the Nuclear-poly-hedrosis virus as a biological insecticide for the control of *Helicoverpa* (Reed and Lateef, 1990). Crude preparations of the virus could be made very cheaply by mixing larvae that have been killed by the virus with water. However, there is some concern that such crudely prepared mixtures may be dangerous, for although this virus is thought to be safe, there are many other pathogens in dead insects and this can not be a guarantee that all are harmless. The virus has so far been produced commercially in the U.S.A. in a purified form, but did not prove to be a commercial success and its production was discontinued (Reed and Lateef, 1990).

Biological control strategies for *Callosobruchus* species have been considered. Though several parasitoids of *C. chinensis* have been identified, their usefulness is not certain (Van Huis, 1991). Haines (1984), considered that classical biological control for insect pests in storage could not be useful because the parasitoids have already had opportunity to spread as fast as their hosts and interact with them wherever they are found. It is, however, considered that the potential of parasitoids can not be assessed currently until they have been studied (Van Huis, 1991). Limited use of parasitoids *Uscana spp* has been attempted in Hawaii and Japan on bruchids (Aitken, 1984).

2.4.6 Use of resistant Varieties

Most of the studies on resistance have been focussed on aspects of the seed storage and these have covered cowpeas, phaseolus beans pigeonpea and mung beans (Reed and Lateef, 1990). In the field pod resistance screening against bruchids has been rare. Those tests reported include faba bean screening on *Bruchus dentipes* (Tahhan and van Emden, 1989).and mungbean on *Callosobruchus* (Telekar and Lin, 1981) and pigeonpea against *C. chinensis* (Silim-Nahdy, 1995). No variety of faba bean was found to be resistant and only one accession of mung bean found to be resistant and some accession lines of pigeonpea were found resistant to *C. chinensis* in the field (Silim-Nahdy, 1995).

Ragupathy and Rathnaswamy (1970), screened several varieties of pigeonpea seeds for resistance to *C. chinensis* but had little success. They concluded that the possibility of utilising bruchid resistant varieties for large scale production then seemed remote.

CHAPTER THREE.

INFLUENCE OF SOME CULTURAL PRACTICES IN FIELD MANAGEMENT OF *CALLOSOBRUCHUS* SPP. *AND* OTHER POST FLOWERING PESTS OF PIGEONPEA.

3.1 Introduction.

Cultural pest control involves regular farm operations that do not require the use of specialised equipment or extra skills, designed to destroy pests or to prevent them from causing economic damage (Hill, 1983). There are a number of cultural practices that farmers can employ in an attempt to control pigeonpea pests both in the field and in storage. But more often such control strategies are directed at storage level only rather than in the field management (Silim-Nahdy, 1995). Perhaps the most common factor in pigeonpea production is the fact that it is grown as an intercrop with other compatible crops in which case the companion crops are harvested before pigeonpea matures, as in the case of medium and long duration pigeonpea types (Reed and Lateef, 1990).

The role of intercropping for pest control in pigeonpea has been controversal. For example, work by Singh and Singh, 1978; Bhatnagar and Davies, 1980; Giri *et al.*, 1980 and Chaudhary *et al.*, 1980), indicate the potential of intercropping for pest reduction. But studies by Bhatnagar and Davies, 1981, Reed and Lateef, 1990), seem to suggest no pest reduction benefits on pigeonpea due to intercropping. Other cultural practices like appropriate sowing dates and the use of tolerant varieties have also been cited for pest management benefits in pigeonpea (Sinha *et al.*, 1979; Patnaik *et al.*, 1986; Kabaria *et al.*, 1990; Goyal *et al.*, 1991). In addition to these, time of harvesting may also be a clue to management of storage pest like the bruchids since infestation starts in the field (Southgate, 1978; Silim-Nahdy, 1995).

It has been suggested that cultural practices for pest management need to be combined with one another if they are to be most effective (Karel and Antrique, 1989; Letourneau, 1994). However, to do this a number of issues have to be addressed. For example, there is need to know the practices in current use, establish the more effective ones, determine combinations which are most compatible and those that are friendly to the farming system in place. Study of interactions between cultural practices in crop pest management in the field and in storage is necessary for reducing field to storage infestation and information on this is lacking or very scanty.

Field infestation of pigeonpea by *C. chinensis* is positively correlated to damage of pods by pod borers e.g *H. armigera*, pod fly (*Melanagromyza* sp.) and the nature of pods, whether split or dehisced (Silim-Nahdy, 1995). This can easily result in subsequent damage by pests of dried seeds of pigeonpea in storage like *C. chinensis* and *C. maculatus* (Patnaik *et. al.*, 1986). Such interactions as the above or factors like weather and variety of crop may also change from time to time as there are modifications in cropping systems.

Therefore there is need to investigate the different cultural practices which can be of benefit in the control of pigeonpea pests especially in the field situation. Moreover, most of the work on cultural practices for pest control in pigeonpea has been carried out in India. There is need to conduct similar studies in Uganda as the importance and production of pigeonpea increases.

The specific objectives of the study were to:

1. Determine the incidence and severity of damage by the major field pests of pigeonpea under different cropping systems.
2. Identify and test some cultural practices (intercropping, time of planting, spacing and time of harvesting) for controlling field infestation of *C. chinensis* and some major flower and pod pests of pigeonpea.
3. Establish the relationship between crop mixtures, crop maturity period, time of planting, spacing, and time of harvest and pest infestation of pigeonpea.

3.2.0 Materials and Methods

To achieve the above objectives three field experiments were conducted.

1) Effect of Intercropping on the incidence and severity of major post floweing pigeonpea pests and yield of pigeonpea seed.

2) Effect of time of planting and spacing on pest damage and yield of pigeonpea.

3) The effect of time of harvesting on damage of pigeonpea seeds by storage pests was also studied under this field trial.

3.2.1 Experimental Site, Varieties and Establishment

The experiments were conducted at Kawanda Agricultural Research Institute located 12Km North of Kampala on 0.4° N, 32.5° E and 1177-1320m altitude, with a bimodal type of rainfall. Two pigeonpea varieties, ICEAP 00360 (short stature and short duration, planted at a spacing of 50x20cm and Kat 60/8 (medium stature and medium duration, planted at 75x20cm) were used. The varieties were grown in pure stands and as intercrops with finger millet and cowpeas. The experiments were carried out over the two rain seasons of 1998 (1998a, 1998b) and during the first rains of 1999 (1999a).

Seed bed preparation was by use of the tractor and hand hoe. Planting was done in the first rains (late April), and second rains (early September). Gap filling was done where germination was poor and pigeonpea seedlings were thinned to 1 plant per hill giving plant population densities of 100,000 and 66,667 plants per hectare, for short and medium duration crops respectively. Millet was thinned at 6 cm within rows giving a population of 25 plants per metre row.

Weeding was done four times per growing season. During each trial, data collection on pests started at flower initiation and ended after pod maturity. The pests which were studied included; flower beetles (*Mylabris sp*), flower thrips (*Megalurothrips sp*), aphids,(A*phis* spp); pod borers,(*Helicoverpa* *armigera*); pod sucking bugs,(*Clavigralla* spp); pod fly (*Melanagromyza* spp) and bruchids (*C. chinensis*).

3.2.2 Effects of Intercropping on field insect pest infestation and yield of pigeonpea

The effects of cropping systems on the pest incidence and/or severity, pigeonpea seed damage by *C. chinensis* and the other post flowering pests were evaluated using the following treatments: 1) short duration pigeonpea intercropped with finger millet (SDPP+M), 2) medium duration pigeonpea intercropped with finger millet (MDPP+M), 3) short duration pigeonpea intercropped with cowpea (SDPP+C), 4) medium duration pigeonpea intercropped with cowpea (MDPP+C), 5) short duration pigeonpea sole crop (SDPPS), 6) medium duration pigeonpea sole crop (MDPPS). The experiment was laid out in a randomised complete block design (RCBD) on 6x4m plots and replicated four times. The intercrops were planted in a replacement series.

At harvest the yield of pigeonpea seed was determined. These yields however, are not in any way indicative of the land productivity of this intercropping systems (Mead and Willey, 1980). Therefore the various land equivalent ratios (LER) and land equivalent coefficients (LEC) were calculated. Since the treatments did not have sole crop components of millet and cowpea, the assumption was that the yields of these crops in sole cropping was at least double what was obtained. This assumption is taken on the grounds that these were replacement series intercropping pattern.

Land Equivalent Ratios and Land Equivalent Coefficients were calculated as follows: LER = Sum of the yields of individual crops in intercrops divided by their yields in sole crops i. e LER = $\sum X_i/Y_i$. LEC is the product of the LERs of the intercrop components i. e. LEC = $y_a/Y_a \times y_b/Y_b$. Data was analysed as completely randomised design using the M-STATC statistical computer package.

3.2.3 Influence of Time of planting (TOP) and Spacing on field pest infestation and yield of Pigeonpea

To study the effect of time of planting and spacing on pigeonpea pests, an experiment with three planting dates and three spacing treatments was carried out. The planting dates were; on-set of rains, 2weeks and 4weeks after on-set of rains. The different spacing were; a) recommended spacing of 50 x 20 cm, b) half the recommended spacing (25 x 10 cm), c) double the recommended spacing (100 x 40 cm), resulting in plant densities of 100,000, 400,000 and 25,000 plants per hectare respectively, after thinning to one plant per hill. The experimental design was a split plot arranged in a randomised complete block, with time of planting in the main plots (14x11m) and spacing in the sub plots (4x3m). The short duration pigeonpea variety ICEAP 00781 was used exclusively. This experiment was carried out over three rain seasons in the first and second rains of 1998 and the first rains of 1999. But there was an unexpected prolonged dry spell in 1998a which hampered crop establishment and further development thus data was not obtained. Data was taken on incidence of field pests as described in section 3.2.1 above. To determine the effect of the treatment on field infestation of the bruchids, all pods from each plot were harvested at 7 days after physiological maturity, (i.e when pods changed from yellow to brown), threshed and cleaned. Samples of 200g of seeds replicated four times were examined for damage due to pod borers, bugs and fly. For each pest the damage was expressed as the percentage of the number of seeds damaged to the total number of seeds in the samples. The samples were further dried in cloth bags in the open sun for two days to reduce the moisture content for storage (Silim and Agona, 1996; Silim-Nahdy, 1995).

The dried samples were then incubated in the laboratory under ambient conditions (24-26 °C and 60-70%R.H.) for emergence of adult bruchids for 2 months. The damage on seeds due to bruchids was measured as a percentage of the number of seeds with emergence holes (windows) to the total number of seeds in the samples. Data was analysed using SAS computer package for mixed models (Ramon *et al.*, 1999).

3.2.4 Influence of time of harvesting (TOH) on pest infestation and Pigeonpea seed damage

The effect of harvesting time on bruchid field infestation was studied using pigeonpea variety ICEAP 00781. There were three different harvesting periods, namely; a) at physiological maturity, b) two weeks after physiological maturity, and c) four weeks after physiological maturity. The pods were harvested, and samples of 200g of dried seeds obtained and stored in the laboratory under ambient conditions. Plastic bottles with perforated lids (0.7mm holes) were used for seed storage to allow ample aeration while preventing emerged adult from escaping. Seeds were dried in cloth bags in the open sun (Silim and Agona, 1996; Silim-Nahdy, 1995). After 1 and 2 months of storage seeds were examined for adult bruchid emergence and damage levels. Data was analysed using M-STATC statistical computer package.

3.3.0 Sampling and Data collection

3.3.1 Infestation of Flower pests

Populations of blister beetles (*Mylabris* sp.) and thrips (*Megalurothrips sjostedti*) were monitored over a period of six weeks at one week intervals from flower initiation to early pod filling. The number of adult beetles was counted on ten randomly selected plants from the two middle rows per plot. Sampling was conducted between 08:00 to 10:00 hours. Thrips populations were estimated from twenty randomly picked flowers in each plot along a diagonal line transect (Nampala, 1998). The flowers were put in glass vials containing 30% ethanol (Kyamanywa, 1988) to dislodge and kill the thrips and transferred to a laboratory where the flowers were dissected and thrips counted under a microscope.

3.3.2 Incidence and severity of Aphids (*Aphis* sp.)

The incidence of aphid infestation was determined by counting the number of plants with aphids on ten plants per plot randomly selected along a diagonal line transect (Nampala, 1998). Severity of aphid attack was described as an estimate of the number of aphids that infested the selected plants (Ogenga-Latigo (1988). A scale of 1-5 was used, as follows: 1= no aphids, 2=1-50 aphids, 3=51-100 aphids, 4=101-150 aphids, 5=>150 aphids (Ogenga-Latigo, 1988).

3.3.3 Infestation and damage of pod borers (*Helicoverpa armigera*)

The infestation build up of pod borers in the different cropping systems were monitored by counting the numbers of lepidopterran larvae on plants. Since a number of pod borer species are known to occur on pigeonpea (Night and Ogenga-Latigo, 1994; Silim-Nahdy, 1995), it was assumed that pod damage was due to a complex of pod borers (Reed and Lateef, 1990). Ten plants were randomly selected per plot along a diagonal line transect and carefully examined for any lepidopterran larvae that were present on the plants and counted.

Records of pod borers (larvae) were established by noting their presence from anthesis up to 75% pod filling stage at intervals of one week for a duration of six weeks. At harvest time (7 days after physiological maturity) all pods from the plots were picked and a sample of 200g of seeds evaluated for damage due to pod borers.

3.3.4 Infestation and damage of pod sucking bugs (*Clavigralla* sp.)

To determine pod bug population it involved counting number of adults, nymphs and eggs on ten plants selected at random along the two middle rows per plot. The direct count method was adopted from (Olatunde *et al.*, 1991a&b). This was from the time of pod formation till maturity (Gangrade, 1963; Singh *et al.*, 1989). At harvest the damage due to pod bugs on pigeonpea seeds was determined from 200g weight samples by counting the number of shrivelled seeds (pod bug damaged) and expressing it as a percentage of the total number of seeds in the sample.

3.3.5 Infestation and damage of pod fly (*Melanagromyza sp.*)

Pod fly incidence and damage of pigeonpeas was assessed after harvest on seeds. Seeds that were mined and had oblong notch eaten into the grain below the testa were attributed to pod flies (Bindra and Jokhmola, 1967; Reed and Lateef, 1990). Pigeonpea seeds were weighed into 200g samples and examined for pod fly damage. The percentage of pod fly damaged seeds in the samples were obtained to determine damage incidence. The number of pod fly adults entrapped in the sticky traps was also recorded.

3.3.6 Infestation of Pigeonpea by *Callosobruchus chinensis*

The population build up of *C. chinensis* in the field was monitored using sticky paper traps made of cardboard paper in a trapizoidal shape and triangular at the ends containing adhesive glue matrix. Each trap measured 30 cm long, 20 cm wide and 15 cm height. The traps were hanged at a height of 1.0m in the short statured, short duration and 1.3m in the medium statured, medium duration pigeonpea varieties and placed at distance intervals of 10m randomly arranged in a linear pattern in two rows.

Eight traps were placed in the field starting at anthesis for a period of 6 weeks. Four traps had baits of 40-60 seeds of pigeonpea while the other four did not have any baits. Bait seeds were first disinfested by solar drying for 6 hrs and freezing for 24 hrs before use (Silim-Nahdy, 1995). The number of adult *C. chinensis* and pod fly caught in the traps were recorded every week for six weeks.

3.4.0 Results

3.4.1 Influence of cropping system on infestation of Pigeonpea by flower beetles (*Mylabris* sp.) and flower Thrips (*Megalurothrips* sp.)

The population build up of flower beetles is presented in Figure 1 and their mean infestation is given in Table 3. Cropping system significantly ($p<0.05$) influenced population of flower beetles. The difference between the three intercropping systems were more pronounced in the first to third week after flower initiation. Population build up of flower beetles peaked at three and four weeks after flower bud initiation. In both rains of 1998, beetle population in all treatments dropped sharply from the third to the fourth week but in 1999 there was an increase (Fig. 1).

There was, however, no significant difference ($p>0.05$) in flower beetle incidence among the pigeonpea genotypes in millet intercrops, although generally the short duration varieties tended to have lower beetle infestations (Table 3). Across the seasons populations of flower beetles were highest during the second than in the first rains. In the two rain seasons of 1998, the population density of blister beetles was lowest in pigeonpea/millet intercrops followed by pigeonpea/cowpea intercrops and highest in pigeonpea sole crop. The pattern was slightly different in the first rains of 1999 where the pigeonpea/cowpea had the lowest incidence of beetles.

The mean population density of flower thrips (*Megalurothrips* spp.) is presented in Table 4 and patterns of population build up shown in Figure 2.

Cropping system significantly ($p<0.05$) affected the thrips population within the seasons. Incidence of thrips was highest at three and four weeks after flower bud initiation in the short and medium duration components respectively, and thereafter dropped in all treatments (Fig. 2). The intercrops with cowpea (SDPP+C and MDPP+C) had significantly lower numbers of thrips on pigeonpea than those with millet combinations or sole crop pigeonpea. Sole crops generally had the highest thrips infestation levels during the three cropping seasons studied.

