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Biotic and abiotic factors influencing the biology and distribution of common storage pests of pigeonpea

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ABSTRACT

Surveys in northern Uganda showed that the bruchid *Callosobruchus chinensis* L. was the most serious and predominant storage pest of pigeonpea (*Cajanus cajan* (L.) Millsp.), infesting both pods in the field and stored seeds. Because of the high damage the bruchid causes, farmers practice a number of cultural management techniques with varying degrees of success.

In the field, various factors affected *C. chinensis* infestation, including infestation by *Helicoverpa armigera* (Hüb.), pod splitting, and pod developmental stage, pod surface hair density, and pod wall thickness. Two polymorphic forms of *C. chinensis* were identified, the flight and flightless forms, which are adaptively suited for survival and for successful propagation under field and storage conditions, respectively. The predominance of emerged adults of the flightless forms in dry seed and the flight forms in green pods were triggered by low moisture content in seed and high moisture content in green pods, respectively.

To reduce the transfer of *C. chinensis* infestation to storage, field application of cypermethrin (0.5% at 1 l/ha) and pod (cf. seed) storage were found effective. In storage, the physical methods found effective were hermetic storage of seed in the traditional mud-straw silo "tua", solar disinfestation and seed splitting. Plant and plant products found to be effective in reducing damage in storage were admixture with *Tephrosia vogelli* Pers. fire-cured tobacco (*Nicotiana tabacum* L.), wood ash, *Tagetes* sp. and *Eichhornia crassipes* Solms.

Resistance screening was conducted on 262 pigeonpea genotypes against *C. chinensis* infestation both on pods (immature and mature) and in stored seed. Significant negative correlations were found between pod surface hair density and pod wall thickness on the one hand and field resistance, in terms of both resistance to oviposition and to adult emergence. In the seeds, significant negative correlations were found between seed coat thickness and infestation. Sixteen pigeonpea genotypes were identified with high resistance to *C. chinensis* in both field and store; two of these showed exceptional resistance to damage in store.

A provisional IPM strategy for reducing pigeonpea seed damage is presented.

CONTENTS

CHAPTER 1. INTRODUCTION

1.1. The pigeonpea

About 30 leguminous species are cultivated by man as a source of food, vegetable oils, green manure and fodder (Southgate, 1978). The world production estimate in 1990 for the major grain legume crops was about 133,940,000t produced from about 181,611,000 ha (FAO, 1990).

Among the grain legumes, the pigeonpea (*Cajanus cajan* (L.) Millsp.) ranks seventh in world production (Table 1). It 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 to pigeonpea and S. E. Asia, E. Africa and Central America account for most of the rest (van der Maesen, 1990). It is the second most important grain legume after beans (*Phaseolus vulgaris* L.) in East Africa where approximately 133,000t are produced from over 249,000ha (Nene *et al.*, 1990). It is mostly intercropped, particularly with cereals (Nene and Sheila, 1990). Production in Uganda is estimated at 22,000t from 63,000ha mostly in the relatively drier northern area and all of it produced from small-holder farms (Nalyango and Emeetai-Areke, 1987).

Pigeonpea is thought to have originated from India where several of its wild relatives are found and where considerable genetic diversity occurs (van der Maesen, 1990). Some authors, however, consider E. Africa, where pigeonpea seems to occur wild, as the centre of origin (Purseglove, 1968; Rachie and Roberts, 1974).

Table 1. World production data for grain legumes

Legume	Area (million ha)	Production (million t)	Yield (kg/ha)
Soyabeans	57.8	114.0	2,058
Peanuts (unshelled)	20.5	23.5	1,141
Drybeans	24.4	16.1	673
Dry peas	8.9	15.9	1,793
Chickpea	9.9	6.9	671
Broad beans	3.7	4.1	1,373
Lentils	3.4	2.4	805
Pigeonpea	3.4	2.4	684
Cowpea	3.1	1.1	400

(after Morton, 1976; FAO, 1987; 1993: Nene *et al.*, 1990)

Pigeonpea is endowed with several unique characteristics. Apart from its food value, it has an important role in the farming systems adopted by the small-holder farmers in a large number of developing countries. It also adds humus and, through symbiosis with Rhizobia, fixes additional nitrogen to the soil, while its deep and wide root penetration improves the soil structure (Nene and Sheila, 1990).

The main use of pigeonpea is for human food. In the Indian sub-continent dry seeds are dehulled and split to make "dahl", a popular Indian dish. In Africa and Central America whole seeds with or without the testa are more popular. Often, sprouted seeds are consumed or the seeds split or ground to flour and used for soups (Nene and Sheila, 1990). They are also planted as backyard or kitchen crops for their tender green pods which are

popular vegetables. Even the cast off pods and husks are useful cattle feed, as are the green leaves. The plant is also an important source of biofuel (Nene *et al.*, 1990). Pigeonpea also has many medicinal attributes (Morton, 1976).

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 (Appendix I).

1.1.1. Taxonomy

Pigeonpea belongs to the genus *Cajanus* of the Cajaninae sub-tribe and the tribe Phaseoleae which contains the many bean species consumed by man. Cajaninae are well distinguished by the presence of vesicular glands on the leaves, calyx and pods (van der Maesen, 1990). There are eleven genera within the sub-tribe and the pigeonpea, *C.cajan*, is the only cultivated food crop of the sub-tribe (van der Maesen, 1990).

1.1.2. Days to flowering and maturity duration

Maturity duration in pigeonpea is a very important factor that determines the adaptation of varieties to various agro-climatic areas and cropping systems (Sharma *et al.*, 1981). A broad maturity classification based on three maturity categories has been in vogue for a long time in India, i.e.

i) early-maturity, genotypes which mature in less than 150 days

ii) medium-maturity, genotypes which mature between 151-180 days, and

iii) late-maturity, genotypes which mature beyond 180 days.

Pigeonpea breeders based at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) have developed a maturity duration scale consisting of 10 classes based on days to 50% flowering (Appendix II). Studies of the world germplasm collection

at ICRISAT Centre, India, found that the number of days to 50% flowering ranged from 55 to 210 days, and the maturity duration from 97 to 260 days (Remanandan *et al.*, 1988). On the basis of this scale, a large number of accessions from the world germplasm collection fell in to maturity groups VIII, VII and VI or late- and medium-maturity groups. In Uganda, medium- and late-maturing landraces are grown, the former predominantly grown in Lango and the latter grown predominantly in Acholi (Jameson, 1970).

1.1.3. Production constraints

Various constraints are encountered in pigeonpea production and post-production systems. The nature and magnitude of these constraints differ among the various production areas. The most consistent constraints, however, are poor seed quality at sowing, lack of genetic improvement, poor agronomic management practices, field diseases and the high pest incidence (Nene *et al.*, 1990). Pigeonpea is one of the grain legumes with the greatest range and incidence of pests both in the field and storage, with more than 200 insect species in India alone (Singh and van Emden, 1979; Lateef and Reed, 1990). Only a few species, however, cause economic damage and are common over large areas (Appendix III). These species are mostly those that feed on flowers, pods and seeds (Lateef and Reed, 1990).

Pigeonpea seeds are attacked by several insect pests both in the field and during subsequent storage. The commonest and most damaging insect pests in storage belong to the order Coleoptera and family Bruchidae (Singh and Jambunathan, 1990).

1.2. Bruchidae

Bruchidae comprise nearly 1,300 species grouped into 56 genera of which three tribes constitute genera of economic importance (Southgate, 1979). Some 20 species belonging to six genera attack grain legumes grown, stored and eaten by man (Southgate, 1979).

Almost all the economically-important bruchids were originally limited to the Old World. Due to international trade, however, their distribution is now world-wide (Appendix IV). Among the bruchids, the most widely distributed are the bean bruchids *Acanthoscelides obtectus* Say and *Zabrotes subfasciatus* Boh. which are of American origin, the southern cowpea weevil *Callosobruchus maculatus* F. which is of African origin, and the adzuki bean weevil *Callosobruchus chinensis* L. which is of Asian origin (Southgate, 1978). They have established footholds in America, Australia, Africa, India, Pacific Islands and parts of the Mediterranean (Southgate, 1978). *Callosobruchus phaseoli* Gyll. and *Callosobruchus rhodesianus* Pic. are mostly confined to Asia and Africa, respectively. *Callosobruchus analis* F., which is Asian in origin, has now reached Tanzania (Mphuru, 1978). The genus of Bruchidae which contains the greatest number of pest species is *Callosobruchus*, and it is also the genus with species found closely associated with pigeonpea and many other economically-important grain legumes of the tropics (Lateef and Reed, 1990; Singh and Jambunathan 1990; Mphuru, 1978).

1.2.1. Biology

The bruchids generally have similar biology. The larva is apodous and eucephalous, moults four times and pupates inside a single seed. 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. Occasionally pupation occurs in a cell not adjacent to the testa and the adult fails to emerge from the seed and dies.

The adults are sexually mature and are ready to mate on emergence. Adults are short-lived

and do not feed under storage conditions, but under field conditions they feed on nectar and fungi (Larsen and Fisher, 1938; Yoshida, 1990). The adults are active fliers and disperse through both seed movement and flight, the latter method being significant in pre-harvest infestations (Alzouma, 1981; Taylor, 1981; Yoshida, 1990).

The adults often begin infestation in the field by ovipositing on mature pods and this intensifies in stored seeds (Booker, 1967; Taylor, 1981; Yoshida, 1990). In *Callosobruchus*, during oviposition the eggs are glued to the pods or seed testa. The adhesion effect in *C. chinensis* results from a fluid secreted from the ovipositor immediately prior to oviposition (Arora and Singh, 1971). At hatching the first instar larva burrows directly into the seed cotyledons.

Extensive observations on rates of development and reproduction of several species of *Callosobruchus*, particularly *C. maculatus*, *C. chinensis*, and *C. rhodesianus*, have been made (Larsen and Simmonds, 1923; El-Sawaf, 1956; Caswell, 1959; Howe and Currie, 1964; Booker, 1967; Giga and Smith, 1983). Howe and Currie (1964) investigated the range of temperatures required for development of *Callosobruchus* species and found that the optimum temperature for development was between 30 and 32.5°C while the shortest mean developmental time was 23-27 days depending on the insect species (Table 2).

Table 2. Temperature range for Callosobruchus *development**

Species	Shortest mean development period (days)	Temperature (°C)		
		Minimum for development	Optimum	Maximum for development
C. maculatus	23.0	17.5-20.0	32.5	35.0-37.5
C. chinensis	22.5	17.5	32.5	35.0-37.5
C. analis	27.0	17.5-20.0	32.5	35.5-37.5
C. rhodesianus	25.0	16.0	30.0	35.0

(after Howe and Currie, 1964)

*Host plants for the estimates did not include pigeonpea.

Observations on the morphology, physiology and biology of adult *Callosobruchus* spp. especially *C. maculatus*, have shown that two different morphic forms occur which are adaptively suited to either field or storage conditions (Southgate, 1979; Messina, 1990). These morphic forms have been called either the active or flight forms and the inactive- or non-flight forms, respectively.

1.2.2. Host plant relationship

Bruchids in general are closely linked to leguminous host plants and this relationship exhibits a more or less strict oligophagy which is considered unique among host plants (Applebaum, 1964). The relationship between species of the genus *Callosobruchus* and the legumes grown by man (Table 3) shows that pigeonpea and cowpea seeds can be infested by various species of *Callosobruchus*, and that considerable cross infestation occurs among legume species (Mphuru, 1978; Southgate, 1978). *C. maculatus* and *C. chinensis* stand out as the most unselective, infesting a total of eight different legume species. Among the host plants, cowpea (*Vigna unguiculata* L.) has the widest range of

bruchid pests (Southgate, 1978) followed by pigeonpea (Mphuru, 1978), mung bean (*Vigna radiata* L.), and chickpea (*Cicer arietinum* L.) (Southgate, 1978).

Various species of *Callosobruchus*, either occurring together or singly, are commonly reported to infest pigeonpea. In India *C. maculatus* and *C. chinensis* were generally reported to be the commonest species on pigeonpea, followed by *C. analis* (Babu *et al.*, 1989; Singh and Jambunathan, 1990; Bhaduri *et al.*, 1990; Khaire *et al.*, 1992). In Hawaii (Bridwell, 1918) and E. Africa (Davies, 1960; Le Pelley, 1959; Mphuru, 1978) both *C. chinensis* and *C. maculatus* were reported on pigeonpea, but in addition *C. rhodesianus* and *C. analis* were reported on pigeonpea in Tanzania (Mphuru, 1978). In Uganda the last record indicated only *C. maculatus* and *C. chinensis* as pests of stored pigeonpea (Davies, 1960).

In all of the literature cited above, no quantitative data were provided on spatial distribution, level of abundance and infestation by any individual species populations, levels and incidence of occurrence, and whether their occurrence was in association with each other and other compatible host plants or not. From the available information therefore, neither the relative preferences of the different species of storage pests on pigeonpea nor the relative pest status is known.

The factors which determine the plant preferences of bruchid species are difficult to define (Southgate, 1979). Research on the relationship between some bruchids and their legume hosts has, however, shown that pods and seeds of legumes attract particular bruchids greatly and stimulate egg production (Labeyrie, 1978; Huingnard, 1976). Host preference in bruchids has been noted at two levels: host selection, which is mostly sensorial, and developmental compatibility with the preferred host (Dethier, 1982; Schoonhoven, 1978; Visser, 1986).

Table 3. Host plants associated with **Callosobruchus** *spp.*

Important host plants	Pest species			
	C. maculatus	*C. chinensis*	*C. analis*	*C. rhodesianus*
Vicia faba L.	x	x		
Cicer arietinum L.	xx	xx		
Lens culinaris Mill.	x	xx	x	
Vigna unguiculata L.	x	x	x	x
Pisum sativum L.	x	x	x	
Cajanus cajan (L.) Millsp.	xx	x	x	x

(after Avidov *et al.*, 1965; Mphuru, 1978; Southgate, 1978; Hariri, 1981; Birch *et al.*, 1985)

Key = xx, most frequent association, x, occasional association

Internally feeding granivorous insects such as bruchids have to make the correct and ideal choice on the resource base for the progeny (Frestwell and Lucas, 1970). The diverse legume host range for *Callosobruchus* spp. indicate parallel evolution with the legumes. Though the diversity of host range is an indication of general developmental compatibility within the true realised niche of individual groups, however, such generalisation may be misleading especially when resource states are not continuously arrayed or host range is limited (Wasserman 1986). In the case of *Callosobruchus*, Wasserman (1986) indicated that it appears that high oviposition preferences for certain hosts are fixed due to genetic architecture of preference characters. Studies on different strains of *C. maculatus* indicate that though it is presented as a generalised feeder upon several legumes, individual populations show great differences in breadth of the ovipositional niche (Wasserman, 1986). In terms of preference, the importance of pigeonpea as an ovipositional and developmental niche for any specific *Callosobruchus* species is not known.

1.2.3. Infestation and damage patterns

In many parts of the tropics, bruchid infestation starts in the field and (in most cases) continues in storage (Caswell, 1968; Southgate, 1978; Taylor, 1981; Lateef and Reed, 1990; Nene and Sheila, 1990). Field infestation is characterised by its insidious nature (Taylor, 1981); eggs are usually laid on maturing to drying pods and the young first instar larvae bore in the seed, such that at threshing seeds either show little or no apparent damage (Booker, 1967; Caswell, 1968; Southgate, 1978).

As with most bruchids, *Callosobruchus* infestation starts in the field (Southgate, 1978). Field infestation by both *C. maculatus* and *C. chinensis* has been observed on adzuki beans and green gram in Japan (Yamamoto, 1990; Yoshida, 1990). In Asia, field infestation has been reported on mung bean, lentils and cowpea (Raina, 1972; Hariri, 1981; Rajapakse, 1990). In Africa field infestation has been extensively reported on cowpea, in West Africa being due to *C. maculatus* and *Bruchidius atrolineatus* Pic (Booker, 1967; Caswell, 1968; Alazouma, 1981; Ouedraogo and Huingnard, 1981; Germain *et al.*, 1987) and in East Africa to *C. maculatus*, *C. chinensis* and *C. rhodesianus* (Olubayo, 1993).

Records of field infestation on pigeonpea are scanty and rather sketchy. Apart from Bridwell's (1918) observations on field infestation of pigeonpea by *C. chinensis* in Hawaii, no other definite information on such patterns of infestation is available.

Pre-harvest infestation often results in little damage. Field damage to seeds by *B. atrolineatus* and *C. maculatus* has been reported on cowpea in West Africa (Booker, 1967; Caswell, 1968, 1975; Alzouma, 1981; Ouedraogo and Huingnard, 1981; Taylor, 1981). In Burkina Faso, 26% of pods were observed with eggs already laid in the field and this was found to result in very low seed infestation during storage (Ouedraogo and Huingnard, 1981). In Niger, Germain *et al.* (1987) reported 80 - 85% and 10 - 15% of pods with eggs of *B. atrolineatus* and *C. maculatus*, respectively. Prevett (1961) and

Booker (1967), reported an average of 2% seed damage in Northern Nigeria due to *C. maculatus*, *B. atrolineatus* and *C. rhodesianus*. No records of field damage on pigeonpea are available. Though the exact infestation and damage in the field is generally low, such infestation nevertheless has serious implications. This is because the insect multiply very rapidly within a short time once transferred to the storage systems, with very high consequent damage (Taylor, 1981).

Seed infestation and damage in storage in tropical countries is very high (Booker, 1967; Taylor, 1981). Though the major origin of storage 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 (Caswell, 1959; Booker, 1967; Southgate, 1979; Alzouma, 1981; Dobie, 1981; Taylor, 1981). Most often an apparently undamaged sample of seeds at harvest becomes heavily infested only after 4-8 weeks of storage (Taylor, 1981).

Though none of the available estimates of the actual quantity of legume seeds lost due to bruchid attack have been obtained using acceptable and reliable loss assessment techniques (Anon, 1978; Harris and Lindbland, 1978), the existing estimates, variable as they are, indicate very high figures. Caswell (1959) observed that a 1% field infestation of seeds at harvest time resulted in 80% damage after only "a few months" of storage. An estimate made by Caswell (1973) based on samples collected in northern Nigerian markets, showed that about 5.5% of cowpea is lost to bruchids every year. Germain *et al.* (1987) observed a massive 90-95% damage on cowpea after only "a few months" of storage. In East Africa, weight loss of 30% has been reported for stored legumes in Kenya (De Lima, 1973), 40% on cowpea in Zambia, and 21% has been reported in grain

legumes in Uganda after 6 months of storage (Silim *et al.*, 1990).

If the above loss estimates are an indication of general losses in legumes, then by inference storage losses in pigeonpea would equally be high. It is, however, imperative that in order to take decisions on pest management options and determine the level of interventions as well as allocate limited resources to the development of appropriate control strategies, a reliable and acceptable loss assessment is required to determine the points, levels and exact causes of losses (Harris and Lindbland, 1978).

1.2.4. Pest management

The storage of grain legumes over long periods is usually difficult in many tropical countries because of their great susceptibility to bruchid damage (Jakai and Daoust, 1986). To avoid excessive losses, some farmers opt to sell most of their grains soon after harvest when prices are lowest (Silim *et al.*, 1990). Various pest management methods are available. These are, however, all targeted at "in storage" seed treatment, and offering no "in field" intervention options which could break the field to storage infestation. Field chemical applications, though not targeted at bruchids, may sometimes reduce their numbers, especially when applied during late podding stages (Southgate, 1978). Cultural practices observed or recommended for reducing field infestation mostly refer to harvest time and inter-cropping patterns (Paddock and Reinhard 1919; Labeyrie and Maison 1957; Prevett, 1961; Caswell, 1968).

In storage, many pest management methods have been reported with varying levels of use and degrees of success. In the relatively rich temperate countries where seeds can be stored and transported in sealed containers, fumigation and/or use of expensive chemicals with low vertebrate toxicity provides satisfactory control of bruchid species (Credland, 1992). However, in the tropics where these bruchids originate and where resources are

very limited these control options are not feasible (Kitch *et al.*, 1992). Moreover, most of the stored grain legume seeds are for continuous consumption, and so the use of hazardous insecticides may not be acceptable to some consumers due to their toxic residues (Khaire *et al.*, 1992).

In addition, many strains of insect pests are resistant to a broad range of insecticides. So far 447 strains of insect and mite species, including stored grain pests, have been recorded as being resistant to one or more classes of insecticides (Georghiou, 1986; Giga and Mazarura, 1990). The most widely-used storage insecticide is pirimiphos methyl "Actellic" (Giga and Biscoe, 1990; Rajapakse, 1990; Silim *et al.*, 1990). Malathion dust formulations are also often used (Giga and Biscoe, 1990; Silim *et al.*, 1990), although some insect biotypes have developed resistance to it (Giga and Mazarura, 1990).

a. Physical methods

Various storage systems for legumes are found in tropical countries. These are designed to meet specific needs and/or perform specific functions. Frequently pest management forms the basis of the storage systems adapted. These may be in terms of the mode of storage, how stored, and where stored.

Pod storage of cowpea has been reported in various countries (Caswell, 1968; Booker, 1967; Silim *et al.*, 1990) and this mode of storage has been shown to reduce the rate of *C. maculatus* damage (Caswell, 1975). Van Huis (1991) observed that in traditional granaries where cowpea was stored on the pod, bruchid damage was reduced by 50%. Similarly, Caswell (1975) found that pest build up in cowpea stored on the pod was very slow. He postulated that in the pod some first instar larvae failed to locate a seed and others may find the pod wall too thick or too tough to penetrate.

Traditional hermetic or sealed storage systems have also been found to reduce damage

(Caswell, 1974; 1975; Van Huis, 1991). In a sealed container filled completely with cowpea, it was found that the oxygen concentration soon dropped to levels lethal to *C. maculatus* (Caswell, 1974).

Bruchid management using high temperatures from solar radiation has also been reported (Zehrer, 1980; Silim *et al.*, 1990). Other useful physical methods include the use of inert dusts such as bentonite (Maceljski *et al.*, 1970), lime on *C. chinensis* (El-Halfawy, 1977), clays on *A. obtectus* (Headlee, 1924), and various types of ash on *C. maculatus* in cowpea (Wegmann, 1983).

b. Cultural pest management

A few cultural practices have been observed to reduce bruchid damage in storage. These include timely harvest (Paddock and Reinhard, 1919), regular weekly harvest of cowpea (Prevett, 1961; Caswall, 1968), inter-cropping of beans and maize (Labeyrie and Maison, 1957), and crop hygiene (De Lima, 1973).

c. Biorational pest management

Peasant farmers the world over often use materials of plant origin to control bruchid damage. These may be in form of oil extracts, plant parts or plant products (Bernard, 1957; Khare and Agrawal, 1972; Schoonhoven, 1978; Nazan, 1983; Pereira, 1983, Don-Pedro, 1985; Ajayi *et al.*, 1987).

Vegetable oils

The practice of adding a small quantity of vegetable oil to grain legume seed is common i several parts of Asia (Van Huis, 1991). Various workers have shown that oil coating i effective in controlling *C. maculatus* (Varma and Pandey, 1978; Boughdad *et al.*, 198 Bhaduri *et al.*, 1990; Cockfield, 1992;), *C. chinensis* (Cruz and Cardona, 1981; Mishra *al.*, 1981; Ali *et al.*, 1983; Khaire *et al.*, 1992) and *Z. subfasciatus* (Schoonhoven, 1978

The vegetable oils tested were extracted from African palm, maize, groundnut, rice bran, soybean, cotton seed, sun-flower, coconut, sesame, neem, mint, rape, mustard and *Acorus calamus*. Regardless of the source, the oils gave adequate protection from bruchids, but crude oil extracts were more effective than purified oils (Schoonhoven, 1978).

The oils were mainly found to act as ovicides, but reduced oviposition and higher adult and larval mortality were also reported (Van Huis, 1991). Credland (1992) postulated that the occlusion in the funnel of *Callosobruchus* eggs by some oils could be the reason for the ovicidal and larvicidal effects.

Plants and plant products

Many plants are known to have either antifeedant, repellent, or insecticidal effects on bruchids, and their actions are sometimes synergistic (Van Huis 1991). The use of plant materials against storage pests have been reported in many countries (Delobel and Malonga, 1987; Morallo-Rejesus *et al.*, 1990; Okongkwo and Okoye, 1992; Van Huis, 1991). Of particular interest is azadirachtin, a compound (tetranortriterpenoid) from neem, *Azadirachta indica* A. Juss., and *Melia azedarach* Mill. The compound is considered a promising alternative to synthetic insecticides and is being investigated in several countries (Jotwani and Srivastava, 1981; Ivbijaro, 1983; Jilani, 1983; Saxena *et al.*, 1989; Schmutterer, 1990). Several other useful plants have been listed but their efficacy has been found to be variable, perhaps due to strain differences or time of harvest and utilisation (Lambert *et al.*, 1985). In the laboratory some plant species have been found to be effective against bruchids (Table 4). Some are said to offer only partial protection and others may act as deterrents or repellents. Very few of the plant materials have been studied under traditional storage conditions (Van Huis, 1991). Consequently the practicality and effectiveness under field usage have been questioned (Taylor and Wet 1979).

Other biorational methods include the use of insect growth regulators, pheromone lures, and ovipositional deterrents (Van Huis, 1991).

d. Biological control

Though several parasitoids of *Callosobruchus* species have been identified, their usefulness is not certain (Van Huis, 1991). Haines (1984) considered that the strategy of classical biological control for insect pests in storage could not be useful because the parasitoids have already had the 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 cannot currently be assessed until they have been studied (Van Huis, 1991). Limited use of the parasitoids *Uscana* spp. has been attempted in Hawaii and Japan on bruchids (Bridwell, 1918; Aitken, 1984).

Table 4. List of some plant species with insecticidal properties against bruchids.

Plants used	Bruchid species	Reference
Azadirachta indica A. Juss.	All	Van Huis (1991)
Melia azedarach Mill.	All	Van Huis (1991)
Hyptis spicigera L.	*A. obtectus*	Lambert *et al.* (1985)
Cassia nigricans L.	*A. obtectus*	Lambert *et al.* (1985)
Annona squamosa L.	*C. chinensis*	Ali *et al.* (1983)
Piper nigrum L.	*C. maculatus* & *C. chinensis*	Su (1977); Morallo-Rejesus *et al.* (1990)
Piper guineense Scum. &Thonn.	*C. maculatus*	Olaifa and Erhun (1988)
Capsicum spp.	*C. maculatus*	Ivbijaro and Agbaje (1986)
Tephrosia spp.	*C. maculatus*	Delobel and Malonga (1987)
Chenopodium spp.	*C. maculatus*	Delobel and Malonga (1987)
Citrus cematifolia L.	*C. maculatus*	Rajapakse (1990)
Ricinus communis L.	*C. maculatus*	Okongkwo & Okoye (1992)
Eichhornia crassipes Mart. Solms	*C. chinensis*	Usha and Jamil (1990)

e. Varietal resistance

The rate of pest population increase is influenced, among other things, by the quality of the food upon which the pest is feeding (Dobie, 1984). In many crops some varieties are less suitable than others for insect development; such varieties are described as being resistant or less susceptible to insect attack (Dobie, 1984). Characteristically a resistant variety should have the ability to cause the pest to reduce egg laying and/or extend its developmental period, and/or cause high mortality on the developing insects (Dobie, 1984).

The rate of egg laying may be reduced by a mechanical barrier, repellent action or simply unsuitability for oviposition (Dobie, 1984). The developmental period may be extended by the indigestibility of hard textures, partial toxicity or nutritional inadequacy of the plant and the death rate may be increased due to the impenetrability, inadequate nutrition, or toxic effect of the variety (Dobie, 1984).

Most of the studies on resistance have focused on aspects of seed storage and these have been mainly on cowpea, beans and mung bean. In the field, pod resistance screening against bruchids has been rare. Those tests reported include faba bean screening on *Bruchus dentipes* (Baudi) (Tahhan and van Emden, 1989) and mung bean on *Callosobruchus* (Talekar and Lin, 1981). No variety of faba bean was found to be resistant, and only one accession of mung bean was found resistant.

In seeds, certain seed coat types of cowpea have been found to present a mechanical barrier to *C. maculatus* first instar entry (Nwanze and Horber, 1976). Also in cowpea, a variety has been identified to be highly resistant to *C. maculatus* due to high levels of protease inhibitors (Gatehouse *et al.*, 1979; Van Huis, 1991; Dobie, 1984). In beans, a wild accession was found to be highly resistant to *Z. subfasciatus*; a toxic protein, arcelin, was shown to be responsible (Cardona *et al.*, 1992). Resistance by mung bean and black gram, *V. mungo*, have also been identified, probably due to antibiosis action (Talekar and Lin, 1981).

1.3 Objective of the study

The overall objective of this study was to improve pigeonpea storage systems through an integrated pest management (IPM) concept. As a prerequisite for the development of an IPM package, the many physical and biological elements within the system had to be recognised, and the multiple inter-actions within understood and quantified.

This required a systematic investigative approach which involved, as a first step, the diagnosis of the pest problems of obvious or of potential economic importance, isolation and identification of the causative agent(s), as well as the quantification of losses.

The second step was to define the management unit in the agro-system. This comprised the total complex of organisms in the crop area together with all aspects of the environment as modified by the various agricultural, social and human activities (Apple, 1980).

And the third step was to develop the management strategy using multiple tactics, the goal being to hold pest numbers and damage to tolerable levels. The fundamental tactics that were studied included the potential utilisation of indigenous natural control, management through cultural practices and use of inherent plant resistance and tolerance.

The study therefore specifically involved :

- **Baseline surveys**

To investigate the many physical and biological elements within the pigeonpea post-production system, to diagnose and quantify the pest problem within the system, and to define the management units within the system.

- **Studies on pest biology and host plant relationship**

To investigate biological and physical factors affecting pest infestation, specifically host plant interrelationships both in the field and within storage.

- **Development of IPM strategies**

From the studies above, develop appropriate management strategies against the major pigeonpea storage pest(s).

CHAPTER 2. SURVEY OF PIGEONPEA POST-PRODUCTION SYSTEMS

2.1. Introduction

The major pigeonpea production areas in Uganda are the drier Northern areas of Uganda where mostly the long-duration genotypes are grown (Jameson, 1970). Pigeonpea in these areas has been adapted to fit in the general cropping patterns and as food, it forms an important component in the diet of the population (Nalyango and Emeetai-Areke, 1987).

Like other legumes, pigeonpea is thought to suffer serious pest problems during production and post-production stages. While some information is available on production practices and constraints (Nalayngo and Emeetai-Areke, 1987), little is known about post-production practices, the nature and magnitude of constraints and how farmers deal with these constraints.

A survey was therefore conducted with the following specific objectives:

- to identify the nature, causes and magnitudes of constraints associated with pigeonpea post-production systems,
- to identify farmers' perceptions of constraints associated with post-production systems,
- to document and characterise the general farming practices of relevance to the post-production system in the major pigeonpea production areas of Uganda,
- to obtain the information necessary for prioritising and designing appropriate applied on-station and on-farm research trials, and
- to provide baseline data for future follow-up, evaluation and monitoring surveys.

2.2. Materials and methods

A. Survey methodology

General

The surveys for pest identification, loss assessment and farmers perceptions of constraints on the pigeonpea crop were made in December 1993 (Apac and Lira) and March 1994 (Gulu). On average crops had been harvested 2 months before the survey.

The survey target areas selected for obtaining information on pigeonpea at on-farm storage, village markets and town markets are in northern Uganda, where pigeonpea production is highest. The three districts selected for the survey were Apac, Gulu and Lira (Fig. 1a). The final marketing chains in the city (Kampala) selected for sampling were within the Owino, Nakawa and Kamwokya markets (Fig. 1b).

On-farm survey

The sample population for on-farm survey was divided into manageable proportions using a multistage, stratified, random sample method as described by Harris and Lindbland (1978).

Administrative boundaries made up the first and second stage units, the final stage being the farming households (Table 5). The survey included a total of 54 final sampling units.

Market surveys

Markets were divided into three categories, primary, secondary and tertiary stages (Table 5). The categorisations were based on the level and status (rural, district, city), central location and size of the market.

Fig. 1b. The locations of the three markets (Kamwokya, Nakawa and Owino) within Kampala City where sampling for pigeonpea was undertaken.

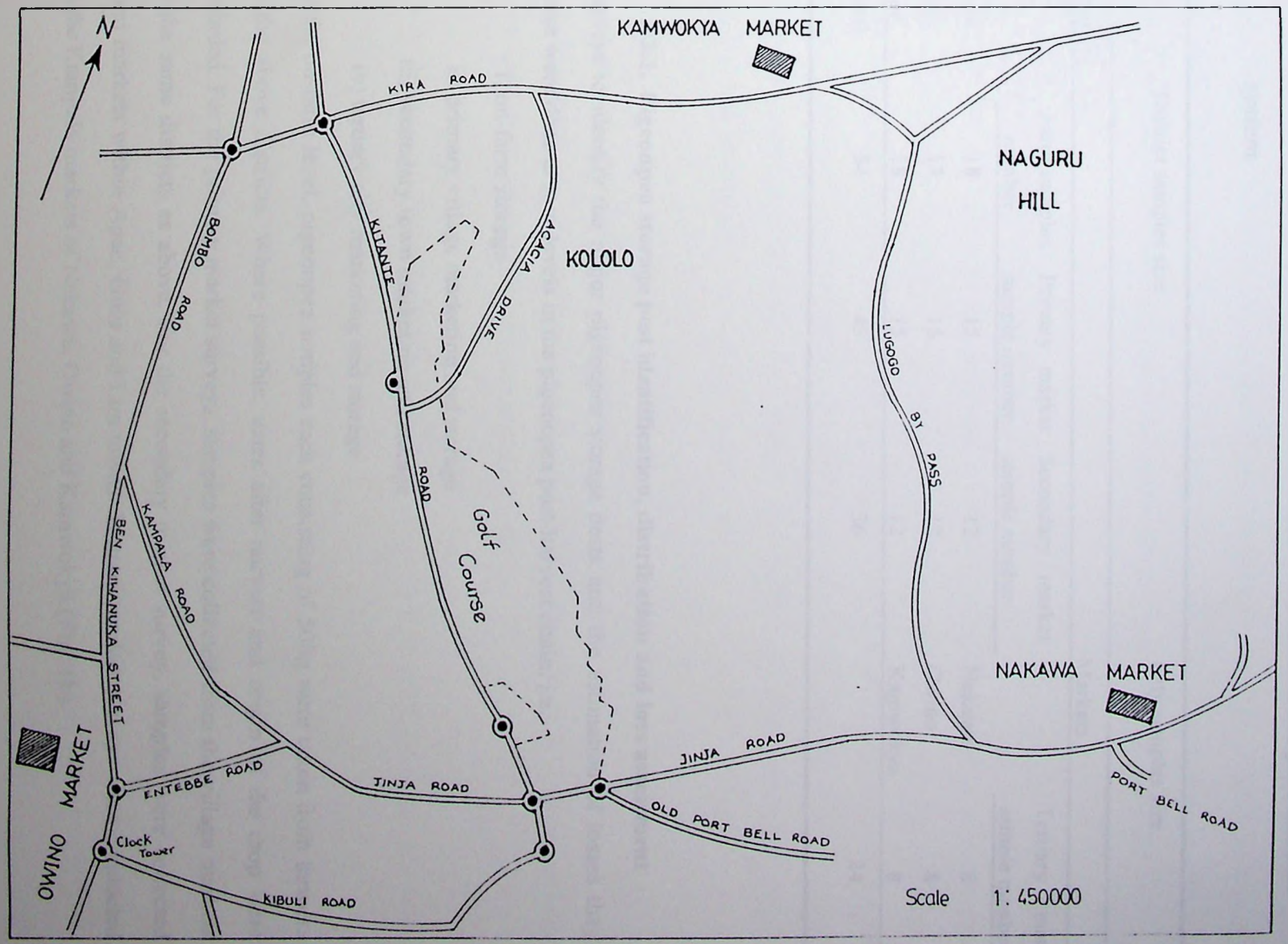


Table 5. Number of samples collected at the different points in the post-harvest system

	District samples size			City samples size	
Districts				Markets	
	Farm samples number	Primary market sample number	Secondary market sample number		Tertiary market sample number
Apac	18	15	12	Nakawa	8
Gulu	18	15	12	Owino	8
Lira	18	15	12	Kamwokya	8
Total	54	45	36		24

2.2.1. Pigeonpea storage pest identification, distribution and loss assessment

Surveys to identify the major pigeonpea storage pests and the estimation of losses they cause were done at four levels in the pigeonpea post-harvest chain, i.e.

i) on-farm storage

ii) primary village marketing and storage

iii) secondary town marketing and storage

iv) tertiary city marketing and storage

At the on-farm level, pigeonpea samples each consisting of 500g were taken from farmers in the above districts. Where possible, dates after harvest and origin of the crop were recorded. For the primary market surveys, samples were collected from the village markets in the same districts as above. For the secondary market survey, samples were collected from markets within Apac, Gulu and Lira towns. Tertiary market surveys were conducted in the Kampala markets of Nakawa, Owino and Kamwokya (Fig. 1b).

The actual number of samples collected from on-farm were 54, representing 18 samples per district (Table 5). The number of market samples comprised 20% to 50% of all pigeonpea traders within each market. The number of samples collected from the primary, secondary and tertiary markets were 45, 36, and 24, respectively (Table 5). This sample number was considered adequate to achieve a reasonable degree of representation and precision.

a. Pest identification and distribution

The samples were taken to the laboratory and insects sieved out (sieves of mesh size 0.25cm), identified, counted and percentage species composition graphically presented. Each sample was divided into two using a Boerner sample divider and standardised to 250g. One half was incubated for 45 days under ambient conditions (22-24°C), and again all insects sieved out, identified and counted. The second half was reserved for single occasion loss assessment.

b. Loss assessment (single-occasion)

Single-occasion loss assessment was done on the second half of samples. The sample units were divided into batches, sub-batches and primary units.

For on farm storage loss assessment, the district formed a batch, the counties the sub-batch, and individual samples the primary units.

For village market loss assessment, again the district formed the batch, the district village market the sub-batch, and the individual market traders the primary units.

For town and city market/storage level, the town/city formed the batch, the market within the town/city the sub-batch and the individual market traders the primary units.

The primary samples from each sub-batch were combined and thoroughly mixed. Thereafter the sub-batches from each batch were combined and also thoroughly mixed.

For purposes of loss assessment analysis, the combined batch was reduced and a submitted sample extracted. To obtain representative samples, the batch was divided using a Boerner divider. The final samples per batch used for the analysis consisted of fifteen 100g samples.

For the purpose of loss assessment, for each sample, hollowed seeds were separated from those that were undamaged by the unaided eye, and weighed.

The parameter used for loss assessment was the percentage seed damage determined from the weight of hollowed seeds per 100g sample, i.e.

$$\% \text{ seed damage} = \frac{\text{Weight of hollowed seeds (g)}}{\text{Original weight of sample (g)}} \times 100$$

This method of loss assessment was considered appropriate as it combines both qualitative and quantitative measures as opposed to weight loss which is purely quantitative.

To compare the losses at the various points in the post-harvest chain, the results were subjected to a one-way analysis of variance and the treatment means separated using Duncan's multiple range test.

2.2.2. On-farm survey of farmers' practices and perceptions on pest damage

The survey methodology used was the same as for on-farm, described in section 2.2.A above. The team comprised of the team leader (myself), the district extension officer, and an interpreter. During the survey a semi-structured questionnaire (Appendix V) was used by the team through informal discussions with farmers. This was to investigate farmers' practices and perceptions on post-harvest constraints and how they deal with them. During the course of the discussions the production profile, field pest species and their seriousness, post production systems and the marketing systems were investigated and results tabulated or presented graphically as frequency of response.

Observations were made on pigeonpea farms to record other relevant information (i.e. pests, production and post-production practices) and to take samples from both fields and stores.

2.3. Results

2.3.1. Pigeonpea storage pest identification, distribution and loss assessment

a. Pest identification and distribution

The Bruchidae species found to infest pigeonpea in the post-harvest system were *C.chinensis*, *C. maculatus* and *A. obtectus;* the overall mean species composition were 96%, 3%, and 1% respectively (Fig. 2a).

However, *C. chinensis* was the only species encountered in surveys of farm stores (Fig. 2b). In village markets in all the districts, the predominant species was *C. chinensis* (mean composition 99.5%). Very low populations of *C. maculatus* (mean composition 0.5%) were, however, detected.

In district markets. *C. chinensis* (mean composition 96.9%) was again the predominant species . There were again low populations of *C. maculatus* (mean composition 2.8%), but higher than at the village markets. *A. obtectus* (mean composition 0.3%), a common storage pest of stored beans was also found, though at very low levels .

In city markets. *C. chinensis* (mean 87.7%) remained the predominant species. Populations of *C. maculatus* and *A. obtectus* (mean of 9.7% and 2.6%, respectively) had markedly increased compared to the above.

b. Loss assessment (single occasion)

After two months of storage, pigeonpea damage was already apparent (mean 4.27%) at all the stages in the post-harvest chain (Table 6).

There was a significant difference in damage between the various points in the post-harvest chain ($P<0.05$).

The lowest damage was recorded in village markets (1.97%) and the highest at the city markets (7.31%), with intermediate levels of damage on farms and town markets. The differences among these cohorts were significant ($P<0.05$).

Among the three districts (Table 7), there were significant differences in damage ($P<0.05$). This was consistently less in Gulu than either Apac or Lira, and significantly so for both on-farm storage and district town markets. There was no significant difference in damage among the three city markets in Kampala ($P>0.05$).