Across the seasons there were consistently higher population of thrips in most of the treatments in both rains of 1998 than infestation in 1999 except in the pigeonpea intercropped with cowpea (Table 4). There was also a significant difference ($p<0.05$) in thrips population between the pigeonpea varieties in millet intercrops in both rains of 1998 but not in the combinations with cowpea or sole crops. In the first rains of 1999, however, there were significant differences between varieties in sole crops and cowpea combinations and not in pigeonpea/millet intercrops.

Table 3: Population density of *Mylabris* sp. on pigeonpea grown as sole crop and intercrops in 1998a&b and 1999a

Crop mixture*	Mean No. of *Mylabris* sp. per 10 plants			
	1998a	1998b	1999a	Mean
SDPP+M	24.7c	30.9c	24.1ab	26.6
MDPP+M	26.6bc	31.1c	21.7b	26.5
SDPP+C	30.5b	35.3b	11.9d	25.9
MDPP+C	29.2b	37.9b	16.1c	27.7
SDPPS	35.5a	40.3a	21.0b	32.3
MDPPS	36.7a	41.3a	26.6a	34.9
LSD	**2.8**	**3.4**	**3.4**	
CV (%)	**6.5**	**6.6**	**12.2**	

* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea, SDPPS= Short duration pigeonpea sole crop, MDPPS= Medium duration pigeonpea sole crop.

Table 4: Population density of Flower Thrips (*Megalurothrips* sp.) on pigeonpea grown as sole crop and intercrops during 1998a&b and 1999a

Crop mixture*	Mean No. of *Megalurothrips* sp. per 10 plants			
	1998a	**1998b**	**1999a**	**Mean**
SDPP+M	158.2a	164.2a	113.8b	145.4
MDPP+M	164.3a	154.7b	99.3c	139.4
SDPP+C	40.8b	57.2c	60.3d	52.8
MDPP+C	35.7b	58.4c	57.0d	50.4
SDPPS	160.9a	152.3b	132.2a	148.5
MDPPS	160.8a	159.8a	117.5b	146.0
LSD	**3.6**	**3.5**	**12.4**	
CV (%)	**20.9**	**20.0**	**9.1**	

* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea, SDPPS= Short duration pigeonpea sole crop, MDPPS= Medium duration pigeonpea sole crop.

3.4.2 Influence of cropping system on incidence and severity of Aphids (*Aphis* sp.)

Aphid infestation build up is presented in Figure 3 while mean incidence and mean severity are shown in Tables 5 and 6, respectively. Infestation of aphids peaked at 3 weeks during 1998a and 1998b and 4 weeks during 1999a after flower bud initiation and thereafter dropped markedly in all seasons. Incidence of aphid infestation was significantly different ($p<0.05$) among the treatments. The highest incidences were in sole crop MDPP in all the three seasons and the lowest were in MDPP+C during 1998a and in the SDPP+C during 1998b and 1999a (Table 5). Generally sole crops had the highest incidences of attack followed by pigeonpea intercropped with millet and pigeonpea intercropped with cowpea. Between growing seasons the highest aphid incidences occurred during the first rains of 1998 followed by that in second rains of 1998 and finally that in first rains of 1999. There were significant differences in aphid severity among the different cropping systems (Table 6). In all the seasons, the short duration pigeonpea/cowpea intercrop had significantly lower aphid severity compared to the sole crop. All the other intercrops had lower aphid severity compared to the sole crop but the difference were not significant.

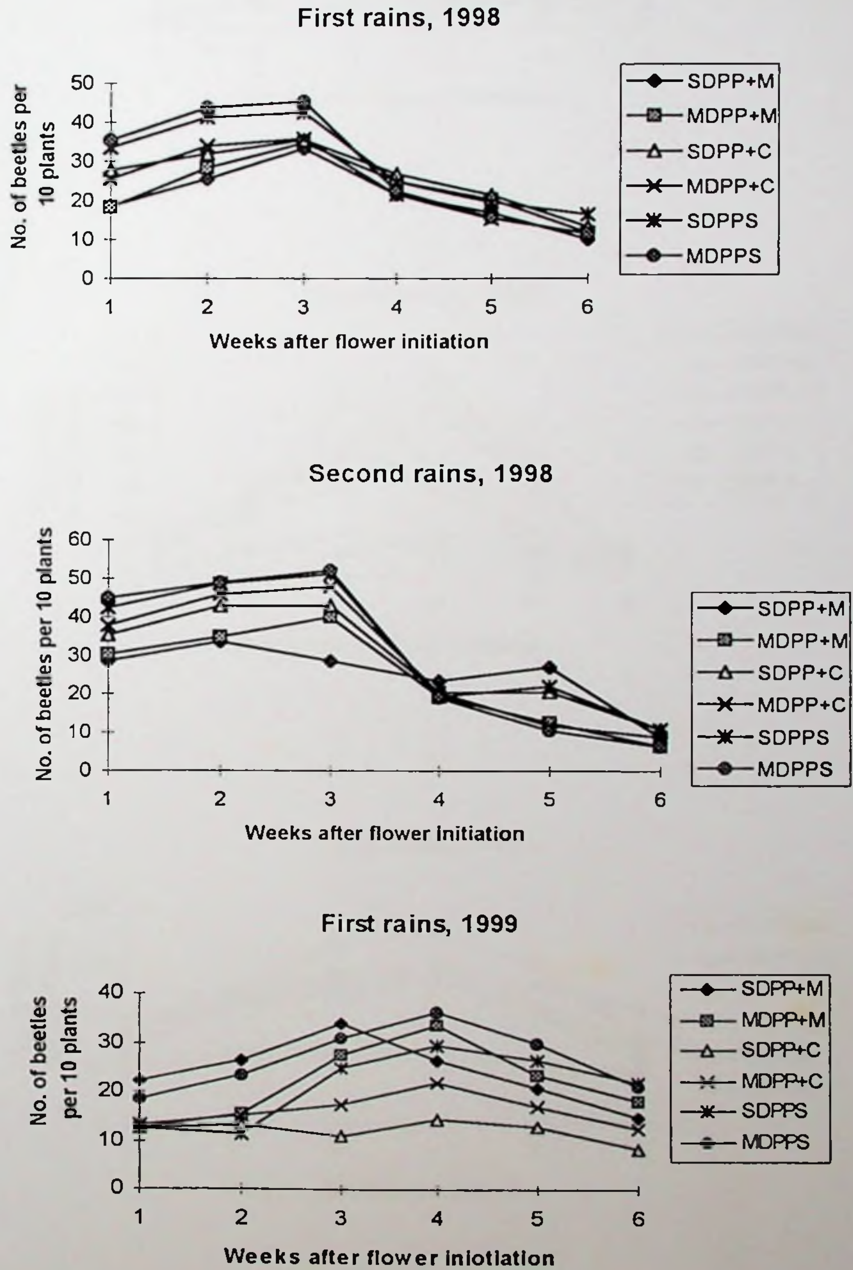
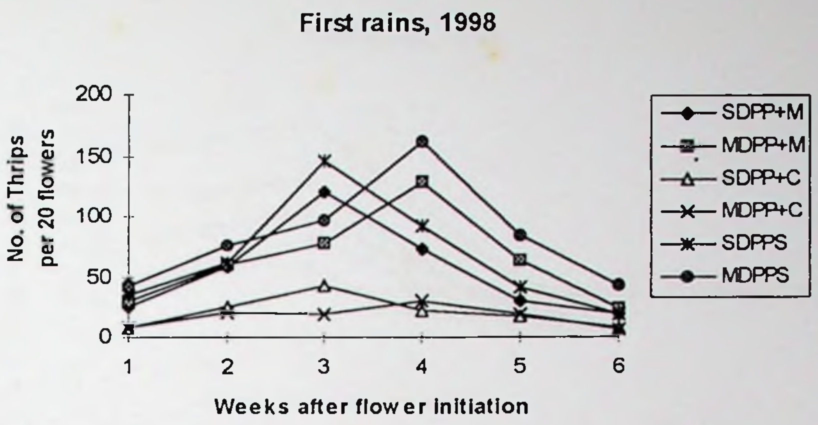
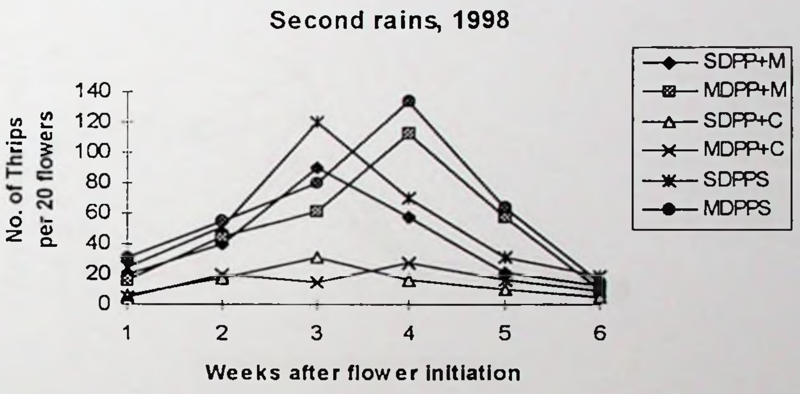


Fig. 1 Infestation build up of flower beetles on pigeonpea in the first and second rains of 1998 and first rains of 1999 after flower initiation.





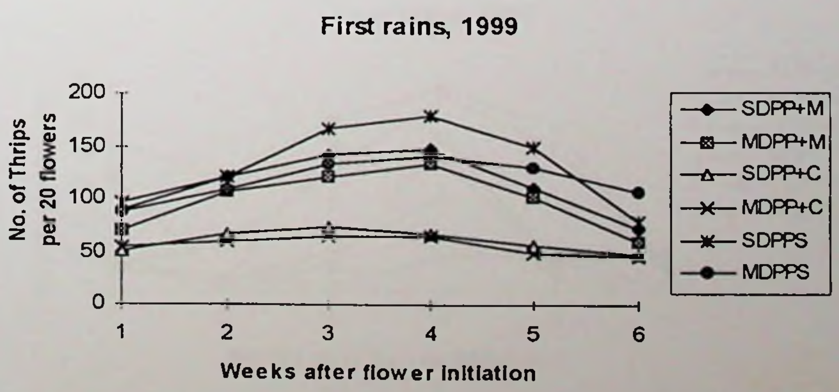
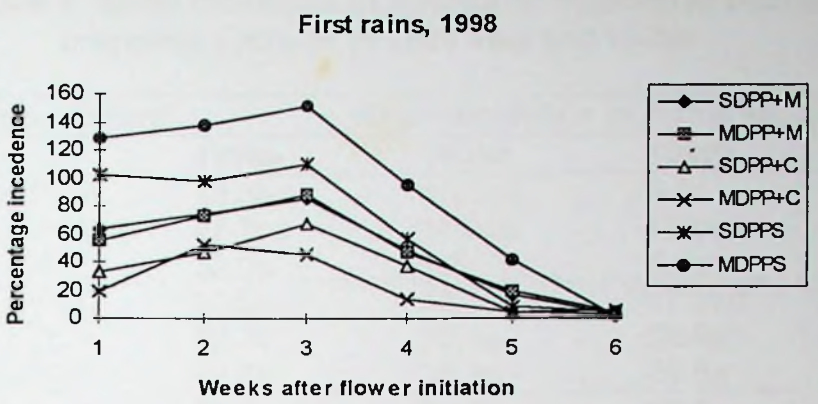
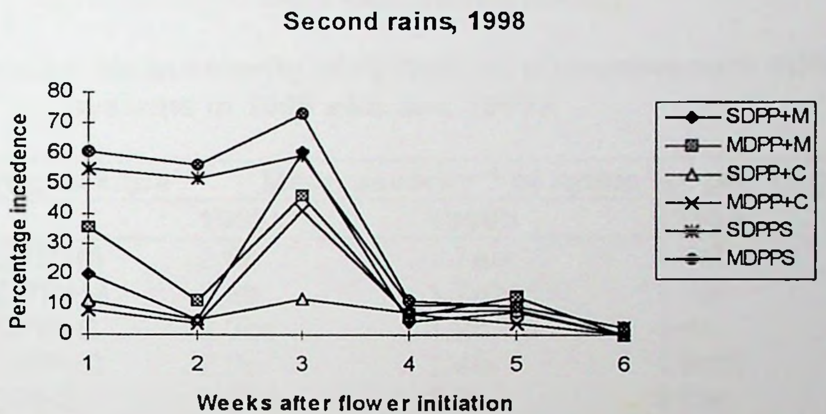


Fig. 2 Infestation build up of flower Thrips on pigeonpea in the first and second rains of 1998 and first rains of 1999 after flower initiation





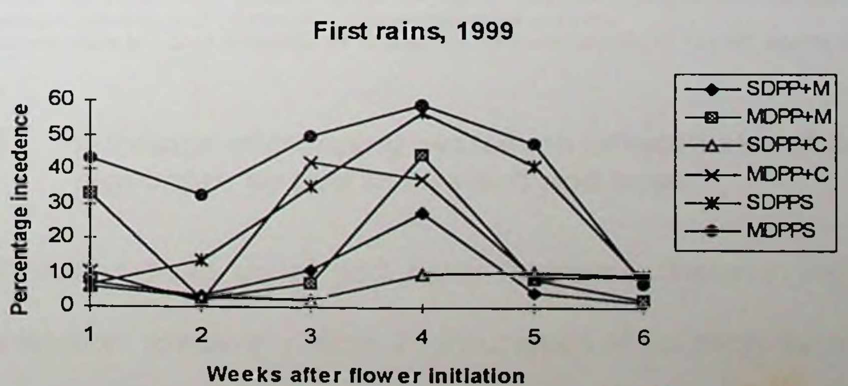


Fig. 3 Infestation build up of Aphids on pigeonpea in the first and second rains of 1998 and first rains of 1999 after flower initiation

Table 5: Mean Incidence of Aphids on pigeonpea with different cropping systems in 1998 a&b and 1999a

Crop mixture*	Mean Incidence of *Aphis* sp. per 10 plants			
	1998a	1998b	1999a	Mean
SDPP+M	48.3bc	16.5ab	9.3c	24.7
MDPP+M	47.7bc	18.6ab	16.0bc	27.4
SDPP+C	32.0c	7.3b	6.6c	15.3
MDPP+C	23.5c	10.5b	18.3bc	17.4
SDPPS	63.3b	35.0a	26.8ab	41.7
MDPPS	92.6a	35.4a	39.8a	55.9
LSD	**24.9**	**22.1**	**15.9**	
CV (%)	**34.7**	**76.5**	**58.1**	

* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea, SDPPS= Short duration pigeonpea sole crop, MDPPS= Medium duration pigeonpea sole crop.

Table 6 Mean severity of Aphids on pigeonpea with different cropping systems in 1998 a&b and 1999a

Crop mixture*	Mean severity** of *Aphis* sp. per 10 plants			
	1998a	1998b	1999a	Mean
SDPP+M	2.8b	1.7ab	1.5ab	1.8
MDPP+M	2.8b	1.7ab	1.7ab	1.9
SDPP+C	2.3bc	1.2b	1.4b	1.5
MDPP+C	2.0c	1.4b	1.8ab	1.6
SDPPS	3.3ab	2.1a	2.0ab	2.3
MDPPS	4.0a	2.2a	2.2a	2.5
LSD	**0.8**	**0.6**	**0.8**	
CV (%)	**19.6**	**35.4**	**31.5**	

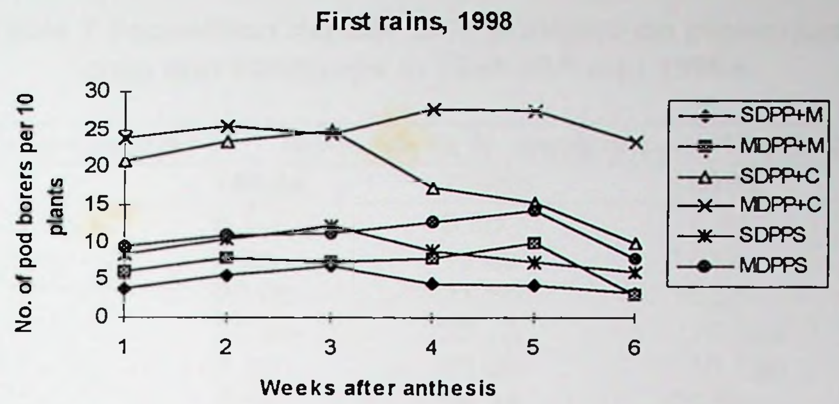
* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea, SDPPS= Short duration pigeonpea sole crop, MDPPS= Medium duration pigeonpea sole crop.
**Severity scale of 1-5: 1= No aphids, 2= 1-50 aphids, 3= 51-100 aphids, 4= 101-150 aphids, 5= > 150 aphids

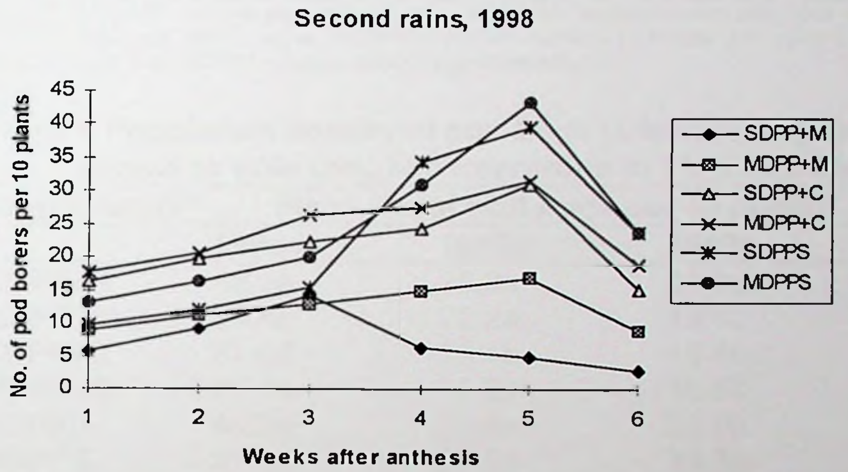
3.4.3 Influence of cropping system on infestation and damage of pigeonpea by pod borers and pod bugs

Infestation build up of pod borer number is shown in Fig. 4 and the mean infestation levels in Table 7. Four types of lepidopteran larvae were found infesting pigeonpea pods and these were: plume moth (*Exelastis atomosa*), legume pod borer (*Etiela zincknella*), cowpea pod borer (*Maruca vitrata*) and American boll worm (*Helicoverpa armigera*). It was noted , however, that *H. armigera* was the most frequent. It was observed that the population of pod borers peaked up from the 3rd to 5th weeks after anthesis in most of the cropping systems combinations (Fig. 4).