Fig.2a. Overall mean percentage composition of bruchid species infesting pigeonpea

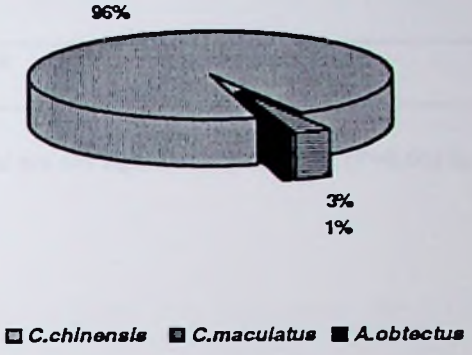


Fig. 2b. Pigeonpea storage pest composition at different stages in the post-harvest system

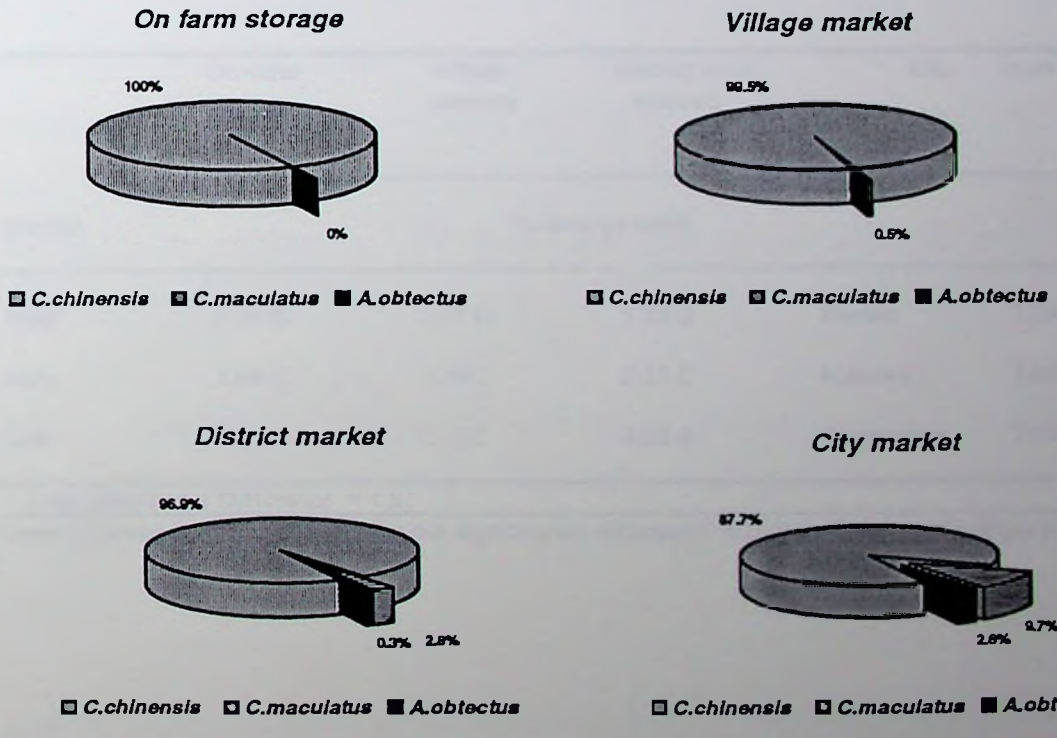


Table 6. Mean percentage damage of pigeonpea at different stages in the post-harvest chain two months after harvest

Post-harvest stage	On-farm storage	Village markets	District town markets	City markets	Mean
Mean % damaged seeds	2.87 BC	1.97 C	3.94 B	7.1 A	4.27

Least Significant Difference = 1.9

Means followed by the same letter are not significantly different (P=0.05) by Duncan's Multiple Range Test

Table 7. Pigeonpea percentage damage at different points in the post-harvest chain within districts/locations two months after harvest

	On-farm storage	Village markets	District town markets	City markets	
District	% damage seeds				
Apac	5.05 B	2.17 C	5.24 B	Owino	7.29 A
Gulu	1.66 C	1.39C	2.35 C	Nakawa	7.05 A
Lira	4.90 B	2.35C	4.23 B	Kamwokya	7.63 A

Least Significant Difference = 1.8

Means followed by the same letter are not significantly different *(P=0.05)* by Duncan's Multiple Range Test.

2.3.2. On-farm survey of farmers' practices and perceptions on pest damage

a. Production profile

In the three districts surveyed, 100% of the respondents grew pigeonpea. The ranking of pigeonpea among the major food crops (by priority, area and production) as given by respondents is shown in Appendix VI. The overall average across the three districts indicates that sweet potatoes and inter-cropped millet/pigeonpea ranked highest among crops grown. Within districts, pigeonpea/millet inter-crops were ranked 3rd in Apac, 5th in Gulu and 1st in Lira.

The mean area per household cropped with pigeonpea was recorded as 0.44 ha. Medium-duration pigeonpea genotypes are the most widely grown. Long-duration genotypes are, however, predominant in Gulu and some parts of Lira district (Appendix VII).

Irrespective of variety, pigeonpea is usually planted once a year, mainly in March, and only rarely twice yearly. Pigeonpea is always inter-cropped and rotated with other crops, (Appendix VIII and IX). The most consistent reason for inter-cropping was reported to be compatibility reflected in terms of growth habits and harvest timing. Reasons given for rotation include reduced pest incidence, increased soil fertility and need for field cleanliness for millet/pigeonpea inter-crop.

Pigeonpea characteristics found to be most desired by farmers in order of priority are high yield potential, early-maturity, quick cooking and good storability, white or cream coloured seed, large to medium sized seed, brown colour and small sized seed and finally taste (Appendix X).

The major source of seed for all the varieties grown is from farmers' own carry over stock, and/or neighbours and only rarely from markets (Appendix XI).

b. Field pests

According to farmers, the most serious field pests are pod borers (*H. armigera*), pod sucking bugs (*Clavigralla* sp.) and flower beetles (*Pachnoda* sp. and *Mylabris pustulata* Thun.). Other pests reported include leaf eating caterpillars, termites and thrips (*Megalurothrips* sp.) (Fig. 3). Of all the farmers interviewed, only 30% felt that there was a positive relationship between field pest damage and the subsequent storage pest infestations (Fig. 4).

c. Post production system

Pigeonpea crop is harvested in October/November (medium-duration genotypes) and January/February (long-duration genotypes). Two methods of pigeonpea harvesting are prevalent (Fig. 5), these being whole plant harvest (Apac and Lira) and pod picking (Gulu). Pigeonpea yields are, however, low and estimated at 360 kg/ha in the pigeonpea/millet inter-crop.

The crop is dried and stored for a while (usually less than 2 months) and threshed following whole plant harvest (Apac and Lira). Following pod harvest, however, the crop is stored within pods without being threshed (Gulu) (Fig. 6). After threshing (Apac and Lira) the seeds are cleaned and stored mainly in gunny bags or in sealed containers, all situated indoors, pods (Gulu) are usually stored in reed woven out-door basket granaries (Fig. 6 & 7).

Fig. 3. Major pigeonpea field pests reported by farmers

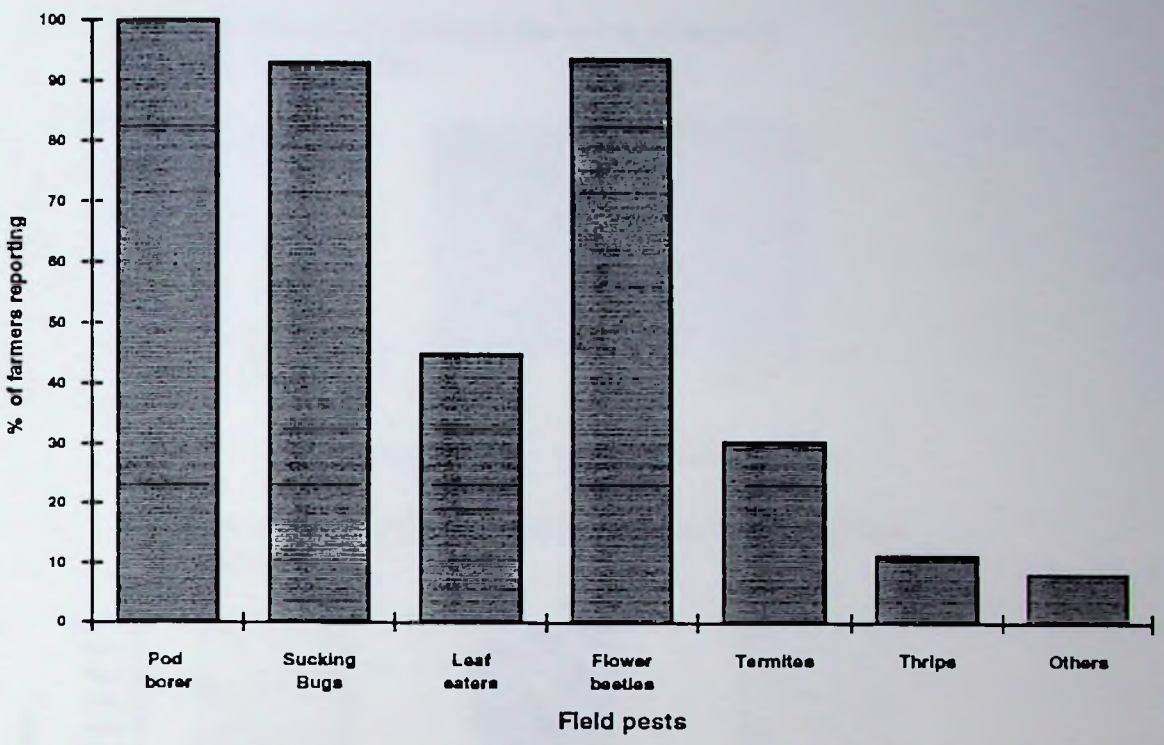


Fig. 4. Farmers' perception on the effect of field pest damage on subsequent storage damage

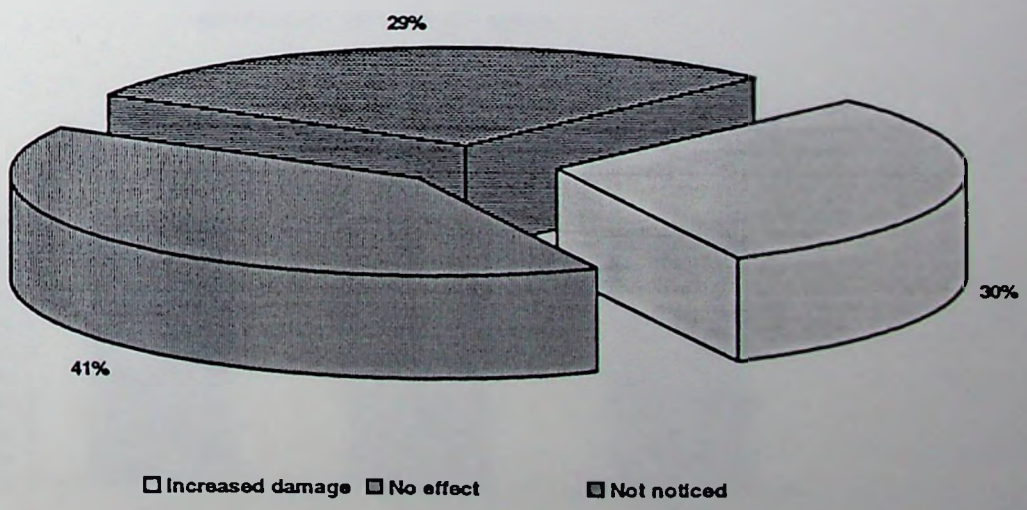


Fig.5. Method of pigeonpea harvest by farmers in Apac, Gulu and Lira

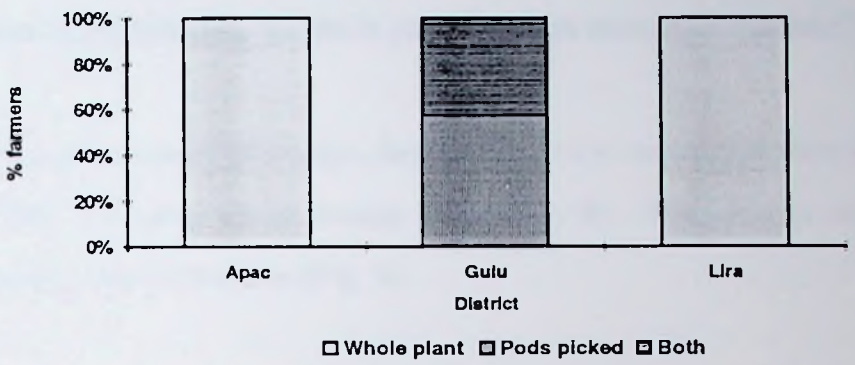


Fig.6. Form of pigeonpea storage by farmers in Apac, Gulu and Lira

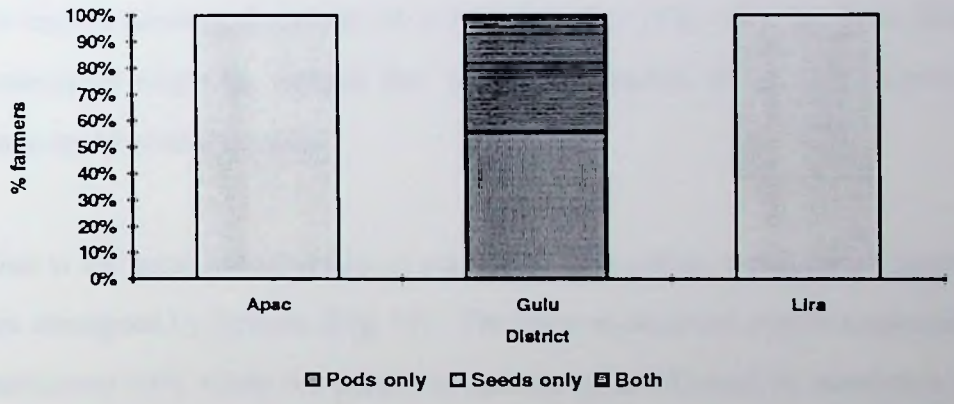
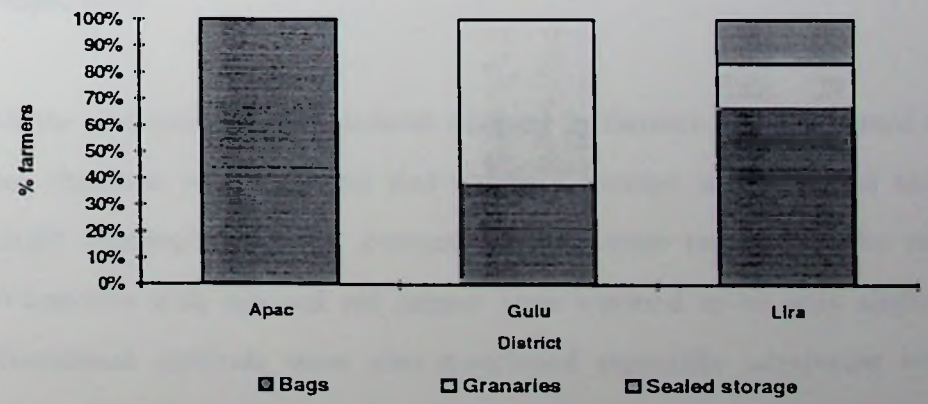


Fig.7. Storage systems used by farmers in Apac, Gulu and Lira



in storage, the crop is used for food within the household, some is kept for seed and sold for cash. The maximum storage duration for pigeonpea varied, from 4 to more 12 months (Fig. 8), but in general typical storage periods are 7 to 12 months.

ring the course of storage, farmers are always concerned about damage due to pests and efts, but rarely about storage space (Fig. 9). The greatest concern, however, was of mage due to bruchids (Fig. 9).

The extent of bruchid damage to pigeonpea was dependent on the duration of storage. The damage in Apac and Lira was expressed as severe for 4-6 months of storage, and very severe for storage durations of over 6 months (Fig. 10). In Gulu district damage was considered slight by farmers for a storage duration of up to 9 months and of medium severity beyond 9 months.

Due to the great susceptibility of pigeonpea to bruchids, a number of management practices are attempted by farmers (Fig. 11). The most widespread pest management method used is admixture with whole red pepper (*Capsicum* sp.), followed by admixture with ash, sunning (resulting in solar disinfestation due to heat and glare), storage within pods, chemical use, slight seed roasting on a frying pan and storage within sealed mud-straw containers respectively.

Of the pest management methods adopted by farmers, those reported to be most ef fective e are chemical pesticides and pod-storage. Storage within sealed mud-straw con ainers s slight roasting/frying and frequent sunning were reported to be moderately ef fectiv ve . Oth h Admixture with ash and red pepper were reported to be only slightly effective eaves ; biorational methods were also mentioned especially admixture with dried l aromatic plants and tobacco .

e of the methods used were entirely effective according to farmers (Table 8). Apart n the above methods, other means which some farmers are aware of but do not use lude slight boiling, admixture with millet, tobacco leaves and other plant leaves (Fig.).

lthough a range of pest management options are known, or have been heard of (Fig.12), nany of them are not being practised for various reasons (Tables 8 and 9). Some of the reasons given for not using some of the above methods were ineffectiveness (mostly for sunning), poor reliability (sunning, red pepper, pod storage sealed storage and roasting), irritates (red pepper), only good for seed purposes (ash) and only good for pigeonpea meant for food (roasting).

Fig. 8. Maximum storage duration of pigeonpea by farmers

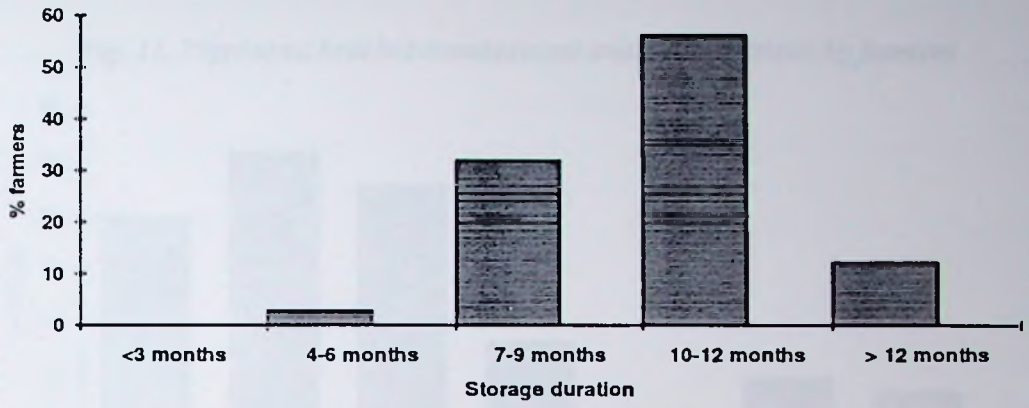


Fig. 9. Major concerns of farmers during pigeonpea storage

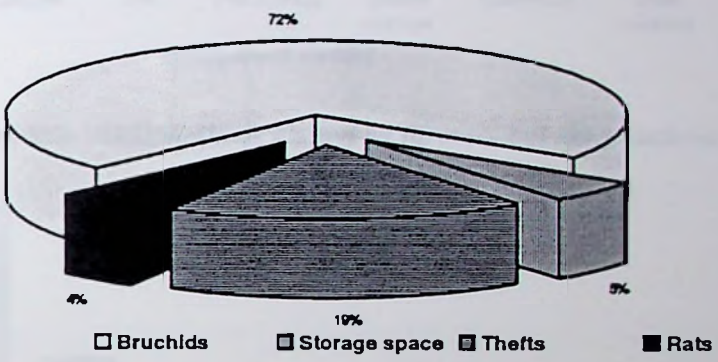
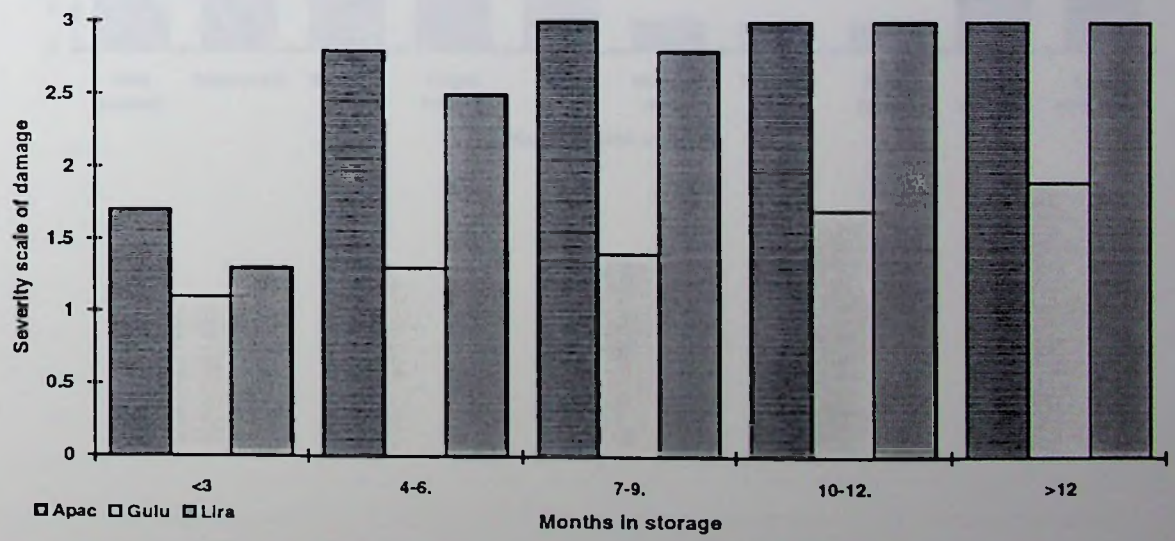


Fig. 10. Scale of pigeonpea damage by bruchids during storage according to farmers in Apac, Gulu and Lira



Key to severity of damage rating scale

0-1 = Very Slight; 1.1-1.5 = Slight; 1.6-2= Medium; 2.1-2.5 = Severe; 2.6-3 = Very Severe.

Fig. 11. Pigeonpea bruchid management methods practiced by farmers

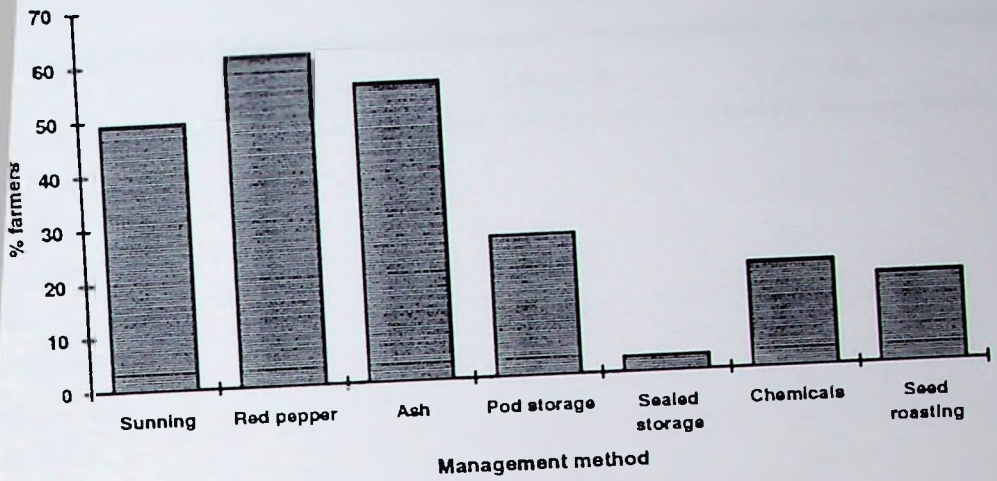
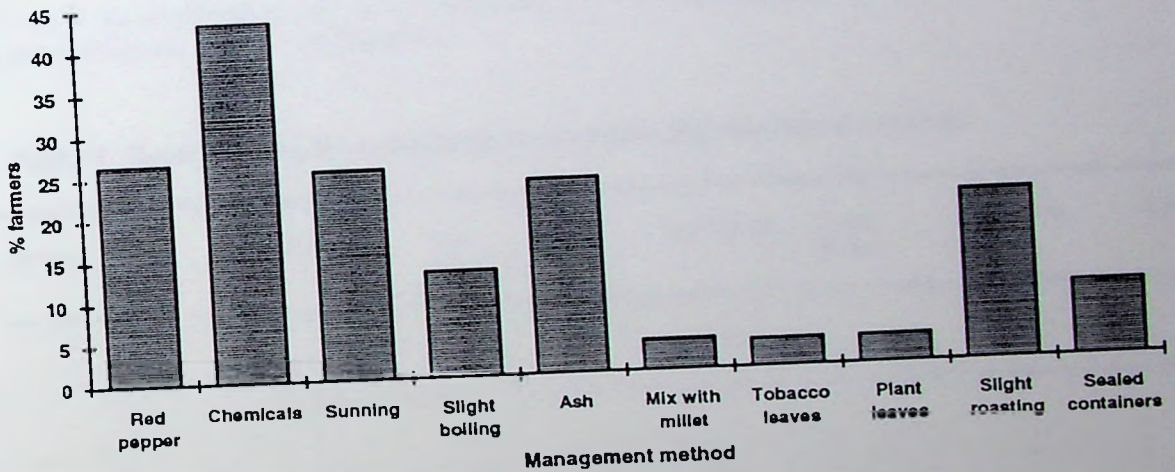


Fig. 12. Pigeonpea bruchid methods known by farmers but not practiced



e 8. Effectiveness of the bruchid management methods used by farmers

hods	District Scores			Mean Score
	Apac (n=18)	Gulu (n=18)	Lira (n=18)	
nning	1.8	-	2.2	2.0
d pepper	2.1	2.3	2.1	2.2
sh	1.9	2.0	2.3	2.1
od storage	-	1.2	-	1.2
ealed storage	-	-	1.6	1.6
Chemicals	1.1	1.0	1.3	1.1
Roasting	1.9	-	2.0	1.9

0 - 1.0 = Very effective, 1.1 - 1.5 = Effective, 1.6 - 2 = Moderately effective, 2.1 - 2.5 = Only slightly effective, 2.6 - 3 = Ineffective

Table 9. Reason given by some farmers for not using the above methods

Reason	Sunning	Red pepper	Ash	Pod storage	Sealed storage	Chemicals	Roasting
	% of farmers						
Not effective	44	16	0	0	11	0	0
Doubtful	37	30	0	30	40	0	0
Not available	0	0	0	0	0	79	0
Expensive	0	0	0	0	0	21	0
Inconvenient	20	30	40	70	49	0	30
Good for seed only	0	0	60	0	0	0	
Good for food only	0	0	0	0	0	0	
Irritates	0	24	0	0	0	0	

NB Percentages exceeding 100% indicate positive response to more than one answer to the same question by a respondent. Percentages of less than 100% indicates no response by some farmers.

d. Marketing

Nearly 67% of the farmers usually market 26-50% of the pigeonpea harvested, 16% market less than 25% and 7% of the farmers never sell any (Fig. 13). About 59% of the farmers normally sell the pigeonpea in village markets only and 41% in both village and town markets (Appendix XII).

Marketing of pigeonpea is a more or less continuous process right from harvest (Fig. 14). Almost all farmers sell some of their pigeonpea soon after harvest. Various factors are responsible for the timing of pigeonpea sales off-farm (Fig. 15). The main reason given for selling soon after harvest is due to the need for immediate cash (57%). Marketing within three months of harvest is due to fear of pest damage (63%), and to some extent, the need for immediate cash (17%). Sales are made from 4-6 months after harvest in order to obtain better than earlier prices (54%) and/or because of fear of insect damage (46%), while selling at 7-9 months is mainly for the very good prices obtainable then (67%) and/or fear of extreme damage by insects pests (33%). Pigeonpea marketing just before the next harvest is, again, mainly due to the good prices obtainable at that time (56%). The need for storage space for the next crop (16%), and fear of total pest damage (29%) were other reasons given.

Fig. 13. Proportion of pigeonpea normally marketed by farmers

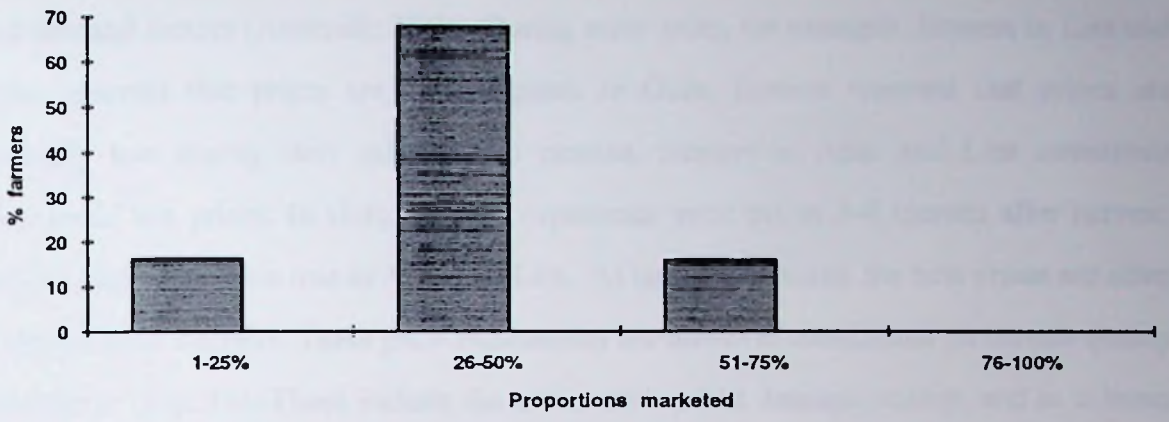


Fig. 14. Period after harvest when farmers normally market pigeonpea

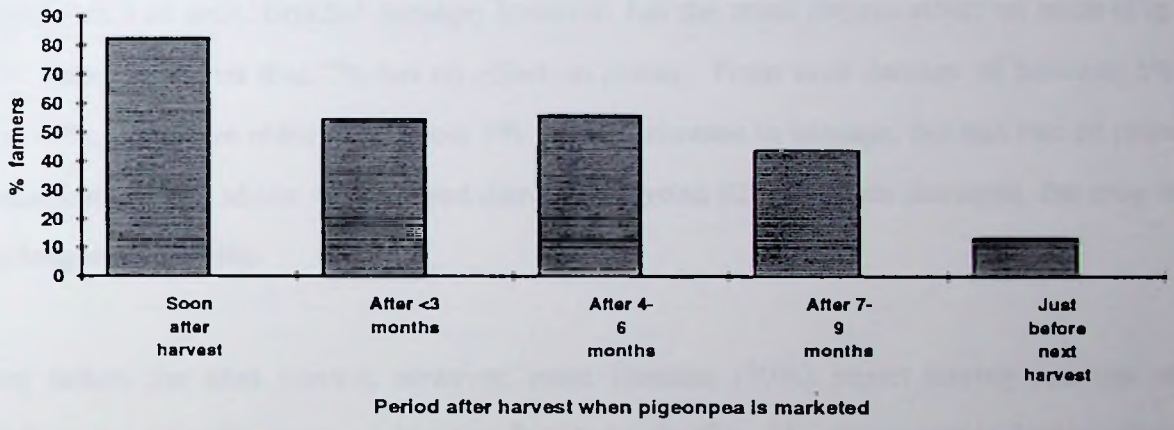
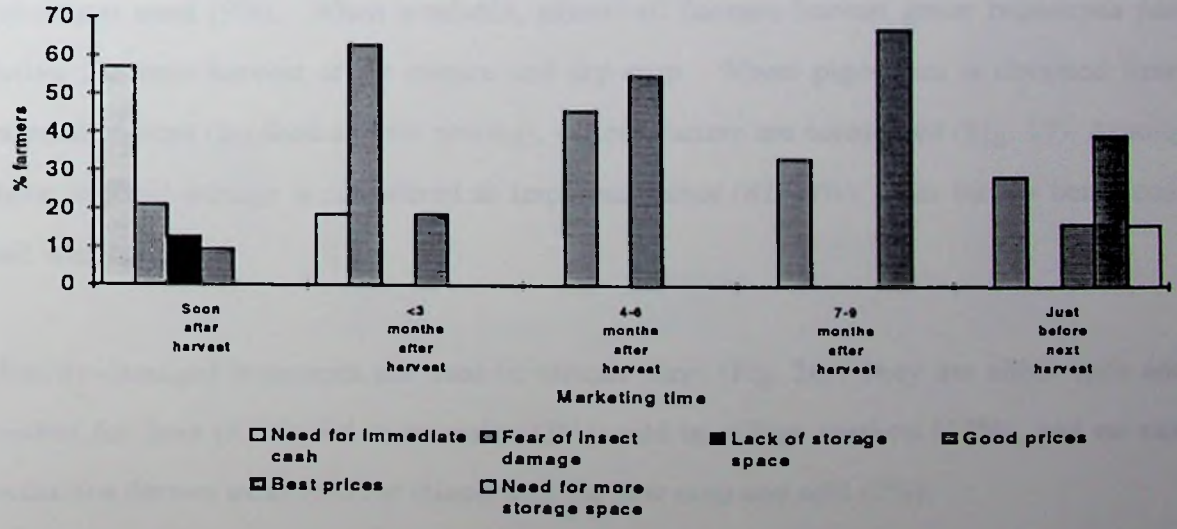


Fig. 15. Reasons given by farmers for marketing pigeonpea at specific times after harvest



Farmers were aware of the price fluctuations during the course of the year caused by supply and demand factors (Appendix XIII). During early sales, for example, farmers in Lira and Apac reported that prices are usually good. In Gulu, farmers reported that prices are normally low during early sale. At 3-6 months, farmers in Apac and Lira sometimes experience low prices. In Gulu, farmers experience good prices 3-6 months after harvest, and the same was often true in Apac and Lira. At late season sales, the best prices are often obtained in all districts. These price fluctuations are however conditional on certain quality parameters (Fig. 16). These include the extent of bruchid damage, colour, and to a lesser extent, size and origin (which may indicate certain undesirable characteristics, e.g. cooking quality etc.) of seed. Bruchid damage, however, has the most serious effect on price (Fig. 17). Damage of less than 2% has no effect on prices. From seed damage of between 5% and 40%, prices are reduced by about 1% per 1% increase in damage, but this rate of price reduction doubles above 40% of seed damage. Beyond 52% of seeds damaged, the crop is no longer marketable.

Just before the next harvest, however, most families (70%) report having run out of pigeonpea. In such instances, to meet family needs (Fig. 18), pigeonpea is bought from markets (23%), bartered with other crops (18%), borrowed from friends (9%), or other substitutes used (9%). When available, almost all farmers harvest green pigeonpea just before the main harvest of the mature and dry crop. Where pigeonpea is obtained from external sources (for food and for sowing), various factors are considered (Fig. 19). Among these, bruchid damage is considered an important factor (82-90%), other factors being cost and seed colour .

Heavily-damaged pigeonpea are used in various ways (Fig. 20). They are either split and cooked for food (52%), fed to animals (33%), sold in village markets (12%), and on rare occasions thrown away (5%) or mixed with the new crop and sold (2%).

Fig. 16. Factors that affect pigeonpea prices other than supply and demand

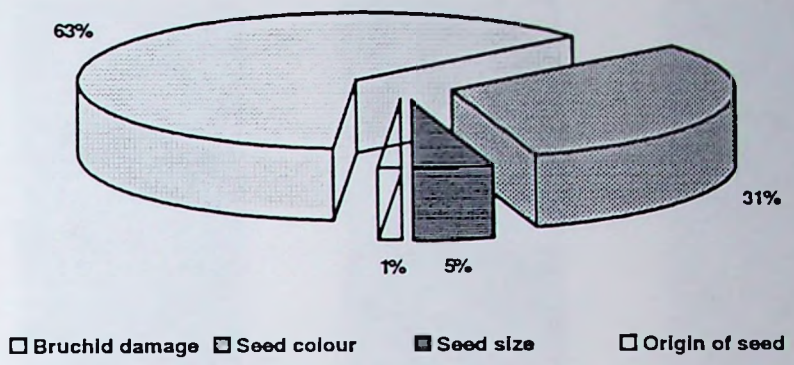


Fig. 17. Influence of bruchid damage on pigeonpea selling prices

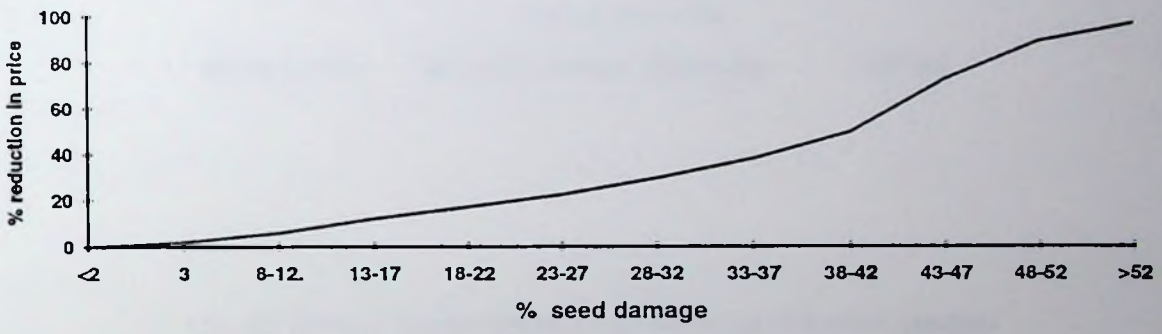


Fig. 18. Ways in which household manage in case of shortage of own pigeonpea during growing season

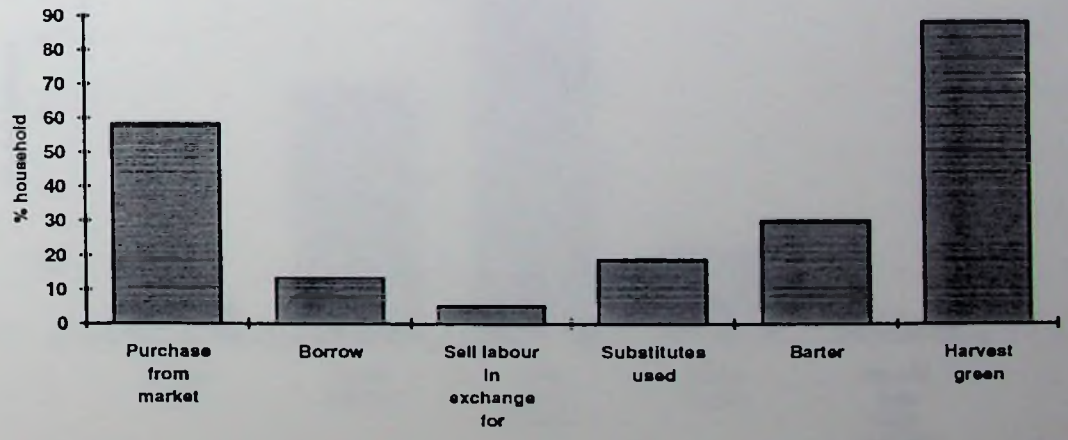


Fig. 19. Factors considered in order of priority before purchase of seeds of pigeonpea

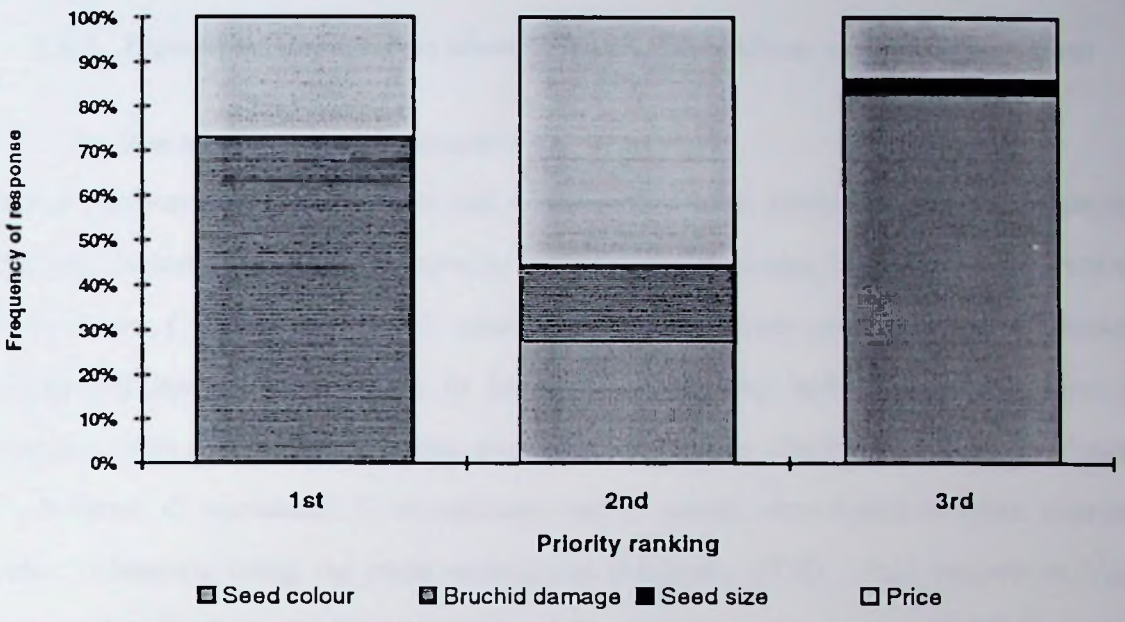
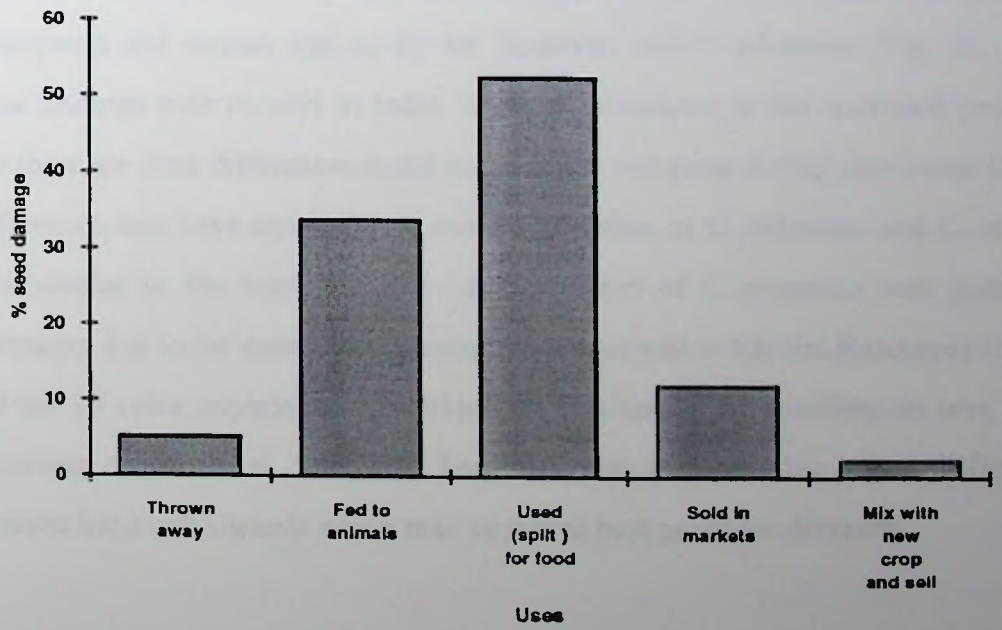


Fig. 20. Uses of heavily-damaged pigeonpea (>50% seed damage)



2.4. Discussion

2.4.1. Pigeonpea storage pest identification, distribution and loss assessment

a. Pest identification and distribution

Stored pigeonpea seed infestation and damage have been attributed to several species of bruchids. In India the important species responsible for storage damage are reported to be *C. chinensis*, *C. maculatus* and *C. analis*, the most serious species being *C. maculatus* (Singh and Jambunathan, 1990). In Jamaica *C. chinensis* and *C. maculatus* have been recorded, with *C. maculatus* as the more serious species (Bridwell, 1918). In Tanzania, *C. chinensis*, *C. maculatus*, *C. rhodesianus* and *C. analis* were found to infest pigeonpea, with *C. chinensis* being the most widespread (Mphuru, 1978). Past records in Uganda indicate that *C. chinensis*, *C. maculatus* and *B. atrolineatus* do commonly infest pigeonpea (Davies, 1960). Their relative incidence and distribution are however not indicated.

The results of the present survey have shown that three bruchid species infest stored pigeonpea in Uganda, these are *C. chinensis*, *C. maculatus* and *A. obtectus*. The most widespread and serious species by far, however, was *C. chinensis* (Fig. 2). Comparing these findings with records in India, where *C. maculatus* is the dominant pest, it appears that there are clear differences in the status of the two pests during pigeonpea storage. Such differences may have arisen due to misidentification, as *C. chinensis* and *C. maculatus* are very similar to the untrained eye. Identification of *C. chinensis* was possible in our laboratory due to the specialised training I had received at Natural Resources Institute, UK, and the 10 years' experience of working on bruchids. The identification was, in addition, positively confirmed at NRI. It is, however, most probable that actual differences occur between India and Uganda which may be due to host genotype diversity.

Observations on beetles have shown that the preference of the Bruchidae to their leguminous host plants is unique among insects (Applebaum, 1964). Many bruchid species, however, show wide variations in their host-specificity ranging from monophagy in *Z. subfasciatus* to polyphagy in several species of *Callosobruchus* (Credland, 1990). Studies have established that some *Callosobruchus* species do occur in a number of genetically distinct biotypes, and this is thought to have arisen due to a degree of geographic isolation allied to local selection pressure and perhaps an initially limited range of genotypes (Credland, 1990). This may explain differences in pigeonpea pest status in India and East Africa.

In India, where little cowpea is grown, the host range of *C. maculatus*, whose origin is Africa, was probably very limited at its time of introduction. The pest status may have therefore been influenced by local selection pressure which led to its adaptation to pigeonpea, the alternate host. In India, *C. maculatus* therefore emerges as the more serious pest, while in East Africa both cowpea and pigeonpea are widely grown, thus *C. chinensis* appears to have remained the more serious pest in pigeonpea and *C. maculatus* remained the most serious pest of cowpea.

In addition to the above factor, in India, pigeonpea are regularly split before storage thus, offering minimal surface curvature, which according to findings by Gokhale *et al.*, 1990 and Yamamoto, 1990, renders the seeds unfavourable for *C. chinensis* oviposition. In the case of *C. maculatus*, since it is the chemical stimuli from the oviposition substrate rather than substrate curvature which stimulate oviposition (Yamamoto, 1990), pigeonpea splitting would have little effect on oviposition. It therefore appears that the condition and form of pigeonpea storage in India positively favoured *C. maculatus* over *C. chinensis*. In East Africa, however, pigeonpea is stored as whole seed, which offers maximal surface curvature, a factor favourable to *C. chinensis* oviposition.

The results of the surveys in farm stores in Northern Uganda showed that *C. chinensis* is the only species infesting pigeonpea. During the marketing chain however, other bruchid species begin infesting the seeds in different proportions, but with *C. chinensis* still remaining the predominant species. At the primary village market for example, very low infestation by *C. maculatus* was noticed (mean composition 0.5%), which was probably due to cross-infestation from cowpea, the common host plant of *C. maculatus*, and which is sold side by side with pigeonpea. At secondary markets (district town markets) a marked increase in *C. maculatus* population was recorded, which is probably attributable to the increased volume of cowpea handled at this stage. In addition, another pest, *A. obtectus*, a common pest of beans in Uganda (Silim *et al.*, 1990; Silim, 1990) also appeared but at very low populations (0.3%). It was again noted that beans were sold side by side with other pulses and could have been a source of the cross infestation. At the tertiary markets (city markets) all the three bruchid species occurred with increased infestation by *C. maculatus* and *A. obtectus*, with *C. chinensis* still the predominant species.

The above polyphagous tendency is a confirmation of earlier observations (Southgate, 1978) that some bruchid species have a wide range of legume host species. Although a certain amount of host specificity within the bruchid biotype is generally true, oviposition is possible on a number of non-host plants otherwise the expansion of host range would not occur (Southgate, 1978). In most instances no progeny are produced, but if they are, then that host becomes part of the acceptable host range (Southgate, 1978). It therefore appears that in their quest for a wider host range or uninfested hosts both *C. maculatus* and *A. obtectus*, under certain conditions, migrate and infest pigeonpea where they have developmental compatibility. This is made easier at the tertiary marketing stages where large quantities of both beans and cowpea, the common hosts to *A. obtectus* and *C. maculatus* respectively, are sold.

The surveys were done on average 2 months after harvest, and at that time infestation had already set in. Such widespread infestation by *C. chinensis*, so soon after harvest, may be an indication that its source of origin is in the field. Observations made on two bruchids infesting beans in Uganda, *A. obtectus* and *Z. subfasciatus*, during surveys conducted 1-3 months after harvest indicated that *A. obtectus* was universally present on beans (Silim *et al.*, 1990). Only after this period, however, did *Z. subfasciatus* make its appearance, if at all (Giga *et al.*, 1992). This phenomenon is thought to be due to differences in methods and timing of initial infestations. In the case of *A. obtectus* field infestation is the most important source of storage damage, while "in-storage infestation" is the most important in the case of *Z. subfasciatus* (Giga *et al.*, 1992).

b. Loss assessment (single occasion)

At the time of survey, seed damage was already apparent at all stages in the post-harvest system, with mean damage of 4.3%. Such extensive amount of damage to seeds, only 2 months after harvest is a reflection of the nature and point of origin of the initial infestation during seed development. In the case of *C. chinensis*, as discussed earlier, initial infestation was most probably of field origin, and this, when transferred within storage, where conditions are favourable for rapid population growth, resulted in severe damage within a short time, if left unchecked.

In addition, it has been observed that generally more damage within a given time span occurs in pigeonpea than in other legumes (Kadam *et al.*, 1989). Mookherjee *et al.* (1970) reported that with equal duration in storage, pigeonpea suffered 32.6% damage while cowpea, urd bean, mung bean and chickpea suffered only 18.5%, 14.9%, 9.9% and 4.8% damage respectively.

Differences in the amount of seed damage were recorded from samples taken from the various points in the post-harvest chain (Tables 6 and 7). The lowest damage was observed from samples obtained from the village markets (2%), followed by samples from on-farm storage (3.7%), town markets (4%) and lastly from city markets (7.3%).

The variation in damage may have arisen due to a number of factors, among which the most important were likely to have been differences in storage management practices. In the village markets, the very low seed damage observed was most probably due to the extra effort exerted by farmers to market their produce rapidly and profitably. This is especially noticed with pulses, which are often hand sorted before and/or during sale (Silim, unpublished). This practice was actually observed in markets during the survey. In addition to this, it has been shown that farmers are often willing and sometimes do use insecticide admixture to protect seeds meant for marketing (Silim *et al.*, 1990).

At the on-farm level, where low infestation was also observed, farmers often practice a number of short- to long-term storage pest management strategies (Silim *et al.*, 1990) and this is especially so with seed reserved for future sowing (Giga *et al.*, 1992). In addition, better storage facilities prevail on-farms than in the marketing chains (Davies, 1972; Silim *et al.*, 1990).

In town markets, damage was higher than in village markets (4%). This level of damage is most probably the result of the generally poor conditions associated with town go-downs (small warehouse) and stores where losses to insects and rodents are high (Davies, 1972).

The highest damage (7.3%) was recorded in samples obtained from city markets. Such damage could have again been due to the poor storage conditions in city stores and warehouses (Davies, 1972). Other factors may probably have been the storage and selling of old and new stocks side by side or even mixed together.

Within the districts, lower seed damage was consistently observed in Gulu, both in the farm and the marketing chain (Table 7). This very significant reduction in damage is likely to be a result of the observed differences in storage forms and systems in use and pest management practices in Gulu, when compared to Apac and Lira (Figs 6, 7, Table 8). In Gulu the commonest form of storage is pod in pod form within reed woven granaries, while in Apac and Lira, storage was in the threshed form and seeds kept in gunny sacks. Though some farmers in Apac and Lira seemed aware of the benefits of pod-storage, it is thought that it was not practised due to the labour involved during pod harvest. In addition to this, traditionally, sealed storage was considered a good control strategy in these districts, although the practice is not widespread.

In cowpea, it has been shown by Caswell (1975) that where pod storage is practised, low pest infestation occurs. This is because some first instar larvae either fail to locate a seed or they find the shell too thick or hard for penetration and consequently infestation builds up rather more slowly on pod stored cowpea than threshed cowpea (Caswell, 1975). This was illustrated on cowpea, where within a period of 2 months only, pest population in threshed seeds increased by a factor of 10 while in pod storage, the population increased by a factor of only 2 (Caswell, 1975). Similar factors may therefore be responsible for the low damage observed in areas where pod storage is practised.

2.4.2. On-farm survey of farmers' practices and perceptions on pest damage

a. Production profile

The survey has shown that in northern Uganda, pigeonpea is still the major legume grown. The three districts, Apac, Gulu and Lira, that were surveyed are among the areas with the greatest concentration of the crop (Jameson, 1970). The survey confirms earlier reports that pigeonpea is mainly inter-cropped with millet (Jameson, 1970). Such an inter-crop is a

result of growth compatibility in which the initial slow growth of pigeonpea is needed for the benefit of the fast-growing cereals such as millet and sorghum (Lawn and Treadson, 1990).

Mean hectarage per farmer under pigeonpea is still very low (0.44ha), which is a reflection of the subsistence nature of pigeonpea cultivation (Chauhan, 1990). Most of the farmers who grow pigeonpea in both Asia and Africa are resource-poor subsistence farmers and their target is mainly to meet household food requirements and other domestic needs as well as to have marketable surplus if possible (Treadson *et al.*, 1990).

During the surveys, farmers indicated that March is the major sowing period for pigeonpea. This confirms the findings of Jameson (1970). The timing coincides with the on-set of the long rains which favours the initial slow growth rate of pigeonpea (Sheldrake and Narayanan, 1979).

Farmers indicated that certain pigeonpea characteristics are generally sought after. These are, in order of priority, high yield potential, early maturity, quick cooking/better storage and white or cream colour. In the pigeonpea production systems, especially in situations common in subsistence agriculture, farmers on their own have not had access to a wide enough genetic base to select for most of the desired traits. This is compounded by the low research emphasis on the crop in the past, whereby, selection and breeding for these traits have been very recent (Swindale, 1990).

b. Field pests

According to farmers, field pests on pigeonpea are very serious, and this is also true in all pigeonpea production systems (Reed and Lateef, 1990). Like elsewhere (Reed and Lateef, 1990) the most damaging pests, as reported by farmers in Uganda (Fig. 3), are those that feed on flowers and pods. According to farmers, the most serious of these are pod borers

(*H.armigera*), pod sucking bugs (*Clavigralla* sp. etc.) and flower beetles (*P. sinuata* and *Mylabris spp.*). With the exception of *P. sinuata*, all other pests have been recorded as serious pests in many other pigeonpea growing areas (Reed and Lateef, 1990).

Most of the farmers did not associate the incidence of field pest damage to the eventual storage pest infestation and damage (Fig. 4). Some farmers (30%) however, felt that an increase in field pest damage is often followed by increased storage damage. No pest species was however identified whose incidence is associated with increased storage damage. Such a relationship has not been indicated in the available literature.

c. Post production system

Pigeonpea is harvested in October/November (medium-duration genotypes), and January/February (long-duration genotypes). The timing of harvest coincides with the long dry spell that prevails in Uganda and is more pronounced in the north of the country, which is most favourable for field and post-harvest drying of the crop.

The average grain yields on subsistence farms in Uganda were found to be very low (0.4t/ha) as compared to the very high yields (2-4t/ha) obtainable from experimental plots (Musaana, 1978) (though the latter is for monoculture). The main reasons for low yields on farmers' fields are thought to be the use of traditional unimproved long-duration landraces (8-10 months duration) which have low yield potential, high susceptibility to diseases and pests, and a narrow genetic base (Nahdy *et al.*, 1992).

The methods of pigeonpea harvest ranged from breaking the stem of the whole plant (Apac and Lira) to directly picking individual pods (Gulu) (Fig. 5). These methods of harvest are directly linked to forms and methods of storage of the crop. Where whole plant harvest is done, storage is of seeds after threshing, and where pod harvest is practised storage is mostly on the pods (Fig. 6). Where seed storage is done, this is mainly in gunny bags

situated in-doors and on rare occasions, in sealed mud/straw indoor traditional stores. Where pod storage is done, however, storage is in tightly woven reed basket granaries (Fig.7).

Storage of bulky commodities (unthreshed legume pods and cereals) in Uganda is associated with outdoor reed basket granaries or large mud/straw/reed granaries. The most important reason for such an association was reported to be lack of storage room indoors and that the bigger bulk of unthreshed discouraged thefts (Silim *et al.*, 1990). In some instances this form of storage was reported to have reduced damage due to pests (Silim *et al.*, 1990).

The harvested crop is used for household food, some reserved for seed, and the excess sold. The use of pigeonpea in Uganda conforms with the subsistence nature of its production and is similar to most other pigeonpea producing countries (Treadson *et al.*, 1990). Since pigeonpea is harvested only once a year, the crop has to be stored until the next harvest or until time of planting (Fig. 8). Due to various reasons, shortages between harvests occur, thus reducing storage duration considerably, but typical maximum storage periods range between 7 and 12 months.

During storage, farmers are mostly concerned about bruchid damage and are acutely aware of the relationship between the extent of damage and period of storage (Fig. 8 & 10). In most stored food commodities such relationships have been established by several workers (Caswell, 1959, 1968, 1973; Singh and Jambunathan, 1990; Silim *et al.*, 1990). The rates of damage were, however, variable. This variation was closely linked to form and methods of storage. In Apac and Lira for example, where seed storage is mostly practised, damage was reported as severe after only 4-6 months of storage. Where pod storage is mostly practised, as in Gulu, damage was considered slight even after 9 months.

In order to reduce bruchid damage in pigeonpea, farmers attempt various pest management strategies (Fig. 11). These include admixture with ash and red pepper (*Capsicum spp*), solar heating, pod storage, insecticide admixture, seed roasting and use of sealed mud/straw storage. Some of the strategies used by farmers in Uganda have been reported for various crops and in a number of countries. Those reported include pod storage in a number of countries in West Africa (Caswell, 1968, 1973) and Uganda (Silim *et al.*, 1990) for cowpea, admixture of various seeds with ash in various countries in West Africa and East Africa (Caswell, 1975; Giga *et al.*, 1992) and seed splitting of pigeonpea coupled with admixture with oils in India (Singh and Jambunathan, 1990). In Uganda mixing legumes with whole red pepper as well as solar heating have also been reported (Silim *et al.*, 1990). Sealed mud-bin storage has been reported in West Africa (Caswell, 1975) and in Uganda (Davies, 1970). No record of seed roasting to control storage pests are available.

The most effective bruchid management technique among the traditional methods was reported by most farmers to be pod-storage (Table 8). Similar observation has been made by Caswell (1975) in West Africa where cowpea is stored on the pod. The remaining methods of pest management used by farmers were reported to be moderately to only slightly effective.

Other pigeonpea bruchid management methods which farmers know about, including the addition of plant parts and products (e.g. tobacco and aromatic plants), have been reported previously on other legumes in Uganda (Silim *et al.*, 1990) and Tanzania (Giga *et al.*, 1992). Tobacco is known to contain nicotine which has been shown to have insecticidal properties. Literature on insecticidal properties of aromatic plants are few, but aromatic plants are generally believed to have only repellent properties. The use of and efficacy of insecticidal admixture on most cereals and pulses in Africa has been most widely reported (McFarlane, 1969; Caswell, 1975; Taylor, 1981; Giga and Biscoe, 1990; Silim *et al.*, 1990;

Giga *et al.*, 1992).

Some of the methods used by farmers are, however, employed only on seeds with specific end-uses, or only infrequently practised, if at all, for reasons other than their efficacy (Table 9). Ash, for example, is reportedly good for seeds meant for sowing only and roasting alone can be done for seed meant for food. In the case of ash, this is most probably due to the need for large quantities required, which is difficult to clean later (especially if meant for marketing). In the case of roasting, the process would most likely kill seeds as well. Other methods are reported to irritate sensitive organs (hot pepper) are inconvenient (sealed and pod storage), or unavailable and/or expensive (commercial insecticides). Many farmers are also doubtful of the efficacy of some of the above management methods, i.e. sunning, red pepper, pod storage and sealed storage.

In the absence of safe, readily available and affordable chemicals for pest management, heavy damage in stored produce will continue. There is, therefore, an urgent need to focus and intensify studies into alternate pest management options that are safe, affordable, relatively effective, convenient to use and sustainable in the long run in order to save farmers' crops from damage and losses.

d. Marketing

The results of the survey showed that pigeonpea is an important crop both for household consumption and marketing (Fig. 13). The quantity of the crop marketed is however very variable. This is probably dependent on various factors among which size of harvest, size of family, family cash needs and amounts of other crops grown are significant.

The greater bulk of pigeonpea marketing is done in village markets. These are monthly or bi-monthly markets which are often less than 15 km from the household. They are

therefore within easy reach of the farmers who carry small quantities of produce on bicycles or as headloads. They are also situated along major trunk roads and are thus easily accessible to town traders who use bicycles and pickups to bring in mixed goods and take out mainly agricultural produce, and at times, animals.

Marketing of pigeonpea starts soon after harvest and continues in a few instances to the next harvest (Fig. 14). Almost all farmers sell some of their pigeonpea soon after harvest, and this is mainly due to the need for immediate cash. Such heavy selling at this period has been reported for most agricultural produce in Uganda (Silim *et al.*, 1990). This, as with pigeonpea, is to meet the needs of the cash strapped peasant farmers at such times when school fees are needed, poll tax is due and money needed for Christmas festivities and many other family needs (Silim *et al.*, 1990).

The reasons for the timing of the subsequent marketing schedules by farmers are several (Fig.15). The most consistent are fear of storage pest damage, better prices and immediate financial needs, respectively. This agrees with previous studies in Uganda which gave similar reasons for the timing of sales for various grains by farmers (Silim *et al.*, 1990).

Supply and demand factors play very significant roles in pigeonpea price fluctuations (Appendix XIII). Very early sales of medium-maturity genotypes in Apac and Lira do benefit from higher prices, but early sales of the long-maturing genotypes in Gulu, harvested on average 2 months later, do not benefit from higher prices. It indeed, dampens market prices through over-supply by adding more pigeonpea to the supply from Apac and Lira. The prices are best at late sales in all cases due to reduced supplies in markets.

The above fluctuation in price is however dependent on certain quality parameters of pigeonpea (Fig. 16). These include the extent of bruchid damage, seed colour and to a lesser extent size of seed.

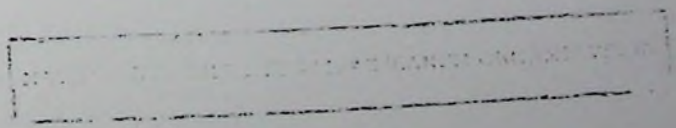
The most important price determinant is however the degree of seed damage by bruchids (Fig. 17). Over time and as market supply of pigeonpea dwindles, so prices increases. These price booms, however, disappear with increased damage by bruchids.

Before the end of any storage season, a farmer's own pigeonpea supply is often exhausted. In such cases farmers may harvest green pigeonpea, purchase from the market, barter them with other crops, use substitutes, borrow pigeonpea or work for pigeonpea (Fig. 18).

Although there are many other factors farmers often consider before any particular pigeonpea is purchased for food or seed (seed colour, seed size and cost price), the survey shows that there is a very strong relationship between price/value and bruchid damage (Fig.19).

The heavily damaged pigeonpea may, however, not be considered a total loss (Fig. 20). Most often these are ground and made in to a paste for sauce, at worst, damaged seeds are fed to chicken and thus providing a source of protein.

It is, therefore, clear that unless a farmer can protect his seeds from bruchids, long term storage is not possible and the benefits of higher prices in later sales are not attainable due to heavy bruchid damage.



CHAPTER 3. BIOLOGY AND HOST PLANT RELATIONSHIP

3.1. Introduction

In grain legumes, field infestation and damage by bruchids are generally low, but this nevertheless results in high damage and losses during extended storage (Taylor, 1981).

In pigeonpea, the information available indicates that *C. chinensis* does infest pigeonpea in the field (Bridwell, 1918). The level and mode of field infestation as well as factors influencing such infestation have, however, not presently been investigated. These needed to be investigated if a comprehensive IPM package is to be developed.

The objective of this study was to determine the importance of field infestation of pigeonpea by bruchids and factors influencing such infestations in order to derive management packages that include field interventions.

This involved:

- collection of field samples to determine the nature and extent of field infestation;
- field and laboratory investigations to determine the relative susceptibility of different
  pod developmental stages; and
- laboratory investigations to determine effect of physical pod characteristics on infestation.

3.2. Materials and methods

3.2.1. Surveys of natural field infestation of pigeonpea pods by bruchids

Field sampling

Surveys were conducted during the pigeonpea harvest period in the districts of Apac (October), Lira (October) and Gulu (January). Five to six pigeonpea fields were randomly selected from three representative counties within each district. Samples per district totalled fifteen altogether. A sample of pigeonpea pods weighing 4-5kg were hand picked from various points within the field. Each sample was divided into three batches (A, B and C), two (A and B) of 1kg each and one (C) of 2kg by coning and quartering.

a. Magnitude of field infestation

The magnitude of field infestation was determined from both pod-stored and seed-stored pigeonpea using the two 1kg batches (A and B) from above. The first batch (A) was stored on the pod and the second batch (B) shelled by hand and stored as seed. These respective samples were placed in cloth bags and incubated for 60 days at ambient temperatures (23-26°C) and emerged adults counted. The data for adult emergence from pods and seeds were compared using the one-way analysis of variance.

b. Effect of field pod damage on *C. chinensis* infestation

The effect of field damage and field pest infestation on bruchid infestation in storage was investigated using the 2kg of pods from the third batch (C).

Pods were first sorted into five physical categories namely; undamaged, pod fly damaged, *H. armigera* damaged, pod bug damaged/shrivelled or physically damaged (split, broken). The sorted pods were shelled separately and weighed. The weights of seeds in each category were standardised to 40g (this was the weight of the smallest category) by coning

and quartering. The samples were incubated for 60 days in glass jars under ambient conditions (about 23-26°C) and emerged adults counted. Comparison of adult emergence was performed using one-way analysis of variance and the treatment means were separated using Duncan's multiple range test.

3.2.2. Artificial infestation

Insects used

All investigations were conducted using *C. chinensis* adults cultured in the laboratory under ambient conditions. In all cases 2-day old adults were used to get maximum oviposition. Sexing was done using the antennal shape, which is serrate in the females and pectinate to very strongly pectinate in males (Southgate, 1958).

Pigeonpea used

In all the trials, the medium-duration local pigeonpea land-race "Apio-Elina" originating from Lira/Apac was used, unless otherwise stated. All the pods and seeds used were grown within Kawanda Agricultural Research Institute 12km north of Kampala (0.4°N, 32.5°E and about 1150m altitude).

a. Relative susceptibility of pigeonpea pod developmental stages to *C. chinensis* infestation

Pigeonpea pod developmental stages

For the purposes of this study, different pigeonpea developmental stages were used. The pod developmental stages were classified into seven categories (Fig. 21), on the basis of physical characteristics such as pod maturity and colour, and stage of seed formation.

For the purpose of repeatability, in each pod developmental stage the time taken from flower opening to the respective pod stage was recorded and graphically presented. In

ıddition to the above. a two stage moisture content (MC) and dry matter content (DMC) letermination was undertaken at each stage using the oven-drying method (pods inclusive ɔf seeds). This was done by placing the sample in small. well covered tins and initially drying (preconditioning) the weighed sample in the oven at 130°C for 10 minutes. Leaving the sample covered. the sample was weighed and thereafter ground to smaller particles. A single stage moisture content determination was conducted on the ground sample by drying it in the oven at 130°C for 2 hours. after which the sample, still within the tins. was placed within a desiccator to cool for 45 minutes and re-weighed. The percentage weight loss of the sample during the drying procedure represented the %MC. while the final weight after drying represented the DMC. The data obtained were graphically presented.

The pod developmental stage description based on physical characteristics were coded as follows:

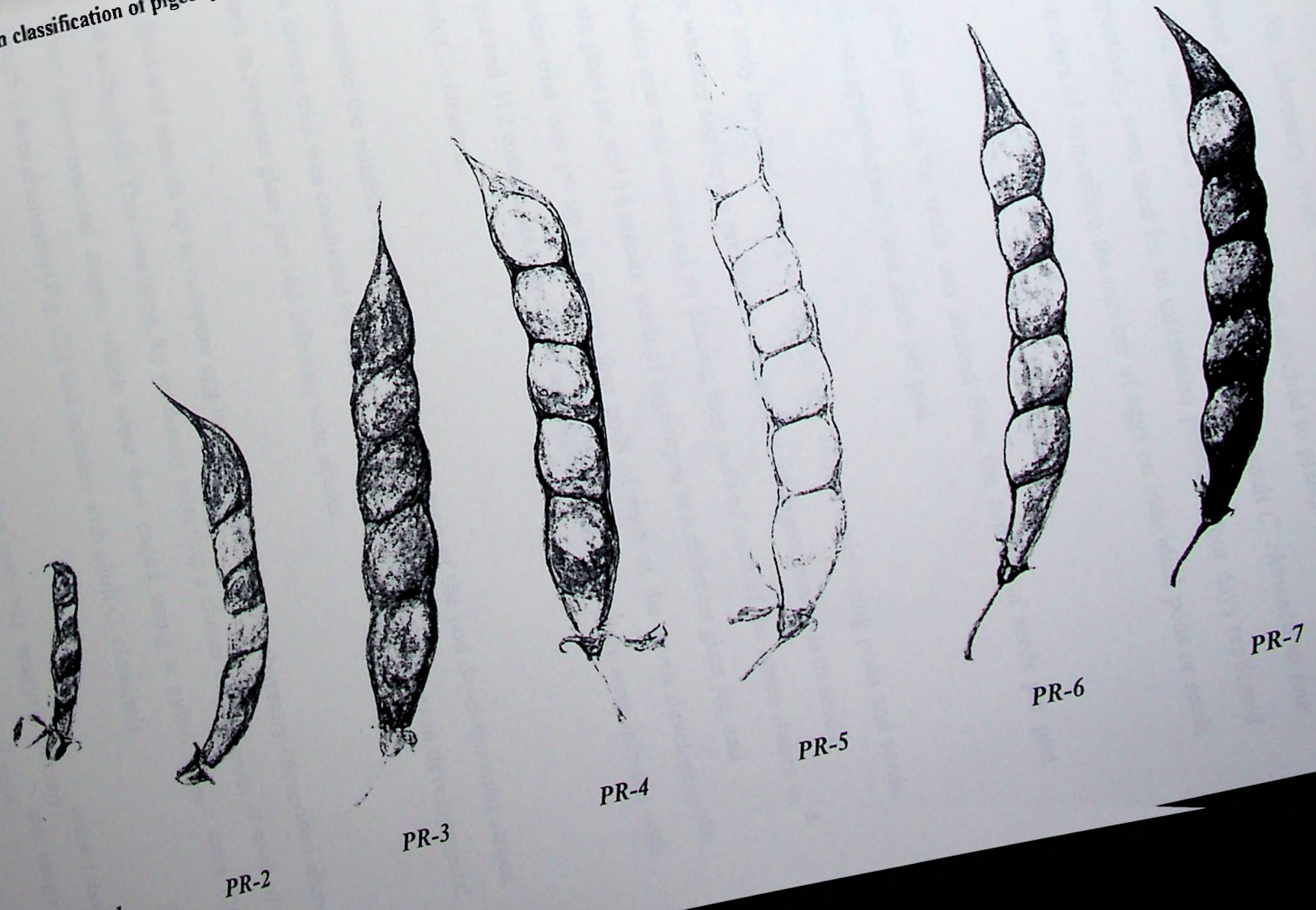
Pod developmental stage	*Coding*
Pod just forming	PR-1
Early pod fill	PR-2
Late pod fill	PR-3
Mature green pod	PR-4
Mature yellow pod	PR-5
Mature dry pod "early"	PR-6
Mature dry pod "late"	PR-7

i. Substrate preferences for egg laying

Investigations were conducted to compare the egg laying preferences of *C. chinensis* given. a) mature seeds and pods. and. b) pods at the seven developmental stages. These were done both under laboratory and field conditions.

Eighty pods at each of the above seven developmental stages were selected for the study.

Fig. 21. The seven classification of pigeonpea pod developmental stages used in the study



Sixty were harvested for laboratory tests, and the remaining 20 caged for field investigations using sleeve cages (Fig. 22) with pods attached to plants. In all the trials, a ratio of five pairs (i.e. five males and five females) of 2-day old adult *C. chinensis* to four pods or 16 seeds respectively, were used for an infestation period of four days replicated five times. After four days of oviposition the number of eggs on individual pods or seeds were counted.

The number of seeds used in the trials was derived from the number of seeds per pod, which in this case was approximately four seeds per pod.

The laboratory study involved setting 'no choice' and 'choice trials' using pods and seeds. To determine whether egg laying preference was greater for pigeonpea pods or seeds;

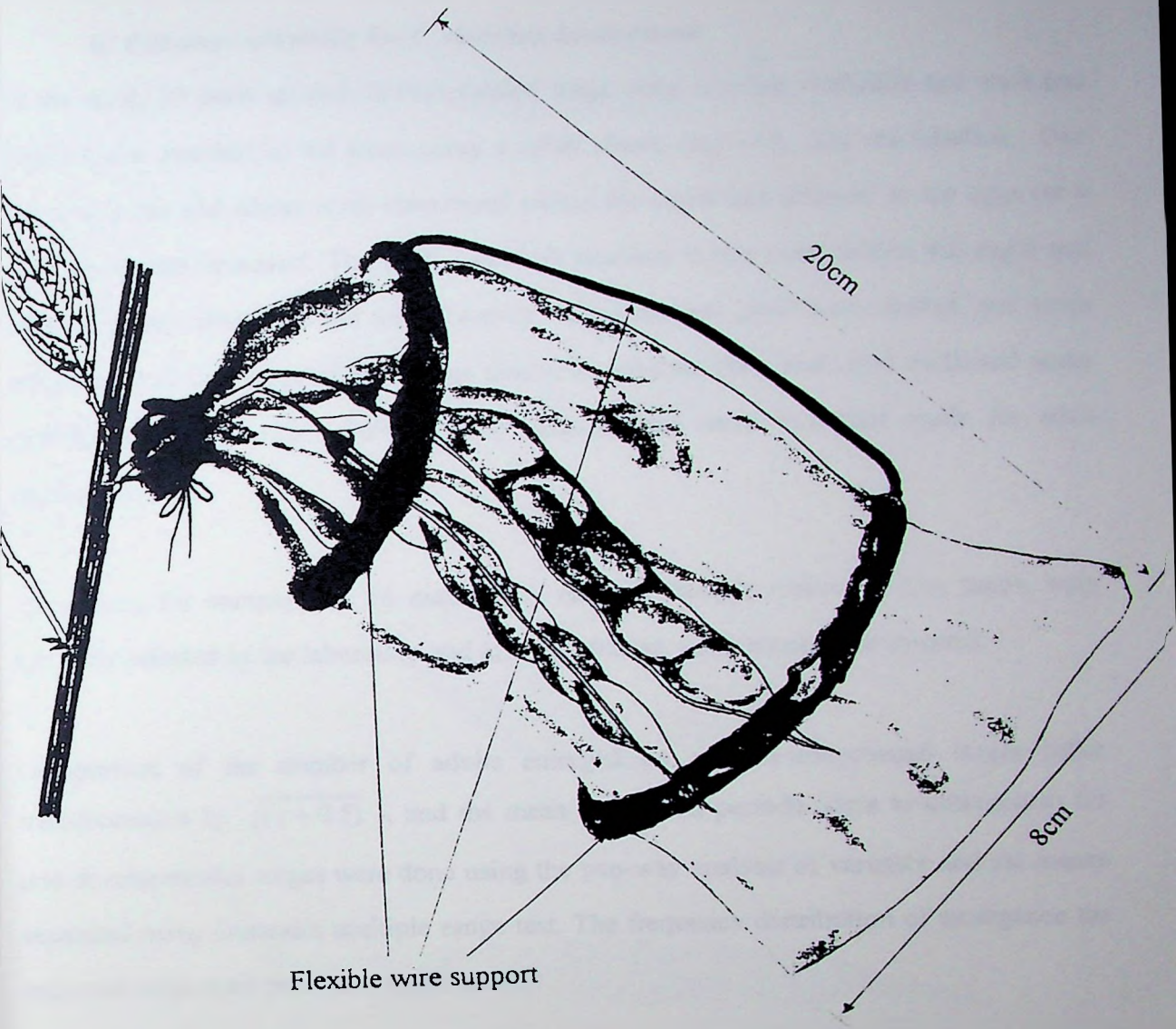
a) a no choice trial was conducted by placing four pods of each of the seven stages in a separate glass jar, and 16 mature seeds of pigeonpea in a different glass jar, and
b) a choice trial was set up by mixing four pods of each of the seven developmental stages and 112 mature seeds within a single glass vial. Both trials were infested with adult *C. chinensis*.

To determine the relative egg laying preference for each of the pod developmental stages, a 'no choice' trial was conducted by placing four pods, at each of the seven developmental stages, in separate glass jars and infesting with adults.

A field trial was set up to compare egg laying capacity in the laboratory (described above) and in the field. This was done, by randomly selecting a cluster of four pods at each of the seven developmental stages, which were then caged using a nylon sleeve cage (20cm length x 8cm diameter) (Fig. 22) and infested with adult *C. chinensis*.

The oviposition results were compared using two-way analysis of variance (choice and oviposition substrate) and the means were separated using Duncan's multiple range test.

g. 22. Diagram of sleeve cage used for deliberate *C.chinensis* infestation of pigeonpea pods in the field.



ii. Pod stage suitability for *C. chinensis* development

In the field, 20 pods at each developmental stage were selected randomly and each pod caged while attached to the plant using a nylon sleeve cage (Fig. 22) and labelled. Two pairs of 2-day old adults were introduced within the cages and allowed to lay eggs for 4 days only, then removed. The pods were left attached to the plant within the cages and harvested only after they had turned brown. After harvest, pods were shelled, and seeds obtained from four pods of each stage placed in separate glass vials and incubated under ambient conditions (23 - 26°C). Daily examinations were thereafter made for adult emergence.

As a basis for comparison, 16 mature dry seeds (13%MC) replicated five times, were similarly infested in the laboratory and after incubation, adult emergence counted.

Comparison of the number of adults emerged on pod developmental stages (after transformation by $\sqrt{(x+0.5)}$), and the mean incubation periods (days to emergence) for pod developmental stages were done using the two-way analysis of variance and the means separated using Duncan's multiple range test. The frequency distribution of emergence for each pod stage were presented graphically.

b. Effect of physical surface characteristics of mature pods on *C. chinensis* fecundity and infestation

Studies were conducted on six different physical pod features (Fig. 23) to determine their effect on infestation *viz;*

a) Normal pods (with stipes)

b) Non-hairy pods

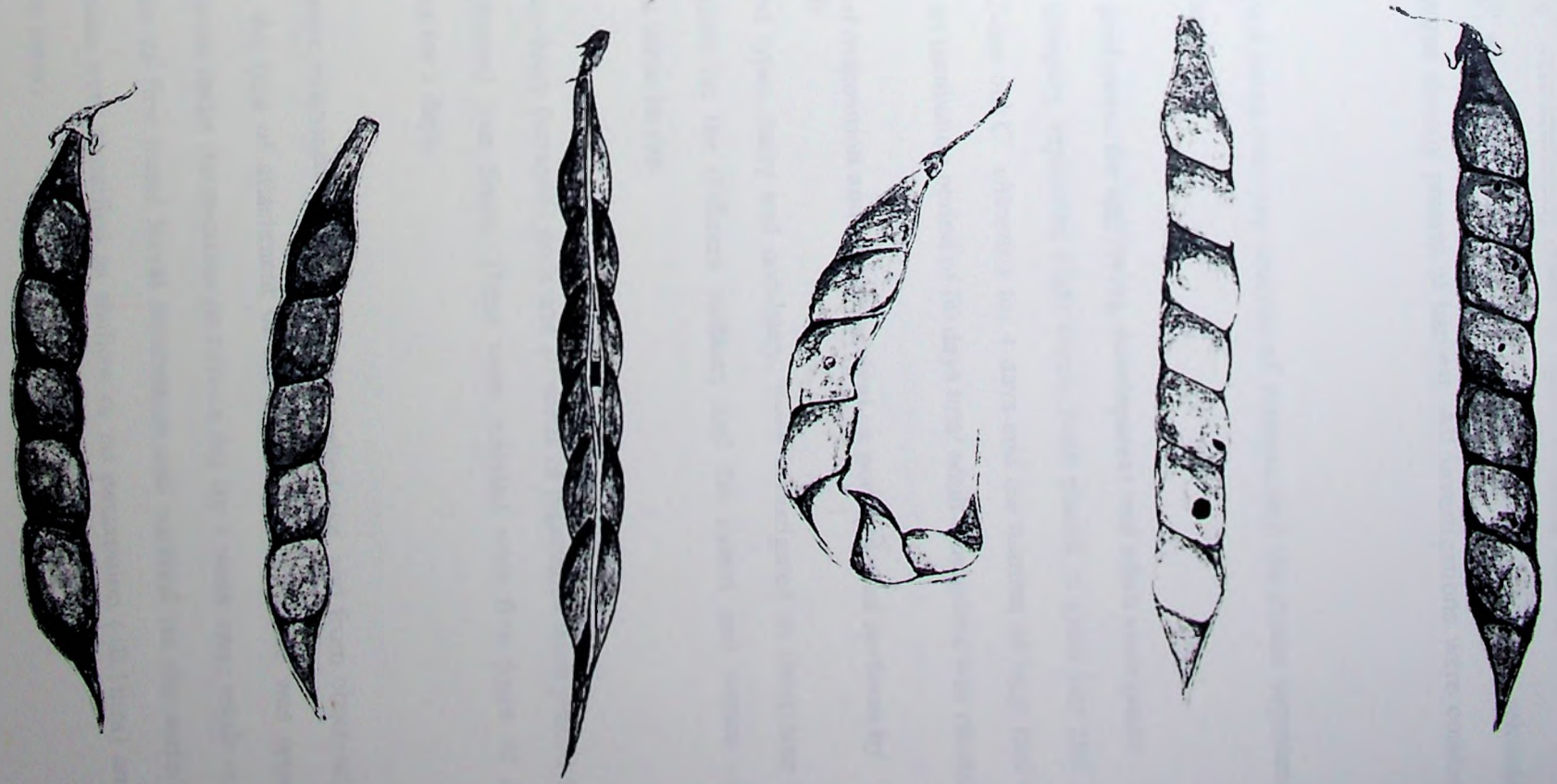
c) Pods without stipes

d) Partially dehisced pods

e) Pods with one *H. armigera* hole

f) Pods with pod fly holes.

Fig. 23. Physical pod characteristics of pigeonpea investigated for *C.chinensis* infestation



Normal pod

Pod without stipe

Partially dehisced pod

Pod sucking bug damage

Pod with H.armigera holes

Pod with podfly holes

Categories "b" and "c" were artificially made by lightly scraping hairs in "b" and breaking the stipe stem in "c" respectively. All the other categories of pods were selected with desired physical features already present at harvest. All investigations were conducted at the PR-7 pod stage.

All data were analysed using one-way analysis of variance and the means separated using Duncan's multiple range test.

i. Pod type preference for egg laying, development and adult emergence

Five pods of each category, replicated eight times, were placed in glass jars and infested with five pairs of 2-day old *C. chinensis* for 4 days and the number of eggs laid on pods determined. After an incubation period of 60 days total adult emergence was recorded.

ii. Nature of oviposition and larval survival on pod and seed surfaces by *C. chinensis*

Seeds and two pod types, hairy and non-hairy, were investigated to determine both the nature of oviposition on the different surfaces and the extent and nature of surface penetration by first instar larvae.

Five hairy, five non-hairy (scraped) pods and 20 seeds of pigeonpea were placed separately in glass jars replicated four times. These were infested with five pairs of 2-day old *C. chinensis* adults for 3 days.

Pods and seeds were examined for eggs using the naked eye, and from observations under the microscope, the type of attachment of the eggs to the substrate was recorded. Pod surface examinations under the microscope twice a day for 1 week were made to record the nature and extent of first instar larval penetration and survival on the surfaces, if any. Surface penetration were classified as shallow or no penetration (<0.1mm) and deep but unsuccessful (>0.1mm).