The results showed that the pattern of cropping system significantly ($p<0.05$) affected the infestation levels of pod borers. Generally, the intercroped short duration pigeonpea variety had lower pod borer infestation than the medium type in all the cropping seasons. Pigeonpea intercropped with millet were the least infested by pod borers in all the cropping seasons studied. (Table 7). Generally, sole crops were the most infested during the growing seasons.

In the first rains of 1998, the population density of pod borers tended to remain consistent throughout the study period (Fig. 4). The population density during this time was significantly higher in the pigeonpea/cowpea intercrops followed by that in the pigeonpea sole crop and least in the pigeonpea/millet intercrop. However, in the second rains of 1998 and the first rains of 1999, the above trend changed.





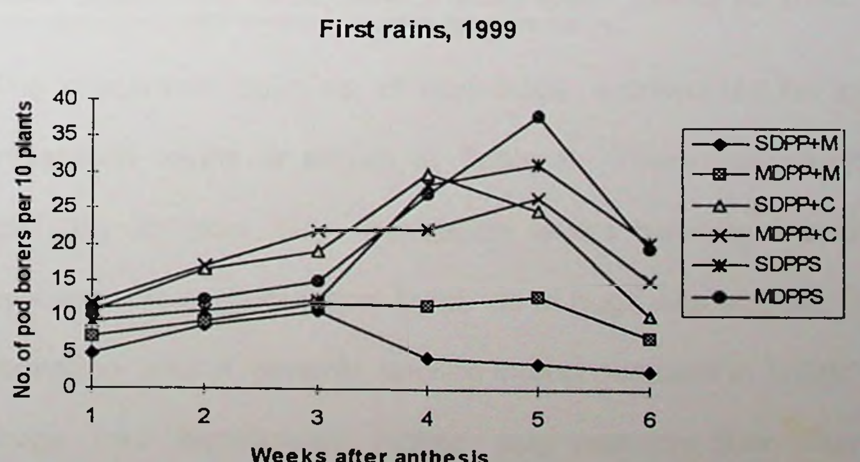


Fig. 4 Infestation build up of pod borers on pigeonpea in the first and second rains of 1998 and first rains of 1999 after anthesis.

Table 7 Population density of *H. armigera* on pigeonpea grown as sole crop and intercrops in 1998 a&b and 1999a

Crop mixture*	Mean No. of *H. armigera* per 10 plants			
	1998a	1998b	1999a	Mean
SDPP+M	5.1d	8.9b	5.8d	6.6
MDPP+M	7.2c	11.9b	10.0c	9.7
SDPP+C	20.9b	21.8a	16.9b	19.9
MDPP+C	23.3a	23.7a	19.1ab	22.0
SDPPS	9.3b	23.6a	18.7ab	17.2
MDPPS	9.6b	26.9a	20.5a	19.0
LSD	**1.9**	**4.4**	**3.2**	
CV (%)	**10.6**	**9.6**	**15.22**	

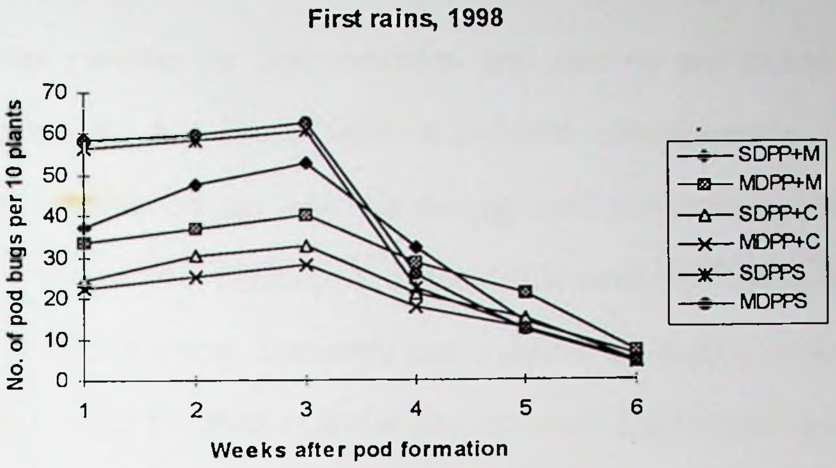
* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea, SDPPS= Short duration pigeonpea sole crop, MDPPS= Medium duration pigeonpea sole crop.

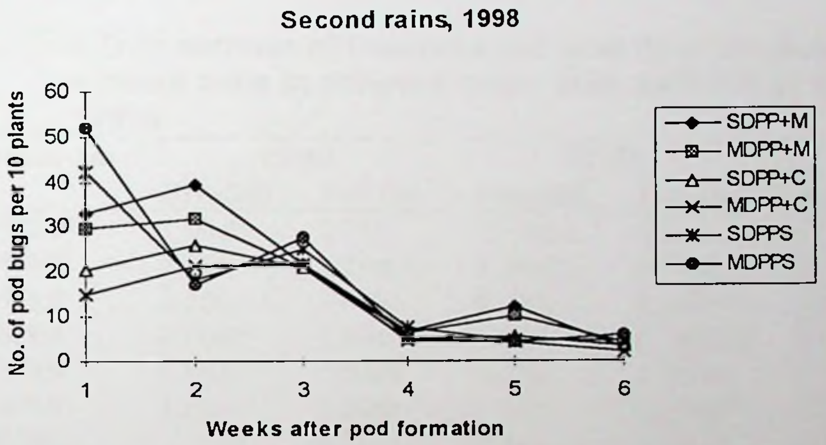
Table 8 Population density of pod bugs (*Clavigralla* sp.)on pigeonpea grown as sole crop and intercrops in 1998 a&b and 1999a

Crop mixture*	Mean No. of pod bugs per 10 plants			
	1998a	1998b	1999a	Mean
SDPP+M	42.3b	25.3a	21.9ab	29.8
MDPP+M	34.8c	22.2a	19.6b	25.5
SDPP+C	27.0d	18.1b	16.4b	20.5
MDPP+C	23.3d	15.8b	16.5b	18.5
SDPPS	49.3a	23.4a	22.9a	31.9
MDPPS	51.6a	25.6a	24.3a	33.8
LSD	**3.8**	**6.4**	**3.9**	
CV (%)	**7.1**	**11.6**	**14.0**	

* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea, SDPPS= Short duration pigeonpea sole crop, MDPPS= Medium duration pigeonpea sole crop.

The population build up of pod bugs is presented in Fig. 5 and the mean infestation levels is shown in Table 8. There were significant differences ($p<0.05$) in pod bug infestation levels between the different cropping systems. Peak population build up of bugs was at 2 and 3 weeks after pod formation and a general decline in bug numbers in 1998b and 1999a. Sole crops had significantly higher bug numbers than intercrops in all the seasons. Within the seasons combinations of pigeonpea with cowpea had lower bug population compared to sole crops or those with millet intercrops. Pod bug population in 1998a was higher than in either of the other two rains.





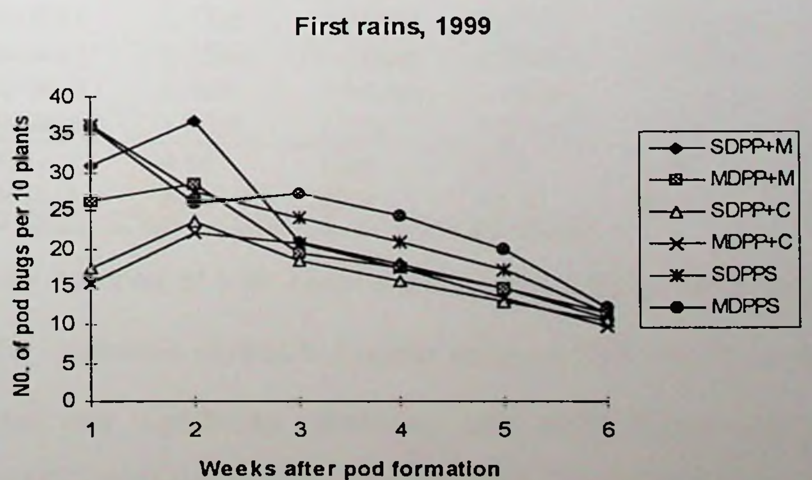


Fig. 5 Infestation build up of pod bugs in the first and second rains of 1998 and first rains of 1999 after pod formation

3.4.4 Population of bruchids and pod fly in traps

Trap catches for both bruchids and pod fly are shown in Table 9 and Appendix 1. There were significant differences in trap catches of *Callosobruchus sp.* with the baiting and non baiting treatments. Bruchid catches in the pigeonpea baited traps were significantly higher than in the non baited traps. Generally the number of pod fly in the traps were more than that of bruchids in all the seasons from the 3rd to 6th week after anthesis.

Table 9 Trap catches of Bruchids and pod fly in the field with or without baits at different times after anthesis in 1998 a&b and 1999a

Treatment	1998a		1998b		1999a	
	Bruchid	**Pod fly**	**Bruchid**	**Pod fly**	**Bruchid**	**Pod fly**
B/Wk1*	1.00ab	0.75c	1.00abc	0.50d	0.75b	0.75c
B/Wk2	1.50a	1.25abc	1.25abc	0.75cd	0.50b	0.75c
B/Wk3	1.50a	1.00bc	0.75bc	1.00bcd	1.00ab	1.25abc
B/Wk4	1.00ab	1.50abc	1.50ab	1.75abcd	1.25ab	1.00bc
B/Wk5	1.50a	2.00ab	1.75a	2.00abc	1.75a	1.25abc
B/Wk6	1.50a	2.00ab	1.75a	2.25ab	1.75a	1.50abc
NB/Wk1	0.75ab	0.75c	0.50c	0.75cd	0.50b	0.75c
NB/Wk2	0.75ab	1.00bc	0.75bc	0.75cd	0.75b	1.00bc
NB/Wk3	0.75ab	1.50abc	0.75bc	1.50abcd	0.50b	0.75c
NB/Wk4	0.75ab	1.25abc	1.00abc	1.50abcd	0.75b	1.00bc
NB/Wk5	0.50b	1.50abc	1.00abc	1.75abcd	0.75b	1.75ab
NB/Wk6	1.00ab	2.25a	1.25abc	2.50a	1.00ab	2.00a
LSD	**0.85**	**1.00**	**0.76**	**1.34**	**0.77**	**0.81**
CV (%)	**56.9**	**49.9**	**47.8**	**32.5**	**52.0**	**48.8**

* B= Baited traps, NB= Non baited traps, Wk= weeks after anthesis

Trap catches of both pests were significantly ($p<0.05$) influenced by the time after anthesis except in the first rains of 1998 where bruchid catches did not show any significant difference with time. There was a general trend of increase in trap catches for both pests from the first week to the sixth week after anthesis. Trap catches of both pests from 3rd to 5th week after anthesis did not vary significantly ($p>0.05$) from one another.

3.4.5 Influence of different cropping systems on *Callosobruchus chinensis* population dynamics and pigeonpea seed damage

The number of adult *C. chinensis* that emerged from incubated seeds and the seed damage percentage are given in Tables 10 and 11, respectively. During the 1998a after one month of seed storage, the mean number of adults that emerged and the percentage damage were significantly different among the treatments. The highest number of adults that emerged was observed in the sole crop MDPP at 2.29 adults followed by MDPP+C and SDPP+C at par while the lowest was from MDPP+M at 1.65 adults followed by SDPP+M at 1.73 adults. The highest percentage damage was in the sole crop SDPP (2.15%) followed by sole crop MDPP whilst the lowest damage was from SDPP+M at 0.85% followed by MDPP+M, all significantly different.

After two months of seed storage there was significant difference ($p<0.05$) between treatment means in the number of adults that emerged and the seed damage levels. The highest number of adults that emerged were from sole crop MDPP at 2.50 adults and the lowest was from SDPP+M at 1.84 adults. The highest seed damage level was in the sole crop SDPP at 2.05% and the lowest was from SDPP+M at 1.12%, significantly different from each other.

In the second rains of 1998, after one month of seed storage, the results showed that the mean number of adults that emerged and percentage seed damage were significantly different ($p<0.05$). The adult emergence and the percentage seed damage was highest from MDPP sole crop at 54.8 adults and 6.02% while the lowest was from SDPP+M at 23.3 adults and 2.61%, respectively, all significantly different from one another. After two months of seed storage all treatment means again showed significant differences in the number of adults emerged and the percentage damage to seeds. The highest mean number of adults emerged and the percentage damage came from MDPP sole crop at 126.0 adults and 10.29% with the lowest from SDPP+M at 76.3 adults and 4.14%, respectively.

During the first rains of 1999 the number of adults that emerged and the percentage seed damage were significantly different ($p<0.05$) between the treatments imposed. After one month of seed storage the highest was in sole crop medium duration pigeonpea (22.8 adults) corresponding with damage level of 4.06% whilst the lowest was in short duration pigeonpea intercrop with millet (7.0 adults) and 1.47% damage level. After two months of storage, the adult emergence and damage levels were still significantly different. The highest mean number of adults emerged were from the MDPP sole crop with 66.3 adults and damage level of 3.75% and the lowest were in SDPP+M at 15.0 adults and 1.92%, respectively. There was a consistent trend showing the highest adult emergence and damage percentage in sole crops followed by pigeonpea intercropped with cowpea and lastly in the pigeonpea intercropped with millet. The patterns of adult emergence and levels of seed damage consistently showed a declining trend between cropping systems in which sole cropping system was highest followed by intercrops with cowpeas and then intercrops with millet (Table 10 and 11).

Table 10 Mean number of *C. chinensis* adults emerged from pigeonpea seeds with different cropping systems after 1 and 2 months of storage in 1998 a&b and 1999 a

Crop mixture*	Mean Number emerged (± SE)					
	1998a		1998b		1999a	
	1 month	2 months	1 month	2 months	1 month	2 months
SDPP+M	1.73 ± 0.08	1.84 ± 0.07	23.3 ± 0.03	76.3 ± 0.04	7.0 ± 0.92	15.0 ± 2.16
MDPP+M	1.65 ± 0.07	2.00 ± 0.07	29.5 ± 0.08	84.0 ± 0.03	9.5 ± 1.04	20.8 ± 2.49
SDPP+C	2.24 ± 0.06	2.35 ± 0.00	36.8 ± 0.08	95.0 ± 0.03	12.5 ± 1.33	29.3 ± 1.65
MDPP+C	2.24 ± 0.06	2.45 ± 0.06	42.3 ± 0.04	105.3 ± 0.04	17.0 ± 1.47	39.3 ± 1.49
SDPPS	2.18 ± 0.06	2.35 ± 0.05	48.3 ± 0.04	113.0 ± 0.02	18.8 ± 1.75	56.3 ± 3.82
MDPPS	2.29 ± 0.06	2.50 ± 0.06	54.8 ± 0.05	126.0 ± 0.05	22.8 ± 1.75	66.3 ± 3.40
LSD	**0.22**	**0.17**	**1.23**	**1.47**	**4.2**	**7.9**
CV (%)	**7.13**	**5.00**	**7.02**	**9.80**	**19.36**	**14.00**

* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea, SDPPS= Short duration pigeonpea sole crop, MDPPS= Medium duration pigeonpea sole crop.