The pods and seeds were thereafter incubated for an additional 35 days and the number of adults emerged counted, in the case of pods this was done before and after pod shelling.

3.3. Results

3.3.1. Surveys of natural field infestation of pigeonpea pods by bruchids

a. Magnitude of field infestation

All the bruchids that emerged from samples collected in the field were identified as *C.chinensis.*

Adult emergence was four times greater from seed-stored pigeonpea than from pod-stored pigeonpea ($P < 0.05$) (Table 10).

The differences in adult emergence among the three districts in both pod-stored and seed-stored pigeonpea (Table 10) were not significant ($P>0.05$).

b. Effect of field pod damage on C. chinensis infestation

As in the above study, the only bruchid that emerged from seeds derived from pods with different damage symptoms were identified as *C. chinensis.*

There was a significant difference ($P<0.05$) in adult emergence in seeds from pods with the different injury symptoms (Table 11). The highest emergence was observed in seeds whose pods had previously been injured by *H. armigera* and by splitting or breaking. Low emergence were recorded in seeds from undamaged and podfly damaged pods and the lowest emergence was recorded from shrivelled pods (Table 11).

Table 10. Mean no of adults of C. chinensis *emerged per sample of pods (1kg) or seeds (shelled from 1kg of pods) stored pigeonpea harvested from Apac, Gulu and Lira*

District	Pod storage	Seed storage
Apac	1.60 (0.38)	7.9 (0.87)
Gulu	1.57 (0.33)	7.8 (0.87)
Lira	1.90 (0.30)	8.2 (0.78)
Mean	1.69	6.94

1. In brackets are standard errors (se)

Table 11. Mean no of adults of C. chinensis *emerged from seeds (40g) of pigeonpea with pods previously showing various types of field damage*

	Nature/source of field damage seen on pods				
	Undamaged	Pod fly damaged	*H. armigera* damaged	Pod bug damaged or shrivelled	Split/broken pods
Mean emergence	2.5BC	2.9BC	5.30A	1.50C	4.17AB
Least Significant Difference (LSD) = 2.2					

Means followed by the same letter are not significantly different at P=0.05 by Duncan's Multiple Range Test

3.3.2. Artificial infestation

a. Relative susceptibility of pigeonpea pod developmental stages to *C. chinensis* infestation

Pigeonpea pod developmental stages

Using the days after flower opening as an index for the estimation of the various pod developmental stages, it was determined that, from flower opening, pod development stage PR-1 was achieved 12 days after flower opening, and pod development ended at pod stage PR-6, 50 days later (Fig. 24). There was a gradual rise in DMC with a corresponding fall in % MC as pods developed from PR-1 to PR-7 stages (Fig. 25).

i. Substrate preferences for egg laying

The mean number of eggs laid on seeds was significantly higher than on pod surfaces ($P<0.05$) (Table 12).

Pod developmental stages affected egg laying by *C. chinensis* significantly ($P<0.05$). There was a progressive increase in the number of eggs laid at later developmental stages, reaching l a maximum when mature pods were yellow (stage PR-5) (Fig. 26).

Given pods alone, irrespective of whether the trials were conducted under field or laboratory conditions, the number of eggs laid per treatment were not significantly different ($P>0.05$). In the laboratory, however, significantly more eggs were laid on pods where there was no choice for pod developmental stage than where there was choice (Table 12).

Given both pods and seeds, in both the choice and no choice trials, significantly more eggs were laid on seeds than on pods (Table 12).

Fig. 24. Time taken (days) for each of the developmental stages after flower opening

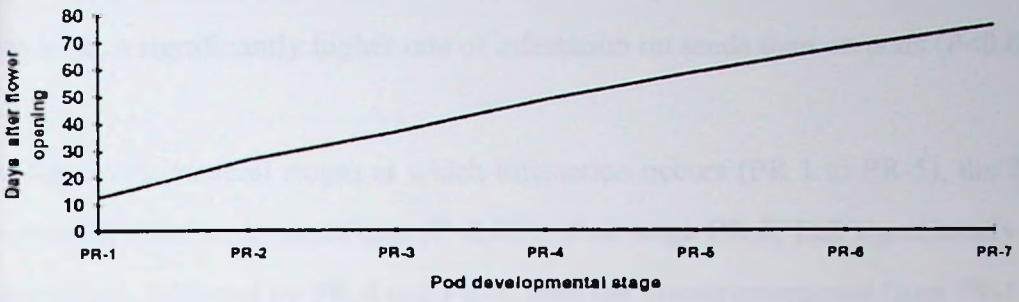


Fig. 25. Dry matter content (g) and moisture content (%) of pigeonpea at different pod developmental stages

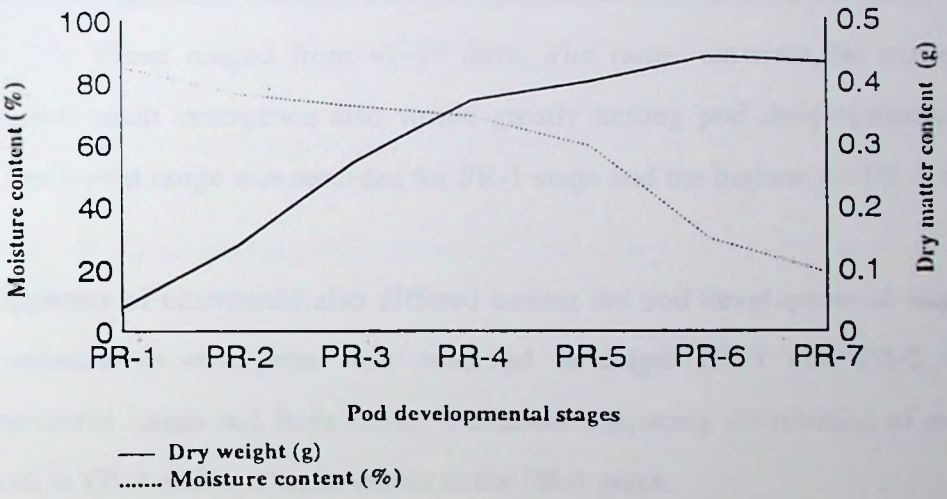
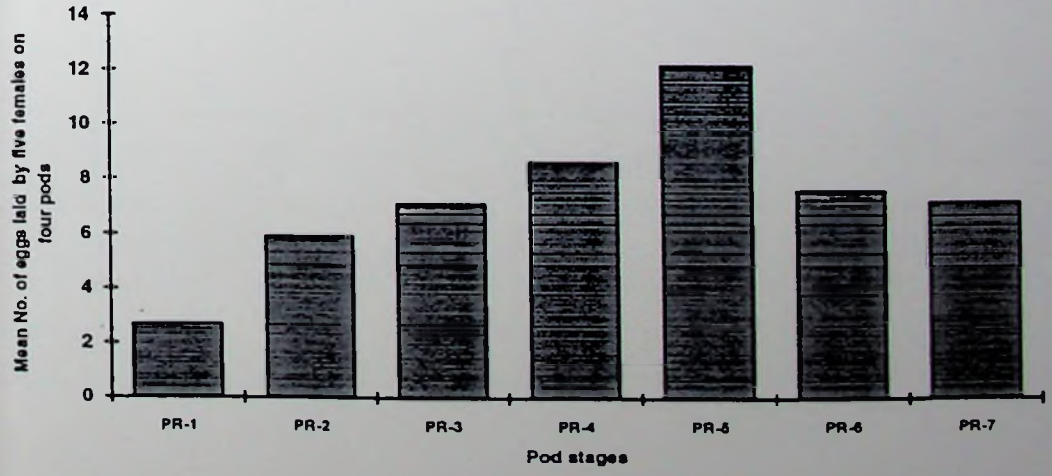


Fig. 26 . Mean number of eggs laid on four pods by C.chinensis at successive pigeonpea pod developmental stages



ii. Pod stage suitability for *C. chinensis* development

The results of artificial field infestation (Table 13) indicate that *C. chinensis* can infest and develop in all pod pigeonpea developmental stages except PR-6 and PR-7. There was, however, a significantly higher rate of infestation on seeds than on pods ($P<0.05$).

At the developmental stages at which infestation occurs (PR 1 to PR-5), the differences in pod infestation were significant ($P<0.05$). Pod stage PR-3, had significantly higher adult emergence, followed by PR-4 and PR-5, with the lowest emergence from PR-1 and PR-2.

There was a significant variation in mean incubation periods from the different pod stages (Table 13). These ranged from 42-45 days. The range between the earliest and latest *C. chinensis* adult emergence also varied greatly among pod developmental stages (Fig. 27). The lowest range was recorded for PR-1 stage and the highest for PR-3 stage.

The frequency of emergence also differed among the pod developmental stages (Figs 28). Less variation in emergence was observed in stages PR-1 and PR-2 than in later developmental stages and from seeds. A bimodal frequency distribution of emergence was observed in PR-4 and to a lesser extent in the PR-3 stage.

Table 12. Mean number of eggs laid under laboratory (no-choice and choice) and field (no choice) conditions on pods and seeds

	Laboratory					Field
	No choice		Choice			No choice
	Means for pods at all developmental stages separately	Seeds alone	Pods of all developmental stages mixed	Pods + seeds of all stages		Mean for Pods at all developmental stages (separately)
	Pods	Seeds	Pods	Pods	Seeds	Pods
Mean No. of eggs laid per pods or 16 seeds	18.7C	58.1A	6.6D	1.8D	38.9B	18.2C
Least Significant Difference = 8.5						

Means followed by the same letter are not significantly different at P=0.05 by Duncan's Multiple Range Test

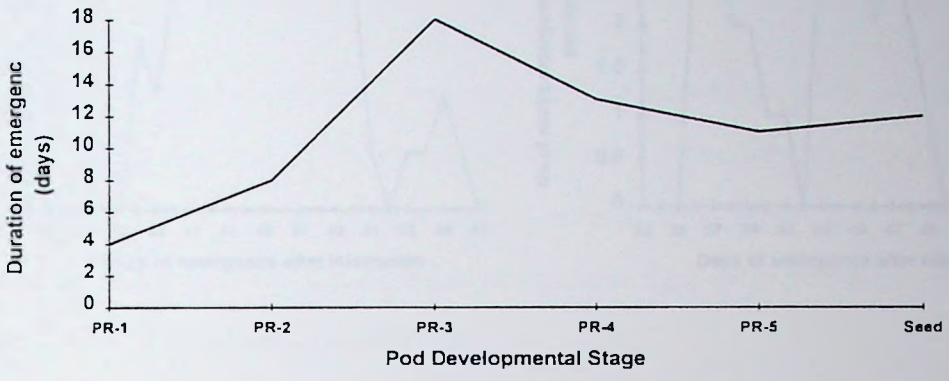
Table 13. Mean developmental period of C. chinensis *and numbers of adults emerged from four pigeonpea pods infested at different developmental stages*

Pod stage	Mean incubation period (days)	Mean number of adults emerged
PR-1	45.09A	0.55D (0.92)**
PR-2	44.69AB	0.65D (0.98)**
PR-3	45.08A	3.10B (1.66)**
PR-4	42.16AB	1.60BC (1.35)**
PR-5	41.97B	1.45CD (1.24)**
PR-6	-	0.00
PR-7	-	0.00
From 16 mature seeds	38.30C	32.30A (6.51)**
Means (PR-1 to PR-5)	43.80	1.47
Least Significant Difference	2.90	(0.356)**

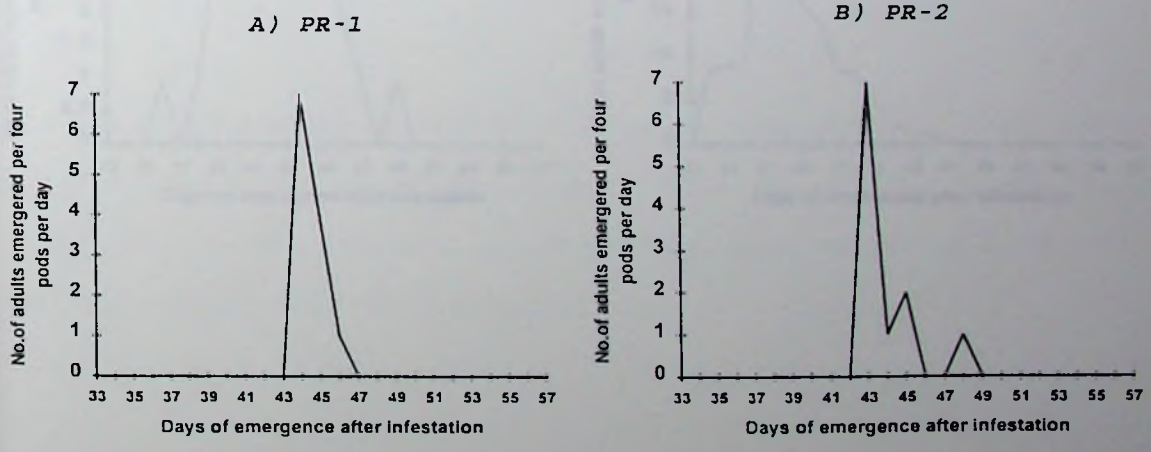
**Data transformed by $\sqrt{(x+0.5)}$, but for clarity means are presented both as untransformed and transformed.

Means followed by the same letter are not significantly different at P=0.05 by Duncan's Multiple Range Test

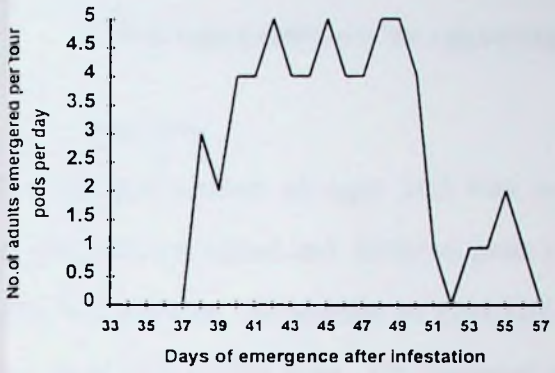
Fig. 27. Duration (days) from first to last adult C.chinensis emergence from pods infested pigeonpea at different developmental stages



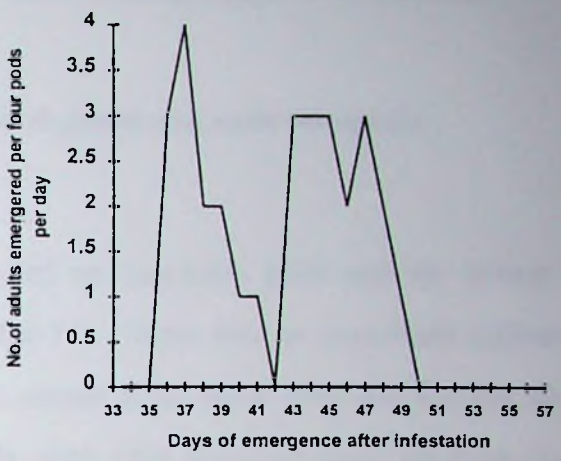
Figs 28. Frequency distribution of emergence of C. chinensis *from pigeonpea pods infested at different developmental stages and from mature seeds*



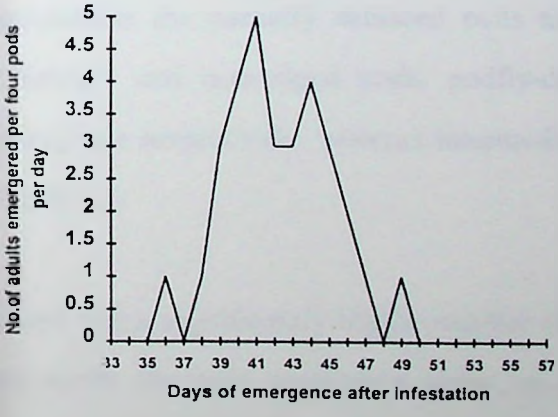
C) PR-3



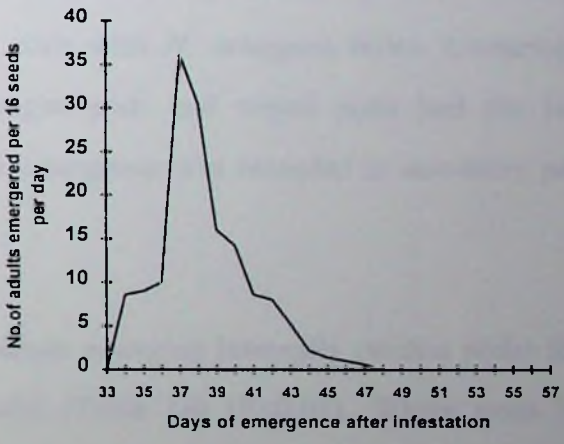
D) PR-4



E) PR-5



F) Mature seed



b. Effect of physical surface characteristics of mature pods on *C. chinensis* fecundity and infestation

i. Pod type preference for egg laying, development and adult emergence

Egg laying

The highest number of eggs laid was recorded on non-hairy pods and the lowest on *H. armigera* damaged and dehisced pods (Table 14). There was no significant difference ($P>0.05$) between the number of eggs laid on normal pods, those with and without stipes and pods with podfly hole. On damaged pods, most eggs were laid direct on seeds, as in dehisced and *H. armigera* damaged pods.

Development and adult emergence

The effect of the different physical pod characteristics on *C. chinensis* larval development and eventual adult emergence was significant ($P<0.05$) (Table 15).

The highest infestation and emergence were recorded in pods with previous damage, particularly the partially dehisced pods and pods with *H. armigera* holes. Undamaged (Normal), and non-stiped pods, podfly-damaged pods and stiped pods had the least emergence respectively, whereas intermediate emergence was recorded in non-hairy pods (Table 15).

There was a significantly higher number of adults emerging internally (within pods) than externally (through emergence holes on pods) (Table 16) ($P<0.05$). Where pods had external injury (by dehiscence or *H. armigera* damage), adults emerged internally but later found their way through the cracks or holes on pods.

Pod types	Normal pods	Non -hairy pods	Pods without stipes	Dehisced pods	With *H. armigera* hole	With podfly holes
Mean number of eggs laid on five pods	4.9B	11.5A	3.9B	0.5C (53.2*)	0.4C (61.1*)	4.5B

Analysis was done after transformation of data using the formula $\sqrt{(x+0.05}$, but for clarity, means are presented untransformed.

* Eggs laid direct on seeds.

Means followed by the same letter are not significantly different at P=0.05 by Duncan's Multiple Range Test

Table 15. Mean number of adult* C. chinensis *emerging from pigeonpea pods with different physical features

Pod types	Normal pods	Non Hairy pods	Pods without stipes	Dehisced pods	With *H. armigera* hole	With podfly holes
Total Adult Number	1.2C	4.0B	1.2C	40.3A	52.0A	1 .3C

Analysis was done after transformation of data using the formula $\sqrt{(x+0.05}$, but for clarity, means are presented untransformed.

Means followed by the same letter are not significantly different at P=0.05 by Duncan's Multiple Range Test

Table 16. Mean number of adult **C. chinensis** *emerging externally (1) and internally (2) from within pigeonpea pods*

Pod type	Normal Pods		Non-hairy Pods		Pods without stipes		Dehisced pods		Pods with *H. armigera* hole		Pods with podfly holes	
Point of emergence	1	2	1	2	1	2	1	2	1	2	1	2
Mean Adult emergence	0.1E	0.9D	1.0D	3.0C	0.0E	1.2D	0.0E	*40.3B	0.0E	*52.0A	1.0D	1.3D

Analysis was conducted on transformed data $\{\sqrt{(x+0.05}\}$, but for clarity, means are presented untransformed.

Means followed by the same letter are not significantly different at P=0.05 by Duncan's Multiple Range Test

*Adults emerged internally, but came out of pods through damage points.

ii. Nature of oviposition and larval survival on pod and seed surfaces by *C. chinensis*

Oviposition

Three methods of oviposition by females were identified on seeds and pods (Table 17). These were, eggs glued on surfaces, eggs firmly lodged between hairs, and eggs lodged between cracks on surfaces. There was a significant difference in oviposition method ($P<0.05$). Overall glued eggs were found more often ($P<0.005$) than lodged eggs, with fewer eggs lodged between cracks than between hairs.

The interaction between mode of egg attachment and type of substrate surface was significant ($P<0.05$). On hairy pods, the commonest mode of oviposition was by egg lodging between hairs, followed by egg gluing and lastly, egg lodging between cracks, respectively. Whereas on smooth pods and seeds, oviposition was mainly by egg gluing (Fig. 29). Egg lodging between cracks was detected on smooth and hairy pods.

Larval penetration

The extent of surface (seed and pod) penetration by the first instar larvae was categorised into successful hollowing, deep (>0.1mm) but unsuccessful hollowing, and shallow (<0.1mm) or no hollowing. The differences between the extent of surface penetration were significant ($P<0.05$) (Table 18). The interaction between the extent of larval penetration of surface and nature of surface was also significant ($P<0.05$) (Fig. 30).

The highest success penetration was recorded on seed surfaces followed by pods with smooth surfaces. Deep but unsuccessful hollowing was mainly recorded on both hairy and smooth pods. Shallow or no hollowing by larvae was greatest on hairy pod surfaces. In all cases, where penetration had been unsuccessful, the larvae eventually died.

Adult emergence

As a proportion of eggs laid on the surfaces, there
percentage of adults that emerged through the differ
and Fig. 31). The highest emergence percentage was
oth hairy and smooth pods very low total adult emerg
m smooth pods was significantly higher ($P<0.05$).

n both normal (hairy) and non-hairy pods, significantly
nally (through emergence holes on pods) than internally

Table 17. Percentage of the egg laying method by **C. chinensis**

Method of oviposition	Eggs glued on surfaces	Eggs lodged between hairs	Eggs lodged between cracks
% Eggs oviposited	75.33A	22.45B	2.22C
Least Significant Difference	12.63		

Means followed by the same letter are not significantly different at P=0.05 by Duncan's Multiple Range Test

Table 18. Mean percentage for extent of surface penetration by the 1st instar **C. chinensis** *larvae*

Extent of surface penetration	Successful penetration	Deep but unsuccessful penetration	Shallow or no penetration
% of 1st instar larvae	46.67A	31.24B	22.08C
Least Significant Difference	10.55		

Means followed by the same letter are not significantly different at P=0.05 by Duncan's Multiple Range Test

Table 19. Mean percentage of adult **C. chinensis** *emergence from eggs laid on the different pigeonpea pod and seed surface types*

Surface types	Pod surface		Seed surface
	Smooth	Hairy	
% adult emergence	3.1B	1.2B	58.1A
Least Significant Difference	11.7		

Means followed by the same letter are not significantly different at P=0.05 by Duncan's Multiple Range Test

Fig. 29. The effect of pigeonpea surface type on the method of egg oviposition by C.chinensis

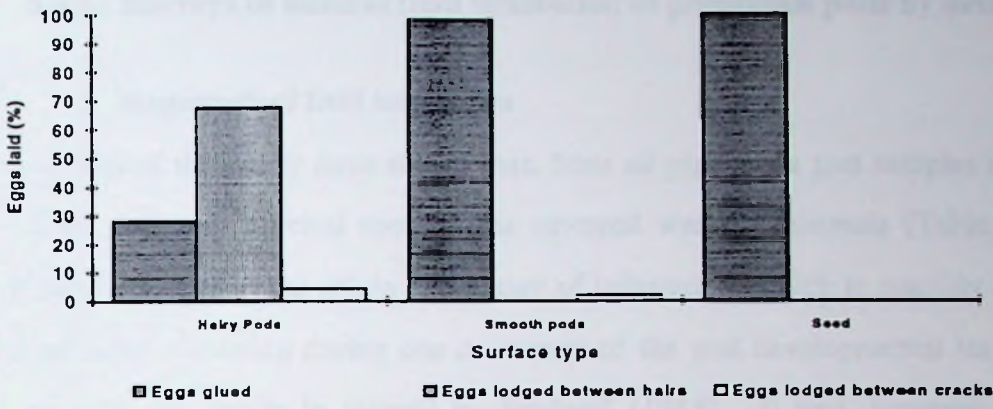


Fig. 30. The effect of pigeonpea surface type on extent of surface penetration by the1st instar larvae of C. chinensis

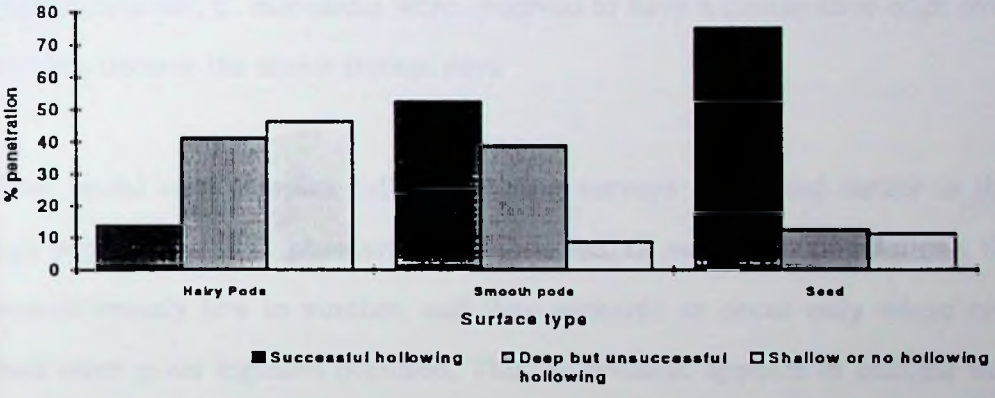
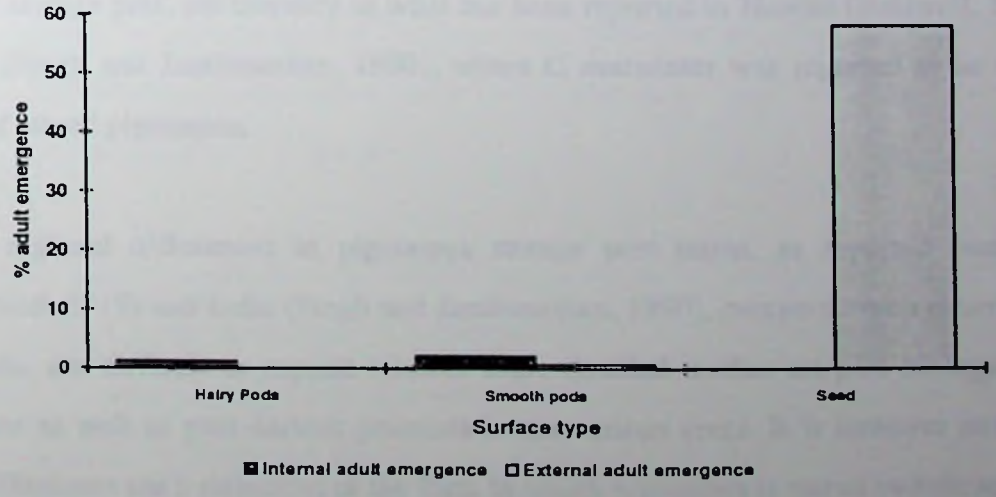


Fig. 31. The effect of pigeonpea surface type on % successful adult C.chinensis emergence and method of emergence



3.4. Discussion

3.4.1. Surveys of natural field infestation of pigeonpea pods by bruchids

a. Magnitude of field infestation

The results of this study have shown that, from all pigeonpea pod samples collected from the field, the only bruchid species that emerged was *C. chinensis* (Table 10). This is probably a pointer to the origin and nature of infestation, which is possibly of field origin and probably occurring during one or several of the pod developmental stages. A similar observation was made in Hawaii by Bridwell (1918). It was, however, reported that though *C. chinensis* were the predominant species from the field, during storage of pigeonpea seeds, *C. maculatus* were observed to have a competitive edge over *C. chinensis* and thus became the major storage pest.

From stored seed samples collected during surveys conducted earlier in this study, very high populations of *C. chinensis* were observed. *C. maculatus* populations, though present, were extremely low in number, and they appeared to occur only where cross infestation from other grain legumes occurred. This observation appears to indicate that, in Uganda, *C. chinensis* remains the most serious pest, infesting from the field and continuing through the pigeonpea storage systems. The findings in Uganda, showing that *C. chinensis* are the major storage pest, are contrary to what has been reported in Hawaii (Bridwell, 1918) and India (Singh and Jambunathan, 1990), where *C. maculatus* was reported to be the major pest of stored pigeonpea.

Such regional differences in pigeonpea storage pest status, as reported from Hawaii (Bridwell, 1918) and India (Singh and Jambunathan, 1990), compared with observations in Uganda, are difficult to explain without more detailed studies on pest biology, farming systems as well as post-harvest practices in the various areas. It is however possible that the differences are a reflection of the form in which pigeonpea is stored (whole seed or pod in Uganda versus split in India) and the cultivation, abundance and storage of other natural

ost plants of *C. maculatus* and *C. chinensis*.

urther observations made from the field samples collected showed that there was a highly ignificant difference in numbers of *C. chinensis* adults that emerged from pod-stored and eed-stored pigeonpea samples (Table 10). From pod-stored samples, adult emergence was nany times lower than from seed-stored samples. Observations by Caswell (1975) on owpea has shown that infestation by *C. maculatus* follows more or less similar patterns, with much lower infestation in pod-stored cowpea than seed-stored cowpea. An initial drop n *C. maculatus* populations could, however, occur in threshed as compared to unthreshed owpea. Thereafter, infestation in threshed seeds rapidly built up very shortly, up to a much higher level than in pod-stored cowpea. It was observed by Caswell (1975) that the loss of eggs during threshing was responsible for the low initial infestation in threshed seeds. During subsequent storage, slower infestation on pods due to the reduced rate of penetration by first stage larvae and reduced adult emergence through the pod walls greatly reduced the rate of pod infestation. In contrast, infestation on threshed seeds continued unhindered. This resulted in a 10 fold increase in *C. maculatus* population in threshed seed as compared to a two fold increase in pod-stored cowpea over the same period of storage (Caswell, 1975).

In this study, the reasons for the observed low infestation and high infestation on pod-stored and seed-stored pigeonpea, respectively, may have been for similar reasons and factors as those reported in cowpea.

From pod samples collected from the different districts of Uganda, no differences in the number of emerging adults were observed (Table 10). This is probably a result of the similarity in susceptibility to field infestation by *C. chinensis* by the genotypes collected or the similarity in the fauna and flora in these areas due to the fact that, the four districts are within the same agro-ecological zone in Uganda, with similar agro-systems growing inter-crossed medium- to long-duration pigeonpea.

b. **Effect of in field pod damage on *C. chinensis* infestation**

om pods collected from the field, but with different damage symptoms, only *C.chinensis* nerged. This is also probably an indication that, irrespective of the status of pigeonpea ods, *C. chinensis* is the most likely pest responsible for field infestation.

was, however, observed that a highly significant difference occurred in *C. chinensis* adult nergence, from seeds originating from pods with different injury symptoms (Table 11). he highest adult emergence was recorded from pods with *H. armigera* injury and dehisced ods, which was probably due to the easy accessibility of adults directly to the seeds within he pods through the injury points. Low emergence was recorded from podfly-injured pods nd uninjured pods, probably as a result of non-accessibility of adults directly to seeds within the pods. The lowest adult emergence was recorded in seeds from shrivelled pods. This may have been due to the distortions on the pod wall and/or reduced seed number and size. Shrivelling could have reduced the ovipositional surface area or rendered the surface unsuitable for oviposition. In addition to this factor, since such injury is often due to pod suckers whose injury results in reduced seed size and fewer seeds, the opportunities and potential areas of pest development and thus adult numbers emerging, may have, equally been reduced.

3.4.2. Artificial Infestation

a. **Relative susceptibility of pigeonpea pod developmental stages to *C. chinensis* infestation**

i. **Substrate preference for egg laying**

Field and laboratory trials have shown that the number of eggs laid on pigeonpea seeds was about four times that on pods (Table 12), which is an indication of the high degree of preference for seed surfaces for oviposition.

This great difference in oviposition preference may be due to differences between seed and

od surface characteristics. Observations on the pod and seed showed that there were several differences in surface characteristics.

n host-plant relationships, the substrate surface is important because the initial contact of nsect pest in search of an ovipositional site is the plant surface, therefore extensive nteractions between the insect and its host occur at this stage (Chapman, 1977). Since the urface is a functional organ, the diversity in surface structures is probably a reflection of nvironmental pressures, both biotic and abiotic, encountered by plants (Jeffree, 1986).

Jeffree (1986) considered that many of the plant surfaces have evolved out of complex interactions between plants and insects. Insects as pests have a profound impact on the plant, and a wide range of structural and chemical attributes of the plant surface are functionally related to defence.

In bruchids, several ovipositional determinants have been attributed to the external appearance of the surface. These include host surface types and curvature, host size and host shape (Schalk *et al.*, 1973; Nwanze and Horber, 1976) . In cowpea, rough seed coats have been associated with low oviposition by *C. maculatus* (Schalk *et al.*, 1973). *C. maculatus* was found to prefer smooth coated and well-filled seeds to rough and wrinkled seeds for oviposition (Nwanze and Horber, 1976; Messina and Renwick, 1985). In mung bean (*Vigna radiata* (L.) Walp.), it was found that varieties with glossy seed coats were less preferred by *Callosobruchus* spp. for oviposition than dull seed surfaces (Dharamasena and Subasinghe, 1986).

In this study, it was observed that the pod surface is generally covered by hairs (Tables 14 and 15) and this factor is probably one of the reasons for low oviposition on pods. In addition to the above surface features, it is possible that the greater curvature on seeds stimulated a greater rate of oviposition than on pods where surface curvature is minimal. This would be in agreement with findings by Gokhale *et al.* (1990) that, a more rounded

host curvature stimulated higher rate of oviposition by *C. chinensis* than flat surfaces.

Apart from the above differences, pod and seed water content were determined (Fig. 25), and this was found to be higher in pods than in seeds. It may, therefore, be possible that, in addition to the above factors, very high moisture content in pods may have had a depressing effect on oviposition, while the low moisture content of seeds encouraged oviposition.

Observations made among the pods showed that, between the pods, the stages of development had a significant effect on oviposition (Fig. 26). There was a progressive increase in egg numbers laid on pods from stage PR-1 until a maximum when mature pods were yellow (PR-5). Thereafter, egg numbers fell by about 30 %. It is probable that in this case, again, pod surface curvature and water content may have determined the ovipositional attraction of the substrates. During pod development, seeds within the pods progressively grow in size and create a bulge on the pod surface. The bulge creates progressively rounded curvature as the pod develops and grows. At PR-1, when the pod is just forming, no seed has formed yet, the pod surface therefore, appears more or less flat which could have minimal attraction for oviposition. As the pod develops and grows, to a maximum at PR-5, the progressively rounded curvature becomes more attractive for *C. chinensis* oviposition, confirming findings by Gokhale *et al.* (1990) on the attraction of rounded curvature for *C. chinensis* oviposition. These characteristics in young pods, especially during early pod stages, probably combined with the high moisture content, may have acted as ovipositional depressant resulting in these early stages being less attractive for *C. chinensis* oviposition.

During the later stages of pod development (PR-6 and PR-7), there was an abrupt reduction in egg numbers laid. This occurs despite the fact that pod surface curvature at these stages is greatest, which would be expected to be more attractive for oviposition than earlier stages. This abrupt reduction in egg numbers laid may have been due to the differences in nature of the numerous surface hairs found on the pods. In mature pods the hairs appear to be longer and stiffer as they reach their maximum development, in younger pods however.

as pod hairs form, differentiate and grow, they appear generally shorter and tender. The long and stiff hairs on more mature pods may have acted as a barrier to egg attachment, either as a physical barrier or as an irritant during oviposition.

ii. Pod stage suitability for *C. chinensis* development

Most of the available references on field infestation mainly refer to pod infestation in general terms. In common bean, (*P. vulgaris*), it has been reported that *A. obtectus* oviposit and develop only in well developed green pods and ripening pods (Larsen and Fisher, 1938; Gopal, 1986). Also in broad bean (*Vicia faba*), fresh-green, fresh-yellow, and dry-yellow pods are reported to induce copulation and stimulate oogenesis in *Z. subfasciatus*, but no reference was made to pest development (Pimbert and Pierre, 1983). In cowpea, low levels of oviposition and development by *C. maculatus* has been reported only on mature dry pods (Caswell, 1975; Alzouma, 1981, Ouedraogo and Huingnard, 1981). In pigeonpea, bruchids were reported to begin their infestation when the pods are in the ripening stage (Singh and Jambunathan, 1990).

In this study, it was confirmed that *C. chinensis* can successfully infest and develop in both pods and seeds of pigeonpea (Table 13, Fig. 28). The degree of infestation was, however, much higher in seeds than in pods by a factor of between 14 and 80, depending on pod developmental stage. The differences in pod and seed infestation is partly a reflection of the initial low levels of oviposition recorded on pods as compared to the very high oviposition on seeds. It is also possible that the pod is nutritionally inadequate and would, thus not provide the nutrition/niche required by the larva as it seeks out the seed. Most, importantly however, the differences in the internal pod physiology during development and seed formation may have adversely affected pest development.

Not all pod stages were equally susceptible to infestation. The susceptible stages ranged from the very young, to the ripe yellow pigeonpea pods (PR-1 to PR-5) (Fig. 28). In PR-1 to PR-5 stages, the highest infestation was recorded in PR-3, PR-4 and PR-5, respectively. The lowest infestation was recorded in PR-1 and PR-2. These differences in pigeonpea pod susceptibility to infestation may have been determined by several factors among which, the nature of pod surface, pod physiology and the hardness of the pods, as mentioned earlier, may have been very significant.

In ripe dry pods (PR-6 and PR-7), however, where there is even greater surface curvature, no adult emergence was recorded. Southgate (1979) observed that in majority of bruchid species, once the egg are on the surfaces, the hatching larvae eat through the egg shell and immediately penetrate the pod wall and enter the closest seed. Larvae that remain within the seed to pupate prepare for adult emergence by eating as close to the surface as possible without actually breaking through, and thus constructing a window of thin outer integument. It is therefore, likely that in *C. chinensis*, as with other bruchids, pigeonpea pod hardness may act as a barrier to larval (first instar) penetration, and where penetration and development occur, adult emergence may have been prevented by pod hardness.

Pod moisture content may have also affected bruchid development, very high moisture content depressing development (as in PR-1 and PR-2) while intermediate water content stimulated development (as in PR-3, PR-4 and PR-5).

In pod stages where development took place, a significant variation in mean incubation periods and adult emergence patterns were recorded from infestations on the different stages (Figs 27 and 28). The range between the earliest and latest days of *C. chinensis* emergence also varied greatly between the developmental stages. Similar observations have been made in *A. obtectus*, where it was found that, although development is possible in developing green pods and mature green pods, the total development period was prolonged by two weeks when oviposition took place in the green pods (Gopal, 1986).

In *C. maculatus*, slower developmental rate has been associated with the active or flight morph stage, and faster development with the normal or sedentary morph (Utida, 1972; Nwanze and Horber, 1976; Messina, 1990; Messina and Renwick, 1985). The active forms have been reported to be an adaptation to field conditions, and the normal forms to storage conditions (Messina, 1990). Sano-Fujii (1984) reported that, the active forms of *C. maculatus* take about 1.5 days longer to develop than the normal forms. It was demonstrated that, in *C. maculatus*, the proximate cues controlling morph ratios include, a rise in temperature and bean water content, resulting from the metabolic activity of crowded larvae (Sano-Fujii, 1979). The sensitive larval stage was found to be the second instar.

In this study, the longest mean developmental period (44 - 45 days) was recorded at PR-1 to PR-3, and in these stages, a single closely clustered emergence pattern was observed (Figs 28A and B). In PR-1 and PR-2 stages, emergence occurred within 2-4 days of each other. In the subsequent developmental stages (PR-4 and to a lesser extent PR-3), bimodal emergence patterns were observed, and/or with wide variation in emergence times (Figs 28C, D and E). These differences in emergence patterns probably indicated the occurrence of polymorphism. It is probable that most, if not all insects that managed to develop and emerge from eggs laid at PR-1 and PR-2, could have been the active morph forms of *C. chinensis*. From stages PR-4 to PR-5 a mixture of the two morph forms probably emerged, with the probable cut off point between the two forms at between 41 and 44 days after oviposition.

The above differences alone are not sufficient confirmation of the occurrence of polymorphism. Further studies are needed to investigate the occurrence of polymorphism, if any, from differences in the physiology and morphology of emerging insects.

b. Effect of physical surface characteristics of mature pods on *C. chinensis* fecundity and infestation

i. Pod type preference for egg laying, development and adult emergence

Egg laying

From the number of eggs laid by *C. chinensis*, smooth pod surfaces appear to be twice as attractive to egg laying than normal hairy pods (Table 14). However, where cracks and holes sufficiently wide to allow female entry existed on pod surface, greater attraction for seeds within the pods were displayed, which allowed direct oviposition on seed than on pod surfaces. This suggests that the factors that could determine attractiveness of any site for egg laying by *C. chinensis* include the nature of the surface of the mature pod and whether or not the female has direct access to the seeds within the pods.

Other pod features, such as podfly holes and the absence of the stipes did not affect oviposition, although oviposition was much lower on these pod types than on non-hairy pods. This is most likely due to the level and scale of injury on the pods which, though present, did not offer access to the seeds within, and at the same time did not affect the nature of the pod surface.

As mentioned earlier, there appear to be great differences in oviposition preference due to differences between seed and pod surface characteristics and between non-hairy and normal pod surfaces. Other than these physical factors, it is likely that the initial location of access points to seeds through injury points, as in *H. armigera* damaged and split pods, was probably through attraction related to sensory stimulation from the seeds within the pods.

Development and adult emergence

The current study showed that the extent of adult emergence from dry pods was dependent on certain pod characteristics. The highest adult emergence was recorded from pods which had been damaged by *H. armigera* and through dehiscence (Table 15). These types of damage, apart from allowing access to adults through the gaps on pods to the seeds, also appeared to allow the newly emerged adults easy exit points from the pods to reinfest more seeds. From pods with other injury symptoms, such as podfly injury and pods without stipes, very low adult emergence was recorded (Tables 11 and 15). This is probably because, these injuries did not initially, allow adult access to seeds to oviposit, and where larval penetration and development occurred, the injury points did not allow newly emerged adults access outside. From uninjured pods, adult emergence was very low, but within this category, the highest emergence was recorded from non-hairy pods, followed by non-stiped pods (Table 15). From very hairy pods, no emergence was observed.