Table 11: Mean percentage damage to pigeonpea seeds by *C. chinensis* with different cropping systems after 1 and 2 months of seed storage during 1998a&b and 1999a

	Mean percentage damage($\pm$ SE)					
Crop mixture*	1998a		1998b		1999a	
	1 month	2 months	1 month	2 months	1 month	2 months
SDPP+M	0.85 $\pm$ 0.03	1.12 $\pm$ 0.04	2.61 $\pm$ 0.14	4.14 $\pm$ 0.01	1.47 $\pm$ 0.20	1.92 $\pm$ 0.01
MDPP+M	1.21 $\pm$ 0.08	1.26 $\pm$ 0.03	3.51 $\pm$ 0.02	4.63 $\pm$ 0.01	1.91 $\pm$ 0.20	2.21 $\pm$ 0.12
SDPP+C	1.48 $\pm$ 0.04	1.55 $\pm$ 0.03	4.23 $\pm$ 0.01	6.24 $\pm$ 0.01	2.52 $\pm$ 0.24	2.50 $\pm$ 0.08
MDPP+C	1.60 $\pm$ 0.04	1.66 $\pm$ 0.04	4.51 $\pm$ 0.02	7.47 $\pm$ 0.01	3.02 $\pm$ 0.07	2.95 $\pm$ 0.05
SDPPS	2.15 $\pm$ 0.05	2.05 $\pm$ 0.05	5.37 $\pm$ 0.02	8.91 $\pm$ 0.01	3.47 $\pm$ 0.25	3.52 $\pm$ 0.08
MDPPS	1.78 $\pm$ 0.05	1.88 $\pm$ 0.02	6.02 $\pm$ 0.01	10.29 $\pm$ 0.03	4.06 $\pm$ 0.16	3.75 $\pm$ 0.09
LSD	**0.22**	**0.08**	**0.15**	**0.09**	**0.57**	**0.26**
CV (%)	**7.13**	**5.00**	**7.02**	**3.88**	**13.92**	**6.15**

* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea, SDPPS= Short duration pigeonpea sole crop, MDPPS= Medium duration pigeonpea sole crop.

3. .6 Effects of different cropping systems on pigeonpea seed damage by pod borers, bugs and fly

The results of effects of damage to pigeonpea seeds by the three pod pests in the different cropping systems is presented in Table 12. There were significant differences ($p<0.05$) in the seed damage levels between cropping systems by the three pod pests. Seed damage by pod bugs was highest, followed by pod borer and then pod fly. Pod borer and pod bug damage levels were significantly lower in pigeonpea intercrop with cowpea than in millet intercrops or pigeonpea sole crops.

Pod fly damage was generally higher in intercropping systems that involved medium than short duration pigeonpea varieties. Across the seasons, damage by pod borer and pod bug were highest in 1998a than in 1998b or 1999a cropping seasons. Damage by pod flies did not vary significantly between the cropping seasons (Table 12).

Table 12: Mean percentage pigeonpea seed damage by pod borers, bugs and flies in the different cropping systems in 1998a&b and 1999a

	Percentage damage								
	1998a			1998b			1999a		
Treatment	Pod borer	Pod bug	Pod fly	Pod borer	Pod bug	Pod fly	Pod borer	Pod bug	Pod fly
SDPP+M	6.2a	18.9a	1.3b	6.5b	14.7b	1.1c	5.8a	13.1a	1.1a
MDPP+M	6.8a	19.1a	1.6a	7.0a	15.6a	1.2b	5.9a	14.0a	1.1a
SDPP+C	5.1b	17.1b	1.1b	4.8d	12.5f	1.0d	4.6b	12.0b	0.9a
MDPP+C	4.9b	17.3b	1.5a	4.8d	12.8e	1.3a	4.3b	12.0b	1.2a
SDPPS	7.0a	18.0ab	1.1b	7.1a	13.2c	1.1c	6.2a	11.9b	1.0a
MDPPS	4.7b	17.0	1.3b	5.1c	12.9d	1.3a	4.3b	11.4b	1.2a
LSD	**1.0**	**1.3**	**0.2**	**0.1**	**0.1**	**0.1**	**0.8**	**1.1**	**0.5**
CV (%)	**11.32**	**5.08**	**9.83**	**8.4**	**9.2**	**4.3**	**10.52**	**5.78**	**30.97**

* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea, SDPPS= Short duration pigeonpea sole crop, MDPPS= Medium duration pigeonpea sole crop.

3.4.7.0 Influence of time of planting (TOP), spacing and time of harvest on pigeonpea seed damage by pod borers, bugs and fly

3. .7.1 Effect of Time of Planting and spacing on pigeonpea seed damage due to pod borers, bugs and fly

Results of pigeonpea seed damage by the three pod pests is shown in Table 13, Figure 6 and appendix 2. Seed damage by pod borers was significantly ($p<0.05$) affected by time of planting but not by spacing or their interaction (Table 13a). In both seasons damage was highest in seeds from the last planting and the lowest was in seeds from the first planting.

Pod bug damage was significantly influenced ($p<0.05$) by time of planting but not by spacing ($p>0.05$), in both rains. The interaction of time of planting and spacing was not significant ($p>0.05$).The highest damage was in the seeds planted at 2 weeks after on-set of rains and at the recommended spacing while the lowest damage was in the seeds planted at the on-set of rains and at half the recommended spacing (Table 13b). Seeds from plots planted at 2 and 4 weeks after on-set of rains and at the recommended spacing had the highest damage but seeds from plots planted at the on-set of rains and at double the recommended spacing had the highest damage. The interaction in 1999a was significant ($p<0.05$). The highest damage was in the last planting and recommended spacing whilst the lowest was in the first planting and recommended spacing (Figure 6) There was no significant difference in results of the two rains although damage in the second rains of 1998 appeared to be higher than that in the first rains of 1999.

There was no significant difference (p>0.05) in seed damage levels due to pod fly infestation with both time of planting and spacing treatments in both rains of 1998 and 1999 (Table 13c). Interaction of time of planting and spacing did not have any significant effect on pod fly damage. Across the seasons there was no significant difference in damage levels due to both factors in both rains. There was also no significant difference in seed damage due to pod fly with the different spacing treatments.

Table 13 Interaction of time of planting (TOP) and spacing on damage of pigeonpea seeds by 3 pod pests in 1998b & 1999a

a) Pod borer

Percentage damage in 1998b					Percentage damage in 1999a				
	Spacing*				Spacing				
Top**	DRS	RS	HRS	overall mean ±0.36	Top	DRS	RS	HRS	overall mean ±0.20
TOP1	5.1de	4.5e	5.5de	5.0b	TOP1	5.2ef	4.5f	5.7def	5.2b#
TOP2	6.1cd	5.6de	6.4cd	6.0ab	TOP2	6.1cde	5.6def	6.8bcd	6.1b
TOP3	8.8a	7.4bc	8.2ab	8.1a	TOP3	9.3a	7.4bc	8.3ab	8.3a
overall mean ±0.30	6.6a	5.8a	6.6a		overall mean ±0.30	6.8a	5.8a	6.7a	

*RS= Recommended spacing, HRS= Half recommended spacing, DRS= Double recommended spacing.
**TOP1= First time of planting; TOP2= Second time of planting; TOP3= Third time of planting
Means followed by the same letters are not significantly different from each other at p=0.05

b) Pod bug

Percentage damage in 1998b				
	Spacing*			
TOP**	DRS	RS	HRS	overall mean ±0.41
Top1	8.0c	7.9c	7.6c	7.8b#
Top2	10.1ab	12.0ab	11.4b	10.8a
Top3	11.0b	11.1a	10.3ab	11.1a
overall mean (±0.38)	9.7a	10.3a	9.8a	

*RS= Recommended spacing, HRS= Half recommended spacing, DRS= Double recommended spacing.
**TOP1= First time of planting; TOP2= Second time of planting; TOP3= Third time of planting
Means followed by the same letters are not significantly different from each other at p=0.05

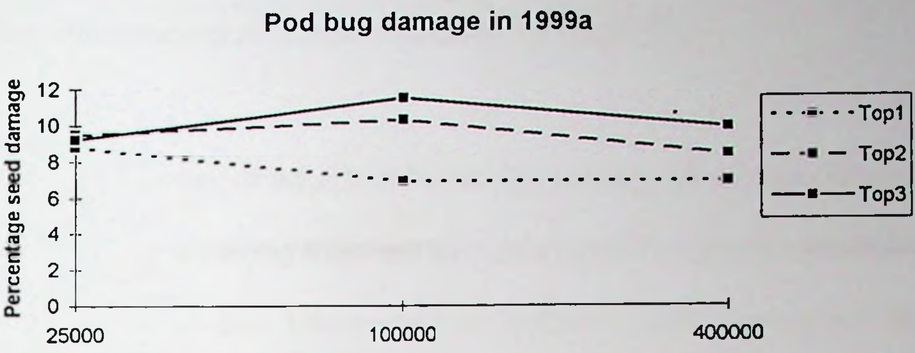


Fig. 6 Interaction of time of planting (TOP) and spacing on pod bug damage of pigeonpea seeds in 1999a

c) Pod fly

Percentage damage in 1998b					Percentage damage in 1998b				
	Spacing					Spacing			
Top	DRS	RS	HRS	overall mean ±0.19	TOP	DRS	RS	HRS	overall mean ±0.19
TOP1	1.0c	1.3bc	1.3bc	1.2a	TOP1	1.2cd	1.0d	1.3bcd	1.2b*
TOP2	1.7abc	1.5abc	1.6abc	1.6a	TOP2	1.6bcd	1.4bcd	1.4bcd	1.5b
TOP3	2.3a	2.1ab	2.0ab	2.1a	TOP3	2.6a	1.9abc	2.1ab	2.2a
overall mean ±0.18	1.7a	1.6a	1.6a		overall mean ±0.17	1.8a	1.4a	1.6a	

*RS= Recommended spacing, HRS= Half recommended spacing, DRS= Double recommended spacing.
**TOP1= First time of planting; TOP2= Second time of planting; TOP3= Third time of planting
Means followed by the same letters are not significantly different from each other at p=0.05

3.4.7.2 Influence of Time of planting (TOP) and spacing on pigeonpea infestation *by C. chinensis*

The results on the effect of TOP and spacing on adult emergence and damage of pigeonpea seeds by *C. chinensis* is shown in Tables 14, 15 and 16, Figures 7& 8 and Appendices 3&4. In the second rains of 1998, at one month of storage of pigeonpea seeds, the mean number of adults that emerged were significantly different among the treatments with time of planting and spacing and their interaction (Figure 7a).

The highest number of adults emerged from pigeonpea seeds planted last, at the third time of planting followed by those from the second and the first time of planting in that order. There was no significant difference in adult emergent numbers in seeds from the first and second planting but were both significantly lower than the emergence in the last time of planting. The mean number of adults from seeds planted at recommended spacing was significantly lower than those from both half recommended spacing and double the recommended spacing in seeds from the late planted crop.

The interaction of time of planting and spacing showed that the highest mean adult emergence was from the last time of planting and double the recommended spacing while the lowest came from the seeds planted earliest at the recommended spacing. Damage levels showed a similar trend as in the adult emergent numbers (Fig. 7b). However, the damage in the last time of planting was significantly higher than those in the first time of planting only. In all the three planting times the highest damage levels were from seeds planted at double the recommended spacing (lowest plant population) while the lowest were from those at the recommended spacing (optimum plant population).

Table 14b: Interaction of time of planting and spacing on pigeonpea seed damage due to *C. chinensis* after 2 months of storage in 1998b

	Spacing*			
TOP**	DRS	RS	HRS	Overall mean ± 2.45
TOP1	5.5bc#	3.9d	4.6cd	4.7b
TOP2	6.7ab	4.5cd	5.2cd	5.5b
TOP3	7.9a	7.4a	7.4a	7.6a
Overall mean ± 2.45	6.7a	5.3b	5.7ab	

* RS= Recommended spacing, HRS= Half recommended spacing, DRS= Double recommended spacing.
** TOP1= First time of planting; TOP2= Second time of planting; TOP3= Third time of planting
# Means followed by the same letters are not significantly different from each other at p=0.05

After two months of seed storage both adult emergence and the percentage seed damage were significantly different among the time of planting and the spacing treatments. However, the interaction of time of planting and spacing on both adult number and seed damage were not significant (Table 14a &14b). For the different time of planting, all means of adult emergence were significantly different from one another (Table 14a). The highest number of emerged adults were from the third time of planting (108.7 adults) and the lowest from the first time of planting (23.5 adults). The highest mean damage was in seeds from the last time of planting (7.6%) and the lowest in seeds from the first time of planting (4.7%), (Table 14b).

The trend for spacing treatment was similar to that of time of planting. The highest and lowest adult emergence were in the double and the recommended spacing respectively. Damage levels revealed similar trends, being highest in seeds planted at double spacing (6.70%) and lowest in those at recommended spacing (5.3%). Interactions at this stage was, however, not significant (Table 14b) but had the highest number of adult emergence from the third TOP with double spacing and the lowest in the first TOP with recommended spacing. Damage levels followed the same trend.

In the first rains of 1999, after one month of seed storage, only planting date significantly influenced ($p<0.05$) the adult emergent numbers and percentage seed damage levels but not spacing or the interaction of planting date and spacing ($p>0.05$), Table 15. The highest adult emergence and the percentage damage were from seeds planted last (18.9 adults and 3.11%) while the lowest were from seeds planted first 5.5 adults and 1.45%), respectively. Adult emergence were significantly higher in seeds from the last date of planting compared to those at the other two planting dates (Table 15a). But the seed damage were significantly different in all the treatments of planting dates (Table 15b).

Table 15a: Interaction of time of planting (TOP) and spacing on number of *C. chinensis* adult emergence after 1 month of storage in 1999a

	Spacing*			
TOP**	DRS	RS	HRS	Overall mean# ± 0.76
TOP1	6.3bc	4.3c	6.0bc	5.5b
TOP2	8.8b	7.3bc	8.3bc	8.4b
TOP3	20.0a	18.8a	18.0a	18.9a
Overall mean ± 0.76	12.0a	10.1a	10.8a	

* RS= Recommended spacing, HRS= Half recommended spacing, DRS= Double recommended spacing
** TOP1= First time of planting; TOP2= Second time of planting; TOP3= Third time of planting
\# Means followed by the same letters are not significantly different from each other at p=0.05

After two months of pigeonpea seed storage both emerged adult numbers and the percentage damage to seeds were significantly different ($p<0.05$).

Table 15b: Interaction of time of planting (TOP) and spacing on pigeonpea seed damage due to *C. chinensis* after 1 month of storage in 1998b

	Spacing*			
TOP**	DRS	RS	HRS	Overall mean# ± 0.10
TOP1	1.61cd#	1.24d	1.48cd	1.45c
TOP2	2.30b	1.94bc	2.00bc	2.08b
TOP3	3.19a	3.13a	3.03a	3.11a
Overall mean ± 0.10	2.37a	2.10a	2.17a	

* RS= Recommended spacing, HRS= Half recommended spacing, DRS= Double recommended spacing
** TOP1= First time of planting; TOP2= Second time of planting; TOP3= Third time of planting
\# Means followed by the same letters are not significantly different from each other at p=0.05

The spacing and the interaction of time of planting and spacing treatments on the number *of C. chinensis* adults emerged was not significant (Table 16). But the interaction of these factors on seed damage showed significant difference (Fig. 8). Both adult number and percentage damage were highest in the last time of planting and lowest in the first time of planting. Damage was highest with double spacing and lowest with recommended spacing. The interaction showed the highest damage with the last time of planting and double the recommended spacing (5.4%) and lowest was with the first planting and recommended spacing (2.6%).

Table 16: Interaction of time of planting and spacing on number of C. chinensis adult emergence after 2 months of seed storage in 1999a

	Spacing*			
TOP**	DRS	RS	HRS	Overall mean ± 1.31
TOP1	19.5bc	13.8c	20.0bc	17.8c
TOP2	26.0b	23.0b	23.0b	24.0b
TOP3	53.3a	48.5a	52.5a	51.4a
Overall mean ± 1.31	32.9a	28.4a	31.8a	

* RS= Recommended spacing, HRS= Half recommended spacing, DRS= Double recommended spacing
** TOP1= First time of planting; TOP2= Second time of planting; TOP3= Third time of planting
\# Means followed by the same letters are not significantly different from each other at p=0.05

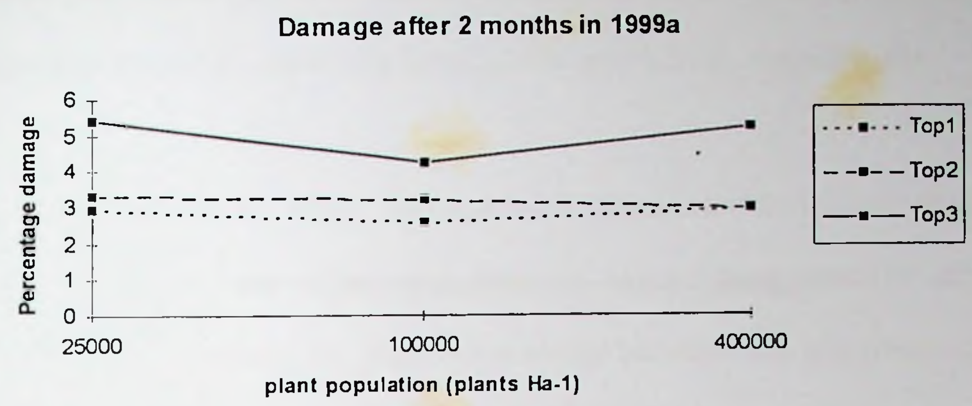


Fig. 8 Interaction of time of planting (TOP) and spacing on pigeonpea seed damage due to *C. chinensis* after 2 months of storage in 1999a

3.4.7.3 Influence of Time of Harvest on infestation of *Callosobruchus chinensis*

The effects of time of harvest on two pigeonpea seed pests is shown in Table 17. Apart from *C. chinensis*, damage on pigeonpea seeds was also due to emergence of adult red flour beetles (*Tribolium castaneum)*. Seed damage by both pests were significantly different ($p<0.05$) between the treatments. The highest damage from *T. castaneum* was from the last time of harvest with 1.73%, 1.88% and 2.00% and the lowest was observed on seeds harvested at physiological maturity with 1.05%, 0.86% and 1.28% in the respective seasons. Damage by *C. chinensis* also followed a similar trend in which the highest and lowest damage levels were observed on seeds that were harvested late and at physiological maturity, respectively.