The results of the current study suggest that, in pigeonpea, pods afford a high degree of protection against *C. chinensis,* not only due to their hairiness, but also their hardness. The pod may offer a barrier to, in the first instance, first instar larval penetration, and where penetration occurred, the same factor could greatly reduce external emergence, which would otherwise be an added source of re-infestation. In hairy pods, the initial low oviposition probably resulted in low infestation in the first place. Even where oviposition occurred, the hairs probably acted as an additional barrier to larval penetration. Where penetration and development took place, adult emergence may have been prevented by pod hardness.

Further investigations showed that, from infested pods, two forms of adult emergence occurred (Table 16), external emergence (insects emerging through emergence holes on pods) and internal emergence (insects emerging from seeds but remaining confined within the pod). The most frequent type of emergence was internal. The high rate of internal emergence is probably due to either the failure of the developing insects to locate and make

emergence windows through both seed and pod concurrently or the hardness of the pod during the process of making the emergence windows.

The findings in this study are similar to observations made on cowpea, where it was reported that pods of cowpea afford better protection than seeds against *C. maculatus* during storage (Booker, 1967; Caswell, 1968). Van Huis (1991) observed that, in traditional granaries where pods were stored, bruchid damage was reduced by 50% compared to seed storage. In the above cases, the pods appeared to offer some degree of physical resistance to infestation and damage (Caswell, 1975).

ii. Nature of oviposition and larval survival on pod and seed surfaces by *C.chinensis*

Oviposition

In the current study (Fig. 29), apart from egg gluing, two other methods of oviposition were identified, and each appeared to be linked to the nature and type of substrate surface. On hairy pods, oviposition was predominantly by egg lodgement between surface hairs, some egg gluing was also observed, and where cracks appeared on surfaces, egg lodging between the cracks was also observed. On smooth pods and seed surfaces, oviposition was mainly by egg gluing, and on pods, a few cases of egg lodgement were also observed.

In *C. chinensis*, the most widespread oviposition method is by egg gluing. As a first line of defence to this mode of egg attachment, pigeonpea pods in the field have probably evolved structural defence attributes in the form of pod hairs to reduce egg attachment. In response to this defence mechanism, and since the pest has 'load' of eggs to dispose, other alternate ovipositional adaptations by bruchids have been evolved whereby eggs are lodged either between hairs or cracks on the surfaces. These alternate methods of oviposition appear few and may therefore result in low infestation.

Larval penetration

In the current study (Fig. 30), it was observed that substrate surface penetration by the first instar larvae was highly dependent on the nature and type of surface. The highest successful penetration was recorded on seeds and pods with smooth surfaces, respectively. Deep but unsuccessful hollowing were mainly recorded on pods of both hairy and smooth surface types. The highest level of shallow or no hollowing by larvae was recorded on hairy pods.

It is probable that successful penetration is dependent upon two factors, substrate surface type (which would determine the mode of egg attachment) and the thickness or hardness of surface (which would determine the success of surface penetration).

Seed surfaces offer two major advantages for the ease of penetration. The smooth seed coat affords an ideal surface for firm egg attachment, while at the same time the thin and soft seed coat is easily penetrated by the larvae. Firm attachment of the egg directly to the seed surface also allows direct access of larvae to the seed, at the same time probably offering firm anchorage to the larvae during seed penetration. These combined characteristics allow easy egg attachment and larval penetration of the seed coat.

Smooth pod surfaces, while ideal for egg attachment, appear generally to be too thick for larval penetration. This therefore, while allowing easy egg attachment, does not, in most cases, facilitate easy penetration by the larvae.

Hairy pods appear to offer other protective measures against infestation other than affording poor egg attachment and difficulties in larval penetration due to pod hardness. Further difficulties in infestation are probably afforded due the relative distance between the point of egg lodgement and pod surface itself, which may require some distance of larval travel before penetration and at the same time may not afford an anchorage for penetration.

Adult emergence

Observations from the current study have indicated that adult emergence seemed also to be greatly influenced by substrate surface type and form (Fig. 31). Higher emergence was recorded from seed (smooth surface) than from pods. From pods, however, higher emergence was recorded from smooth pods than from hairy pods.

The above results are probably due to a combination of several factors, among which the mode of egg oviposition and ability of larval penetration has already been mentioned. Another factor is probably the inability of the developed adult to emerge outside of the pod (externally), again probably due to surface thickness or hardness or even the inability of the larvae to complete larval development in an appropriate site within the seed to allow direct access to the pod for purposes of making emergence windows. It is also probable that, even where larval development was completed in an appropriate site, the emergence window may still be misplaced, in this case, instead of the larvae cutting the window on the pod, it could be cut only on the seed, which would result in internal adult emergence.

CHAPTER 4. HOST-PLANT RELATIONSHIP:

DIFFERENCES IN MORPHIC CHARACTERISTICS BETWEEN *C. CHINENSIS* ADULTS EMERGING FROM POD INFESTED AND SEED-INFESTED PIGEONPEA

4.1. Introduction

Among natural populations of *C. maculatus* and *A. obtectus*, slower developmental rates have been associated with the active or flight morph stage, and faster development with the normal or sedentary morph stage (Utida, 1972; Nwanze and Horber, 1976; Messina *et al.*, 1984; Messina and Renwick, 1985; Gopal, 1986).

The results presented in Chapter 3 showed that among the pod developmental stages where *C. chinensis* development took place, a significant variation in mean incubation periods and adult emergence patterns occurred following oviposition at different pod stages. In particular, the range between the earliest and latest *C. chinensis* adult emergence also varied greatly between the pod stages. This, it was postulated, may have been due to polymorphic differences represented by the flight and flightless forms, which are different in several other ways.

The differences in several characteristics between the flight and flightless forms of bruchids have been reported to be due to the differences in the ecological niches they occupy, flight forms being adapted to field conditions and the normal forms to post-harvest seed storage conditions (Messina, 1990).

It has been demonstrated that, in stored seeds, the proximate cues controlling morph ratios in *C. maculatus* include a rise in temperature and bean water content resulting from the metabolic activity of crowded larvae (Sano-Fujii, 1979).

In the current study, it was found that the longest mean developmental period of *C. chinensis* occurred with infestation in the PR-1 to PR-3 pod developmental stages (44 and 45 days, respectively) (Figs 28, a and b). In the next developmental stage, PR-4 (and to a lesser extent PR-3 and PR-5), bimodal emergence patterns were observed with a wide dispersion in emergence times (Figs 28, c and d), the earliest and latest adults to emerge occurring on the 35th and 57th days after oviposition, respectively.

It was postulated that most, if not all, *C. chinensis* that developed and emerged from eggs laid in PR-1 and PR-2 stages could have been the active morph forms. From eggs laid on pods at stages PR-4 to PR-5, a mixture of the two morph forms appeared to have emerged with the probable cut off point between the two forms being adult emergence at between about 41 and 44 days after oviposition.

Since these forms are also different in a number of morphological, physiological and behavioural characteristics (Utida, 1954, 1956, 1972, 1981), differences indicated in pre-imaginal development periods alone are therefore not sufficient confirmation of the occurrence of the forms.

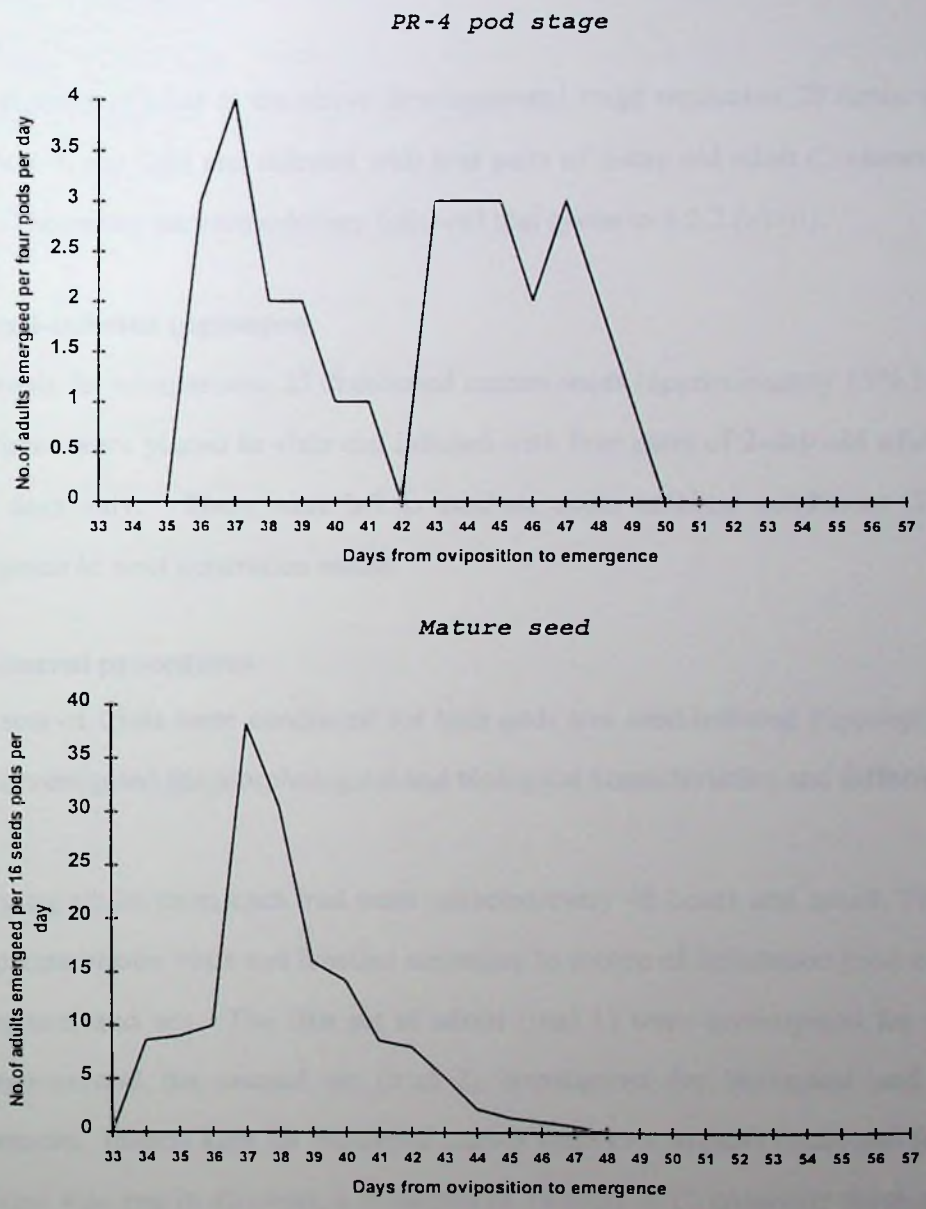
Further investigations were therefore conducted with the following objectives:

- to confirm and/or discern morphic differences, if any, from physiological and morphological characteristics of insects emerging from pod- and seed-infested samples on different days after oviposition, and

- to determine the significance of the occurrence of the two morphic forms, if at all, to any management strategies to be developed.

For this study, insects emerging following infestation on PR-4 were further investigated, as the biomodal emergence pattern offered a clear cut-off between early- and late-emerging insects (Fig. 32).

Fig. 32. Frequency distribution of emergence times C. chinensis *in pod- and seed-infested pigeonpea following oviposition on pods during PR-4 and mature seeds (refer to Chapter 3)*



A bimodal pattern of emergence is apparent in the former, whereas in the latter only a mode is apparent.

4.2. Materials and methods

Pod-infested pigeonpea

Mature green pods, at pod developmental stage PR-4 were used in this study, this was based on results of adult emergence from pod-infested pigeonpea which showed a bimodal pattern in contrast to emergence patterns from seed-infested pigeonpea (Fig. 32).

Four clusters of pods at the above developmental stage replicated 20 times were caged on the plant in the field and infested with four pairs of 2-day old adult *C. chinensis* for 4 days only. Thereafter the methodology followed that given in 3.2.2.(a) (ii).

Seed-infested pigeonpea

As a basis for comparison, 25 disinfested mature seeds (approximately 15% MC) replicated four times were placed in vials and infested with four pairs of 2-day old adult *C. chinensis* for 4 days only. These were left to incubate under ambient conditions (23-26°C) until emergence of next generation adults.

General procedures

Two sets of trials were conducted for both pod- and seed-infested pigeonpea. The adults were investigated for morphological and biological characteristics and differences.

Emerging adults from each trial were collected every 48 hours and sexed. These were kept in separate plastic vials and labelled according to source of infestation (pod or seed), day of emergence, and sex. The first set of adults (trial 1) were investigated for morphological differences and the second set (trial 2) investigated for biological and physiological differences. Insects kept for biological studies were kept in pairs (male and females) within the same vial and in all cases, a minimum of 10 pairs of *C. chinensis* were used, classified according to the respective origin of infestation and per trial.

a. Morphological characteristics (trial 1)

The objective of this investigation was to determine whether or not there were differences in morphological characteristics between:

a) insects emerging from seeds whose infestation origin were pods and those whose infestation origin were seeds, and

b) insects emerging on different days.

A number of physical features were observed and recorded in both sexes for adults emerging on each day from first adult emergence.

The morphological characteristics recorded were:

- Fore wing colour and hues
- Wing dimensions (length and width)
- Body length
- Pygidium length
- Distance between the compound eyes

Classification of elytral hue was done using the naked eye. Records were taken for both the upper and lower end of the elytra. Hue was scored 1-3 on a subjective basis, depending on the darkness or lightness of the brown to black as follows:

1 = very dark,

2 = moderately dark, and

3 = light.

Measurements of dimensions (length and width) were done under the binocular microscope using an eye-piece graticule. Frequency distribution for wing hue are graphically presented. All data collected were compared using two-way analysis of variance and mean measurements and other data for each day of adult emergence from pod infested samples were, in addition, presented graphically.

b. Biological and physiological differences (trial 2)

From the second set of insects, a number of biological characteristics were investigated to determine differences, if any, between,

a) insects emerging from seeds whose infestation origin were pods and those whose infestation origin were seeds, and

b) insects emerging on different days after the initial infestation.

The characteristics measured were:

- the moisture content of individual adults,
- time taken for the females, from first day of emergence, to egg laying (pre-maturation period),
- number of eggs laid in adult life time (fecundity), and
- male and female adult longevity.

A two-stage moisture content (MC) measurement using the oven method was taken for individual adults from the first set of insects after all the observations were made (as described in Chapter 3: 3.2.2a).

To determine the first day of egg laying, single pairs of newly emerged adults were placed in glass vials containing 10 uninfested pigeonpea seeds. The seeds were examined every 12 hours for eggs, and the day and time the first egg was laid was recorded for each insect.

To determine fecundity, the same adults as above were allowed to continue laying eggs. Seeds with eggs were carefully removed every 2 days, the egg number counted on seeds and the exact number of seeds removed were replaced with uninfested seeds. This process continued until no further egg laying was recorded. Final egg counts gave the total number of eggs laid per female.

Adult life span was also determined from this insect population. This was done by daily observations of insects, by the naked eye, through glass vials without disturbing them. Adult activity and position at rest gave the first clue of the status of the insect. Where inactivity or an unnatural position at rest of the adult were noted, the suspect insect was carefully removed to determine whether it was dead or alive. This was done by gently blowing humid air (from the mouth) on the insect and/or exposing it to heat and glare from a naked electric bulb. Daily mortality was recorded and tabulated until all insects had died.

All data collected were subjected to the one-way analysis of variance, and for data on days of emergence from pod-infested samples the results were in addition graphically presented.

4.3. Results

4.3.1. Differences between adult *C. chinensis* emerging from seed- and pod-infested pigeonpea

a. Morphological, physiological and biological differences

Significant differences in the morphology, biology and physiology of *C. chinensis* of both sexes were observed between insects emerging from seed- and pod-infested pigeonpea (Tables 20a & b, Fig. 33).

The mean body and pygidial lengths, mean male elytral width and elytral lengths were significantly longer ($P<0.05$) on adults emerging from pod-infested than from seed-infested pigeonpea. The mean distance between the compound eyes was significantly less ($P<0.05$) in females but greater in males emerging from pod-infested than from seed-infested pigeonpea. The mean body moisture content (%) of both sexes and fecundity of females, were significantly lower ($P<0.05$) in adults emerging from pod-infested than seed-infested pigeonpea. The mean pre-maturation periods of females and adult longevity of both sexes were significantly longer ($P<0.05$) for adults emerging from pod-infested than seed-infested pigeonpea.

Table 20a Differences in C. chinensis *(males and females) emerging from pod-and seed-infested pigeonpea*

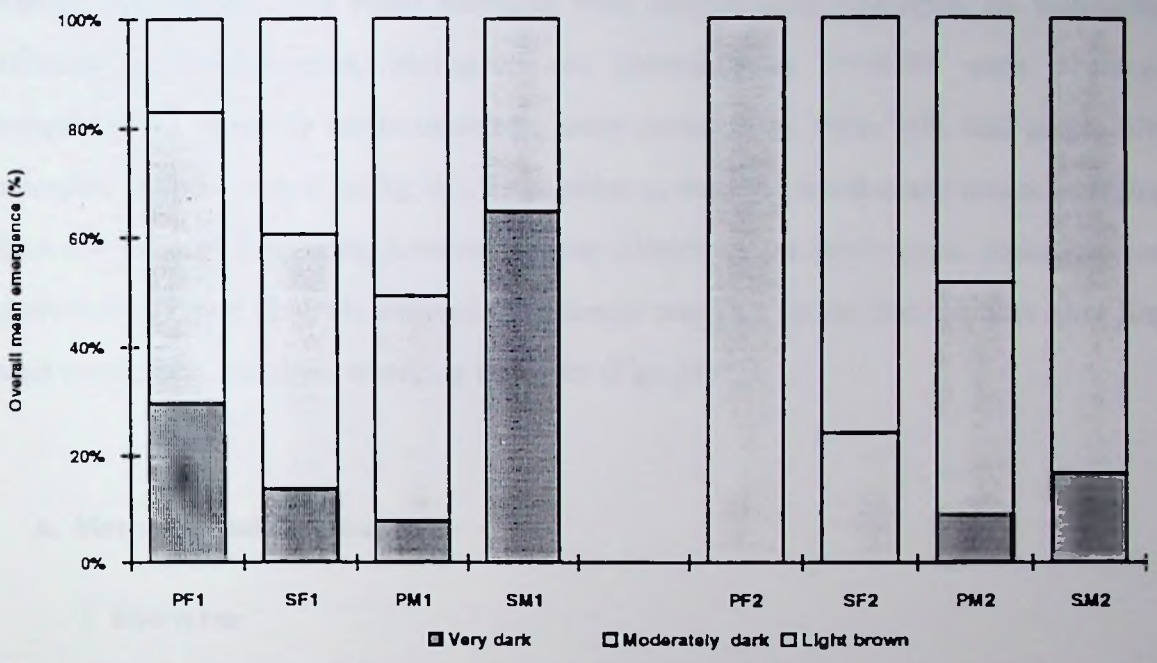
Major characteristics compared	Sex	Comparison of the differences by origin of infestation	
		Infested green pod	Infested mature seed
Elytral colour	Male	Lighter	Darker
	Female	Slightly darker	Slightly lighter
Wing dimensions	Male	Wider	Narrower
	Female	Not different	Not different
Body length	Male	Longer	Shorter
	Female	Longer	Shorter
Distance between the compound eyes	Males	Wider	Narrower
	Female	Narrower	Wider
Length of pygidium	Male	Longer	Shorter
	Female	Longer	Shorter
Moisture content (%)	Male	Lower	Higher
	Female	Lower	Higher
Pre-maturation period (days to egg laying)	Female	Longer	Shorter
Fecundity	Female	Fewer eggs	More eggs
Adult longevity	Male	Longer	Shorter
	Female	Longer	Shorter

Table 20b Mean of differences in C. chinensis *(males and females) emerging from pod- and seed-infested pigeonpea*

The characteristics	Sex of the insect	Origin of infestation and differences in the characteristics		P
		Infested green pods	Infested mature seeds	
1. Elytral dimensions (mm)				
-length	Female	1.74 (0.010)	1.72 (0.010)	>0.05
	Male	1.61 (0.010)	1.50 (0.010)	<0.05
-width	Female	0.77 (0.010)	0.76 (0.010)	>0.05
	Male	0.67 (0.018)	0.51 (0.016)	<0.05
2. Body length (mm)	Female	3.31 (0.056)	3.09 (0.038)	<0.05
	Male	2.64 (0.160)	2.27 (0.136)	<0.05
3. Distance between compound eyes (mm)	Female	0.24 (0.003)	0.25 (0.003)	<0.05
	Male	0.19 (0.002)	0.17 (0.002)	<0.05
4. Length of pygidium (mm)	Female	1.29 (0.016)	0.88 (0.010)	<0.05
	Male	0.76 (0.010)	0.54 (0.018)	<0.05
5. Moisture content (%)	Female	48.70 (0.355)	50.70 (0.411)	<0.05
	Male	47.00 (0.970)	51.50 (1.296)	<0.05
Pre-maturation period (days to egg laying)	Female	2.46 (0.056)	1.31 (0.107)	<0.05
Fecundity (no of eggs)	Female	44.52 (3.500)	58.60 (3.520)	<0.05
Adult longevity (days)	Female	8.90 (0.201)	8.18 (0.179)	<0.05
	Male	11.20 (0.402)	10.21 (0.379)	<0.05

1: In brackets are the standard errors (se)

Fig.33. Differences (mean) in elytral colour of C.chinensis emerging from pod- and seed- infested pigeonpea



4.3.2. Differences between adult *C. chinensis* emerging on different days from seed- and pod-infested pigeonpea

Among both females and males emerging from seed-infested pigeonpea, no significant differences (morphological, biological and physiological) ($P>0.05$) were observed irrespective of when the adults emerged (means presented in Table 20b, and graphically presented as and example in Fig. 43). From either or both the females and males emerging from pod-infested pigeonpea, however, several differences (morphological, biological and physiological) were observed between *C. chinensis* emerging on the first 6-8 days after first adult emergence, and those emerging thereafter (Figs 34-42).

a. Morphological characteristics

i. Elytral hue

Among female and male adults emerging from pod-infested pigeonpea, the posterior end of the elytra was darker on earlier- than later-emerging adults, and this progressively became lighter on the subsequent days of emergence (Figs 34a & b). In males, the anterior elytral colour became progressively lighter on successive days of emergence (Fig. 34d). In the females, however, irrespective of the day of emergence, anterior elytral colour did not change (Fig. 34c).

Fig. 34. Elytral hue (mean) variation in males and females of C. chinensis *emerging from pod-infested pigeonpea 2-14 days after the first day of emergence*

Fig. 34 a. Posterior elytral hue of female

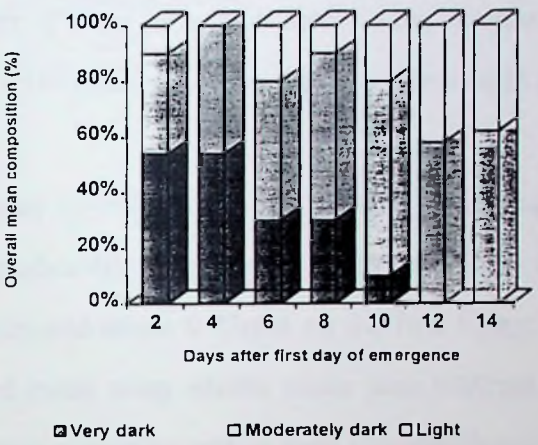


Fig. 34b. Posterior elytral hue of male

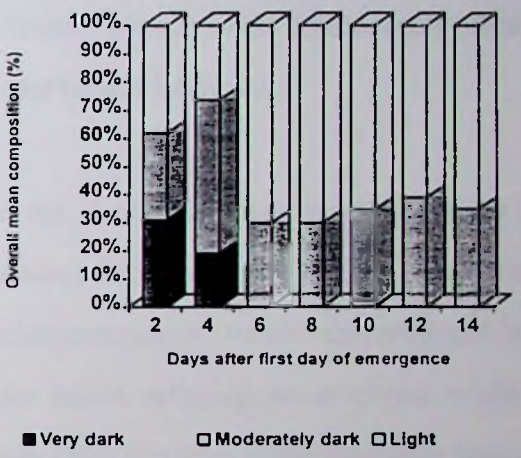


Fig. 34 c. Anterior elytral hue of female

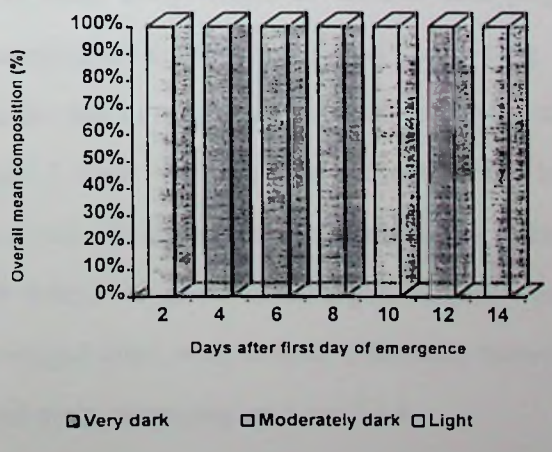
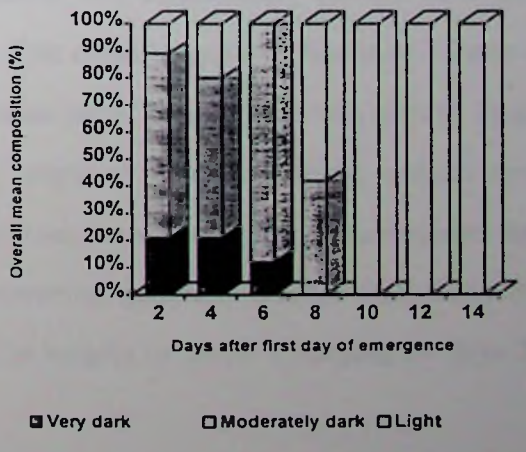


Fig. 34d. Anterior elytral hue of male



ii. **Wing (elytral) dimensions, length and width**

From pod-infested pigeonpea, both the females and males emerging on successive days, from the first to 14th day of emergence showed a significant difference ($P<0.05$) in elytral length (Fig. 35a). Mean elytral lengths on females were significantly shorter ($P<0.05$) (less than 1.74mm) on the first 6 days of adult emergence, and these became generally longer (greater than 1.77mm) for later emerging adults. In the males, the adults emerging on the first 6 days also had mean wing lengths (1.59mm) which were significantly shorter ($P<0.05$) than those emerging on days eight and later (about 1.64mm).

Mean elytral widths of females emerging on the first few days were found to be significantly narrower ($P<0.05$) than those that emerged later (Fig. 35b). The mean width measured about 0.75mm on the first 6 days of adult emergence. Adults that emerged later had mean wing widths wider than 0.80mm. In the males, although mean elytral width of adults emerging earlier were not significantly wider ($P>0.05$) than those emerging later for comparisons between any two observations, there was a consistent increase in wing width throughout this period (Fig. 35b); from 0.630mm on the first day to 0.697mm on the last.

iii. **Body length**

The mean body length of females emerging earliest was significantly shorter than those emerging on subsequent days ($P<0.05$) (Fig. 36). The mean length was less than 3.2mm on adults that emerged on the first six days, but female mean body length was always longer than 3.4mm thereafter. In the males, the body length of adults emerging earliest were, however, found not to be significantly different from those emerging on subsequent days ($P>0.05$). Those that emerged earliest were, however, generally shorter than those that emerged later, with a clear difference between the lengths of males emerging on days 2-6 and those emerging on days 8-14.

iv. Distance between the compound eyes

From pod-infested pigeonpea, there was no significant difference in the mean distance between the compound eyes of females that emerged on the first few days and those that emerged later ($P > 0.05$), although a negative trend is apparent (Fig. 37). In the males, although the width between the compound eyes of adults emerging from the first to the last days were not significantly different ($P>0.05$), there was a similar trend of a gradual decrease in width from the widest on the first few days (1.192mm), to the narrowest on the last few days (1.180mm).

v. Length of pygidium

The mean length of the pygidia of females emerging from pod-infested pigeonpea gradually increased from 1.21mm on the first days of emergence to about 1.44mm on the last days of adult emergence (Fig. 38), and these differences were significant ($P<0.05$). The biggest increase in pygidial length on females occurred after the sixth day of adult emergence. In the males, from pod-infested pigeonpea, the pygidial length of adults emerging from the first to the last days did not vary significantly ($P>0.05$).

Fig.35a. Mean elytral length (female and male) of C.chinensis emerging on different days from pod (PR-4) infested pigeonpea

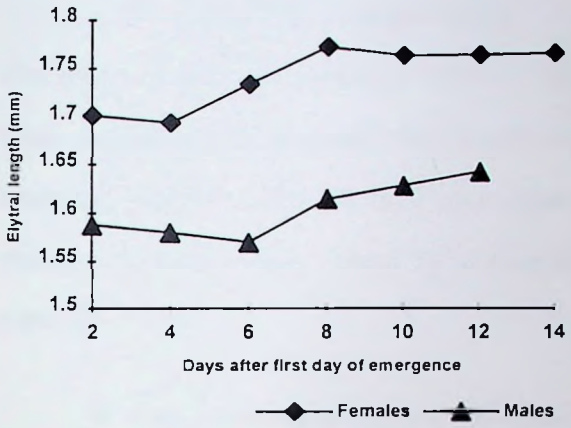


Fig.35b. Mean elytral width (female and male) of C.chinensis emerging on different days from pod (PR-4) infested pigeonpea

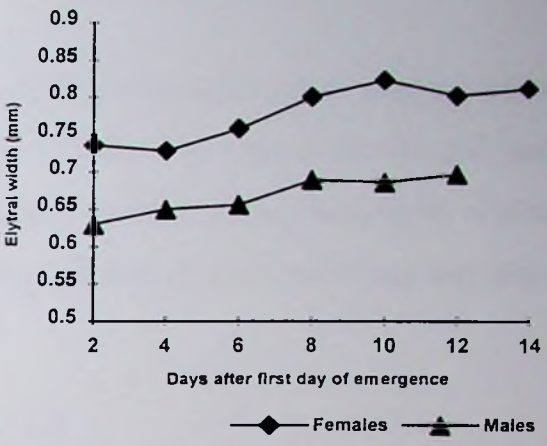


Fig. 36. Mean body length (female and male) of C.chinensis emerging on different days from pod (PR-4) infested pigeonpea

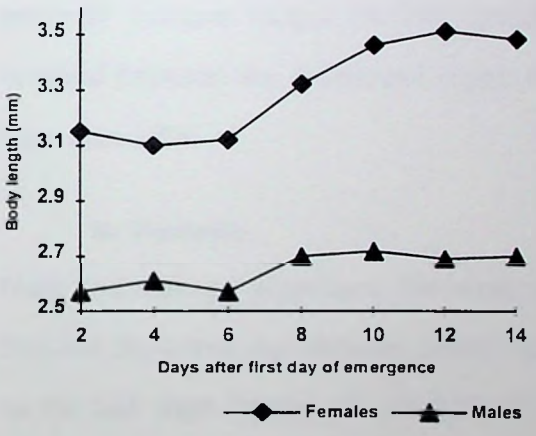


Fig. 37. Mean distance between the compound eye (female and male) of C.chinensis emerging on different days from pod (PR-4) infested pigeonpea

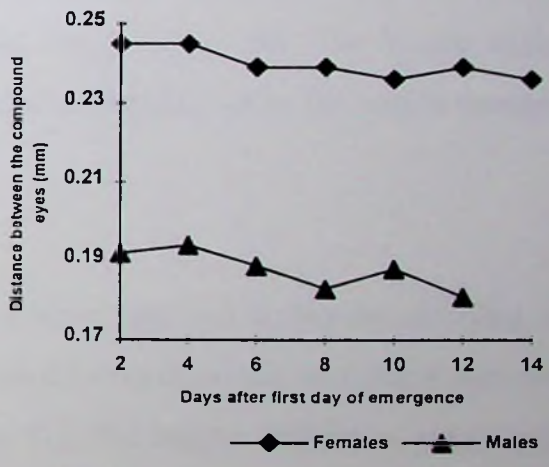
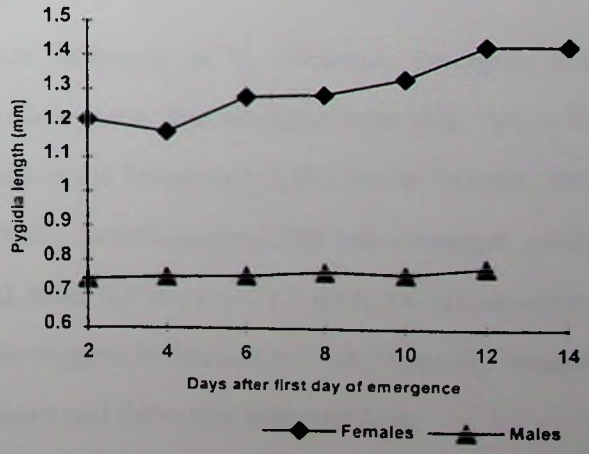


Fig. 38. Mean length of the pygidia (female and male) of C.chinensis emerging on different days from pod (PR-4) infested pigeonpea



b. Biological and physiological differences

i. Percentage body moisture content

The mean percentage moisture content (Fig. 39) of females and males emerging earliest from pod-infested pigeonpea was significantly different from that of females and males emerging last ($P<0.05$). On the first 6 days of adult emergence, the mean %MC of adults was significantly higher (about 50%) than adults emerging on each subsequent day (below 47%) ($P< 0.05$).

ii. First day of egg laying (pre-maturation period)

Females that emerged from pod-infested pigeonpea earliest took a significantly shorter time to begin laying eggs than females that emerged later ($P<0.05$). The pre-maturation period generally became longer on later-emerging females (Fig. 40). The biggest difference occurred between the fourth and eighth day of emergence, when this period increased by more than 30%.

iii. Fecundity

From pod-infested pigeonpea, the mean number of eggs laid by females emerging on the first few days was significantly greater (about 54) than those laid by females that emerged on the last days (about 38) ($P<0.05$) (Fig. 41). The biggest difference, again, occurred around the sixth day.

iv. Adult longevity

Mean female and male longevity of *C. chinensis* emerging early from pod-infested pigeonpea was shorter than those that emerged later (Fig. 42). These differences were, however, only significant in the females ($P<0.05$). In the females, these ranged from a mean of 7.6 days to 9.8 days for earlier-emerged and later-emerged adults, respectively, and in the males, these ranged from 9.0 days to 11.3 days for earlier-emerged and later-emerged adults, respectively. The biggest difference in adult longevity occurred between adults that emerged on the first 6 days and those that emerged later.

Fig. 39. Mean percentage moisture content (female and male) of C.chinensis emerging on different days from pod (PR-4) infested pigeonpea

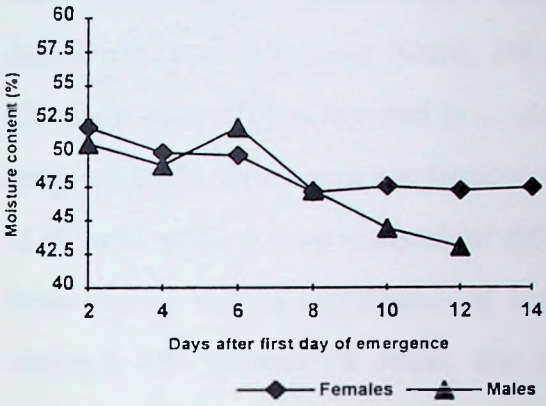


Fig. 40. Pre-maturation period of female C.chinensis emerging on different days from pod (PR-4) infested pigeonpea

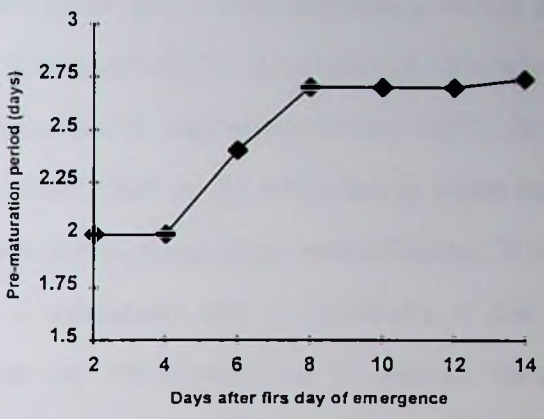


Fig. 41. Fecundity of newly emerged female C.chinensis emerging on different days from pod (PR-4) infested pigeonpea

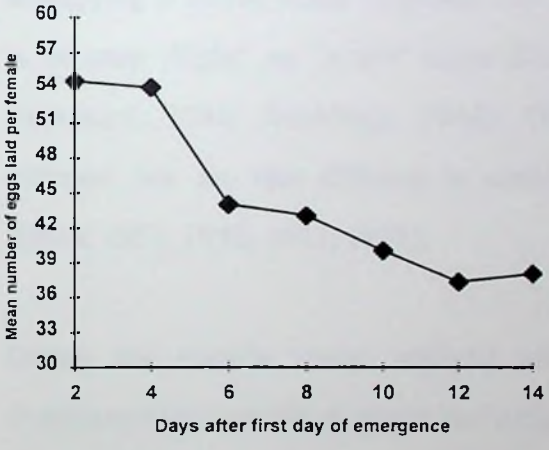


Fig. 42. Longevity of female and male of C.chinensis emerging on different days from pod (PR-4) infested pigeonpea

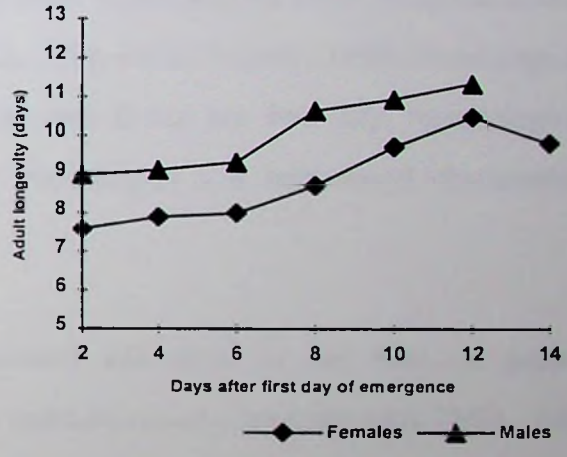
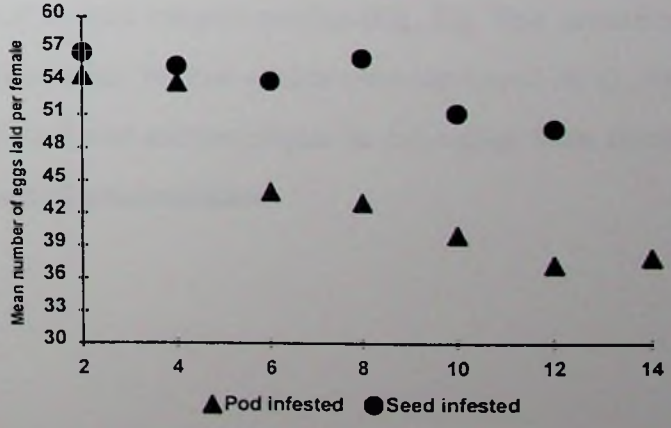


Fig. 43. Fecundity of newly emerged female C.chinensis emerging on different days from pod (PR-4) and seed infested pigeonpea



4.4. Discussion

Observations on polymorphism have been few in the genus *Callosobruchus*, except phase dimorphism in *C. maculatus* (Utida, 1981). The possibility of the existence of cytological polymorphism has been reported in *C. chinensis* and *C. maculatus* (Utida, 1981). In both species, chromosome number in females was determined as 20, while that in males studied by different authors using materials of different geographical origin was different, 19 or 20. From various rearing populations of both *C. maculatus* and *C. chinensis*, it has been observed that mutants do occur, and these are often expressed in various forms of morphological characteristics, most notably elytral colour (Utida, 1981). Under natural conditions however, two distinct forms of *C. maculatus* adults have been reported, one multiplying in stored beans "flightless", or "normal" forms, and the other living out of doors in the crop "flight" ,or "active" forms (Utida, 1954, 1972; Caswell, 1959; Ouedraogo and Huingnard, 1981; Sano-Fujii, 1984). These two forms are not only morphologically different, but are also different in certain physiological and behavioural characteristics (Utida, 1954, 1956, 1972, 1981).

During the current study, artificial infestation was done in the field on pods at developmental stage PR-4, which had a high moisture content (approximately 75%). Adults that emerged from infested pods showed a clear bimodal pattern of emergence, and in addition, there was a very wide range (in days) between the earliest and latest days in adult emergence as compared to seed-infested samples (Fig. 32). This pattern was thought to be an expression of polymorphism. Further studies were conducted on *C. chinensis* to confirm the existence of morphic forms and investigate its expression from certain morphological, physiological and biological characteristics.

4.4.1. Differences between adult *C. chinensis* emerging from seed- and pod-infested pigeonpea

a. Morphological differences

Observations reported in this chapter for comparisons of emerging adults from pod-infested pigeonpea (stage PR-4) and seed-infested pigeonpea revealed significant variation in morphological, physiological and biological characteristics, in at least one or both sexes, between adults emerging from pod- and seed-infested pigeonpea (Table 20). Certain differences on the morphology, physiology and biology have also been observed in adult *C. maculatus* (Utida, 1981). It was noted that these differences are expressions of the different morphic phases (Utida, 1981).

In the current study, in both female and male populations, variation in the colour of both the posterior and anterior end of the elytra were observed between adults emerging from pod-infested and seed-infested pigeonpea (Figs 33 & 34). The elytral colour (both posterior and anterior) in males was generally darker in adults emerging from seed-infested pigeonpea and lighter from pod-infested samples. In females, both posterior and anterior elytral colour were darker in adults from pod- than seed-infested samples. On *C. maculatus*, Southgate *et al.* (1957) and Utida (1972) observed that the most pronounced morphological differences in the two morphic forms is the elytral colour and pattern, which is darker in the flightless forms due to the absence of the pubescence on many parts of the cuticle. In the flight forms, the brown colour is determined by the presence of the pubescence. The pattern of hairs also causes differences in elytral colour patterns between the two forms (Southgate *et al.*, 1957; Utida, 1972).

Further investigations in this study showed that in *C. chinensis*, there were also differences in certain body dimensions between adults emerging from seed- and pod-infested pigeonpea. In *C. maculatus*, differences in various body dimensions of the morphic forms have also been observed (Utida, 1972; Utida, 1981). In this study, generally, wing dimensions (both length and width) of *C. chinensis* were found to be greater in adult males

emerging from pod-infested than seed-infested pigeonpea (Tables 20). The insect size (as determined by length) was also greater in adults emerging from pod-infested than from seed-infested pigeonpea (Table 20). The width between the compound eyes was narrower in females but wider in males, emerging from pod-infested as compared to seed-infested pigeonpea (Table 20). In addition to these differences, the pygidial length in both females and males were greater in adults emerging from pod-infested than from seed-infested pigeonpea (Table 20). In *C. maculatus*, the wing dimensions appear to be larger in the flight forms than the flightless forms, and the body size appears to be larger in the flight forms than the flightless forms. Other morphological differences also observed between flight and flightless forms of *C. maculatus* were the width between the compound eyes, which is generally wider in the flightless form than in the flight forms, and the pygidial length, which is longer in the females of the flightless forms than in flight forms, but in males the pygidia is longer in the flight forms than the flightless forms.

If the above differences, in *C. chinensis*, are pointers to morphic forms, as in *C. maculatus*, then it is apparent that pod infestation in the field stimulates the formation of flight morphic forms or conversely, dry seeds suppressed formation of flight morphic forms. These morphic forms are expressed, among other things, through differences in wing colour, body size, wing dimensions, distance between the compound eyes and pygidial length.

b. Physiological and biological differences

In this study, various physiological and biological differences were observed in *C. chinensis* between adults emerging from pod-infested and seed-infested pigeonpea. In adult *C. maculatus*, apart from morphological differences, various physiological and biological differences have also been recorded, these being indicative of the occurrence of the two morphic phases (Utida, 1981).

Among the differences observed on *C. chinensis* in the current study, were the percentage water content, which in both sexes were higher in adults emerging from seed-infested pigeonpea than from pod-infested pigeonpea (of PR-4 stage) (Table 20). In *C. maculatus*, differences in the body water content in both sexes have also been observed, these differences were ascribed to morphic differences, where the water content was higher in the flightless forms than in the flight forms (Utida, 1972).

The pre-maturation period (as measured from the first day of egg laying) of *C. chinensis* in the current study was found to be shorter by 50% in adults emerging from seed-infested pigeonpea than from pod-infested pigeonpea (Table 20). Utida (1972) found that in the flight forms of *C. maculatus* at emergence, the abdominal cavity was filled with fat bodies, whereas in the flightless forms it was filled with reproductive organs. The presence of fatty bodies at emergence in the former instead of reproductive organs is presumed to be indicative of possible delay in pre-maturation period.

Observations on fecundity in the current study showed that the total number of eggs laid by each female that emerged from seed-infested pigeonpea was more than those laid by females that emerged from pod-infested pigeonpea (58.6 and 44.5 eggs, respectively). Utida (1972, 1981) working on *C. maculatus*, showed that the number of eggs in the abdominal cavity of the flightless forms was more than in the flight forms, indicating reduced fecundity in flight forms.

In *C. chinensis*, it was observed that adults emerging from pod-infested pigeonpea lived longer than those that emerged from seed-infested pigeonpea, and in each circumstance the males lived about 2 days longer than the females (Table 20). In *C. maculatus*, it has been reported that adult longevity was about twice as long in the flight forms than the flightless forms (Utida, 1972, 1981; Taylor and Agbaje, 1974).

The fact that the differences observed in this study (in morphology, physiology and biology) between adult *C. chinensis* emerging from seed- and pod-infested pigeonpea is comparable to differences observed in morphic forms of *C. maculatus* signifies that such differences are most probably expressions of polymorphism. It also suggests that pod infestation in the field does stimulate the formation of morphic forms. Thus from pod-infested pigeonpea, a greater proportion of the active morphs emerged than in seed-infested pigeonpea where the flightless forms appeared to predominate.

Findings by Utida (1954, 1965) have shown that, among the environmental factors considered to be responsible in stimulating the production of polymorphic active forms, larval crowding is the most potent. The effects of larval density can be ascribed analytically to two different elements: the behavioural interface between individuals, and the influence of environment conditioned or modified by the metabolic interference of behaviour and the biological conditioning of environment (Utida, 1981). Of the two, the behavioural interface is less convincing, as larvae live, feed and grow in different and completely separate cells. On the other hand, biological conditioning of the environment is more convincing, as the high larval population density increases bean temperatures far beyond air temperature (Utida, 1981). The other biological change caused by larval crowding in bean heaps include a change of water content. It has been shown that, though high bean water content plays an important role in the production of the active forms of *C. maculatus*, this happens only when this is combined with high temperatures (Sano-Fujii, 1984). If, indeed green pod infestation by *C. chinensis* stimulates the occurrence of the flight morphic forms as it appears in this study, then it is possible that the high bean water content at pod formation stages acted as the greatest stimulus, and where higher temperature was needed, then the day-time exposure of the green pods to the sun may have raised pod temperatures sufficiently to stimulate the occurrence of polymorphism. It is, however, also possible that the formation of flight morph form is suppressed in dry seeds in storage.

4.4.2. Differences between adult *C. chinensis* emerging on different days from seed- and pod-infested pigeonpea

Further investigations showed that no significant variation in these morphological, physiological and biological characteristics occurred on *C. chinensis* of either sex emerging on each successive day from seed-infested pigeonpea from the first day of emergence (means presented in Table 20b, and as an example Fig.43). From pod-infested pigeonpea, however, adults emerging earliest were significantly different from those that emerged later, in a number of morphological, physiological and biological characteristics, either in one or both sexes (Figs 34-42). The greatest difference in these characteristics was generally apparent between those emerging in 6 days or less from first emergence and those emerging in 8 days or more from the first emergence; i.e. categories which matched the bimodal pattern of adult emergence (Fig. 32).

a. Morphological characteristics

i. Elytral hue

Amongst adults emerging from pod-infested pigeonpea, there was a shift in the proportion of insects of different elytral colour depending on the day of emergence. In all cases, except for the posterior end of female elytra, it was observed that the earliest-emerging insects had a higher proportion of darker adults, while those that emerged last had a very high proportion of light or brown insects.

From pod-infested pigeonpea, the percentage of adults with dark elytra emerging on the last 8 days either declined or was reduced to zero, with all the rest of the insects either predominantly lighter or completely light in colour.

The above observations indicate that, as in *C. maculatus*, elytral colour in *C. chinensis* is probably one of the expressions of polymorphism, which in this case may have been manifested due to the environmental conditions under which development occurred, in this

case, pod stage PR-4, which was at much higher moisture content than mature dry seeds (Fig. 25).

This variation is probably an adaptation, especially by the flight forms, to field conditions, where light colour offers appropriate camouflage within the field bio-system against the numerous potential predators and parasites. Under storage conditions, where there is almost constant darkness and fewer natural enemies, such camouflage is probably not necessary.

ii. Wing (elytral) dimensions, length and width

From pod-infested pigeonpea, the wing dimensions of adults were greater on insects emerging on the last eight days (Figs 35a & b). This trend was, however, much more pronounced in the females than the males, which is probably due to the greater mobility needed in the females for the purposes of searching for suitable oviposition sites.

It has been reported that, offered suitable conditions for the production of morphic forms, both *C. maculatus* and *C. chinensis* could probably react in the same way under similar conditions for similar purposes (Nakamura, 1968; Utida, 1981). The observations on *C. chinensis* would therefore, be an indication that from pod-infested pigeonpea more active forms appeared within adults that emerged later than those that emerged earlier. If this is indeed the case, then it is probably true that as in *C. maculatus*, wing dimension in *C. chinensis* is one of the indicators of flight morphs, and are adaptations to field conditions where there is greater need for increased mobility.

iii. Body length

The proportion of insects with smaller sizes emerging from seed-infested samples, particularly in the females, were about the same as those that emerged on the first 6-8 days from pod-infested pigeonpea. From pod-infested pigeonpea, the body size (as measured by body length) of adult females was greater on insects emerging on the last 8 days than those emerging on the first 6 days (Fig. 36). This trend was, however, much less pronounced in

the males than in the females, which is probably due to the need for greater food reserve needed for mobility, especially during the search for oviposition sites by females.

iv. Distance between the compound eyes

The distance between the compound eyes is probably an indicator of the size of the eyes. The wider space between the compound eyes would mean that the eyes occupy less area and are therefore smaller in size and *vice versa*. If insects emerging from pod-infested pigeonpea are taken in isolation, the indications are that in females, irrespective of the morphic forms (flight and flightless) the eyes are more or less the same in size. In males, however, where the width between the compound eyes was wider in earlier emerged-adults (presumed to be flightless forms) than those later-emerged (presumed to be flight forms), the eyes would, by inference, be smaller in insects that emerged earlier and larger in those that emerged later.

The need for larger eyes, indicated in later emergence (flight forms) from pod-infested pigeonpea, which was much more pronounced in the males, is probably due to the greater mobility and visual needs in the males for purposes of searching for female mating partners. In females, there was no variation in the size of the eyes, probably because the initial location of the ovipositional sites requires senses other than visual.

v. Length of pygidium

As in *C. maculatus*, pygidial length differences in *C. chinensis* is probably another pointer to morphic forms. In *C. chinensis*, however, both male and females showed increases in pygidial length in what could be considered the flight forms (Fig. 38). In *C. maculatus*, on the other hand, pygidial length increase was only recorded in males, while in females a reduction in length was recorded (Utida, 1981).

The probable reasons for the increase in pygidial length in both sexes are difficult to explain without conducting abdominal dissections. In *C. maculatus*, however, it was found that, in the flight forms, the abdominal cavity in both sexes was filled by fat at adult emergence, whereas in the flightless forms at this stage, the abdominal cavity was filled with reproductive organs (Utida, 1972). If the above findings are applicable to *C. chinensis*, then by inference the results would indicate that the fully developed and bigger quantity of reproductive organs in insects which emerged earliest (presumed to be flightless forms) were responsible for the larger pygidial length, and the absence of these organs in later emergence (presumed to be the flight forms) responsible for the smaller pygidial length.

b. Biological and physiological differences

i. Percentage body moisture content

The percentage moisture content of insects emerging from seed-infested samples (presumed to be predominantly flightless forms), depending on sex (Table 2), were to a certain degree about the same as those that emerged on the first 6-8 days (presumed to be flightless forms) from pod-infested pigeonpea (Fig. 39). From pod-infested pigeonpea, the percentage water content was lowest for adults emerging during the last 8 days (presumed to be flight forms).

In *C. maculatus*, it was observed that the crude fat content is higher in the flight forms than in the flightless forms and higher in males than in females. Conversely, the water content was lower in flight forms than in flightless forms and is higher in the males than the females (Utida, 1972). The observations by Utida (1972) on *C. maculatus* are in agreement, where body water content is concerned, with observations made in the current study using *C. chinensis* and is a further indication of the occurrence in high proportions of flight forms in adults from pod-infested pigeonpea, especially those that emerge latest. The need to store more fat in the body and less water is probably as a result of the greater energy required for mobility in flight forms and is adaptively suited to field conditions.

ii. First day of egg laying (pre-maturation period)

From pod-infested pigeonpea, adults emerging earliest had shorter pre-maturation periods than those that emerged later (Fig. 40). In pod-infested pigeonpea, the greatest difference in the pre-maturation period occurred between adults emerging on the 4th to 8th days.

The pre-maturation period of insects emerging from seed-infested samples (presumed to be predominantly flightless forms) was, to a certain degree, about the same as those that emerged on the first 6-8 days (presumed to be flightless forms) from pod-infested pigeonpea. From pod-infested pigeonpea the longest pre-maturation periods were recorded in females emerging on the last 8 days (presumed to be flight forms).

The observations of delayed egg laying in *C. chinensis* during the current study conforms with observations on *C. maculatus* by Utida (1972), and is a further indication that an increased pre-maturation period is an indicator of flight morph forms, which in this case occurred in high proportions in pod-infested pigeonpea, and especially occurring within insects that emerged latest.

Increased pre-maturation period in flight forms is also thought to be an adaptation to field conditions, whereby it is probably adaptively more advantageous in the short term to invest in fatty bodies for energy and food storage than the immediate production of reproductive organs. Fatty bodies would be a more useful adaptation for the migratory life under field conditions where oviposition sites are not often immediately available. In the flightless forms, where migration and extended flight is not necessary, it is probably more useful to devote all resources to rapid reproduction.

iii. Fecundity

From pod-infested pigeonpea, adults emerging earliest laid more eggs than those that emerged later, and the greatest difference in eggs umbers laid, again, occurred between

females emerging on the first 6 days and those that emerged later (Fig. 41).

As with other characteristics, the number of eggs laid by insects emerging from seed-infested samples (presumed to be predominantly flightless forms), were to a certain degree, about the same as those that emerged on the first 6-8 days (presumed to be flightless forms) from pod-infested pigeonpea.

The number of eggs laid per female *C. chinensis* during the current study is also in agreement with similar observations made by Utida (1972) on *C. maculatus*, and is a further indication that fecundity is another factor which distinguishes the two morphic forms, which in this case occurred in high proportions in pod-infested pigeonpea, and especially from the sixth day of adult emergence.

Reduced fecundity in flight forms is likely to be another adaptation to field conditions, whereby it is adaptively more advantageous in the short term to invest in fatty bodies for energy and food storage than immediate production of reproductive organs. Fatty bodies would be more useful resources for the greater mobility under field conditions where fewer oviposition sites are available (in the case of females), and (for males) mating partners are scattered. In the flightless forms, where migration and extended flight is not necessary, it is probably more useful to devote available resources to reproduction and progeny multiplication.

iv. Adult longevity

From pod-infested pigeonpea, longevity of earlier-emerging adults was less than that of adults which emerged later (Fig. 42). The greatest difference in adult longevity appeared between females emerging on the first 6 days and those emerging subsequently. The longest adult longevity was recorded from adults emerging on the last days (presumed to be flight forms).

As with other characteristics, adult longevity by insects emerging from seed-infested samples (presumed to be predominantly flightless forms), were to a certain degree, similar to those that emerged on the first 6-8 days (presumed to be flightless forms) from pod-infested pigeonpea.

Increased longevity in the flight forms is, again, probably another adaptation to field conditions, where few or widely-dispersed oviposition sites prevail. The need for more time to search for suitable ovipositional sites by females and for mating partners by males of the flight forms would therefore require longer life-span than the more sedentary flightless forms.

In the case of the flightless forms, the abundant ovipositional sites and mating males close-by under storage conditions demands rapid reproduction and production of progeny. The strategy in this case would be competition with man for food and so to multiply as fast as possible and before the seeds are utilised by man.

c. Combined considerations

From the foregoing discussion, it is concluded that, most of the differences observed in the above characteristics (elytral colour, wing and body dimensions, pygidial length, width between the compound eyes, days to egg laying, fecundity and adult longevity) are expressions of morphic phases in *C. chinensis*. It is also concluded that a high percentage of adults that emerged from pod-infested pigeonpea were the flight forms, and, like in *C. maculatus*, those that emerge latest or develop slowest are more likely to develop in to flight forms than those that emerge earliest or develop fastest. High moisture contents in immature pods most likely trigger the development of the flight forms during adult development.

Wigglesworth (1954), based upon his studies of the physiology of insect metamorphosis,

emphasised that polymorphism could be regarded as different phases of development whereby each stage is regulated in its development by the hormonal balance between juvenile hormone and the hormone secreted from brain and prothoracic gland. In this sense, the different metamorphic stages (larva, pupa and adult) represent successive polymorphism. Kennedy (1956) applied this idea to cases of polymorphism in locusts and aphids, and Utida (1972) indicated that if their theory is applied to *C. maculatus*, then it can be assumed that the flightless form is a neoteny, while the flight form is relatively more adult.

Similar theory can also be applicable to *C. chinensis*, where observations such as shorter developmental period, smaller body size, smaller wing dimensions and smaller eyes in flightless forms probably indicate incomplete development or metamorphosis, and *vice versa* the flight form represents complete metamorphosis. This would probably indicate that, where infestation takes place on dry seeds, the dry seeds to a certain extent suppressed full metamorphosis leading to the predominance of flightless forms in *C. chinensis*.

The occurrence of polymorphism in *C. chinensis*, which shows that the different morphic forms are adaptively suited to different niches, flight forms to field conditions, and flightless forms to storage conditions, may have implications on long term management strategies to be adopted, which in this case should aim at both flight and flightless forms of the pest. This would probably help in breaking the cycle from field to storage and *vice versa*.

CHAPTER 5. DEVELOPMENT OF *C. CHINENSIS* MANAGEMENT STRATEGIES

5.1. Introduction

This research has confirmed that field infestation of pigeonpea pods by *C. chinensis* plays an important role in subsequent seed damage during storage. It was shown that, with the exception of the dry pods, pods at all other developmental stages can be infested during growth in the field. It was also shown that, certain levels and types of field pod damage (*H. armigera* and splitting) greatly increase the chances of pod infestation by *C. chinensis*. From these studies, it was concluded that the "flight" morph forms which are adaptively suited to field conditions are probably the most important forms responsible for the field to storage infestation and *vice versa*.

Similar cycles of bruchid infestation have been reported on various grain legumes with very heavy consequent damage during grain storage. To protect grains against damage, various pest management methods have been attempted. All are, however, targeted at "in storage" seed treatment. No strategies have been formulated to deal with the field to storage cycle. In storage, various pest control methods have met with varying levels of usage and degrees of success. The more modern pest control options (insecticides and fumigants), though very effective, have several drawbacks including lack of sustainability in usage by resource-poor peasant farmers in developing countries (Kitch *et al.*, 1992), and their hazardous nature in stored food grains if not properly applied.

As an alternative to chemical control, farmers adopt various methods to prevent losses. These include; use of neem and vegetable oils (Sangappa, 1977; Schmutterer, 1990), hermetic storage (Van Huis, 1991; Srivastava *et al.*, 1991), biorationals (Nazan, 1983), sunning, pod storage and various physical methods (Booker, 1967; Caswell, 1968). Surveys have shown that some of the above methods are also practised in Uganda.

Promising as some of the above methods have been shown, few of them have found widespread acceptance (Murdoch and Shade, 1991). The efficacy of some of these methods have also not been proven under laboratory and/or field conditions.

5.2. Objective of Study

Due to the continued loss of pigeonpea during storage at the farm and market level and unavailability of viable, sustainable and easy to use options for the management of *C.chinensis* infestations, various investigations were conducted to identify viable management packages that could fit within the farming systems.

The major objective of the study was, therefore, to investigate and develop management strategies for *C. chinensis* during both pigeonpea pod development in the field and during seed-storage, and also to determine the effect of pigeonpea seed damage on seed viability.

The specific objectives were:

- To investigate and determine the effect of various levels of seed damage on final seed germination.
- To develop an IPM package for *C. chinensis*, targeted at both field and storage infestation. This included investigations on:
  - effect of field insecticidal spraying to control *C. chinensis* populations and damage during storage,
  - efficacy of various cultural and physical *C. chinensis* management methods during seed-storage; *i.e.*, sealed storage, traditional mud-straw-cowdung silo "tua", pod-storage, storage of split seeds, disinfestation by solarization, and
  - efficacy of various natural products on *C. chinensis* infestation in storage.

5.3. Materials and methods

5.3.1. Effect of bruchid seed damage on germination

Pigeonpea of the local land race, "Apio Elina", were bulk disinfested by fumigation using aluminium phosphide tablets, at a dosage rate of 5g/t, for four days under a gas tight fumigation chamber. After disinfestation, the seeds were hand-sorted to remove all hollowed seeds. The non-hollowed seeds were divided in to six treatment samples, each weighing 250g and replicated four times.

The treatment involved infesting samples with 10, 20, 30, 40, 50 and 60 pairs of adult *C. chinensis* for 6 days only. The samples were allowed to incubate under laboratory conditions until all adults emerged.

The hollowed seeds were, thereafter, sorted and categorised into six groups according to the number of emergence holes per seed. The groups were, one, two, three, four, five and six emergence holes per seed, respectively.

Within each category, 100 seeds were tested for viability under ambient conditions (23-26^{o}C) using wet sterilised white sand contained in plastic plates measuring 17cm in diameter. These tests were concluded after 7 days. The percentage seed viability was calculated from seeds that germinated. The results were subjected to one-way analysis of variance and graphically presented.

5.3.2. Development of an IPM package for *C. chinensis*

a. Effect of field insecticidal spraying on *C. chinensis* population and damage during storage

Pigeonpea of the variety "KAT 60/8" was sown on plots each measuring 4 x 3m in a complete randomised block design (CRBD) replicated four times. Sowing was done at a

spacing of 40cm and 10 cm between the rows and within the rows, respectively. A guard row, 1m wide, was planted with maize to minimise insecticide drift during spraying.

Two treatments, sprayed (using a motorised sprayer) and unsprayed were made, replicated four times. In the sprayed plots, cypermethrin (Ambush) (5% emulsifiable concentrate "e.c") diluted to 0.5% was applied at a rate of 10 l/ha, as recommended by the manufacturers for field pests of pigeonpea. Spraying was done four times, commencing at 50% flowering of plants and thereafter, at 10-day intervals.

At maturity, pods in each plot were harvested and hand sorted into *H. armigera* damaged and non-damaged pods. Each category was counted, and the percentage of pods damaged calculated. The pods were then returned to the main sample.

Pods from each plot were dried for 5 days in the open sun (to seed moisture content of about 15%) and shelled separately. The seeds were divided into representative samples weighing 500g using the Boerner divider and each sample was incubated separately in closed plastic jars (0.25 litre) for 2 months in the laboratory under ambient conditions (23-26°C).

At monthly intervals, emerging insects from each jar were sieved, identified, and counted. The damaged seeds were also sorted and weighed and percentage damage analysed. The results of adult emergence and seed damage were thereafter compared using one-way analysis of variance.

b. Efficacy of some cultural and physical management methods on *C. chinensis* infestation of stored pigeonpea seed

i. Effect of sealed storage: traditional mud-straw-cow dung silo "tua"

Construction procedures and materials for mud-straw silo "tua"

The materials used for the construction of the silo were strands of grass locally known as "ochwici" or "lumbugu" (*Digitaria* sp.), red clay soil from an ant-hill, and cow dung.

Before construction, the grass strands were piled and covered with banana leaves for two days to allow the strands to soften. To make the silo, clay soil was mixed with water to make a light paste and grass strands made into bundles (approx. 3cm thick), immersed in and smeared with the soil paste. The straw bundles smeared with mud were then moulded in a continuous but circular motion to the desired silo shape and size.

First to be made, was the flat bottom, made to sit on a flat wooden pallet, followed by the wall and finally a separate lid. After the construction, the structure was smoothed with mud and finally cow dung and left to dry. The average volume of the silos made was 150 l. with the top and bottom measuring about 39cm and 58cm in diameter, respectively, and the height measuring about 58cm. The silo was made in a semi-conical shape with a slight bulge in the middle (Fig. 43).

Treatment procedures

Freshly-harvested pigeonpea "Apio Elina", a local land race, were purchased from Lira market and used for the trial. Prior to the treatment, all damaged seeds were hand sorted and discarded. To get rid of all internal infestation, clean seeds were bulk disinfested by fumigation using aluminium phosphide tablets at a dosage rate of 5 g/t for 4 days under a gas tight fumigation chamber. After the treatment ,the sample was aerated for 24 hours.

The treatment involved 40kg samples replicated three times. The treatments made were; a) silo "tua" storage with loosely placed cover, and b) silo "tua" storage with the cover sealed using a clay/cow dung mixture. As a control, gunny bag storage was used.

Each treatment involved infesting the seeds with 24 pairs of 2 day old adult *C. chinensis* within the respective containers. These were stored for 3 months under ambient conditions (23 - 26°C). At the end of storage, the temperature within each container was taken. The seeds were thereafter sieved and the total insect number determined. The percentage seed damage was also determined from a representative sub-sample of 250g obtained from the main sample using a Boener divider. Thereafter, seed viability (as in 5.3.1) was conducted on 200 representative seeds sampled from each treatment. The data recorded for temperature were subjected to one-way analysis of variance, and for adult emergence, percentage seed damage and percentage seed viability the two-way analysis of variance was used.

ii. Effect of pod storage on *C. chinensis* infestation and damage on pigeonpea

Pigeonpea pods of the local variety "Adyang" from Gulu district were hand harvested and used for the trials. Pods weighing about 250kg were thoroughly mixed, placed within gunny bags and fumigated at a dosage rate of 5g/t in a gas-tight fumigation chamber for 96 hours. By coning and quartering, the pods were divided in to 25kg treatment samples replicated four times.

The two treatments made were:

- unshelled "in-pod" storage in open-reed traditional granaries (Fig. 44)
- shelled "seed" storage in cloth-bags.

During shelling in the second treatment, the number of adult *C. chinensis* were recorded, and from 200g representative sample, the percentage seed damage was determined. This

Fig. 43. The traditional mud-straw silo "tua" used for pigeonpea grain storage.

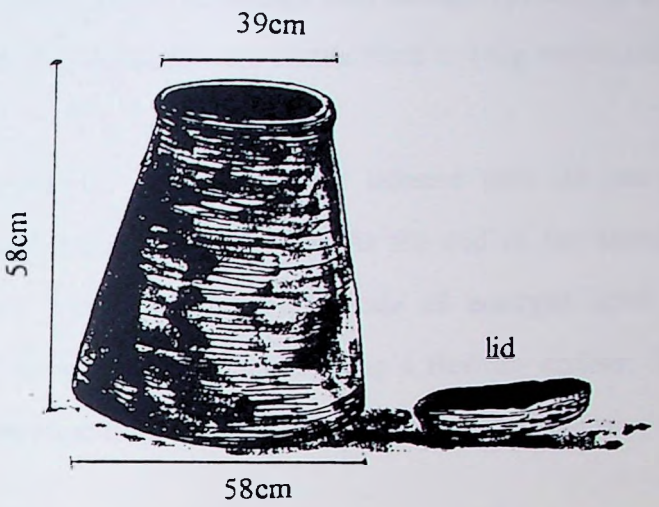
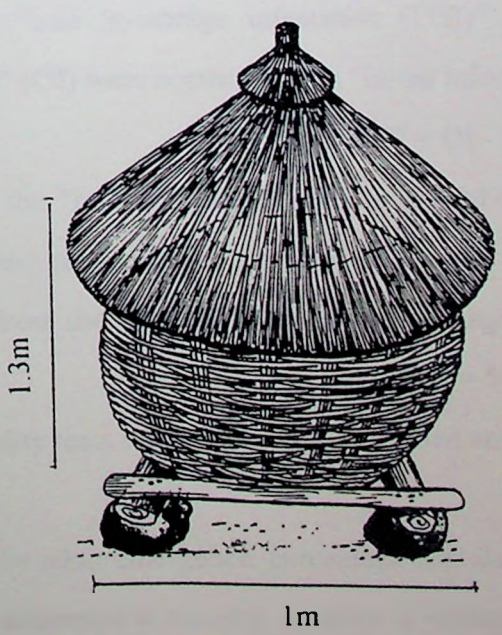


Fig. 44. Open-reed traditional granary used for pod-storage of pigeonpea



was done to determine "initial infestation (II)" and "% initial seed damage (% ISD)" as a correction factor for determining the true in-storage infestation (TISI)" in pod-stored pigeonpea and true (actual) in-storage seed damage (TISD)" in both pod- and seed-stored pigeonpea. The shelled seeds were standardised to 15kg before infestation.

In all the treatments, pigeonpea were infested with 24 pairs of 24-hour old adult *C. chinensis* and stored for 3 months. At the end of the storage duration, seed-stored pigeonpea were sieved and a count made of emerged adult *C. chinensis.* From a representative sample of 200g ,taken using a Boerner divider, the number of damaged seeds were determined, from which percentage seed damage was calculated.

From pod-stored pigeonpea, the total insect count was obtained from the sum of the insect numbers from sieved unshelled pods, and the insect count during the process of pod hand shelling. From a representative sample of 200g (taken using a Boerner divider) of shelled seeds, the number of damaged seeds was determined, from which the percentage seed damage was calculated.

To obtain "true in-storage infestation (TISI)" in pod-stored pigeonpea, the "overall infestation" (OI) were corrected from "initial infestation" (II) as follows:

$$\mathbf{TISI = OI - II}$$

To obtain the "true percentage increase in seed damage during storage " (% TISD), for both pod and seed stored pigeonpea, the "overall percentage seed damage" (%OSD) were corrected from the "initial percentage seed damage" (%ISD) as follows:

$$\mathbf{\%TISD = \%OSD - \% ISD}$$

Seed viability tests were, thereafter, conducted on 200 seeds as described above.

The data for adult emergence, percentage seed damage and percentage seed viability were thereafter subjected to one-way analysis of variance.

iii. Effect of seed splitting on *C. chinensis* infestation of pigeonpea during storage

Fifty kilograms of pigeonpea seeds of the local land race, "Apio Elina", were used for the study. The seeds were bulk disinfested as described above and divided into two samples using a Boerner divider. The sample lot was split using the traditional method using grinding stones. The seeds were sieved (in 2.5mm mesh) to remove small particles and hand-sorted to remove all broken cotyledons and unsplit seeds. The split seeds were soaked in water for 10 minutes and the remaining testa rubbed off by hand. Thereafter, the split seeds were sun dried for about 4 hours (to about 14% MC). The second sample (at 14% MC) was left unsplit and used as the control. Each sample was divided into four (replicates) and standardised to 5kg treatment samples.

Each treatment sample was placed separately in tightly knitted cotton cloth bags, infested with 10 pairs of 24 hour old *C. chinensis* and stored for 3 months within sealed cloth bags.

At monthly intervals, insect numbers were determined, all dead insects discarded and live ones returned to the container. At the first insect count, the initial number of insects used during infestation was deducted from the total to get the number of emerged insects during the storage duration. At each subsequent insect count, the number of insects were adjusted to account for the live insects returned to the containers during prior insect counts. The data for adult emergence were compared using a two-way analysis of variance.

iv. Effect of solar disinfestation on *C. chinensis* infestation and damage of pigeonpea

The solar heat disinfestation, as described and used by Murdoch and Shade (1991), to control *C. maculatus* infestation in cowpea was used in this trial. This consisted of a simple solar heater using a dark plastic under-layer with a sheet of clear plastic cover, to trap the solar radiation. An insulating mattress between the soil and the black plastic

consisting of threshed beans pods was used to achieve maximum effectiveness (Fig. 45). Two sets of trials were prepared as follows:

Solar heater evaluation

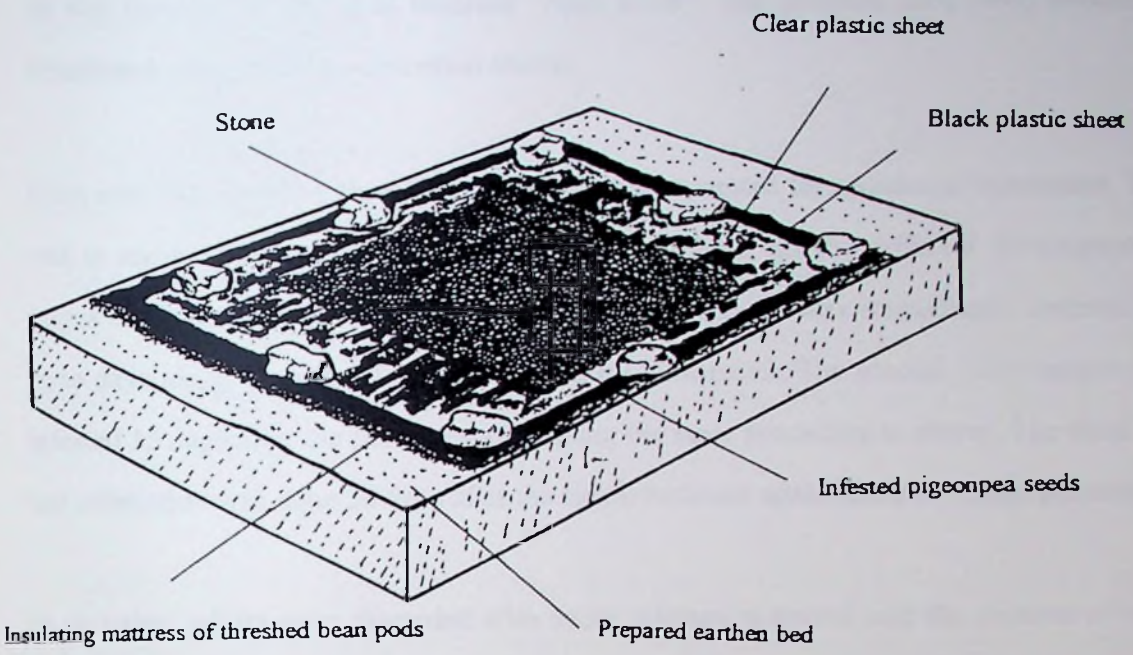
The solar heater, as described by Murdoch and Shade (1991), was investigated for efficacy in controlling infestation of *C. chinensis* in stored pigeonpea. The treatments used were the paired main treatment (solar heater *vs* ambient temperature) replicated four times.

The heaters were constructed by placing black polyethylene (1.5m x 1.5m) directly on an insulating mattress (1m x1m) consisting of 6-10 cm layer of threshed bean trash laid on the bare soil surface. Infested pigeonpea was placed between the black and clear polyethylene for the treatment. During the treatment records were made and scores given on the general weather condition (Table 21).

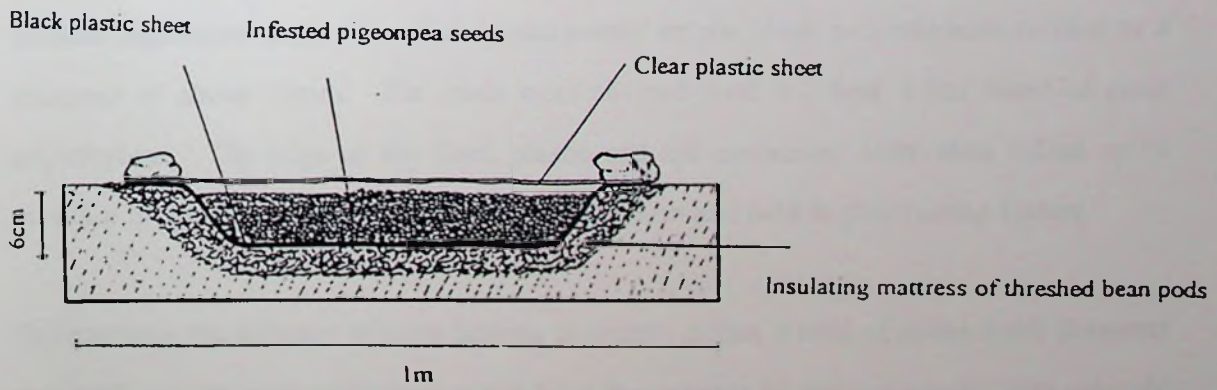
Table 21 Scoring procedures for weather condition during the six-hour solar heater operation

Score	1	2	3	4	5
Period of sunshine during the study (h)	0.0 - 1.2	1.3 - 2.4	2.5 -3.6	3.7 - 4.8	4.9 - 6.0
Proportion of sunshine hours during the treatment (%)	0 - 20	21 - 40	41 - 60	61 - 80	81 - 100

Fig. 45. Diagram of the solar-heater used against *C.chinensis* infestation of pigeonpea



Cross-section of the solar-heater



The performance of the solar heaters in eliminating *C. chinensis* infestation, was assessed on 4kg samples of the local landrace "Apio Elina". The samples used were previously disinfested using methods described above.

From each 4kg samples, three 100g samples were separated for sequential infestation. This was to ensure that at the time of solar heat treatments, all the different developmental stages of *C. chinensis* were present. The first 100g sample was immediately infested for three days using 10 pairs of 24-hour old adult *C. chinensis*. The second 100g sample was infested 15 days after the first infestation using the same procedure as above. The third and last infestation was done 30 days after the first infestation again using the same procedure.

In all cases, adults were discarded after every infestation period and the number of eggs laid on seeds per jar (100g) were standardised to 250 eggs by scraping off excess eggs, three days after each infestation.

Each of the three infested seed samples (each of 100g) were thereafter returned to the original treatment samples of 4kg. These were then thoroughly mixed by hand.

Infested pigeonpea seeds were then spread evenly on the black polyethylene surface to a thickness of about 15mm. The seeds were covered with a 1.5mx 1.5m sheet of clear polyethylene. The edge of the black plastic and the perimeter were then rolled up to maintain internal temperature and limit air circulation and held in place using stones.

To determine the efficacy of solar heating to control adults, a hole of about 8mm diameter was made on the clear polyethylene and from an aspirator 10 pairs of adults were released

within the treatments, the control was equally treated. The holes were subsequently sealed using a clear sellotape.

As a control, infested seed were held at ambient temperature (23 - 26°C) in the laboratory in cloth bags. In the solar heat treatments, temperatures attained in each of the solar heater replicates "among the grains", were measured using an electronic thermometer every 30 minutes for six hours, beginning 30 minutes after the closure and sealing of the trial. Two separate trials were conducted each for 6 hours on a clear sunny day in mid-January and mid-February 1993.

Immediately after the termination of the heat treatment, counts were made of live insects (LI) which were then discarded. Thereafter, the samples were incubated for 45 days in the laboratory and observed daily for adult emergence. The total number of adults that survived the heat treatment and the total number adults that emerged, were used to measure the effectiveness of the heater in controlling infestation.

Total percentage mortality (%M) was calculated as follows:-

$$\%M = \frac{(IA + OE) - (LI + EA)}{IA + OE} \times 100$$

Where: IA = No. of introduced adults; OE = Total oviposited eggs

LI = No. of live adult insects; EA = Total emerged adults

Percentage seed germination was determined from 100 seeds obtained from each of the treatment bags, using plastic germination trays held at ambient laboratory conditions. Daily observation of germination were made until no further germination occurred.

An evaluation of different under-layers

Investigations were also conducted to determine the effectiveness of other types of materials for under-layers as solar heat absorbing materials. The solar heaters were constructed as in the experiment above but using different materials as under-layers, while using the clear polyethylene sheeting as over-layers. The materials tested were; blue cotton cloth, white nylon sacking, black polyethylene and brown sisal sack. The infestation and disinfestation procedures and data collection were as above.

Adult emergence, percentage mortality and percentage seed viability in the treatments were analysed using one-analysis of variance after data transformation $\{\sqrt{(x+0.05)}\}$.

c. Efficacy of natural products (biorationals and sand) on *C. chinensis* infestation of stored pigeonpea seeds

i. Plant products and other materials used

Various plant and plant products were tested to determine their efficacy in controlling *C.chinensis* infestations on stored pigeonpea seeds. The natural products tested were: leaves of tobacco (*Nicotiana tabacum* L.), lantana camara (*Lantana camara* L.), water hyacinth (*Eichhornia crassipes* Solms.), tephrosia (*Tephrosia vogelli* Pers.), castor oil plant (*Ricinus communis*), Mexican marigold (*Tagetes* sp.), and lemon grass (*Cimbopogon citratus*); seeds of melia (*Melia azedarach*); fruits of chilli or hot pepper (*Capsicum frutescens*); peels of lime and lemon (*Citrus* spp.); corn oil; juices made from

ripe fruits of pineapple (*Ananas* sp.); banana (*Musa* sp.), and pawpaw (*Carica papaya*); ash and river sand.

Leaves of lantana camara, water hyacinth, tephrosia, Mexican marigold and lemon grass were collected from their natural environment and dried in the sun. Tobacco leaves, cured using three different methods, flue, fire, and burley, were obtained from the British American Tobacco Company in Kampala. The leaves were separately ground in a mortar and into finer granules using an electric grinder and kept separately in sealed glass jars.

Fruits of capsicum (red-pepper) and melia (China-hemp) and peel of lemon and lime were also dried separately in the sun and ground as above. Juice from pineapple and banana were extracted using an electric blender and sieved using a fine mesh cotton cloth. The corn oil used and all the edible fruits listed above were purchased from the local market. Melia seeds were picked from the wild. Ash was obtained by sieving from burnt firewood (assorted) and the sand from the banks of River Mayanja, 1 km from Kawanda.

ii. Treatment procedures

Pigeonpea seeds were first disinfested by freezing for 72 hours. The non-hollowed seeds sorted and separated for the trials. For each treatment, 200g of pigeonpea seeds were used and replicated four times. These were placed in plastic jars covered with perforated lids (about 0.7mm holes).

For each treatment, seeds were infested three times, each for 4 days at intervals of 15 days. At the end of each infestation duration (4 days) all adults were removed. After the last infestation the infested samples were incubated for 10 days (or just as the first adults emerged) and then treated using each of the above products. The above infestation procedure was used in order to try to simulate actual conditions in the field, where various insect developmental stages may be present at the same time.

The biorational treatment involved five different dosage rates for each product. 0.0g, 0.5g, 1.0g, 2.0g, 4.0g per 200g of seeds respectively. These were separately placed in the different jars and thoroughly mixed with the infested seeds.

The treatments were kept for 8 weeks at ambient conditions in the laboratory. At weekly intervals, all adult insects that emerged were counted and a record kept of dead and live insects. At each recording, all dead insects were discarded and live ones put back into the respective jars. A cumulative record of live and dead insects were kept over the 8 weeks.