In the second rains of 1998 damage by *T. casteneum* and *C. chinensis* on pigeonpea seeds again showed significant differences among the time of harvest treatments at all stages considered. The highest mean damage on pigeonpea seeds due to *T. casteneum* was 1.86% and the lowest was 1.28% while that due to *C. chinensis* were 2.01% and 1.31%, respectively.

In the first rains of 1999, damage by *T. castaneum* and *C. chinensis* were higher than in the other two previous rains There was no consistent difference in damage to pigeonpea seeds between the two pests although damage by *C. chinensis* appeared to be higher than that by *T. castaneum*. The highest damage levels by both pests were in the last harvest and the lowest were in the first harvest in all the three seasons.

The means of *C. chinensis* emergent adults and the percentage seed damage levels in storage in the various treatments are shown in Tables 18 and 19, respectively. In the first rains of 1998, after one month of storage of pigeonpea seeds the highest mean number of adults emerged from seeds harvested last, 1.77 adults. This corresponded to damage level of 0.96% whilst the lowest adult emergent number was from physiological maturity (0.84 adults) with damage level of 0.65%.

Table 17: Mean percentage damage of pigeonpea seeds by *C. chinensis* and *T. castaneum* at harvest at different time of harvest in 1998 a&b and 1999a

	% damage by pest (Mean ± S.E.)					
	1998a		1998b		1999a	
Time of Harvest	*T. castaneum*	*C.chinensis*	*T. castaneum*	*C.chinensis*	*T. castaneum*	*C.chinensis*
PM*	1.05 ± 0.04	0.95 ± 0.05	0.86 ± 0.03	1.31 0.02	1.28 ± 0.01	1.15 ± 0.06
2 wk after PM	1.53 ± 0.01	1.58 ± 0.04	1.22 ± 0.02	1.42 0.02	1.55 ± 0.01	1.60 ± 0.02
4 wk after PM	1.73 ± 0.06	1.85 ± 0.03	1.88 ± 0.02	2.01 0.02	2.00 ± 0.06	2.05 ± 0.06
LSD	**0.14**	**0.13**	**0.02**	**0.03**	**0.10**	**0.15**
CV(%)	**5.13**	**5.24**	**13.0**	**19.2**	**3.56**	**5.48**

PM =Physiological maturity; wk = week

Table 18 Mean number of *C. chinensis* adults emerged at different times of harvest in 1998a&b and 1999a after 1 and 2 months of storage duration

	Mean number emerged (Mean ± S.E.)					
	1998a		1998b		1999a	
Harvest time	**1 month**	**2 months**	**1 month**	**2 months**	**1 month**	**2 months**
PM*	0.84 ± 0.13	1.2 ± 0.00	19.8 ± 0.8	67.5 ± 1.0	15.5 ± 1.7	52.8 ± 3.5
2 wk after PM	1.13 ± 0.28	1.8 ± 0.07	33.0 ± 1.3	100.8 ± 1.4	23.8 ± 1.9	101.8 ± 4.7
4 wk after PM	1.77 ± 0.20	2.1 ± 0.01	61.0 ± 1.6	291.3 ± 1.1	55.3 ± 4.3	213.8 ± 3.7
LSD	**0.52**	**0.29**	**4.4**	**3.7**	**9.2**	**13.9**
CV (%)	**24.31**	**9.67**	**6.65**	**1.40**	**18.22**	**7.08**

*PM =Physiological maturity; wk = week

Table 19: Mean percentage pigeonpea seed damage due to *C. chinensis* at different times of harvest in 1998a&b and 1999a after 1 and 2 months of storage duration

	percentage seed damage (Mean ± S.E.)					
	1998a		1998b		1999a	
Harvest time	**1 month**	**2 months**	**1 month**	**2 months**	**1 month**	**2 months**
PM*	0.65 ± 0.04	1.72 ± 0.01	0.79 ± 0.02	3.82 ± 0.01	1.59 ± 0.08	3.56 ± 0.21
2 wk after PM	0.80 ± 0.03	2.98 ± 0.01	0.94 ± 0.03	6.91 ± 0.01	1.99 ± 0.13	4.96 ± 0.06
4 wk after PM	0.96 ± 0.03	6.13 ± 0.06	1.19 ± 0.04	19.8 ± 0.12	3.86 ± 0.11	9.74 ± 0.22
LSD	**0.08**	**0.12**	**0.07**	**0.26**	**0.34**	**0.57**
CV	**5.48**	**8.31**	**4.39**	**4.51**	**8.50**	**5.83**

*PM =Physiological maturity; wk = week

After two months of pigeonpea seed storage, there were significant differences in adult bruchid emergence and percentage seed damage among the treatment means. Again the highest number of adult *C. chinensis* emerged from pigeonpea seeds harvested last (2.1 adults) and the lowest from the harvest at physiological maturity (1.2 adults). The damage levels were 6.13% and 1.72% respectively.

In the second rains of 1998, after one and two months of seed storage the mean *C. chinensis* adult emergence and the percentage seed damage were still significantly different ($p<0.05$). The highest mean adult emergence at one month storage occurred in seeds from last harvest (61.0 adults) and the lowest from seeds harvested at physiological maturity (19.8 adults). The damage levels were 1.19% and 0.79% from the last and the first harvest, respectively. At two months of storage the highest adult number emerged was 291.3 adults and the lowest was 67.5 adults, corresponding to damage levels of 19.81% and 3.82%, respectively.

In the first rains of 1999 there were significant differences in the adult *C. chinensis* emergence between the harvest time treatments. After one month of seed storage, the highest mean adult emergence was from seeds derived from the last harvest (55.3 adults) and the lowest was from the first harvest seeds (15.5 adults). After two months of storage, a similar trend was observed, with 213.8 adults and 52.8 adults from seeds derived from the last harvest and at physiological maturity, respectively. The damage figures being 3.86% and 9.74% while the lowest were 1.59% and 3.56% after 1 and

2 months from seeds harvested last and at physiological maturity, respectively.

3.5.0 Influence of Cultural practices on crop Yields

3.5.1 Effects of cropping system on pigeonpea Yields

The effect of cropping system on crop yields is shown in Table 20. Cropping system significantly affected yields of pigeonpea obtained in all the three rain seasons. Generally the highest yields were in sole crops followed by intercrops with cowpea and lastly in intercrops with millet. Across the seasons the lowest yields were in the first rains of 1998 and the highest were in the first rains of 1999.

Yields of pigeonpea in pigeonpea/millet intercrops were not significantly different from each other throughout the three rain seasons. However, yields of pigeonpea in cowpea intercrops were significantly different among the treatments in the second rains of 1998 and first rains of 1999 but not in the first rains of 1998. In sole crops, yields were significantly different from one another in the second rains of 1998 only although there was a tendency of higher yields in the short duration pigeonpea.

The various land equivalent ratio (LER) and Land equivalent coefficient (LEC) are shown in Table 21. The LER for the pigeonpea/millet intercrops were lower than that of pigeonpea/cowpea intercrops. There were generally lower LER in all combinations in the second rains of 1998 than in the other two rains. The combinations of short or medium duration pigeonpea with either millet or cowpea did not significantly influence LER throughout the three rains. All LER were more than 1.0 but less than 1.5. Land equivalent coefficient (LEC) followed a similar pattern as for LER. But the LEC in the first rains of 1998 was higher than those in the other two rains. The lowest LEC was in the second rains of 1998 in the short duration pigeonpea/millet intercrop (31.3%) and the highest was in the first rains of 1998 in the short duration pigeonpea/cowpea intercrop (46.1%). All LEC were however, more than 25%.

The yields of companion crops (millet and cowpea) in the pigeonpea intercrops is given in Table 22. There were significant differences ($p<0.05$) in the yields of both millet and cowpea whether intercropped with short duration or medium duration pigeonpea. Across the seasons, there were significantly lower yields of both companion crops in the first rains of 1998 than in the other two subsequent rains.

Table: 20 Yields of pigeonpea seed with different cropping systems in 1998 a & b and 999a

	Yields (Kg Ha^{-1})		
Cropping System*	**1998a**	**1998b**	**1999a**
SDPP+M	603.5d	710.5e	755.3d
MDPP+M	614.0d	708.8e	805.8d
SDPP+C	737.5bc	883.0c	1003.0b
MDPP+C	688.3c	804.0d	926.3c
SDPPS	799.3a	1136.8a	1123.8a
MDPPS	748.0ab	1010.3b	1065.5ab
LSD	**54.7**	**77.7**	**76.3**
CV (%)	**5.2**	**5.9**	**5.4**

* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea, SDPPS= Short duration pigeonpea sole crop, MDPPS= Medium duration pigeonpea sole crop.

Table 21 Land Equivalent Ratios (LER) and Land Equivalent Coefficients (LEC) for pigeonpea intercropping system in 1998a&b and 1999a

	LER			LEC (%)		
Cropping system*	**1998a**	**1998b**	**1999a**	**1998a**	**1998b**	**1999a**
SDPP+M	1.3	1.1	1.2	37.8	31.3	33.6
MDPP+M	1.3	1.2	1.3	41.0	35.1	37.8
SDPP+C	1.4	1.3	1.4	46.1	38.8	44.6
MDPP+C	1.4	1.3	1.4	46.0	39.8	43.5

* SDPP+M= Short duration pigeonpea with millet, MDPP+M= Medium duration pigeonpea with millet, SDPP+C= Short duration pigeonpea with cowpea, MDPP+C= Medium duration pigeonpea with cowpea

Table: 22 Yields of companion crops (millet and cowpea) in the pigeonpea interctrops for 1998 a&b and 1999a

	Yields (Kg Ha^{-1})		
Companion crop*	**1998a**	**1998b**	**1999a**
Millet (in SDPP)	873.8a	1005.3b	1083.3a
Millet (in MDPP)	705.3b	1133.8a	1055.3a
Cowpea (in SDPP)	171.5c	281.5c	281.3b
Cowpea (in MDPP)	169.5c	266.8c	290.5b
LSD	**52.4**	**48.5**	**34.0**
CV (%)	**6.82**	**4.51**	**3.14**

*SDPPS= Short duration pigeonpea, MDPPS= Medium duration pigeonpea.

3.5.2 Effects of different Times of Planting (TOP) and spacing on Yields of pigeonpea

The yields of pigeonpea in the different TOP and spacing treatments are presented in Table 25a &b. There were significant differences ($p<0.05$) in the yields of pigeonpea depending on Time of planting (TOP) and spacing but their interaction was not significantly different ($p>0.05$). The highest yields were from the first TOP and the double recommended spacing. Yields of the first and second TOP, or from the recommended and half recommended spacing were not significantly different from each other in both rains.

3.6 Discussion

Infestations of flower beetles (*Mylabris pastulata*) on pigeonpea in the millet intercrops were the lowest. Further observations, however, indicated that millet also supported populations of the flower beetles. This would suggest that both the pigeonpea and the millet attracted the flower beetles, thus even distribution on both crops with consequent low population on pigeonpea. This observation is supported by Pant and Kalode (1963), who indicated that the flower beetles are a major pest of millet. The non significant difference of *Mylabris* sp. infestation on the pigeonpea varieties evaluated agrees with the results obtained by Khan *et al.* (1983), who noted that the pest do not show preference for any pigeonpea variety.

The short duration pigeonpea combinations had higher beetle numbers. They also flowered first and had more flowers per plant than the medium duration type. It could be that the early flowering attracted beetles quickly and sustained their presence even when the medium duration variety flowered. Findings by Patnaik *et al.* (1993), also indicated that plant growth habits influenced blister beetle population. Higher infestation of pigeonpea by *Mylabris* sp. in the second (short) than first (long) rains was observed. Perhaps low rainfall amounts in the first season did not favour production of many flowers to support a large number of beetles. This was shown by the retarded growth and poor development of the crop in the first rains of 1998 compared to the other two subsequent rains.

The significantly low infestation of thrips on pigeonpea in intercrops with cowpea compared to sole crop pigeonpea or pigeonpea intercropped with millet could have been due to difference in micro climates. The pigeonpea/cowpea mixture may have created higher relative humidity compared to that in sole crop pigeonpea. High relative humidity (>80%) has been shown to reduce thrips population in cowpea/ maize crop mixtures (Kyamanywa, 1988). Alternatively, since there were two scenarios of choice (pigeonpea + cowpea) and no choice (pigeonpea sole crop), the thrips probably have more preference for cowpea than pigeonpea in the mixture, perhaps also influenced by the early flowering of cowpea, while in the no choice condition pigeonpea had the whole load of the pest without sharing it with an alternative host plant.

Many studies of cropping systems on thrips infestation have revealed different results. For instance, Ezueh (1991), reported that infestation by cowpea flower thrips increased in cowpea/maize intercrops. Singh *et al.* (1978), reported reduced thrips population in cowpea /bean intercrop compared to sole crops. Kyamanywa and Tukahirwa (1989), observed reduced thrips infestation on cowpea intercropped with maize. Sharma and Sowley (1984), working on pigeonpea/maize intercropping pattern observed that the incidence of thrips was not significantly different in any of the pigeonpea/maize combinations. In the present study, the intercrop of pigeonpea with millet had significantly higher infestations in the medium duration geno-types. This may have been as a result of a higher initial population level due to movement of thrips population from the short to the medium duration crop as the latter came to flower at a later date in the season.

Aphid infestation was observed from 7 weeks after emergence and showed peak infestation at 3 or 4 weeks after flower initiation. Night and Ogenga-Latigo (1994), reported that aphids on pigeonpea is a pest of the vegetative stage. But in this study, aphids occurred during the vegetative stage, flower and pod stages. The higher rate of infestation build up of aphids in the first rains could be due to the drier conditions that prevailed. Ingram (1969), and Ogenga-Latigo (1988), have reported that drier conditions tended to favour aphid population build up.

The lower severity of aphid attack on intercrops than sole crops of pigeonpea could be a result of buffer effect of the companion crops to the pest. The higher severity of aphids in the first rains could be attributed to dry weather conditions that prevailed. Similar observation has been made on phaseolus beans by Ogenga-Latigo (1988), who indicated that aphid severity is higher during the drier periods of weather. Perhaps the bigger aphid colonies on water stressed plants in the dry season is the reason for higher severity of aphid attack. During the wet seasons, aphids can be washed away by rains and die in puddles of water or are blown off plants by strong winds that accompany the rains.

The predominance of *H. armigera* to the other lepidopterran pod borers confirms results by Night and Ogenga-Latigo (1993), and Silim-Nahdy

(1995), that this is the most commonly occurring lepidopteran pod borer in Uganda. Infestation build up of *H. armigera* with peaks at 3 to 4 and 5 weeks after anthesis in the short and medium duration varieties respectively, may be due to response to some stimuli from the plant (leaves or pods). This corresponds to the time when pods are tender and thus can be easily bored by the pest.

Pod borer infestations were lower in the short duration pigeonpea genotypes. This observation was also made by Night and Ogenga-Latigo (1993), who found that medium duration pigeonpea had higher *H. armigera* larvae numbers than the short duration varieties. Because short duration pigeonpea matured early it may have escaped pod borer attack because the pods were formed and filled at a time when pest population build up was low. This could also explain why actually there was more damage on medium than short duration pigeonpea, signifying increased pest population build up and activity on the later crop. Combinations of pigeonpea with millet had lower pod borer infestations. A similar observation was made by Singh and Singh (1978). They attributed this to modification of the micro environment due to the crop canopy.

Pigeonpea appears to be infested by several pod bug genera namely; *Clavigralla* sp., *Riptortus* sp., and *Anoplocnemis* sp., however, *Clavigralla* sp. was the most frequently encountered. Night and Ogenga-Latigo (1994), and Silim-Nahdy (1995), have both reported *Clavigralla* sp. as the most frequent pod bug species in Uganda. The low infestation in the seasons with high amounts of rains could be due to low rate of population build up compared to the low amounts of rains. Singh *et al.* (1989), reported that heavy rains did not favour population build up of pod bugs on pigeonpea. They also observed reduced adult *Clavigralla* sp. population due to low temperatures in India. Perhaps wetter conditions provided low temperatures which could have reduced egg numbers and increased developmental time since eggs are laid on pods and are exposed to such adverse weather as rainfall.

The low number of pod bugs on pigeonpea intercropped with cowpea possibly indicated alternative host selection, in which cowpea was more preferred by the bugs. Therefore at any one time, because of spread of the same pest on both crops the count on pigeonpea is lower than say on sole crops where there is no pest divergence on to another crop.

There were higher bruchid catches in baited traps, probably indicating that dry pigeonpea seeds may have some attractants that helped in luring the pest into the traps. Pod fly catches were higher than that of bruchids, suggesting that pod fly are more abundant compared to bruchids in the field and/or more attracted by the pigeonpea. Increased pest catches in the traps with time after anthesis suggests that as flowers and pods were produced, plant substances, probably kairomones were being produced that attracted the pests to the crop. Trap catches from 3-5 weeks after anthesis which were not significantly different, coincided with much of the pod formation and pod filling stages. Perhaps the attractant plant substances were less produced from the pods at these stages thus less pest populations.

Damage of pigeonpea seeds by pod borers was high in the last planted crop. Delayed planting could have exposed the crops when the pest levels were higher as the season progressed. In a related study, Kushwaha and Malik (1987), showed that early sowing of pigeonpea reduceed damage on pigeonpea seeds by *H. armigera*. Minja (1997), also observed reduced damage on pigeonpea seeds due to pod borers (*H. armigera*) with early planting.

Seed damage by pod borers was affected by TOP alone and not by spacing. This seems to suggest that the lepidopterran larvae of *H. armigera* responds to weather conditions rather than plant population. As the rains progressed, heavy rains may have had the effect of drowning or washing away most eggs and larvae thus increasing their mortality. In addition higher rainfall amounts could have afforded the young plants vigour of growth to compensate losses. But with reduced rains warm conditions prevailed and this may have been more conducive to larval development and survival thus increasing their population, consequently more infestation. Chaudhary *et al.* (1980), recorded higher pod borer damage to pigeonpea pods with delayed planting dates. Weather factor has been identified to affect the activity of *H. armigera* and this is mainly due to the occurrence of pupal diapause during colder months (Lal *et al.* 1986; Yadava *et al.*, 1988).

There was no significant difference in pod borer damage with spacing(plant population). This result confirms similar observation by Reed *et al* (1978), at

ICRISAT centre, India. Chaudhary *et al* (1980), also found that sowing of pigeonpea crops at different row spacing neither gave any significant difference in the incidence of pod borer nor in the yield in the two years of 1977 and 1979. Seasonal variations did not affect pigeonpea seed damage. This could be due to the fact that there were similar conditions of weather such as temperatures and rainfall, with closely related amounts and distribution pattern over the growing period of the crops (Appendix 1).

Pod bug damage showed no significant differences with both TOP and spacing in the two rains. This is an indication that both of these parameters did not affect pest populations and thus damage of pigeonpea seeds. But Minja (1997),recorded reduced pigeonpea seed damage due to pod bugs with early planting. She however, used wider time intervals of one month or one year. Since the interval of planting in this study was only two weeks, this could have provided similar conditions of temperature and relative humidity which had little influence if any.

There was no significant difference between pod fly damage with both TOP and spacing. However, there is some evidence to suggest that TOP may influence pigeonpea seed damage by the pod fly. This is shown by the tendency of the last TOP to have higher seed damage due to pod fly. Perhaps the range of time interval employed in this study was not as widely varied as to cause significant difference in damage. Kabira *et al* (1990); Minja, 1997, also indicated that sowing time did not influence pigeonpea seed damage by pod fly, but rather damage was more influenced by the variety of the crop. In this study however, the aspect of variety in relation to pigeonpea seed damage by pod fly was not investigated.

The number of *C. chinensis* emergent adults and the percentage damage on pigeonpea seeds were influenced by TOP alone and not by spacing of the crop or the interaction of TOP and spacing. As *C. chinensis* manifests itself more in storage than in the field (Silim-Nahdy, 1995), it is likely that higher populations would occur with increased storage duration. Increased adult emergence and damage with late planting may be due to an accumulation of pests from previous crops. This was clearly shown in the results, that significantly higher adult emergence were recorded and higher seed damage in the last TOP than in the first TOP.

The findings are similar to that reported by Patnaik *et al.* (1986), on infestation of pigeonpea by *C. maculatus,* where significant differences were observed in the extent of grain infestation with sowing date and a strong cultivar x sowing date interaction. Similarly, they reported that infestation and damage were lowest for the earlier sowing dates and highest in the late planted crop.

Spacing of pigeonpea did not appear to have a consistent influence on *C. chinensis* infestation and damage to seeds. In the second rains of 1998, however, spacing significantly affected adult bruchid emergence but not damage to seeds, whilst in the first rains of 1999, no significant differences were observed in adult emergence and percentage seed damage with spacing after a storage duration of 1 month. However, after 2 months of seed storage, TOP evidently affected adult emergence and percentage damage to seeds.

After one month of pigeonpea seed storage significant differences were observed in the number of emergent adults. This suggests the importance of the pest status at this very early stage of storage. Results in this study showed that early planting reduced bruchid infestation compared to late planting. This indicates that earlier planted crops escaped the bruchid field infestation. However, late planted crop encountered heavier infestation due to increased pest population build up. Similarly, the damage to pigeonpea seeds with TOP and spacing is directly attributed to the number of adults that emerged from the seeds.

After an extended seed storage duration of 2 months, the results confirmed earlier results that adult emergence and the percentage seed damage are both dependent on TOP and spacing. In the parameters studied there is strong evidence that seeds from the third TOP had more adults emerged and higher damage level than the other two. One possible explanation for this trend is that late planting exposes the crop in the field with higher pest population after the others have been harvested. With this built up infestation, more eggs are laid on the crop as it remains in the field. These eggs are subsequently transferred to the store where they are incubated, hatch into larvae and emerge as adults.

Yields from intercropping were considered in terms of land productivity, whereby land is said to be productive under intercropping system if LER is more than 1 and LEC is more than 25%(Mead and Willey, 1980). As shown in Table 23 it is evident that this cropping system gave reasonable land productivity values. It appeared from both parameters that land productivity with cowpea is higher than that with millet intercropping. This could be due to the beneficial effect of legume crops such as cowpea that have the advantage of fixing nitrogen for plant growth.

Results also indicated that land productivity in the first rains of 1998 was higher than in the subsequent two rains, more especially derived from the LER. This could explain the advantage of mixed cropping in drought periods since this season was marked by dry conditions compared to the other two seasons. This may be one reason why pigeonpea is grown in relatively drier areas and normally grown in intercrops.

TOP and spacing influenced yields of piogeonpea grains but their interaction did not have any effect. The earlier planted crops had significantly higher yields than the last planting, in this respect, two main factors could have been important. First, the earlier planted crops could have escaped from the major pests attack thus suffering less damage compared to the late planted crop. Secondly, the earlier planted crops could have captured more rainfall for grain filling than the late crop as it filled at the time when rains were subsiding.

The reasons why the yields from the first two plantings were not significantly different but both significantly different from the last, could be that there were similar growth and pest situations in the first two week interval. But this situation could have changed drastically after the second planting causing the significant difference observed. With spacing, the recommended or half recommended spacing had higher yields probably due to the higher plant populations compared to the double spacing.

CHAPTER FOUR

BOTANICALS AND A SYNTHETIC INSECTICIDE IN FIELD MANAGEMENT OF BRUCHIDS (*CALLOSOBRUCHUS SPP.)* AND OTHER POD PESTS OF PIGEONPEA

4.1 Introduction

Plant materials for pest control have always been in use by farmers in many countries of the world (Van Huis, 1991). The use of plant parts and products such as leaf, bark or seed and plant products such as oils, juices and ash by small scale farmers for management of pulse weevils has been reported in many countries in Asia and Africa (Silim *et al.*, 1990). For example, tobacco leaves have been used as an insecticide for many years (Mcldoo, 1945). The leaves were either used as an extract, dust or burnt to control the numerous field pests (Hill, 1983).

Ofuya (1986), used powder from dried tobacco leaves and found that the treatment reduced egg-laying by *C. maculatus* and also reduced egg-hatching. Williams and Mansingh (1993), reported that application of crude extract of tobacco (*Nicotiana tabacum),* resulted in 100% mortality to adults of *Tribolium confusum.* Saxsena *et al.* (1992), using an extract of aerial parts of *Lantana camara* found that when this was applied *on C. chinensis* at 5% concentration there was complete antifeedant effect. It also provided 10-14% mortality at 1-5% concentration. In addition it also resulted in less fecundity at higher dosages.

Extracts from the seeds of neem, *Azadirachta indica* have been shown to negatively influence the reproduction of female insects from several Orders (Lowery and Isman, 1995). The demonstrated efficacy of the botanical neem (based on seed kernel extracts of *A. indica*) and its recent approval for use in the USA has stimulated research and development of other botanical insecticides (Isman, 1997).

In pigeonpea, a number of botanicals have been tested for their insecticidal properties against some storage insect pests. The plants that have shown high potential in the control of *C. chinensis* include; Tephrosia, tobacco and wood ash, applied as dusts (Silim-Nahdy, 1995). Several workers have explored the use of neem and found it a potential source for managing the pod borer complex of pigeonpea in the field (Sachan and Lal, 1990; Sadawarte and Sarode, 1997). However, there is little or no detailed information on the use and efficacy of botanicals in the field management of *C. chinensis* and the other pod pests of pigeonpea.

This study was intended to investigate the influence and efficacy of selected botanicals and a synthetic insecticide, in order to reduce field infestations of pigeonpea storage pests. The specific objectives therefore were to:

1) Establish the potential of selected botanicals compared to synthetic chemical insecticides in controlling *Callosobruchus* sp. and other pod pests in the field.

2) Evaluate the efficacy of selected botanicals in controlling *C. chinensis* and other pod pests in the field.

4.2.0 Materials and Methods

4.2.1 Establishment of field experiments

The experiment was conducted at Kawanda Agricultural Research Institute (KARI) located 12 Km north of Kampala on 32° 32'E and 0.5° N at an elevation ranging from 1177 to 1320 metres above sea level. The landscape around Kawanda is typically that of a dissected pediplain having undulations of about 90-120m amplitude.

A short duration pigeonpea variety ICPL 87091 of the International Crops Research Institute for Semi-Arid Areas (ICRISAT) series was planted in the first (short) and second (long) rains of 1998 (1998 a&b) and the first rains of 1999 (1999a) respectively. The experimental design was a Randomised complete block design on a plot size of 4 x 3 m and replicated four times. Field preparations involved slashing, ploughing and harrowing by both tractor and hand hoe in all the three seasons.

Planting was done in late April and early September of 1998 and early April of 1999 in the three rain seasons, respectively. A plant spacing of 50 x 20 cm was used throughout in all the seasons. Two to three seeds were planted per hole and later thinned to one plant per hill, two weeks after emergence and this gave a plant population of 100,000 plants Ha^{-1}. Germination was evident within 4-6 days after planting and was estimated at about 80%. Gap filling was done 3 to 4 days after germination. The crops were weeded four times and generally kept weed free all the time.

From early pod fill stage (80 days after planting), a regime of botanicals and synthetic insecticide treatments were begun and applied four times at 7 days interval lasting for one month until crop maturity. Nine treatments were applied and included the following: a) Fermented Melia seed extract (MSE), b) Fermented Tephrosia, c) Fresh MSE, d) Fresh Tephrosia, e) Fresh tobacco extract, f) Fresh formulation of ash, g) Fresh extract of compound mixture of MSE and Tephrosia, h) Synthetic insecticide (cypermethrin), and I) Control treatment without either botanical or synthetic insecticide of any of the above.

4.2.2 Preparation of Treatment Materials

4.2.2.1 Fermented Formulations of MSE and Tephrosia.

Fresh yellow or dried seeds of China hemp (*Melia azedarach*) were collected from the tree or those fallen on the ground at KARI. A 200g weight was soaked in 2 litres of water and left to ferment for four days; longer than four days was found to be unsuitable for use as spray because it encouraged too much fungal growth that scorched the plants. For tephrosia, fresh leaves and twigs of *Tephrosia vogelli* were picked from the growing plants at KARI and pounded in a local motar into a paste. A 200g weight of the paste was fermented in 2 litres of water for four days. In both preparations the fermented extracts were diluted to 3 litres of water to spray an area of $48m^2$ and applied at the rate of 625 l Ha^{-1} of the whole solution.

4.2.2.2 Fresh Formulations.

Fresh MSE and fresh tephrosia formulations were similar in preparation to those in A) above except that they were not fermented. They were freshly prepared at least four hours before application. Fresh tobacco formulation was obtained by soaking 2-3 dried fire-cured tobacco leaves (200g) in 1 litre of water and allowed to stand for at least four hours and diluted to 3 litres before application. For fresh formulation of ash, 200g of fresh ash got from burning assorted firewood was put in 2 litres of water, left to stand for at least four hours, decanted and later diluted to 3 litres. The compound mixture of MSE and tephrosia had 100g of either of the constituents with similar preparations as the previous independent components. Application rates used were maintained at 625 litres Ha^{-1} of the solutions made. The synthetic insecticide used was cypermethrin (Ambush) and applied at the rate of 1.0 litre Ha^{-1} as recommended for use on pigeonpea pests (Silim-Nahdy, 1995).

At harvest, pigeonpea seed damage due to the different pod and seed pests namely, pod borers, pod bugs, pod fly and bruchids were evaluated. One week after physiological maturity, pods were harvested and threshed. Seeds were further dried for two days in the open sun in cloth bags in order to reduce moisture content and guard against non-field infestations. (Silim and Odong, 1993; Agona and Silim, 1998; Silim-Nahdy, 1995). The number of bruchids and the percentage damage to seeds at harvest time were recorded.

After the 2-day drying period, seeds were then stored for up to two months in the laboratory under ambient conditions (temperature range of 24-26°C).

Samples of 200g of pigeonpea seeds were incubated in plastic jars with perforated lids (0.7mm diameter). Records of adult emergence and percentage damage to seeds at one and two months of seed storage were taken. Yields of the pigeonpea crop were also evaluated with the different treatments of biorationals and synthetic insecticide. Data analysis was by the MSTAT-C computer statistical package.

4.3.0 Results

4.3.1 Composition of *Callosobruchus* species

Results of the composition of the bruchid species is presented in Table 23. In all the three rains the results revealed two pigeonpea bruchid species, both before and during storage. These two species were; *Callosobruchus chinensis* and *C. rhodesianus* with *C. chinensis* as the dominant species, with species ratio of up to 1:182 (0.6%:99.4%). In all the three seasons there were significant differences ($p<0.05$) in the number of adults that emerged and the percentage damage to pigeonpea seeds among the treatments.

4.3.2 Effect of botanical products and a synthetic insecticide on *C. chinensis* adult emergence and pigeonpea seed damage

The effects of botanical products on adult emergence and percentage damage to pigeonpea seeds is shown in Table 24 and Table 25 respectively. At harvest, in both seasons of 1998, the highest mean number of adult bruchids was in the seeds from control plots followed by that from the plots treated with ash formulation while the lowest were in seeds treated with cypermethrin, fermented Tephrosia and tobacco extract. Seed damage levels followed a similar trend. After one and two months of seed storage there were again significant differences ($p<0.05$) in the number of adult bruchids emerged and the percentage damage to seeds among the treatments.

After one and two months of seed storage, the highest number of adults emerged after one and two months of seed storage were from the control and ash treatments whilst the lowest were from cypermethrin and tobacco treatments. Generally there were more adult emergence and higher percentage damage in the second than first rains of 1998. In the first rains of 1998, a range of 0.25 - 3.00 adults and 0.25 - 4.25 adults compared to 2.25 - 9.25 and 3.25 - 59.50 adults in the second rains, after one and two months respectively. The range of damage levels were 0.55-1.22% and 0.57-1.57% compared to 1.60-2.60% and 1.93-10.8% in the first and second months of storage respectively.