From the total number of emerged insects in the treatment control (0.0g dosage) and the total number of live insects at each increment of dosage (0.5g, 1.0g, 2.0g and 4.0g), the percentage mortality was calculated as follows:

$$\% \text{ Mortality} = \frac{\text{Total No. of live insects at 0.0g dosage - Total No. of live insects at particular dosage}}{\text{Total No. of live insects at 0.0g dosage}} \times 100$$

To determine the relative efficacy of the various treatments at the various dosage rates, data for adult emergence and percentage mortality were subjected to the two-way analysis of variance. Duncan's multiple range test was used for mean separation. The effect of the various dosage rates on adult emergence and percentage insect mortality are presented graphically as regression lines.

5.4. Results

5.4.1. Effect of bruchid seed damage on germination

Seed damage by *C. chinensis* significantly ($P<0.05$) affected seed viability (Fig. 46). The highest seed germination was recorded in undamaged seed (91%) and this progressively dropped from 84% in seeds with one emergence hole to zero germination in seeds with five emergence holes. Although some germination occurred from seeds with four emergence holes, this was very low (2%).

5.4.2. Development of an IPM package for *C. chinensis*

a. Effect of field insecticidal spraying on *C. chinensis* population and damage during storage

There was almost a ten-fold reduction in field damage by *H. armigera* ($P<0.05$) as a result of the spraying regime using cypermethrin. Pod damage was reduced from 10.7% in unsprayed to 1.1% in sprayed fields.

The field spraying regime also reduced *C. chinensis* pest population ($P<0.05$) and damage ($P<0.05$) in stored pigeonpea seeds (Table 22). After 1 month of storage of seed harvested from the sprayed fields, a mean of only three adult *C. chinensis* emerged, whereas from the unsprayed fields a mean of 19.7 adults emerged. After 2 months of storage, from the seeds from sprayed fields, a mean of 68.8 adults emerged, whilst a mean of 633 emerged from the seeds from unsprayed fields.

After 1 month of storage, seeds from the sprayed fields showed very low damage (0.18%), whereas in those from unsprayed fields the damage was over six times higher (1.23%) (Table 22). After 2 months of storage, seed damage of 5.08% and 29.25% % were recorded from the sprayed and unsprayed fields, respectively.

Fig. 46. Percentage germination of pigeonpea seed with 1-5 C. chinensis emergence holes

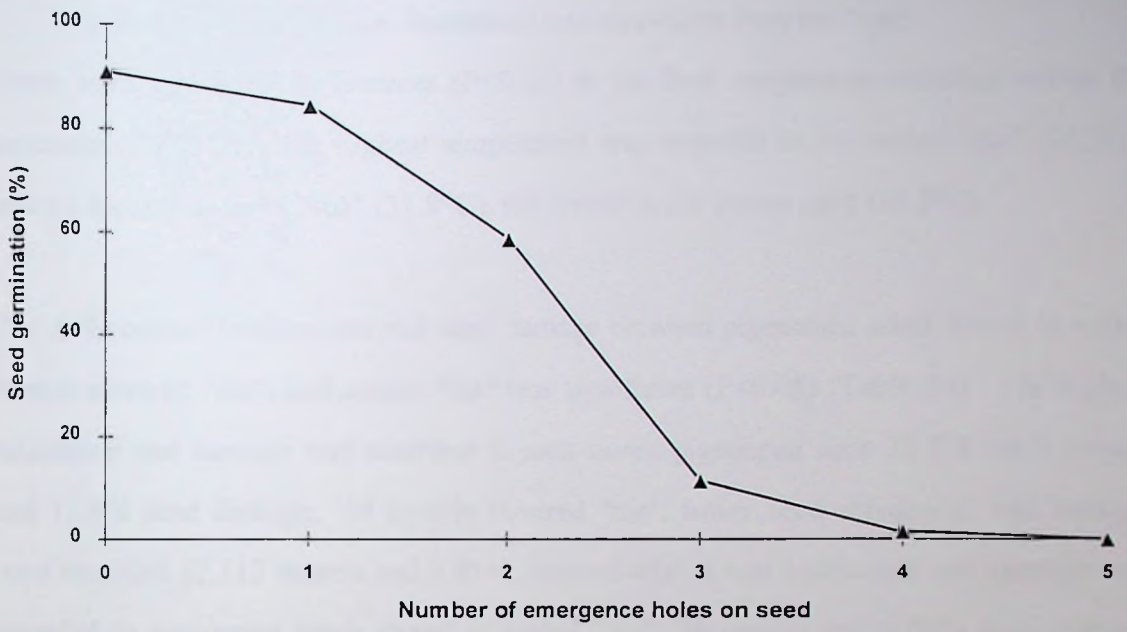


Table 22 C. chinensis *emergence and percentage seed damage of stored pigeonpea originating from cypermethrin treated and untreated plots*

Storage duration (months)	Mean number of emerged insects from 500g		% seed damage	
	Treated	Untreated	Treated	Untreated
1	3.0	19.7	0.18	1.23
2	68.8	633.0	5.08	29.25

b. Efficacy of some cultural and or physical management methods on *C. chinensis* infestat of stored pigeonpea seed

i. Effect of sealed storage: traditional mud-straw-cow dung silo "tua"

There were significant differences ($P<0.05$) in the final temperature readings within the container (Table 23). The highest temperature was recorded in the sealed "tua" (36.2°C) and the loosely covered "tua" (31.8°C), the lowest in the gunny sack (25.5°C).

The differences in infestation and seed damage between pigeonpea seeds stored in sacks, loosely covered "tua", and sealed "tua" was significant ($P<0.05$) (Table 24). The highest infestation and damage was recorded in sack-stored pigeonpea with 75,728 adult insects and 17.6% seed damage. In loosely covered "tua", lower seed infestation and damage were recorded (2,512 insects and 3.81%, respectively). Least infestation and damage was recorded in pigeonpea seeds stored in sealed "tua" (56 insects and 0.06% seed damage respectively) and all the adult *C. chinensis* were found dead.

Seed viability was also significantly lower ($P<0.05$) in sack-stored seeds (35%) than in loosely covered (76%) and sealed "tua" (73%).

ii. Effect of pod storage on *C. chinensis* infestation and damage on pigeonpea

The results showed that pod storage was very effective in controlling *C. chinensis* infestation (Table 25). It significantly reduced pest infestation ($P<0.05$) from 45.010 to 3.9 insects and seed damage from 19.8% to 0.04% in seed- and pod-storage respectively.

Pod-stored pigeonpea seeds also maintained higher viability (86%) compared to seed-stored pigeonpea (45 %) (Table 25).

Table 23 Temperature recording in the various storage containers at the end of the storage trial (3 months)

Storage container	Gunny sack	Loosely covered "tua"	Sealed "tua"
Temperature (°C)	25.5 (0.511)	31.8 (1.080)	36.2 (0.967)

1. In brackets are standard errors (se).

Table 24 Mean **C. chinensis** *infestation and percentage seed damage on pigeonpea stored for three months in gunny sacks, loosely covered "tua" and sealed "tua".*

Treatment	Mean No. of emerged adults	Mean % seed damage	% seed viability
Gunny sack storage (control)	75,728	17.6	35
Loosely covered "tua"	2,512	3.81	76
Sealed "tua"	56	0.06	73
Least Significant Difference	17.467	3.131	10.59

Table 25 Mean number of **C. chinensis** *emergence and percentage seed damage in pod-stored and seed-stored pigeonpea after two months of storage*

Form of storage	Mean No. of emerged adults	Mean % seed damage	% seed viability
Seed	45,010.0 (1318)	19.80 (0.932)	45 (2.440)
Pod	3.9 (0.248)	0.04 (0.012)	86 (1.476)
S.E.D	±1648.0	±1.200	±4.822

1. In brackets are standard errors (se).

iii. Effect of seed splitting on C. chinensis infestation of pigeonpea during storage

Pigeonpea splitting reduced infestation by *C. chinensis* ($P<0.05$) for all storage durations (Table 26). In split seeds, there was a reduction in pest numbers on each subsequent month of storage, from 221 insects on the first month of storage to 8 insects on the third month of storage. In whole stored seeds, there was a sharp rise in the pest population from about 900 in the first month to over 10,000 insects in the third month of storage.

iv. Effect of solar disinfestation on *C. chinensis* infestation and damage of pigeonpea

Solar heater evaluation

Temperatures in excess of 80°C were achieved in the solar heater in bright sunshine (Table 27). Whereas a mean mortalities of 22% and 13% (Jan. and Feb. trials, respectively) were registered from the seeds held at ambient conditions (control), no *C. chinensis* survived in any of the solar heater treatments (Table 28).

An evaluation of different under-layers

Results of alternative solar heater under-layer materials showed that the various materials used had a significant effect ($P<0.05$) on the temperatures attained in the heaters (Table 29). The blue- and black-coloured cloth under-layers generated higher temperatures (maxima of 80° and 68°C, respectively) than the light coloured polyethylene sack (maxima of 66° and 56°C, respectively).

The consequent effects on adult emergence and percentage mortality were also significant ($P<0.05$) (Table 30). Whereas a mean of 0.7% mortality was recorded from seeds held at ambient temperature, 100% mortality was recorded from trials held with the black and blue under-layer materials, 99.3% and 89.7% from trials using brown sisal sack and white polyethylene sack, respectively. Seeds viability was, however, significantly reduced in treatments with black-polyethylene under-layers. The correlation between seed viability and temperature was significant ($P<0.05$) and negative ($r = -0.937$).

Table 26 Mean adult **C. chinensis** *emergence from split and whole seed*

	Number of adults emerged per 5kg per month				
Month of storage	1st	2nd	3rd	S.E.D	Mean
Split seed	220.8 (8.411)	68.2 (2.063)	8.2 (0.689)	± 9.534	99.1
Whole seed	900.5 (34.24)	3,450.1 (70.14)	10,121.0 (825.4)	± 703.8	4823.9
S.E.D					± 771.2

1. In brackets are standard errors (se)

Table . 27 Temperature in the solar heater and in the control treatment

Month	Treatment	Temperature range (°C)	Temperature mean (°C)
Jan.	Solar heater	45.0 - 90.0	80.9
	Control	25.0 - 32.0	30.0
Feb.	Solar heater	28.0 - 83.0	78.0
	Control	28.0 - 32.0	31.0

Table 28 Effect of solar heater exposure on adult **C. chinensis** *emergence per 4kg.*

Month	Treatment	Mean number of emerged adults	Percentage mortality
Mid Jan.	Solar heater	0	100
	Control	585	22
Mid Feb.	Solar heater	0	100
	Control	653	13

Table 29 Temperature profile in the solar heaters with various under-layers.

Month and weather score	Under-layer	Temperatures attained in the heater (°C)		
March		Mean	SE	Range
2	Black polyethylene	70.0	±2.10	23-80
2	Blue cotton cloth	59.6	±2.09	23-68
2	Brown sisal sack	55.6	±2.12	23-66
2	White polyethylene sack	49.5	±2.07	23-56
	Control	29.6	±2.01	23-32
S.E.D		1.436		
Least Significant Difference		4.425		

Table 30 Effect of solar heaters constructed with various under-layers on adult **C. chinensis** *emergence, mortality and on seed viability*

Treatments	Mean % of emerged adults	Mean Percentage mortality	Mean Percentage seed viability
1. Black polyethylene	0.0B	100.0A	72.6B
2. Blue polyethylene	0.0B	100.0A	87.3AB
3. Brown sisal sack	0.7B (1.055)	99.3A (10.00)	90.0AB
4. White polyethylene sack	10.3AB (3.243)	89.7B (9.475)	90.0AB
5. Control	99.3A (9.950)	0.7C (1.110)	97.0A
Least Significant Difference	(7.010)	(0.430)	17.5

Analysis were carried on transformed data $\{\sqrt{(x+0.05)}\}$. but both non-transformed and transformed results are shown for clarity.

Means followed by the same letter are not significantly different ($P<0.05$) by Duncan's multiple range test

Correlation coefficient (at 3 degrees of freedom) between temperature and seed viability ($P<0.05$) = -0.937

c. Efficacy of natural products (biorationals and sand) on *C. chinensis* infestation of stored pigeonpea seeds

Among the natural products tested, the effects of the treatments on *C. chinensis* emergence and percentage mortality were found to be significant ($P<0.05$) (Table 31).

All plant leaves reduced the number of *C. chinensis* adults which emerged from pigeonpea below non-treated controls (Table 31a, Fig. 47a). Tephrosia treatment had the lowest overall mean adult emergence (4.0); this was followed by fire-cured tobacco (4.6), Mexican marigold leaves (8.8), burley-cured tobacco (20.6), flue-cured tobacco (58.2), water hyacinth leaves (99.2), castor oil leaves (113.6), *Lantana camara* leaves (114.6) and lemon grass (159.4), respectively. In treatments using plant leaves, percentage mortality of *C. chinensis* in infested pigeonpea were in all cases higher than in non-treated controls. Percentage mortality of *C. chinensis* was again highest in the tephrosia treatment (100%) followed by fire cured tobacco (98.6%), Mexican marigold (91.1%), burley tobacco (87.3%), water hyacinth (83.3%), lemon grass (81.7%), castor oil leaves (74.1%), flue-cured tobacco (62.6%) and *L. camara* leaves, respectively (44.2%).

Fruits and fruit products, ash and sand were less effective in controlling *C. chinensis* than plant leaves (Table 31b, Fig. 47). Among these, wood ash was the most effective in reducing adult emergence with only 16.2 adults emerging; followed by banana juice (39), corn oil (52.4), melia seeds (100.2), pineapple juice (106.8), chillies (132.8), papaw juice (134.2), lime peel (140.6) and lemon peel (170.4), respectively. Sand treatment had no significant effect on *C. chinensis* population. The percentage adult mortality was also highest in ash treatment (96.3%); this was followed by banana juice (81.7%), melia seed (76.1%), corn oil (73%), lemon peel (62.3%), lime peel (60.7%) and chillies (50.9%), respectively. There was no significant increase in insect mortality in treatments with juices of pineapple (50.6%) and papaw (42.8%) (Fig. 47). Sand treatment, especially at a lower dosage, reduced ($P<0.05$) *C. chinensis* mortality (39.5%) to below controls (42%).

Table 31(a) Efficacy of various plant leaves (mean of 0.5 - 4.0g dosage to 200g of pigeonpea) on C. chinensis *(number emerged adults and percentage mortality) infesting pigeonpea for 8 weeks*

Treatment	Overall mean number of insects emerged	Overall % insect mortality
Burley cured tobacco	20.6E	87.3 AB
Flue cured tobacco	58.2 D	62.6 CD
Fire cured tobacco	4.6 E	98.6 A
Lantana camara leaves	114.6 C	44.2 D
Water hyacinth leaves	99.2 C	83.5 ABC
Tephrosia leaves	4.0 E	100.0 A
Castor oil leaves	113.6 C	74.1 BC
Mexican marigold leaves	8.8 E	91.1 AB
Lemon grass	159.4 B	81.7 ABC
Control	251.0 A	42.0 D
Least Significant Difference	22.8	24.1

Means followed by the same letter are not significantly different ($P < 0.05$) by Duncan's multiple range test.

Table 31(b) Efficacy of various fruits and fruit products, wood ash and sand (mean of 0.5 - 4.0g dosage to 200g of pigeonpea) on C. chinensis *(number emerged adults and percentage mortality) infesting pigeonpea for eight weeks*

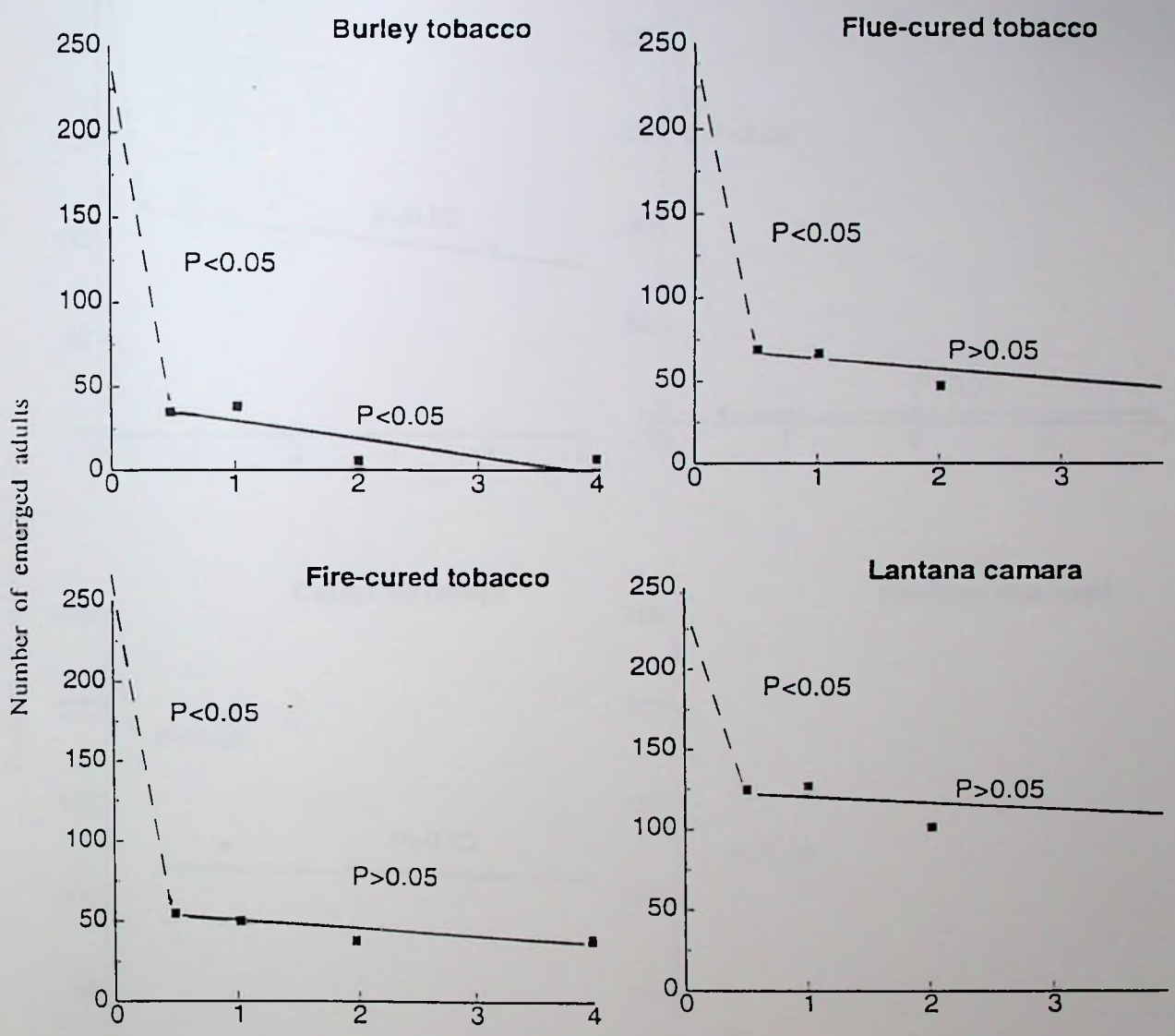
Treatment	Overall mean number of insects emerging	Over-all % insect mortality
Melia seed	100.2 E	76.1 AB
Chillies	132.8 DE	50.9 CD
Lime peel	140.6 D	60.7 BCD
Lemon peels	170.4 C	62.3 BCD
Corn oil	52.4 F	73.0 BC
Pineapple juice	106.8 E	50.6 CD
Banana juice	39.0 FG	81.7 AB
Papaw juice	134.2 D	42.8 D
Wood ash	16.2 G	96.3 A
River sand	212.4 B	39.5 D
Control	251.0 A	42.0 D
Least Significant Difference	23.17	23.13

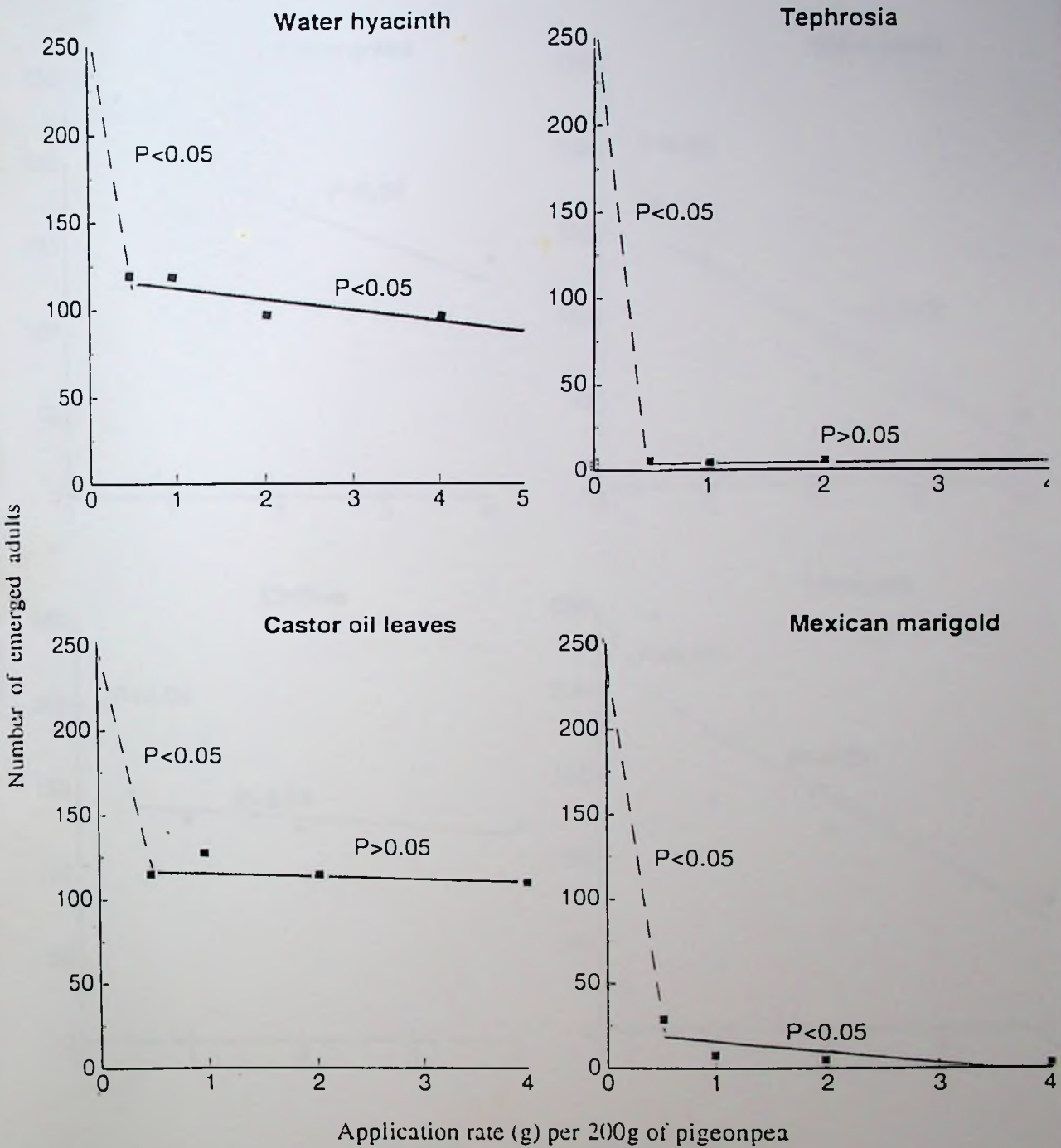
Means followed by the same letter are not significantly different ($P < 0.05$) by Duncan's multiple range test.

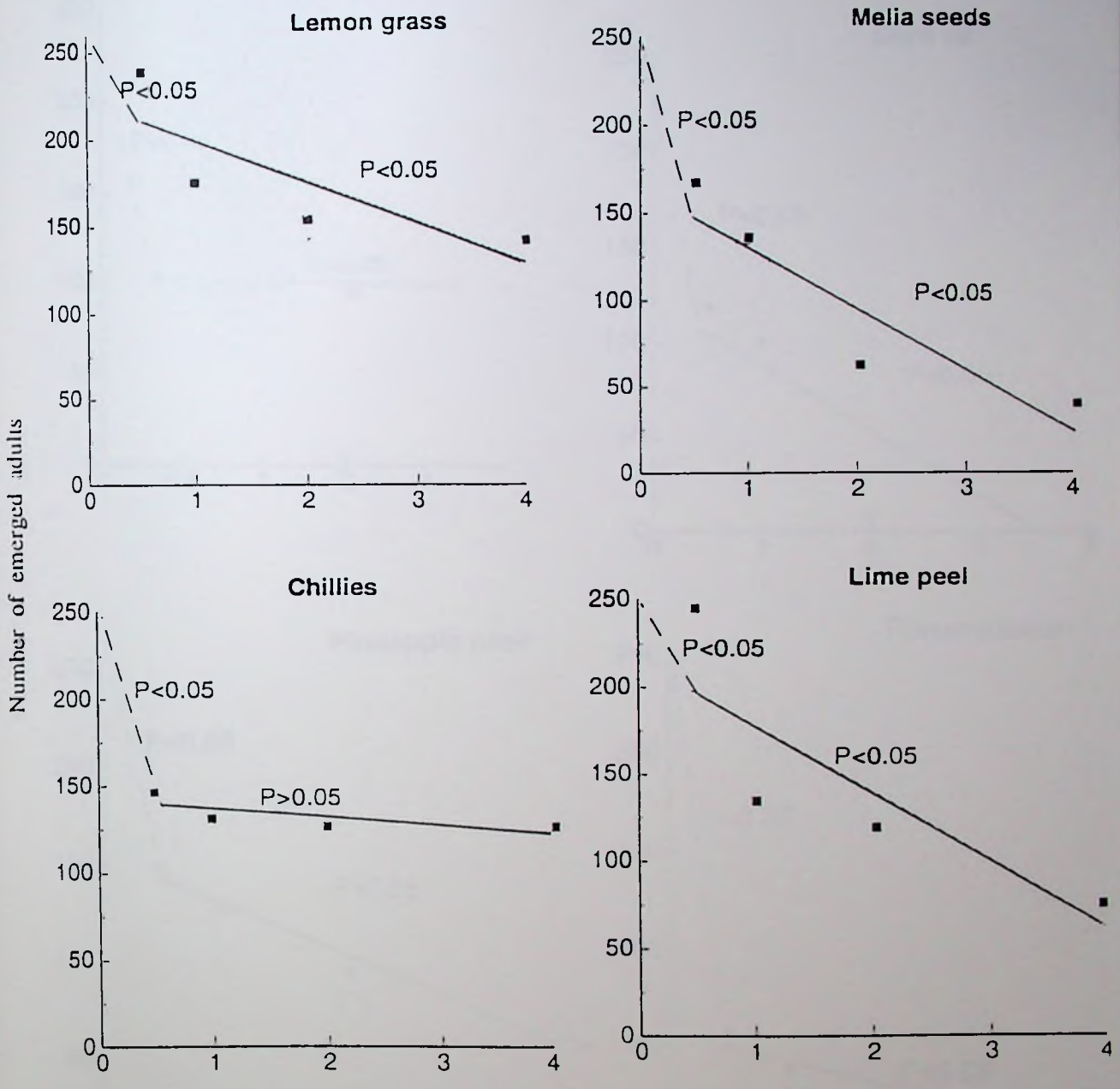
The effect of the different application rates on *C. chinenesis* emergence and percentage mortality also varied among treatments (Figs 47a and 47b). There were significant reductions ($P<0.05$) in adult emergence with increased application rate in treatments with burley tobacco, water hyacinth leaves, Mexican marigold leaves, lemon grass, melia seed, corn oil, pineapple juice, banana juice, river sand and lime peel (Fig. 47a). No significant effect of increased dosage ($P>0.05$) was recorded in adult emergence for flue-cured and fire-cured tobacco, lantana camara leaves, tephrosia, castor oil leaves, lemon peel, papaw juice, wood ash and chillies. In treatments with flue-cured tobacco, fire-cured tobacco and tephrosia, although there was no significant dosage effect on adult emergence, the number of emerged insects at the lowest dosage (0.5g) was already low.

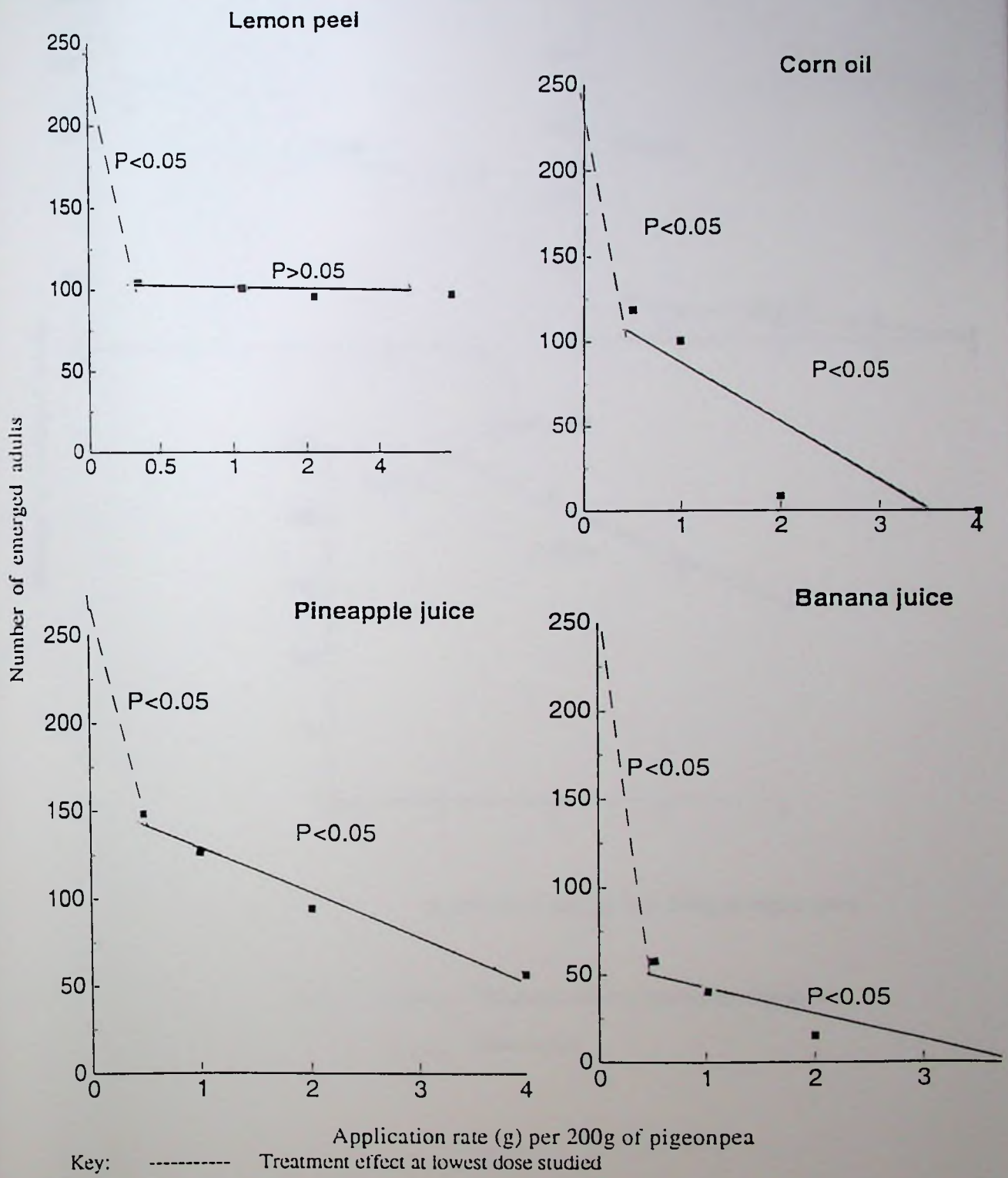
There were significant increases ($P<0.05$) in percentage insect mortality with progressive increase of the dosage rate using burley tobacco, flue cured tobacco, lantana camara leaves, water hyacinth leaves, Mexican marigold, melia seed, corn oil, banana juice, river sand and lime peel (Fig. 47b). No significant effect ($P>0.05$) on insect mortality was recorded with progressive increase of the dosage rate using fire cured tobacco, tephrosia, castor oil leaves, lemon grass, lemon peel, pineapple juice, papaw juice, wood ash and chillies. Although no significant effect was recorded with increased dosages using fire-cured tobacco, tephrosia and wood ash, this was not surprising because the initial kill with the least dosage (0.5g) in all cases was close to 100%.

Fig. 47 (a) Mean number of emerged adult C. chinensis *from infested pigeonpea treated with various natural products*




Water hyacinth
Tephrosia
Castor oil leaves
Mexican marigold
P<0.05
P>0.05
Number of emerged adults
Application rate (g) per 200g of pigeonpea
Key:
Treatment effect at lowest dose studied
Dose effect


Lemon grass
Melia seeds
Chillies
Lime peel
P<0.05
P>0.05
Number of emerged adults
Application rate (g) per 200g of pigeonpea
Key: ---------- Treatment effect at the lowest dose studied
_____ Dose effect


Lemon peel
Corn oil
Pineapple juice
Banana juice
Number of emerged adults
P<0.05
P>0.05
Application rate (g) per 200g of pigeonpea
Key:
Treatment effect at lowest dose studied
Dose effect