Table 23 Composition of *Callosobruchus* sp. from the field and after 1&2 months of storage over the three rains of 1998a, 1998b and 1999a

		1998a			1998b			1999a		
Time	Species	Total	Av/samp.	Sp. Ratio*	Total	Av/samp.	Sp. ratio	Total	Av/sample	Sp. ratio
Harvest C	*C. chinensis*	60	1.67	1:60	72	2.00	1:72	81	2.25	1:41
	C. rhodesianus	1	0.03		1	0.03		2	0.06	
1 month C	*C. chinensis*	44	1.22	1:9	166	4.61	1:6	70	1.94	1:18
	C. rhodesianus	5	0.14		3	0.08		4	0.11	
2 months C	*C. chinensis*	63	1.75	1:31	730	20.28	1:182	132	3.67	1:17
	C. rhodesianus	2	0.06		4	0.11		8	0.22	

*= species ratio (*C. rhodesianus* : *C. chinensis*)

Table 24 Mean *C. chinensis* adult emergence from pigeonpea seeds at harvest, after 1 and 2 months of storage duration in 1998 a&b and 1999 a

	Mean number of adults (Mean ± S.E.)								
	1998a			1998b			1999a		
Treatment	Harvest	1 month	2 months	Harvest	1 month	2 months	Harvest	1 month	2 months
Ferm.MSE	1.25 ± 0.25	0.25± 0.25	0.50 ±0.29	2.00± 0.41	3.75± 0.41	11.0± 0.76	1.18± 0.18	5.0± 0.70	10.5± 0.50
Ferm.Teph	0.25 ± 0.29	0.75± 0.25	1.25± 0.25	1.75± 0.25	2.50± 0.25	8.75± 0.44	1.06± 0.21	4.31±0.25	9.80± 0.95
Fresh MSE	1.50 ± 0.29	1.25± 0.25	2.25± 0.25	2.50± 0.29	5.25± 0.21	18.5± 0.25	1.27± 0.21	6.50±0.50	13.5± 0.90
Fresh Teph	2.50 ± 0.29	1.75± 0.48	2.75± 0.25	2.00± 0.41	3.50± 0.25	12.5± 0.56	1.18± 0.18	6.0 0±0.70	12.3± 1.93
Fresh Tob.	0.25 ± 0.25	0.25± 0.25	0.25± 0.25	1.25± 0.48	2.50± 0.25	7.75± 0.41	0.97± 0.15	3.00±0.70	9.80± 0.48
Fresh Ash	3.00 ± 0.41	3.00± 0.41	3.50± 0.29	3.00± 0.41	9.25± 0.41	48.0± 0.49	1.35± 0.25	15.8±1.37	24.5± 1.50
Cpd Extract	1.50 ± 0.29	0.50± 0.26	0.75± 0.25	2.00± 0.41	3.25± 0.41	13.3± 0.41	1.31± 0.09	6.0 ±0.70	13.0± 0.70
Cyperm.	0.50 ± 0.29	0.25± 0.25	0.25± 0.25	0.75± 0.48	2.25± 0.21	3.25± 0.11	1.06± 0.21	2.0 ±0.41	7.50± 0.65
Control	4.00 ± 0.41	3.00± 0.41	4.25± 0.48	2.75± 0.49	9.25± 0.21	59.5± 1.03	1.47± 0.16	21.0±1.08	31.3± 1.70
LSD	**0.96**	**0.98**	**0.87**	**1.22**	**1.07**	**2.11**	**0.54**	**2.6**	**3.7**
CV (%)	**39.26**	**54.97**	**34.01**	**41.67**	**15.92**	**7.14**	**30.99**	**22.91**	**17.36**

Ferm.MSE=Fermented melia seed extract (MSE); Ferm. Teph.= Fermented Tephrosia; Fresh Tob= Fresh Tobacco; Cpd Extract= Compound Extract; Cyperm.= Cypermethrin

Table 25 Mean percentage pigeonpea seed damage by *C. chinensis* at harvest, after 1 & 2 months of storage duration in 1998 a&b and 1999 a

	Percentage damage (Mean ± S.E.)								
	1998a			1998b			1999a		
Treatment	Harvest	1 month	2 months	Harvest	1 month	2 months	Harvest	1 month	2 months
Ferm.MSE	0.48± 0.02	0.59± 0.02	0.97± 0.02	0.70± 0.01	1.96± 0.02	6.04± 0.12	0.48± 0.07	1.78± 0.07	4.07± 0.22
Ferm.Teph	0.47± 0.02	0.59± 0.04	0.89± 0.02	0.46± 0.02	1.84± 0.04	5.20± 0.14	0.48± 0.09	1.66± 0.23	3.64± 0.32
Fresh MSE	0.75± 0.03	0.66± 0.02	1.20± 0.03	0.92± 0.03	2.14± 0.01	7.36± 0.23	0.59± 0.13	1.97± 0.07	4.66± 0.29
Fresh Teph	0.88± 0.02	1.00± 0.03	1.43± 0.03	0.58± 0.01	1.86± 0.07	7.37± 0.22	0.50± 0.09	1.87± 0.10	3.87± 0.33
Fresh Tob.	0.35± 0.01	0.55± 0.01	0.80± 0.03	0.39± 0.01	1.83± 0.03	4.04± 0.10	0.43± 0.05	1.21± 0.06	2.82± 0.11
Fresh Ash	0.92± 0.01	1.18± 0.08	1.46± 0.02	1.18± 0.02	2.59± 0.01	10.8± 0.23	0.80± 0.15	2.61± 0.09	6.81± 0.30
Cpd Extract	0.78± 0.22	0.89± 0.02	1.37± 0.03	0.49± 0.02	1.84± 0.02	5.31± 0.31	0.51± 0.07	1.50± 0.09	3.19± 0.75
Cyperm.	0.43± 0.02	0.57± 0.06	0.48± 0.02	0.33± 0.01	1.60± 0.03	1.93± 0.06	0.50± 0.06	0.96± 0.08	1.99± 0.30
Control	1.11± 0.02	1.22± 0.02	1.57± 0.02	1.00± 0.02	2.60± 0.03	9.83± 0.12	0.76± 0.13	2.84± 0.10	7.32± 0.36
LSD	**0.05**	**0.11**	**0.06**	**0.05**	**0.12**	**0.63**	**0.28**	**0.32**	**0.79**
CV (%)	**4.80**	**9.46**	**3.70**	**5.14**	**4.11**	**6.93**	**34.65**	**11.98**	**12.79**

Ferm.MSE=Fermented melia seed extract (MSE); Ferm. Teph.= Fermented Tephrosia; Fresh Tob= Fresh Tobacco; Cpd Extract= Compound Extract; Cyperm.= Cypermethrin

In the first rains of 1999, a similar trend as in the previous two rains was observed. A range of 2.0 -21.0 adults emerged from seeds in the first month and 7.5 -31.3 adults in the second month with the range of damage levels as 0.96% - 2.84% and 1.99 - 7.32%, respectively. There were lower adult emergence and percentage damage in seeds from plots treated with fermented MSE and Tephrosia than those from plots treated with their corresponding fresh formulations. The number of emerged adults in seeds from plots treated with compound extract of MSE and tephrosia in the first rains of 1998 were significantly lower than those from plots treated with fresh tephrosia in the first rains and fresh MSE in the second rains of 1998.

However, in the first rains of 1999, *C. chinensis* emergence in seeds from the compound extract treated plots were not significantly different from that of either Fresh MSE or Tephrosia treatments. Damage levels were significantly lower than in both fresh MSE and Tephrosia treatments after one month of storage. Across the seasons, at harvest, adult emergence was lower in the first rain of 1998 compared to the other two rains with the second rains of 1998 having the highest mean adult emergence in most treatments.

After one month, the adult emergence numbers and the percentage seed damage were still lower in the first rains of 1998 than in the other two rains with the highest observed in the first rains of 1999. After the two months' storage duration, adult emergence from seeds was lowest in the first rains of

1998 but highest in the second rains of 1998. The percentage damage to seeds showed a similar trend as for adult emergence.

4.3.3 Effect of Synthetic insecticide and Botanical products on Pigeonpea Seed damage due to pod borers, bugs and fly

Seed damage by the three pod pests are presented in Table 26. There were significant differences ($p<0.05$) in pod borer (*H. armigera)* damage levels between the treatments. Seeds from the control had the highest damage and the lowest was from cypermethrin treated plots. This trend of damage levels was observed in all the three rain seasons. Across the seasons damage levels did not vary significantly from season to season in most of the treatments although damage in the first rains of 1998 appeared to be lower than in the other two rains.

The highest pod bug *(Clavigralla* sp), damage to seeds was in the control and ash treatments while the lowest were obtained in the cypermethrin and tobacco treated plots. Across the seasons, first rains of 1998 gave the lowest seed damage compared to the other two seasons. Damage in the first rains of 1999 appeared to be the highest in all the seasons. With *Melanagromyza sp.* (pod fly), a significant difference was observed in damage levels to seeds in a similar trend as for the pod borers and pod bugs. Damage levels did not vary significantly across the seasons although it tended to be lower in the first rains of 1998 compared to the other two subsequent rains.

Table 26 Pigeonpea Seed damage by pod borers, bugs and fly with botanical products and a synthetic insecticide treatment in 1998 a&b and 1999a

	Percentage Seed damage								
	1998a			1998b			1999a		
Treatment	Pod borer	Pod bug	Pod fly	Pod borer	Pod bug	Pod fly	Pod borer	Pod bug	Pod fly
Ferm.MSE	4.15	8.10	2.54	3.54	9.89	2.76	3.70	10.91	2.70
Ferm.Teph	3.39	9.02	2.48	3.29	9.22	2.58	3.64	10.04	2.65
Fresh MSE	4.06	9.56	3.14	4.35	10.69	3.30	4.71	11.63	3.24
Fresh Teph	3.72	8.82	2.93	3.92	9.38	3.18	3.82	11.05	3.22
Fresh Tob.	3.15	6.23	1.98	2.82	7.98	2.44	2.90	9.62	2.31
Fresh Ash	4.10	7.65	4.19	5.37	11.39	4.05	5.25	12.67	4.03
Cpd Extract	3.86	9.04	2.95	4.00	10.03	3.55	4.73	11.30	3.30
Cyperm.	2.16	5.48	2.01	2.64	6.99	2.13	2.78	7.91	2.16
Control	5.06	11.06	4.28	5.68	11.90	4.40	5.36	13.26	4.35
LSD	**0.83**	**1.11**	**0.86**	**0.68**	**1.15**	**0.79**	**0.41**	**0.94**	**0.43**
CV (%)	**15.30**	**9.09**	**19.93**	**11.73**	**8.13**	**17.09**	**6.31**	**5.95**	**9.28**

Ferm.MSE=Fermented melia seed extract (MSE); Ferm. Teph.= Fermented Tephrosia; Fresh Tob= Fresh Tobacco; Cpd Extract= Compound Extract; Cyperm.= Cypermethrin

4.3.4 Pigeonpea seed yields with botanical products and synthetic insecticide treatments

Yields of pigeonpea seeds obtained after treatment with botanicals are presented in Table 27. There were significant differences ($p<0.05$) in yields of pigeopea seeds treated with different botanical products and synthetic insecticide. This was true for all the three rain seasons. Across the seasons, yields in the second rains of 1998 were the highest while those in the first rains of 1998 were the lowest.

In the first rains of 1998 the highest yields were recorded in treatments with cypermethrin followed by that from tobacco and the lowest came from the control. In both second rains of 1998 and first rains of 1999 the highest yields were from the tobacco, followed by cypermethrin treated plots. The lowest yield in second rains of 1998 was from the ash treatment and that in first rains of 1999 was from the control .

Table 27 Yields of pigeonpea seeds from plots treated with different botanicals and synthetic insecticide in 1998a&b and 1999a

	Yields (Kg Ha^{-1})		
Treatment	**1998a**	**1998b**	**1999a**
Ferm.MSE	896ab	971cde	890cd
Ferm.Teph	1000ab	1187bc	1053bc
Fresh MSE	854b	937def	946bcd
Fresh Teph	854b	1251b	968bcd
Fresh Tob.	1041ab	1691a	1553a
Fresh Ash	583cd	723f	810d
Cpd Extract	833bc	1142bcd	1121b
Cyperm.	1146a	1689a	1544a
Control	520d	783ef	588e
LSD	**270.3**	**234.1**	**177.4**
CV (%)	**21.57**	**13.91**	**11.55**

Ferm.MSE=Fermented melia seed extract (MSE); Ferm. Teph.= Fermented Tephrosia; Fresh Tob= Fresh Tobacco; Cpd Extract= Compound Extract; Cyperm.= Cypermethrin

4.4 Discussion

Two pigeonpea bruchid species were observed to be present on pigeonpea seeds in this study namely, *C. chinensis* and *C. rhodesianus*. It has been reported that *C. chinensis* may occur together with *C. maculatus* in Uganda (Davies, 1960; Silim and Odong, 1993, Silim-Nahdy, 1995). This may be considered to be mainly due to cross infestation of the bruchids between commodities when cowpea and pigeonpea are stored together. But *C. rhodesianus* has been reported in Tanzania, (Mphuru, 1978). However, the presence of *C. rhodesianus* in these samples studied could be associated with the new incoming seeds from ICRISAT-Nairobi or from across the boarders.

The highest mean number of adult emergence and percentage damage to pigeonpea seeds in the ash treatment indicates that its potential for bruchid control is low. On the other hand the performance of cypermethrin and tobacco against bruchids, strongly suggests that they are more superior against bruchids under field situation than the other treatments evaluated. Silim-Nahdy (1995), used cypermethrin against *C. chinensis* in the field and found that it reduced population of the pest and damage to stored pigeonpea seeds. He found that after one month of storage of pigeonpea seeds from sprayed fields, a mean of three adult *C. chinensis* emerged compared to 19.7 adults in the unsprayed fields. Then after two months, 68.8 adults compared to 633 adults emerged respectively.

Damage levels after one month was more than six times in unsprayed fields (0.18% compared to 1.23%) and 5.08% compared to 29.25 after two months of storage. In this study, however, the adult numbers in the unsprayed plots were at least more than four times higher than in the sprayed plots. Percentage damage levels were at least two times more in the seeds from unsprayed than those from the sprayed plots after 2 months of storage.

Across the three rain seasons evaluated, there were lower *C. chinensis* adult emergence and percentage seed damage in the first rains of 1998 than in the other two subsequent rains. This would be explained by the dry spell that was experienced in the first rains of 1998 (Appendix.5.), which could have provided very harsh conditions for the survival and population build up of the pest. Secondly, the higher rainfall in the latter two seasons could have provided relatively warmer conditions, which may have encouraged population build up of the pest in the field rather than the hot and dry conditions. It would also be expected that because of the dry spell there was less dry matter in the seeds due to poor pod filling compared to higher dry matter in the wetter seasons which the pest could have taken advantage of.

Damage caused by pod borers showed significant difference among treatments. This implies that these treatments have the potential of controlling pod borers on pigeonpea. The result also confirms work carried out by Sadawarte and Sarode (1997), that the pod borer complex of pigeonpea of which *H. armigera* is predominant, can be managed using a combination of botanical products of plant or animal origin; together with use of appropriate synthetic insecticide.

The reasons why there was no significant difference among seasonal seed damage by pod borers, may be due to the effectiveness of the botanical products and synthetic insecticide treatments in controlling the pest irrespective of the season. Although there were seasonal differences in pod borer population build up it can be concluded that this application of botanical products and synthetic insecticide in all the seasons was able to manage the pest activity of the borers on the pigeonpea crop.

Damage by Clavigralla sp. showed significant differences among treatment means, which confirms the effectiveness of botanical products in controlling the pest. Cypermethrin and tobacco treatments were more superior in controlling pod bugs than the rest of the treatments. The results from the control where the highest damage was recorded indicates that the crop needs some form of chemical pest control strategy in order to reduce yield loss due to insect pests.

Damage in the first rains of 1999 was the highest while that in the first rains of 1998 was the lowest. This could be attributed to warmer conditions in the former rather than the harsh conditions in the latter. Alternatively, since there was higher rainfall in the first rains of 1999, this could have had the effect of washing away the chemicals from the plants making them less effective.

Pod fly damage was also significantly different with the different treatments. This again confirms the effectiveness of the treatments applied in controlling the pod fly pest. The pod fly being one of the pigeonpea pod borer complex can be controlled by using a combination of biorational products (Sadawarte and Sarode, 1997). The lower damage level in the first rains of 1998 compared to the other two rains could be due to unfavourable conditions of the dry spell, which characterised that season.

CHAPTER FIVE

GENERAL DISCUSSION AND CONCLUSIONS

The importance of pigeonpea as human and livestock food cannot be overemphasised. Its production in the recent past clearly indicates its potential in Ugandan Agriculture, (Table 1). Among the production constraints in pigeonpea, insect pest damage takes the lead (Reed and Lateef, 1990; Silim-Nahdy, 1995). Pod and seed damage starts in the field due to pod borers, pod sucking bugs, pod fly and bruchids. Bruchid infestation of pigeonpea is linked to damage by pod pests and so it is worth making a study on these pests in relation to one another. Bruchids are the most important pests on pigeonpea in storage (Silim-Nahdy, 1995).

Different control strategies that have been suggested for bruchids are concentrated in the storage and ignoring field management options. In addition, modern control measures seem to rely on synthetic chemical application. But chemicals applied in food grains in storage have the danger of health hazards to humans and pollution to the environment due to residues. They are also expensive to the resource poor farmers who are the majority in the case of pigeonpea. As a result such farmers have always explored and used products of plant origin to combat insect pest attack and damage on their crops.

The objectives of this study were to; investigate some cultural practices in the management of pigeonpea bruchids and other major pigeonpea pests in the field condition, establish the bruchid pest load on pigeonpea seed carried from the field to the store and identify some botanical products that could be used as insecticides against bruchids and other major pests of pigeonpea in the field.

Trap catches of *C. chinensis* and pod fly showed the highest population at 5 and 6 weeks after anthesis and there after a decline. This indicated that the presence of these pests depended on the growth stages of the crop. At this time the pods are fully formed and seeds are matured thus may have a greater potential to attract more pests. Perhaps the transition of flight (active) to flightless (sedentary) forms takes place at this stage, thus not many are trapped. This transition stages have been reported by Silim-Nahdy, (1995).

Population density of flower beetles (*Mylabris* sp.) was significantly affected by intercropping. The pigeonpea intercropped with finger millet had significantly lower beetle infestations than either pigeonpea intercropped with cowpea or sole pigeonpea. It is possible that the millet crop acted as a trap crop which reduced beetle population thus making pigeonpea attract less number of flower beetles. The seasonal variation showed higher beetle infestations in the wetter and short rains. It is possible that the low relative humidity and the high temperatures characteristic of this weather did not favour the population build up of the pest.

The significantly low infestation of thrips on pigeonpea intercropped with cowpea could be due to the difference in micro-climate. The pigeonpea/cowpea mixture may have created higher relative humidity compared to sole crop pigeopea. High RH (>80%) has been shown to reduce thrips population on cowpea in cowpea/maize intercrops (Kyamanywa, 1988). Apart from modification of the micro climate, cowpea flowers could have attracted more thrips since it flowered first. In this case cowpea may be a trap crop to divert thrips from pigeonpea. Cowpea has been shown to be one of the main hosts to flower thrips (Nampala, 1998).

Aphid infestation was observed as late as 7 weeks after plant emergence and peak infestation was at 3 and 4 weeks after flower initiation. This indicated that the pests were more attracted to the flowers, buds and pods more than perhaps the leaves at the vegetative stage of the crop. As the infestation increased with crop maturity and reduced rainfall in the seasons, it could be due to response to dry weather conditions. Aphid population build up has been reported to be favoured by drier conditions (Ogenga-Latigo, 1988). Higher rains could have had the effect of washing away the aphids from the plants therefore reducing their potentials of establishment on the plants (Lateef and Reed, 1990).

Infestation of pigeonpea by pod borers in the different cropping systems revealed that intercrops with short duration pigeonpea had lower borer larvae infestations compared to the medium duration types (Table 7). Low pod borer infestations in short duration than medium duration pigeonpea has been reported by Night (1993). Pigeonpea in millet intercrops showed consistently lower pod borer infestation than the other treatments. This may partly explain the popularity of pigeonpea mixture with millet ir

growing areas in Uganda since pod borers are

(Silim-Nahdy, 1995; Lateef and Reed, 1990). Seaso

borer infestation in that there were higher pod bo

rains. This trend was also reported by Night (19

species on pigeonpea, *H. armigera* was the most

have been recorded in India (Bhosale and Nawe

1986; Kabaria *et al*., 1988) and in Uganda (Silim-Nah

Pod bug population dynamics indicated that sole c

vulnerable to pod bug attack than pigeonpea int

cowpea. This showed that the crop mixtures mo

probably due to the greater canopy cover which di

population build up. Such results were also reco

(1978),in India. Among the different species of

Clavigralla sp. was the most abundant.

Pigeonpea seed damage by pod sucking bug

significantly influenced by cropping systems. But da

significantly influenced by cropping systems. Grai

were higher in the present study, (with a range

obtained by Night (1993),with a range of 0.3-3.0%. T

borer pest problem in Uganda is on the increase

due to the increase in production of pigeonpea in

these damage levels are still lower than those in Ind

21.5-47.1% pod damage (Reed and Lateef, 1990). This may be so because pigeonpea is more widely grown in India compared to Uganda.

Seed damage by pod bugs were much higher than that by pod borers or pod fly. It was assumed that shrivelled seeds were due to pod bug damage. But seed shrivelling may also be caused by fungal infection and drought Troedson *et al.*, (1990). These two phenomena were actually observed, with drought taking a lead compared to a few fungal infection that were thought to be negligible. But even in the no drought seasons, pod bug damage was still highest, thus confirming that pod sucking bugs cause the greatest damage compared to pod borer or pod fly damage.

Pod fly damage to pigeonpea seeds was relatively low compared to the damage by pod borers or podbugs. This indicates that the damage by the other two pests are still more important than that of the pod fly, though it cannot be overlooked. This pod fly damage level (0.9-2.2%) is much lower than that in India, for example, 0.9%-37.2% with an average of 9.8% by pod fly in Bharuch, India (Kabaria *et al*,1988).

Time of harvest significantly affected damage of pigeonpea by both *C. chinensis* and *T. castaneum.* At harvest, the highest seed damage by *T. castaneum* ranged from 1.73%-2.00% and the lowest from 0.86%-1.28% while for *C. chinensis*, the highest ranged from 1.85%-2.05% and the lowest from 0.95%-1.31%. The highest *C. chinensis* adult emergence and percentage seed damage were from seeds harvested last and the lowest from seeds harvested first. Delayed harvesting could have exposed the seeds to greater infestation pressure due to either pest multiplication or due to split pods that provided bruchids easier access to seeds.

Earlier work by Davies (1960), indicated that *Callosobrucuus maculatus* infested pigeonpea in the field. Silim-Nahdy (1995), showed that *C. chinensis* was the bruchid species on pigeonpea in the field in Uganda. In this study, however, *C. chinensis* and *C. rhodesianus* were found infesting pigeopea from the field. But *C. rhodesianus* was not observed in the traps, perhaps because it is not a very active flier compared to *C. chinensis* as observed, or because its infestation was relatively low.

From the different botanicals tested against bruchid on pigeonpea in the field, tobacco showed high potential for control. This was followed by extracts of tephrosia and melia seed extract. Tephrosia has been shown to have insecticidal properties (Gaskins *et al.,* 1972; Hasanali and Lwande, 1989). Okech *et al.*, (1997) reported the use of tephrosia extracts by Zambian farmers in fishing and for controlling stalk borers for many years. The effectiveness of tephrosia and tobacco in this study confirms results from studies done on these botanicals in storage (Silim-Nahdy, 1995), that they can be used against pigeonpea bruchids. Therefore these botanicals can be used to reduce *C. chinensis* field infestations.

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Appendix 1

Analysis of variance (ANOVA) for trapping of bruchids and pod fly in 1998a, 1998b and 1999a

C. chinensis (1998a)

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	0.417	0.139	0.3957	
Trap method	1	4.083	4.083	11.6331	0.0017
Time of trapping	5	0.917	0.183	0.5223	
Interaction	5	0.917	0.183	0.5223	
Error	33	11.583	0.351		
Total	47	17.917			

Melanagromyza spp. (1998a)

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	0.729	0.243	0.5007	
Trap method	1	0.021	0.021	0.0429	
Time of trapping	5	9.354	0.271	3.8536	
Interaction	5	1.354	0.485	0.5579	0.0074
Error	33	16.021			
Total	47	27.479			

C. chinensis (1998b)

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	0.063	0.021	0.0748	
Trap method	1	2.521	2.521	9.0544	0.0050
Time of trapping	5	4.104	0.821	2.9483	0.0262
Interaction	5	0.604	0.121	0.4340	
Error	33	9.187	0.278		
Total	47	16.479			

Melanagromyza spp. (1998b)

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	1.500	0.500	2.3571	0.0896
Trap method	1	0.083	0.083	0.3929	
Time of trapping	5	18.167	3.633	17.1286	0.0000
Interaction	5	0.917	0.183	0.8643	
Error	33	7.000	0.212		
Total	47	27.667			

C. chinensis (1999a)

Source	d.f	S.S	M.Sq.	F value	Probability
Replication	3	0.396	0.132	0.5544	
Trap method	1	2.521	2.521	10.5915	0.0026
Time of trapping	5	4.186	0.838	3.5188	0.0117
Interaction	5	1.854	0.371	1.5581	0.1992
Error	33	7.854	0.238		
Total	47	16.813			

Melanagromyza spp. (1999a)

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	1.896	0.632	2.0141	0.1310
Trap method	1	0.188	0.188	0.5976	
Time of trapping	5	6.104	1.221	3.8909	0.0070
Interaction	5	1.438	0.288	0.9163	
Error	33	10.354	0.314		
Total	47	19.979			

Appendix 2

Analysis of variance (ANOVA) for interaction of time of planting and spacing on Pigeonpea seed damage by pod borers, bugs and fly in 1998b and 1999a

Pod borer

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	1.534	0.511	0.3179	
TOP (A)	2	59.317	29.659	18.4332	0.0027
Error	6	9.654	1.609		
Spacing (B)	2	5.744	2.872	3.2509	0.0623
Interaction (AxB)	4	1.701	0.425	0.4814	
Error	18	15.902	0.883		
Total	35	93.852			

Pod bug

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	8.034	2.678	1.5555	0.2948
TOP (A)	2	78.326	39.163	22.7464	0.0016
Error	6	10.330	1.722		
Spacing (B)	2	2.640	1.320	1.0316	0.3766
Interaction (AxB)	4	6.469	1.617	1.2638	0.3205
Error	18	23.033	1.280		
Total	35	128.833			

Pod fly

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	0.823	0.274	0.5288	
TOP (A)	2	5.012	2.506	4.8301	0.0562
Error	6	3.113	0.519		
Spacing (B)	2	0.007	0.003	0.0090	
Interaction (AxB)	4	0.442	0.110	0.2997	
Error	18	6.632	0.368		
Total	35	16.027			

Appendix 3a

Analysis of variance (ANOVA) for *C. chinensis* adult emergence and pigeonpea seed damage at different time of planting and spacing in 1998b after 1 month of seed storage

Adults

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	209.194	69.731	0.9782	
TOP (A)	2	6941.167	3470.583	48.6846	0.0002
Error	6	427.722	71.287		
Spacing (B)	2	815.167	407.583	40.2367	0.0000
Interaction (AxB)	4	429.167	107.292	10.5919	0.0001
Error	18	182.333	10.130		
Total	35	9004.750			

Males

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	18.000	6.000	0.5012	
TOP (A)	2	1237.056	618.528	51.6636	0.0002
Error	6	71.833	11.972		
Spacing (B)	2	143.722	71.861	16.3389	0.0001
Interaction (AxB)	4	95.111	23.778	5.4063	0.0049
Error	18	79.167	4.398		
Total	35	1644.889			

Females

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	145.194	48.398	2.0065	0.2146
TOP (A)	2	2377.722	1188.861	49.2887	0.0002
Error	6	144.722	24.120		
Spacing (B)	2	277.389	138.694	37.0767	0.0000
Interaction (AxB)	4	191.278	47.819	12.7834	0.0000
Error	18	67.333	3.741		
Total	35	3203.639			

Damage

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	1.468	0.489	1.3750	0.3376
TOP (A)	2	18.060	9.030	25.3800	0.0012
Error	6	2.135	0.356		
Spacing (B)	2	1.887	0.944	5.7172	0.0120
Interaction (AxB)	4	0.161	0.040	0.2445	
Error	18	2.971	0.165		
Total	35	26.682			

Appendix 3b

Analysis of variance (ANOVA) for *C. chinensis* adult emergence and pigeonpea seed damage at different time of planting and spacing in 1998b after 2 months of seed storage

Adults

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	98.750	32.917	0.3989	
TOP (A)	2	47451.056	23725.528	287.4854	0.0000
Error	6	495.167	82.528		
Spacing (B)	2	3411.722	1705.861	21.8415	0.0000
Interaction (AxB)	4	623.111	155.778	1.9945	0.1386
Error	18	1405.833	78.102		
Total	35	53485.639			

Males

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	94.306	31.435	1.7260	
TOP (A)	2	7040.056	3520.028	193.2705	0.0000
Error	6	109.278	18.213		
Spacing (B)	2	640.389	320.194	22.4552	0.0002
Interaction (AxB)	4	181.611	45.403	3.1841	0.0308
Error	18	256.667	14.259		
Total	35	8322.306			

Females

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	5.889	1.963	0.0303	
TOP (A)	2	18374.056	9187.028	141.8440	0.0000
Error	6	388.611	64.769		
Spacing (B)	2	1112.056	556.028	14.1363	0.0002
Interaction (AxB)	4	534.611	133.653	3.3980	0.0308
Error	18	708.000	39.333		
Total	35	21123.222			

Damage

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	0.088	0.029	0.1011	
TOP (A)	2	52.839	26.419	91.2227	0.0000
Error	6	1.738	0.290		
Spacing (B)	2	12.693	6.347	7.7976	0.0036
Interaction (AxB)	4	3.089	0.772	0.9489	
Error	18	14.650	0.814		
Total	35	85.212			

Appendix 4a

Analysis of variance (ANOVA) for *C. chinensis* adult emergence and pigeonpea seed damage at different time of planting and spacing in 1999a after 1 month of seed storage

Adults

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	13.667	4.556	1.4261	0.3247
TOP (A)	2	1195.056	597.528	187.0522	0.0000
Error	6	19.167	3.194		
Spacing (B)	2	22.722	11.361	1.3137	0.2934
Interaction (AxB)	4	7.611	1.903	0.2200	
Error	18	155.667	8.648		
Total	35	1413.889			

Males

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	3.639	1.213	1.4719	0.3137
TOP (A)	2	320.389	160.194	194.3933	0.0000
Error	6	4.944	0.824		
Spacing (B)	2	5.722	2.861	0.7446	
Interaction (AxB)	4	8.444	2.111	0.5494	
Error	18	69.167	3.843		
Total	35	412.306			

Females

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	5.111	1.704	1.1720	0.3956
TOP (A)	2	280.389	140.194	96.4395	0.0000
Error	6	8.722	1.454		
Spacing (B)	2	5.056	2.528	0.7822	
Interaction (AxB)	4	1.444	0.361	0.1117	
Error	18	58.167	3.231		
Total	35	358.889			

Damage

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	0.196	0.065	1.1619	0.3988
TOP (A)	2	17.038	8.519	151.6515	0.0000
Error	6	0.337	0.056		
Spacing (B)	2	0.457	0.228	1.6509	0.2196
Interaction (AxB)	4	0.182	0.045	0.3285	
Error	18	2.491	0.138		
Total	35	20.701			

Appendix 4b

Analysis of variance (ANOVA) for *C. chinensis* adult emergence and pigeonpea seed damage at different time of planting and spacing in 1999a after 2 months of seed storage

Adutls

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	18.778	6.259	0.4832	
TOP (A)	2	7696.722	3848.361	297.0858	0.0000
Error	6	77.722	12.954		
Spacing (B)	2	132.389	66.194	2.5902	0.1026
Interaction (AxB)	4	40.278	10.069	0.3940	
Error	18	460.000	25.556		
Total	35	8425.889			

Males

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	10.444	3.481	0.7769	
TOP (A)	2	1778.000	889.000	198.3719	0.0000
Error	6	26.889	4.481		
Spacing (B)	2	41.167	20.583	2.4591	0.1137
Interaction (AxB)	4	30.833	7.708	0.9209	
Error	18	150.667	8.370		
Total	35	2038.000			

Females

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	260.778	86.926	0.8925	
TOP (A)	2	1396.500	698.250	7.1690	0.0257
Error	6	584.389	97.398		
Spacing (B)	2	499.500	249.750	2.1152	0.1496
Interaction (AxB)	4	384.500	96.125	0.8141	
Error	18	2125.333	118.074		
Total	35	5251.000			

Damage

Source	d.f	S.S	M. Sq.	F value	Probability
Replication	3	0.113	0.038	0.3579	
TOP (A)	2	31.448	15.724	149.2737	0.0000
Error	6	0.632	0.105		
Spacing (B)	2	1.861	0.930	7.1673	0.0051
Interaction (AxB)	4	2.077	0.519	4.0002	0.0171
Error	18	2.337	0.130		
Total	35	38.468			

Appendix 5 Weather data for KARI in 1998a, 1998b and 1999a

1998	Rainfall (mm)				Temperature (°C)			
Month	Total	Highest Fall	No. of days	Av.	Mean Max.	Highest Max. .	Mean Min.	Lowest Min
Mar.	108.6	59.9	16	5.8	29.7	33.0	17.5	15.0
Apr.	197.2	53.3	13	6.6	29.4	32.1	17.2	14.5
May	177.8	54.4	10	5.7	28.6	30.8	16.5	14.5
Jun.	25.4	16.0	4	0.8	28.2	31.0	15.8	14.0
Jul.	8.6	2.2	5	0.3	28.1	29.8	15.4	14.0
Aug.	89.7	26.4	9	2.9	26.4	30.0	14.8	14.5
Sep.	126.4	48.9	13	4.2	28.0	31.0	15.3	14.5
Oct.	137.0	43.4	13	4.4	26.4	32.0	15.7	14.0
Nov.	61.3	28.6	8	2.0	28.6	32.2	16.6	14.5
Dec.	67	19.1	8	2.2	30.0	33.0	16.1	15.0
1999								
Jan	86.3	46.6	4	2.8	29.4	34.0	15.4	13.0
Feb	5.3	2.5	3	0.2	31.2	36.0	17.3	13.5
Mar	188.2	43.3	13	6.1	26.4	31.0	16.0	14.0
Apr	71.0	14.1	16	2.3	28.0	30.5	16.1	14.5
May	142.1	35.0	16	4.6	27.7	31.0	16.4	14.0
Jun	68.7	24.3	10	2.3	26.6	30.8	16.4	13.0
Jul	116.6	67.0	9	3.3	26.7	30.2	15.4	12.5
Aug	195.9	47.5	11	6.3	26.4	29.8	15.8	13.5