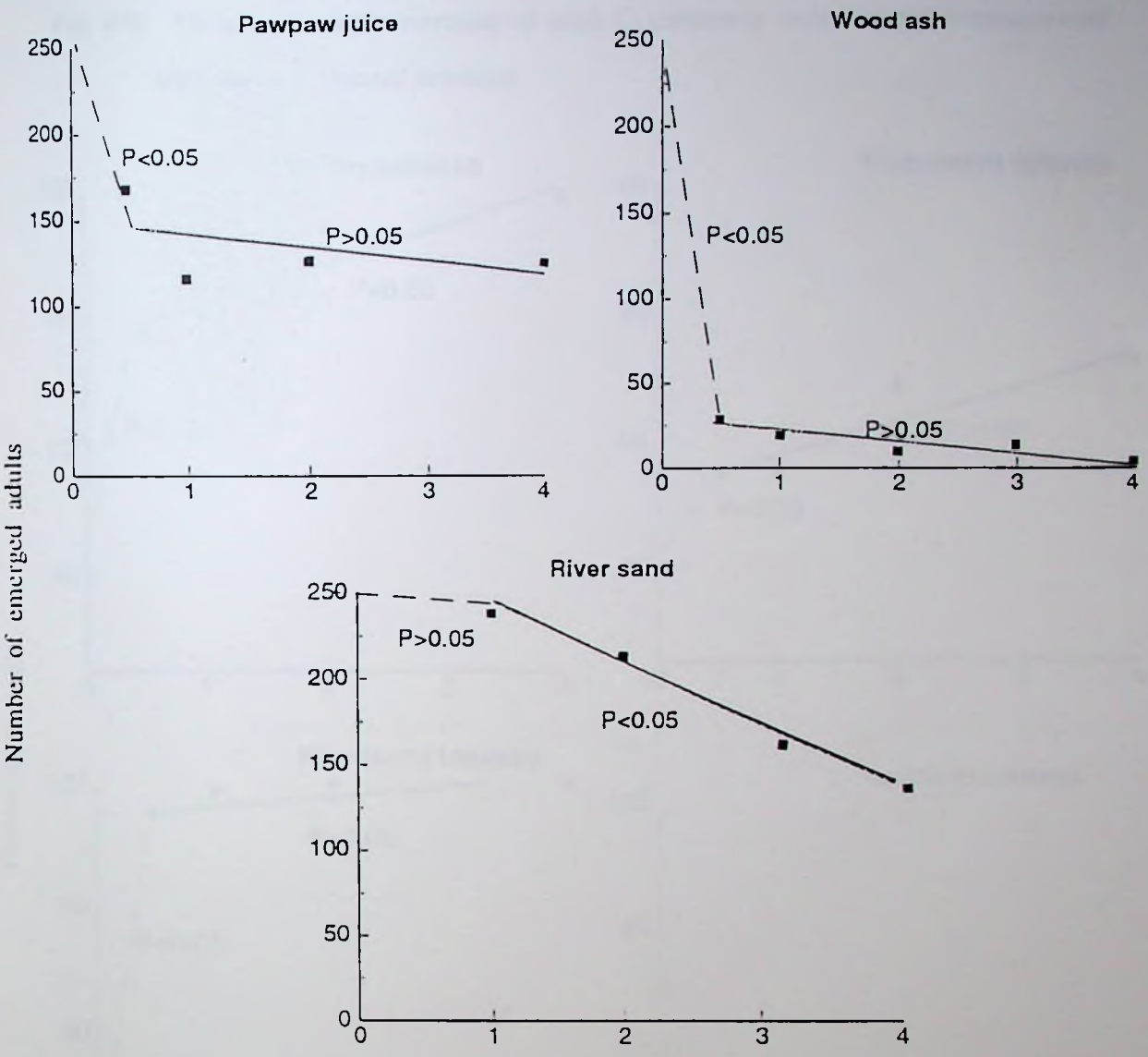
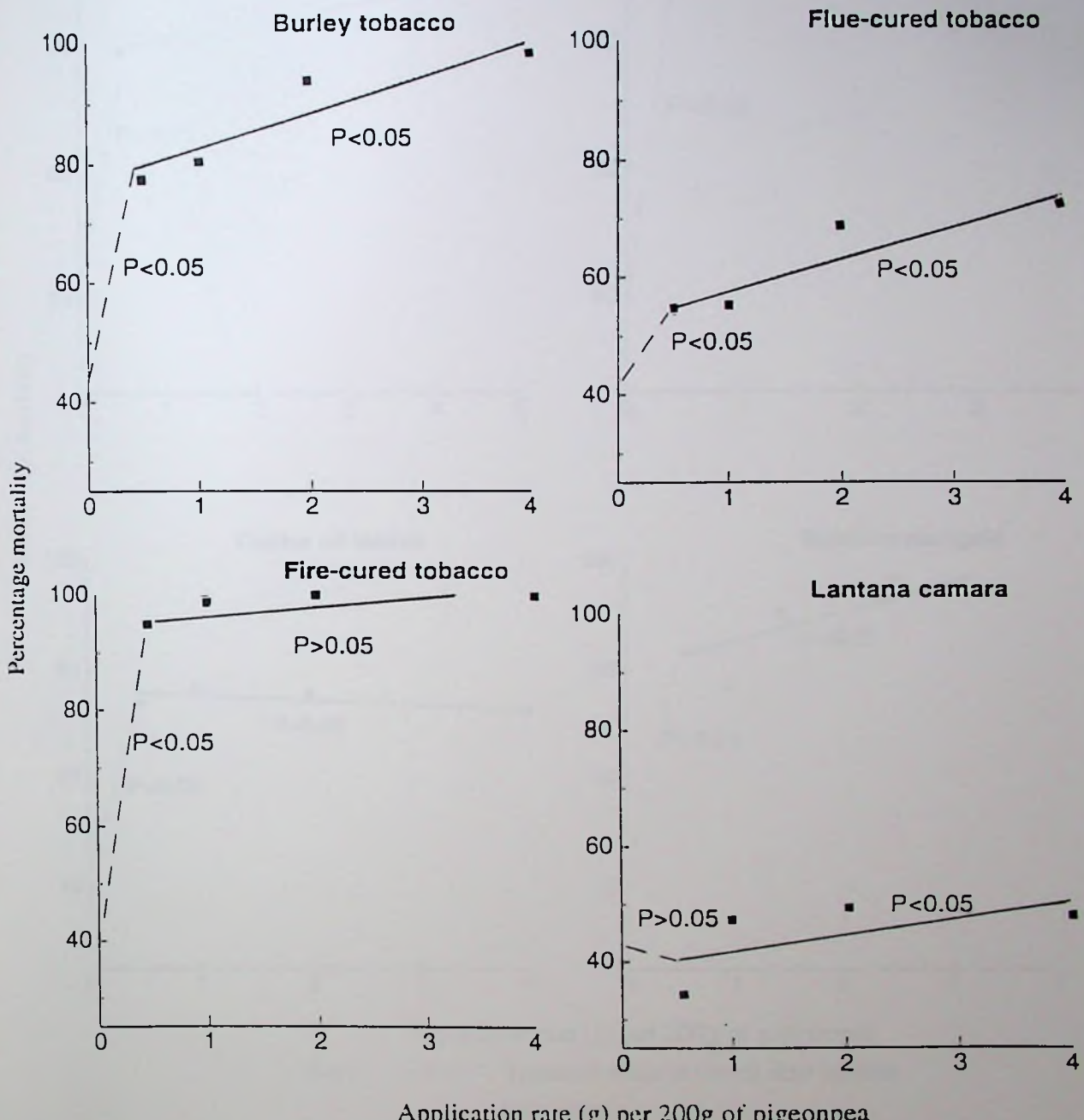
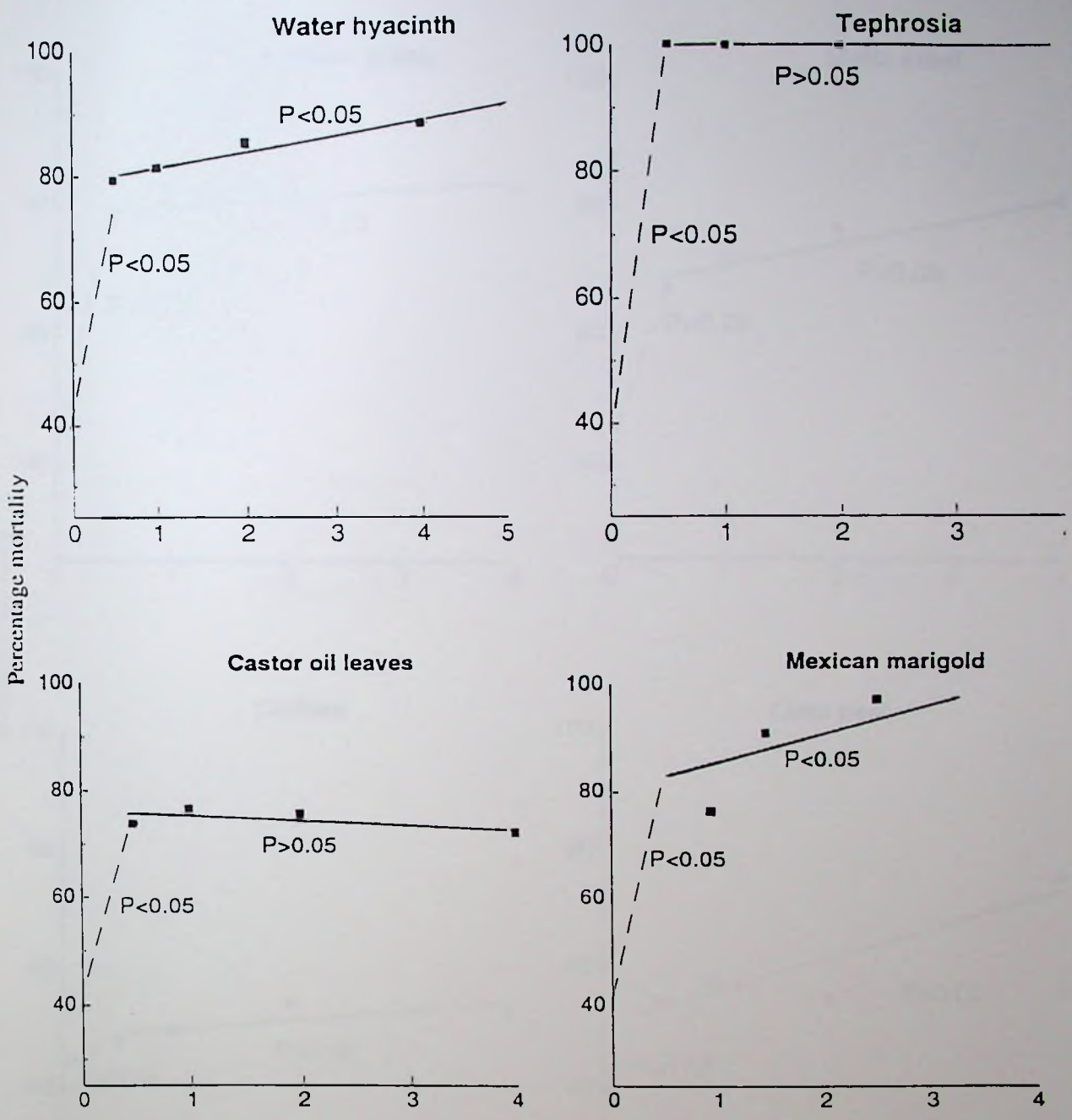
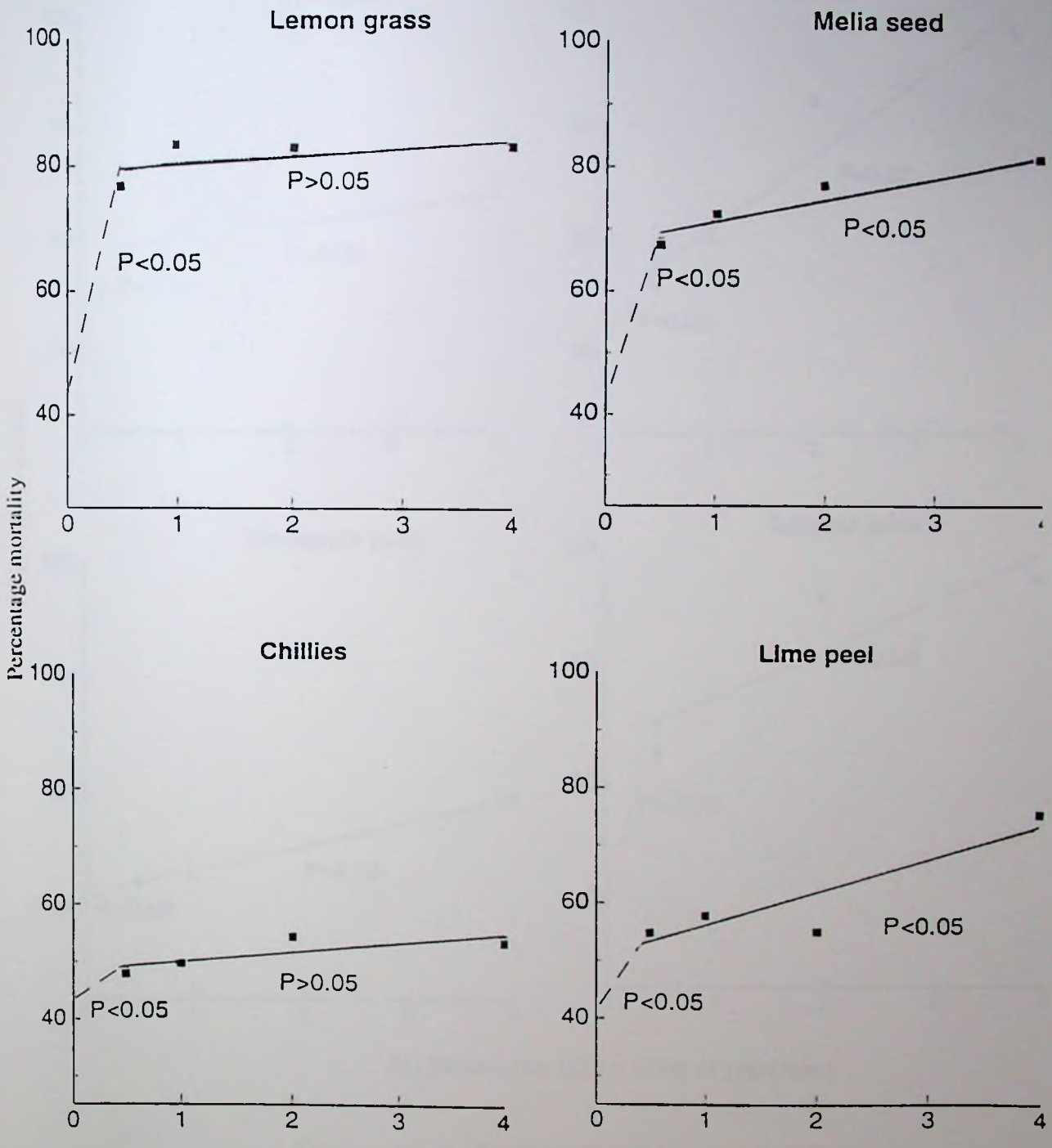
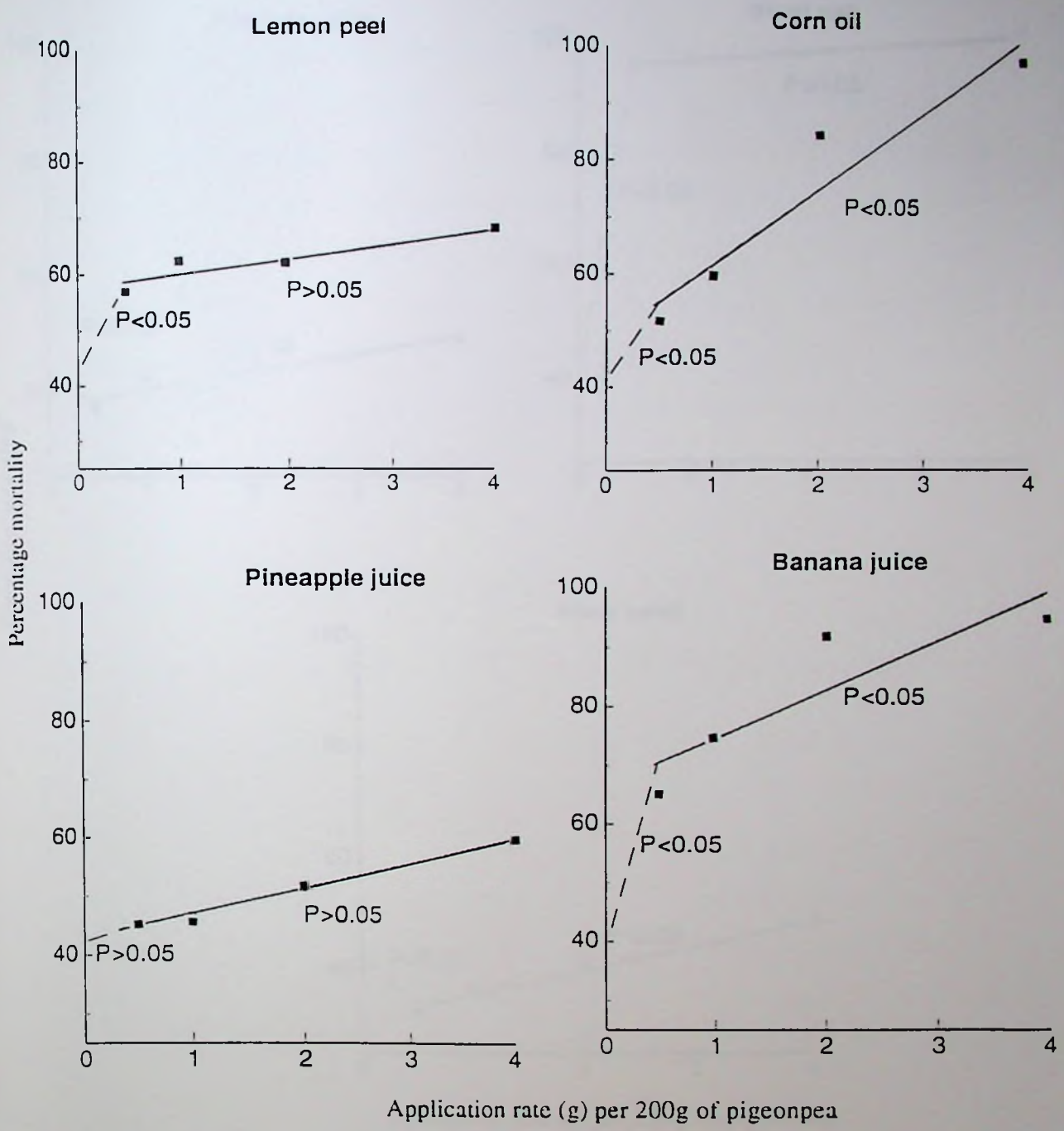

Pawpaw juice
Wood ash
River sand
Number of emerged adults
250
200
150
100
50
0
0
1
2
3
4
P<0.05
P>0.05
P<0.05
P>0.05
P>0.05
P<0.05
Application rate (g) per 200g of pigeonpea
Key:
Treatment effect at lowest dose studied
Dose effect

Fig. 47b Mean percentage mortality of adult C. chinensis *infesting pigeonpea treated with various natural products*



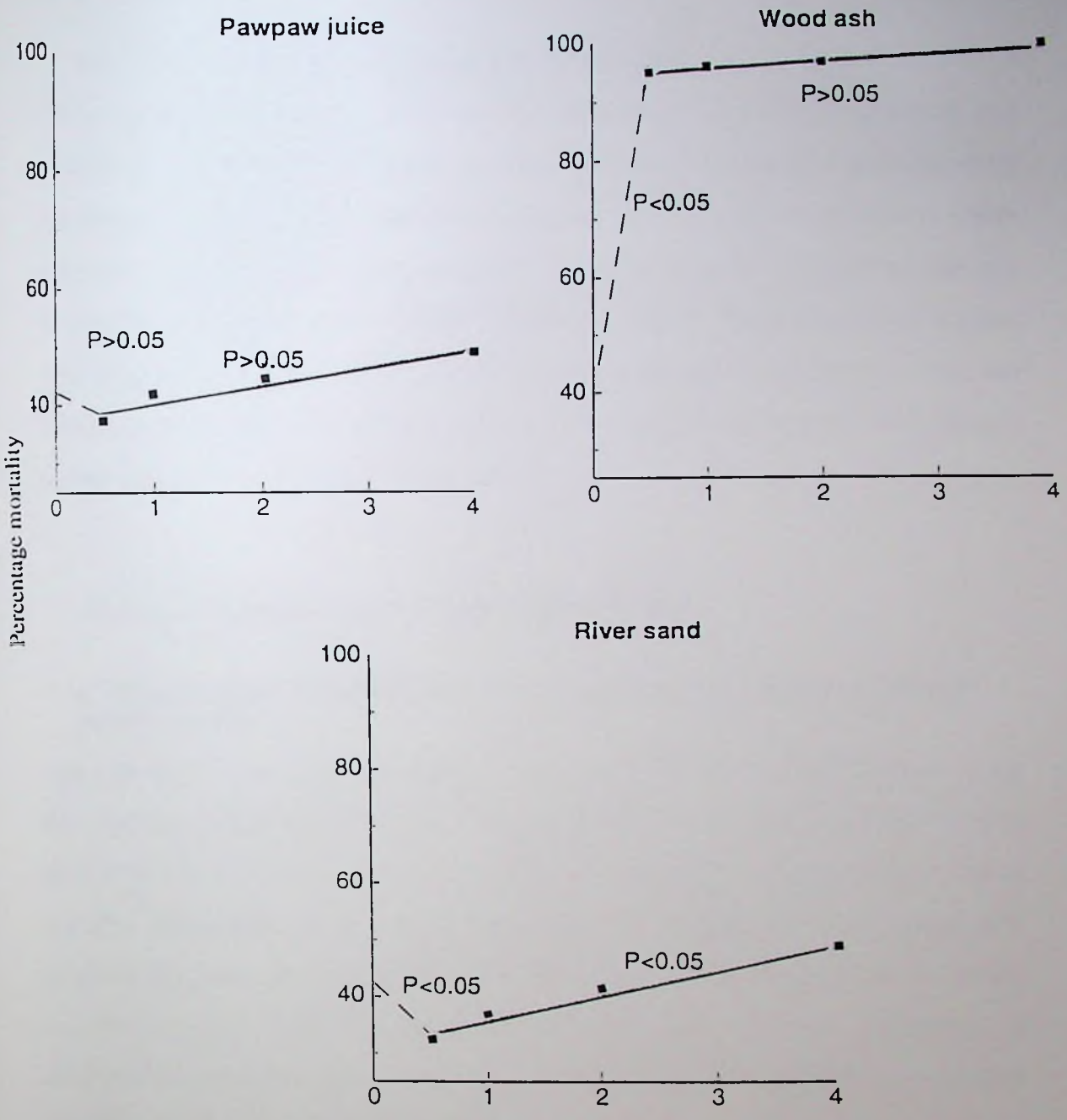

Water hyacinth
Tephrosia
Castor oil leaves
Mexican marigold
P<0.05
P>0.05
Percentage mortality
Application rate (g) per 200g of pigeonpea
Key: ---------- Treatment effect at lowest dose studied
_____ Dose effect


Lemon grass
Melia seed
Chillies
Lime peel
Percentage mortality
100
80
60
40
0
1
2
3
4
P>0.05
P<0.05
P<0.05
P<0.05
P>0.05
P<0.05
P<0.05
P<0.05
Application rate (g) per 200g of pigeonpea
Key:
Treatment effect at lowest dose studied
Dose effect



Key: ---------- Treatment effect at lowest dose studied

_____ Dose effect


Pawpaw juice
Wood ash
River sand
Percentage mortality
100
80
60
40
0
1
2
3
4
P>0.05
P>0.05
P<0.05
P>0.05
P<0.05
P<0.05
Application rate (g) per 200g of pigeonpea
Key:
---------- Treatment effect at lowest dose studied
_____ Dose effect

5.5. Discussion

5.5.1. Effect of bruchid seed damage on germination

The progressive increase in pigeonpea seed damage led to very rapid reduction of seed viability (Fig. 46). This rapid drop in seed viability is probably a result of the direct loss of viability due to seed damage by the bruchid larvae, or due to secondary infection by micro-organisms. It is also possible that during viability tests, rapid water imbibition through pest damage holes on the testa and cotyledon resulted in imbibition damage with a consequent reduction in seed viability. Ellis *et al.* (1990) studying the effect of moisture content and method of rehydration to pea seeds observed that damage to seeds of very low moisture content was a result of rapid water imbibition.

5.5.2. Development of an IPM package for *C. chinensis*

a. Effect of field insecticidal spraying on *C. chinensis* population and damage during storage

Although it is known that with several legume species bruchid infestation starts in the field, the literature available does not advise or cite the field application of insecticide to prevent field to transfer of storage infestation. Early harvest is, however, recommended to minimise subsequent storage damage (Van Huis, 1991). In the case of pigeonpea, early harvest might have a minimal effect as infestation takes place in all pod stages except the very mature pods (Chapter 3). The results of this study have shown that *C. chinensis*, in the form of the flight morph form, which is highly adapted to field conditions, is most probably responsible for field infestations.

It was, therefore, postulated that if field infestation was managed, then the cycle from field (flight) to storage (flightless) could be broken and the resultant storage infestation could either be eliminated or greatly reduced. It was also postulated that the recommended insecticidal application rates for controlling field pests would probably be equally effective in controlling *C. chinensis* infestation and damage.

The results from the insecticide application using cypermethrin (5% e.c) diluted to 0.5% applied at a rate of 10 l/ha reduced field infestation by both *H. armigera* and *C. chinensis* and consequently reduced storage infestation and damage by *C. chinensis* (Table 22). In the sprayed treatments, *H. armigera* damage was reduced ten fold, and after one month of storage *C. chinensis* population in stored seed was reduced seven fold and seed damage was reduced six fold, and after two months of storage adult *C. chinensis* population from stored seed was reduced nearly ten fold and seed damage was reduced six fold compared to control treatment.

The results confirm earlier findings and suppositions, that *C. chinensis* infestation during storage is mostly of field origin and which can therefore be greatly reduced by the application of insecticide. Field application of insecticides could, therefore, be recommended as one of the options for *C. chinensis* management. This would serve the dual purpose of controlling both field and storage pest.

Field spraying may, however, not be able to totally prevent transfer of infestation to storage. This is due to the insidious and hidden nature of *C. chinensis* infestation, which once established, could escape surface application of contact insecticide, and also within storage through cross-infestation other sources of seed infestation could occur.

b. Effect of some cultural and physical management methods on *C. chinensis* infestation of stored pigeonpea seed

i. Effect of sealed storage: traditional mud-straw-cowdung silo "tua"

Results of the current study showed that the differences in infestation and seed damage after 3 months of storage, between pigeonpea seeds stored in sacks, loosely covered "tua" and in sealed "tua" were significant (Table 24). The highest infestation and damage was recorded in sack-stored pigeonpea with 75,728 insects in 40kg of seed and 17.6% of seed damage. In loosely covered "tua", a 30-fold reduction in insect population and 4.5-fold

reduction in seed damage were recorded. In the sealed "tua" only 56 adults were recorded. Moreover all were dead and damage was less than 0.1%. Seed viability was also lower in sack-stored seeds, and much higher in both loosely covered and sealed "tua".

These results are similar to observations made by several workers on the effect of various storage containers on storage pest infestation and damage. Sinah (1990), ascribed the multiplication rate of storage pests during storage to, among other factors, the nature and quality of the storage structure. Vincente *et al.* (1972), reported that percentage seed damage during storage was four times lower in plastic bags than in glass jars. Jalote and Vaish (1976), reported lower grain damage in gunny bag storage than in polyethylene bag storage. Caswell (1975), compared *C. maculatus* multiplication in four types of bags and found that baft bags had the lowest number of insects followed by woven polyethylene, multiwall paper and jute bags, respectively. He reported that grain stored in steel drums had least damage provided the drum was full and the lid tightly fitted. Sinah (1990) compared the effect of five storage containers, namely, glass jars, tin containers, plastic containers, earthen pucca and earthen kaccha, on the population of *C. chinensis*. The highest number of adults after 35 days of storage was recorded in the earthen pucca, glass containers, earthen kuccha and plastic containers, respectively. He postulated that the differences in the micro-climatic conditions within the containers may have been responsible for the differences in pest population, especially the level of available oxygen and other conditions such as temperature and humidity.

In this study the presence of insects within the sealed "tua" may have, with time, resulted in reduction in oxygen levels due to insect respiration to levels which were lethal to *C. chinensis*. This may have suffocated and killed all insects with time due to the hermetic effect. In loosely-sealed "tua" it is probable that some degree of sealing may have been possible, depending on the tightness of the lid and smoothness of the contact surfaces, which resulted in insufficient oxygen for survival. The high final temperatures recorded in both sealed (36.2°C) and loosely covered "tua" (31.8°C) is considered too low to have a

sterilising effect on *C. chinensis* as these were within the temperature range for development to adult (17.5 - 37.5°C) (Howe and Currie, 1964).

These results are comparable to findings in Nigeria, where hermetic storage of cowpea in plastic bags with cotton lining was very effective against *C. maculatus* infestations (Caswell, 1974). When these containers were completely filled with cowpea seed, oxygen concentration dropped to about 1% within two weeks due to *C. maculatus* infestation, after which the beetles died. At an oxygen concentration of about 1% with 10% carbon dioxide, 100% adult mortality was recorded after only 2 days of storage, and 100% mortality after 4 days for eggs, 5 days for 7-14 day old larvae, and 8 days for older larvae and pupae (Storey, 1981).

The results show that the traditional method of pigeonpea storage in sealed "tua" is an effective pest management option. Even the loosely covered "tua" controlled pest multiplication and seed damage to some extent. These traditional storage system which are constructed with locally available materials are easy to construct, cheap and fit in with customary practices of most communities growing pigeonpea in Uganda.

ii. Effect of pod storage on *C. chinensis* infestation and damage on pigeonpea

Pod storage is effective in controlling *C. chinensis* infestation (Table 25). It significantly reduced pest multiplication (from about 45,010 to 4 in seed- and pod-storage, respectively) and seed damage (from 19.8% to 0.04% in seed- and pod-storage, respectively) during 3 months of storage. High seed viability was also maintained in pod storage.

Storage of cowpea in the pod has been reported in several countries (Booker, 1967; Caswell, 1968; Silim *et al.*, 1990) and these methods of storage have been shown to reduce *C. maculatus* populations and damage (Caswell, 1975). In northern Nigeria cowpea pods sampled after nine months of storage had 32% damage while 87% damage was recorded

from seed-stored cowpea (Caswell, 1968). It was however reported that pod-storage only offered partial protection against *C. maculatus* and additional protection was needed to reduce losses.

Reduced infestation and seed damage as observed in pod-stored pigeonpea in this study, is most likely a result of resistance to infestation, due to the presence of numerous surface hairs on the pods, which formed a barrier to egg attachment and pod penetration by the first instar larvae (Chapter 3). In addition, it has been shown that the pod itself acted as a barrier to both larval penetration and adult emergence (Chapter 3). Non location of seed for development immediately after pod penetration may have also resulted in reduced infestation. It is also probable that non-location of the inner-pod wall for the purpose of cutting the emergence window by the last larval stage, could have further reduced the opportunities for external emergence of adults. In cowpea, Caswell (1975), observed that reduced infestation by *C. maculatus* during pod storage could have been either due to failure by the first instar larvae to locate a seed or the thickness of the pod wall reducing entry of the larvae.

The study has shown that pigeonpea pod storage, as practised in the Gulu district using traditional granaries, is probably one of the most effective management methods for *C. chinensis* still in use. This is probably the most important reason why this form of storage has persisted in this part of Uganda.

iii. Effect of seed splitting on *C. chinensis* infestation of pigeonpea during storage

The current study showed that although oviposition and development was possible in split pigeonpea, the infestation was considerably lower than in whole seeds (Table 26). In split pigeonpea, in addition to the low infestation, there was a sharp reduction in infestation with prolonged storage time, and by the end of the third month hardly any adults were recorded. Whereas in whole stored seed, by the end of the third month there was almost a ten-fold increase in adult number. These results are comparable to findings in India where pulses like pigeonpea, mung bean, chickpea and Urd bean (*Vigna mungo*) are regularly split, and these, with or without oil coating, were reported to afford good protection against bruchid attack (Singh and Jambunathan, 1990).

The above infestation trend observed in split pigeonpea is probably due to three factors. First, the effect of reduced surface curvature as described by Gokhale *et al.* (1990), may have initially reduced the attractiveness of the split seed for oviposition thus reducing the rate of multiplication. Secondly, with the removal of the smooth seed coat, exposed cotyledon on the split seed surface which are rough, may not be ideal for egg attachment. Finally, since *C. chinensis* has to begin and complete development in a single seed, the split seed may have not afforded sufficient requirements both nutritionally and volume-wise to complete development to adult. The combined effect would have most likely, especially with extended storage time, reduced the pest population to zero.

iv. Effect of solar disinfestation on *C. chinensis* infestation and damage of pigeonpea

As a means of controlling *C. maculatus* infestations, a simple solar heater was developed and tested by Murdoch and Shade (1991). The solar heater, which consisted of a dark solar radiation absorbing plastic covered with a sheet of clear plastic to trap the solar radiation, was found to be effective in disinfesting cowpea.

In this study, using similar methods and using materials with different colours as under-layers, very high temperatures were attained (Table 29). The black under-layer generated

the highest maximum temperature (80°C), followed by blue cotton under-layer (68°C), brown sisal sack (66°C) and the white polyethylene sack (56°C). These differences are probably due to the absorptive capacity of the different colours and the nature of the materials themselves. Darker coloured surfaces, especially black and blue, are very good heat absorbers while the brown surface are intermediate and the white surfaces are poor absorbers. Heat retention within the system was facilitated by the insulating mattress of the pea trash and pods provided beneath the solar heat chamber. It is, however, likely that the open knitted surfaces in cotton cloth material, sisal sack and polyethylene sack allowed direct air circulation between the system and the external environment, which probably resulted in the reduced temperatures recorded.

All the different materials used as under-layers proved effective in controlling *C. chinesis* infestation in pigeonpea (Table 30). With the exception of the white under-layer materials, all other materials used registered almost 100% mortality. The highest mortality was recorded where black and blue materials were used as under-layers (100%). Brown sisal and white polyethylene under-layers caused 99.3 and 89.7% mortality, respectively. The results obtained in the study are in conformity with studies conducted by Murdoch and Shade (1991) who obtained lethal temperatures on *C. maculatus*.

Solar disinfestation had some effect on seed germination (Table 30). Whereas 97% germination was recorded in untreated seed samples, seed samples from the solar heater where black polyethylene under-layer was used registered the lowest seed germination (72.6%), higher germination were recorded from samples obtained from heaters where blue under-layer cloth (87.3%), brown sisal sack (90%) and white polyethylene sacks (90%) were used. Seed viability was negatively correlated with the temperatures generated in the solar heaters. Higher temperatures reduced germination while lower temperatures had less effect on viability. This is consistent with the negative exponential relationship between seed longevity and storage temperature (Dickie *et al.*, 1990).

Solar disinfestation, although very effective, easy to use and provides a once for all treatment, might have to be recommended with caution, especially under the peasant farming systems where the seed source is the farmers own carry over stock. Where grain is destined for the market or for home consumption, however, the above concern is inconsequential.

c. Efficacy of natural products (biorationals and sand) on *C. chinensis* infestation of stored pigeonpea seeds

The mixing of plant parts (leaf, bark, seed) and plant products (juices, oils, ash) by peasant farmers for management of pulse weevils, has been reported in many countries in Asia and Africa (Gill and Lewis, 1971; Teotia and Tiwari, 1971; Ketkar, 1976; Pandey *et al.*, 1981; Morallo-Rejesus *et al.*, 1990; Silim *et al.*, 1990). Such naturally-occurring substances are increasingly being studied for their potential in the sustainable management of stored product pests (Abo-El-Ghar *et al.*, 1987).

In the current study it was found that, with the exception of river sand, most treatments reduced the number of insects that emerged and increased percentage mortality after two months of storage (Table 31; Fig. 47). There was, however, very wide variability in efficacy among the different treatments. The effect of increased application rate on insect emergence and percentage mortality also varied among treatments.

Tobacco leaves have been used as an insecticide for many years (McIdoo, 1945). The leaves were either used as an extract, dust or burnt to control the numerous field pests. The major biologically active principle was identified as nicotine. 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 the application of the crude extract of *N. tabacum* resulted in 100% mortality to adults of *Tribolium confusum*. In the current study, the efficacy of tobacco leaves on *C. chinensis*

which were cured in three different ways, burley (air-cured), flue-cured (heat-cured) and fire-cured (heat and smoke-cured) differed. Fire-cured tobacco was found to be the most effective, followed by burley and flue-cured tobacco which reduced adult emergence by 98.8%, 91.8%, and 76.8%, respectively, and overall adult mortality of 98.6%, 87.3% and 62.6%, respectively. There was no significant reduction in insect number due to dosage effects in fire-cured and flue-cured tobacco. It was, however, significantly manifested in burley tobacco. Insect mortality was increased with increased dosage of burley and flue-cured tobacco, but not with fire-cured tobacco, which, even at the lowest dosage (0.5g) resulted in nearly 100% mortality.

Without conducting further investigations, it is difficult to tell why there was so much variation in percentage mortality after treatment with each of the three tobacco curing types. It is, however, possible that more changes in the nicotine content may have occurred in one curing procedure than the other due to heat effect, smoke effect or time taken in curing. Higher temperatures during flue-curing may have had little effect on adult mortality, as it has been found that although heat hastened chemical changes, the difference in the amount of nicotine between green and flue-cured tobacco was insignificant (Askew, 1947; Indian Tobacco Central Committee (ICTC), 1960). It is also possible that differences in soil conditions, climatic factors, fertiliser use and cultural practices may have caused the differences in nicotine content. This is supported by the fact that most of the flue-cured tobacco is produced in the West Nile region of northern Uganda, while the burley and fire-cured tobacco is mostly produced in the Bunyoro region of Mid-Western Uganda (Mackenzie, 1971). These places are distinct, in soil types, climatic conditions, ethnically and culturally. This is supported by findings in India that, partly on account of the inherent characteristics of the variety and partly due to differences in soil, climate, fertiliser and cultural practices, the different commercial types of tobacco possess distinct differences in their chemical composition including nicotine (ICTC, 1960).

Saxena *et al.* (1992), using an extract of the aerial parts of *L. camara* found that, when this was applied on *C. chinensis* at 5% concentration there was complete anti-feedant effect. It also provided 10-40% mortality at 1-5% concentration. Loss of fecundity was also noticed at higher doses. In the current study, dried leaves of *L. camara* had an intermediate effect, reducing adult emergence by 54.4% compared with controls, but had no effect on mortality even with increased dosage. The low efficacy noted in this study may have been the result of chemical breakdown during the drying process, or the low dosages used in the study or low toxicity of the plant.

Usha and Jamil (1990), studied the chemosensory response of *C. chinensis* to the water hyacinth and found that, besides producing an attraction, the extract of the weed also caused mortality to the adults. It was postulated that the extract may contain more than one compound acting as a positive stimulus as well as a poison. Using the same plant in the current study, similar results were obtained. Overall, intermediate adult emergence (40%) and high mortality was recorded (83.5%). With increased dosage, reduced adult emergence and increased mortality were recorded.

Before the Second World War, considerable work was done to assess the possibility of using *Tephrosia* spp. from Africa, Asia and Latin America as a source of insecticide with low mammalian toxicity and short persistence (Le Pelley and Sullivan, 1936; Klocke, 1989). The biological activity of the plant was attributed to a group of isoflavonoid-type of compounds known as rotenoids (Klocke, 1989). Against insects, rotenone is active as a contact and stomach poison. Interest on the plant has been shown recently, and its potential investigated on a number of field pests (Ampofo, persnl. comm.). Some investigations have also been conducted to determine its efficacy on storage pests. Delobel and Malonga (1987) found that the application of the powder of dried leaves of *T.vogelli* at a rate of 1:40w/w caused 98.8% mortality to *Carydon serratus*. Silim (unpublished) found that powdered dried leaves of *T. vogelli* at application rate ranging from 1g/400g - 8g/400g had no effect on the bean weevil *A. obtectus*, however.

In the current study, however, irrespective of the application rates *T. vogelli* reduced adult emergence to almost zero and caused 100% mortality. Due to the effect of the plant even at the lowest dosage (0.5g/200g), even lower dosages than used in the current study might probably work equally well.

Using dried leaves of *R. communis*, Okongkwo and Okoye (1992), found that at 5g of the ground product mixed with 300g of *C. maculatus* infested cowpea seed achieved mortality of up to 100% in 7 days. It was found that the grains were protected from damage for more than three months thereafter. In the current study using the same plant, it was found that although the treatment reduced the overall number of insects that emerged (by 54.7%) and increased mortality (by 32%), there was no dosage effect thereafter both on insect emergence and mortality. It is probable that the plant only produces a physical barrier to oviposition or very low toxicity or it may have low persistence or stability resulting in the low efficacy.

Oil extract from Mexican marigold (*T. minuta*), has been reported to be a useful repellent against several field and domestic pests (Jacobson, 1983). Against mosquitoes, the oil was found to be highly toxic, predominantly owing to the presence of *a*-tetrathienyl. In storage the ground leaves were effective against *A. obtectus* at an application rate of 1g/250g of infested beans (*P. vulgaris*) (Agona, persnl. comm.). In the current study, Mexican marigold was found to be highly effective against *C. chinensis*. Very low overall emergence (3.5%) and high mortality of adults (91%) were recorded on the pest by the treatment. There was also an effect of dosage, where adult emergence was reduced to zero and mortality was 100% at the highest dosage (4g).

Ivbijaro and Agbaje (1986), using dried chilli pepper (*Capsicum* sp.) fruits found that the treatment greatly increased mortality of *C. maculatus* . The toxicity to the insect was attributed to the amide compound pipercide. In the current study using chilli treatment, it

was found that adult emergence was reduced (by 50.8%) and mortality only slightly increased (by 8%) over controls. There was, however, no further dosage effect on both adult emergence and percentage mortality. This lack of response to increased dosages is probably due to lack of toxicity on *C. chinensis*.

El-Sayed and Abdel-Razak (1985), reported that peel oils from three citrus fruits reduced oviposition and egg hatchability of *C. maculatus*. Su *et al.* (1972), using sour orange (*Citrus aurantium*) oil consisting of 98% limonene, reported 100% mortality on *C. maculatus*. In the current study, it was found that lime peel had the greater effect on *C. chinensis* emergence while lemon peel had the greater effect on insect mortality. Lime peel reduced adult emergence by 44% and increased mortality by 18%. Lemon peel reduced adult emergence by 32% and increased mortality by 20%. Compared to the other plant products tested, the toxic effect of citrus peel is, however, low.

Various vegetable oils have been shown to be effective against bruchids in pulses. Vegetable oil coating has been shown to be effective against *Z. sufasciatus* infestation in beans (Schoonhoven, 1978), *C. maculatus* infestation on cowpea (Singh *et al.*, 1978; Pandey *et al.*, 1981; Pereira, 1983; Boughdad *et al.*, 1987; Don Pedro, 1985) and *C. chinensis* infestation on cowpea (Ali *et al.*, 1983; Cruz and Cardona, 1981). Some of the vegetable oils tested were of African oil palm, maize, groundnut, coconut, rice bran, soyabean, cotton seed, neem, mee kernel (*Bassia talifolia* L.), mint (*Mentha* spp.), sesame (*Sesamum orintale* Linn.), karite (*Butyrospermum parki* (G. Don) Kotchy) and mustard (*Brassica* spp). Regardless of the source of oil, all gave protection from bruchid attack (Van Huis, 1991). It was postulated that the occlusion of the funnel found on some bruchid eggs by the oils, was the reason for their ovicidal and perhaps larvicidal effects (Credland, 1992). In this study, it was found that corn oil reduced overall adult emergence four fold and increased overall mortality by 31%. There was a very sensitive response of adult emergence and percentage mortality to dosage. At the highest dosage (4g/200g of seed) adult emergence was reduced to zero and 100% mortality registered.

The seeds of neem tree, *A. indica*, which contains a compound azadirachtin, is considered a very promising alternative to synthetic chemical pesticides and has been investigated against several storage pests with some success (Schmutterer, 1990; Saxena *et al.*. 1989). *Melia azedarach*, widely growing in Uganda, and which is closely related to neem, also contains azadirachtin. The investigations on *M. azedarach* in this study showed that crushed melia seeds reduced overall adult emergence by about 60%, and increased overall mortality by 34%. Adult emergence and percentage mortality showed a clear dose response. Increase in dosage from 0.5g to 4g reduced adult emergence by 66.7% adults in controls to just under 80, and increased mortality from 42% in controls to 80%. It therefore appears that like neem, melia probably contains some chemicals which are toxic to insects (azadirachtin). It however appears, from the low kill on *C. chinensis*, that the compound is either present only in small quantity or in a form which is not as toxic as in neem.

Studies on ashes of several woody trees, has shown that they have some controlling effect on storage pests (Van Huis, 1991). In all cases, however, large volumes of ash were required to give sufficient control. It was suggested that free movement of the adults for oviposition is prevented by the wood ash which had filled the inter-granular spaces (Ofuya, 1986: Pierrard, 1986). In the current study, it was found that wood ash treatment reduced insect emergence nearly fifteen fold and increased the percentage mortality nearly two fold (to 96%). There was a very high dosage response on both adult emergence and percentage mortality. At the highest dosage (4g), adult number had dropped to almost zero, and percentage mortality increased to almost 100%. Comparing other treatments mentioned above and ash, it appears that ash may not only act as a physical barrier to oviposition but probably act as a toxicant (probably as a desiccant) on one or all the developmental stages of *C. chinensis* (adults, eggs, the pre-imaginal).

In surveys in several parts of Uganda, Tanzania and Zimbabwe (Giga *et al.*, 1992), several plant and plant products were reported to be used by farmers to control the bean weevil, *A. obtectus*. These included lemon grass (*Cymbopogon* sp.), banana juice (*Musa* sp.), wood ash and pawpaw juice (*C. papaya*). Surveys in Uganda also showed that in addition to the above products and pineapple juice, wood ash and soil were also being used to protect beans from *A .obtectus* damage (Silim *et al.*, 1990).

In the current study, lemon grass, banana juice, pineapple juice, pawpaw juice, and river sand were tested for efficacy. Banana juice and lemon grass were found to be the most effective (82% mortality), followed by pineapple juice (51%), pawpaw juice (43%) and lastly river sand (40%). It is probable that the former, and especially banana juice (which showed a very high response to dose), may have had certain toxic effects on *C. chinensis* either during development or as adults or may have deterred or barred oviposition. The remaining treatments appear to have had minimal effect on the insect at the applied dosage, and probably only acted as minor barriers to oviposition.

The results of the materials used could therefore be classified in to three categories depending on treatment and dose effects: a) very high treatment effect, whereby, even at the smallest dosage used the treatments were effective (tephrosia and fire-cured tobacco and wood ash, respectively); b) high treatment effect and high dose response, because full control needed slightly higher dosage than the minimum used (burley tobacco, water hyacinth and Mexican marigold); c) high or medium or low treatment effect but medium or low dose response, because full control could probably only be obtained at a dose level much higher than the highest dosage used (melia seed, lemon grass, corn oil, banana juice, lemon peel, flue-cured tobacco, *Lantana camara*, chillies, pineapple juice, pawpaw juice and sand).

The treatments with probable toxic effects on the insect and therefore, the highest potential for use against *C. chinensis* may be found in categories (a) and possibly (b)

above, with the rest being of medium to low potential. The effect of the treatments in lowest categories (c) above on *C. chinensis* is probably due only to their roles as temporary barriers or deterrents to oviposition.

CHAPTER 6. SCREENING PIGEONPEA GENOTYPES FOR RESISTANCE TO *C. CHINENSIS*

6.1. Introduction

Results from previous chapters (2, 3 & 4) showed that pigeonpea infestation by *C. chinensis* begins in the field and continues during storage with heavy consequent damage. During storage, cross-infestation may also occur which results in further damage to stored seeds. The study also showed that, the two morphic forms, flight and flightless, which are adaptively suited to field and storage conditions, respectively, are responsible for the field to storage cycle and *vice versa.*

Because of the heavy damage to pigeonpea seeds, various management options are practised. All of these practices target infestations during storage, however. No management options are currently available which rely on inherent host-plant characteristics to control infestation in the field before harvest.

The current study has, however, shown that under field conditions, certain host-plant characteristics such as pod surface hairs may have evolved as a counter to some hostile external biotic environmental effects on the plant such as pests. It was found that some of these characteristics had a depressing effect on *C. chinensis* development and infestation. It was, therefore, postulated that during the spatial evolution of pigeonpea, differences in resistance to *C. chinensis*, under either field or storage conditions or both, may have evolved due to differences in pest pressures. If such resistance occurred it could, therefore, be exploited in the long term for a sustainable IPM strategy.

6.2. Objectives

The objective of this study was to screen a number of pigeonpea genotypes for resistance against *C. chinensis* both in the field and during subsequent storage and to determine the relationship between this resistance, if any, to physical characteristics.

The study, therefore, involved:

- screening developing green pods in the field,
- screening mature unshelled dry pods,
- screening mature dry seeds,
- studying the correlations between infestation among the various developmental stages (immature green pod, mature dry pod and dry seed), and
- studying the relationships between certain physical pod and seed characteristics and *C. chinensis* infestation.

6.3. Materials and methods

General

Insects used

Adults of *C. chinensis* used in all resistance trials of all genotypes were reared on seeds of the landrace "Apio-elina" i.e. the local landrace which already showed quite a high resistance to field infestation by *C. chinensis* (resistant genotype of pigeonpea selected to ensure as virulent a pest as possible). The original insect cultures were from infestations from damaged pigeonpea seeds (Apio-elina) freshly collected from northern Uganda and cultures were renewed after every two generations i.e. there was no selection by repeated laboratory culture at Kawanda.

Insects were reared under laboratory conditions (about 24°C) in 3 l glass jars with perforated lids (perforated using a dissecting needle).

Adult *C. chinensis* used in all the trials were sexed using differences in antennal shape as described earlier (Chapter 3). Infestations were made using paired insects (i.e. a male and a female).

Pigeonpea genotypes

The genotypes screened were obtained from the International Crops Research Institute for the Semi Arid Tropics (ICRISAT), India. They also included two local landraces collected from northern Uganda. The genotypes from ICRISAT included collections from Africa, Asia and Australia. These were divided in to short-, medium- and long-duration genotypes as well as on the basis of geographic origin. All together 262 genotypes were screened, composed of 67 short-, 168 medium- and 27 long-duration genotypes (Appendix XIV).

Pigeonpea accessions of the three different maturity durations were separately planted in three different blocks at Kawanda Agricultural Research Institute. Each genotype was planted in a plot which varied in dimension depending on the maturity duration. The short-duration genotypes, which are very short and least bushy, were planted in a single plot measuring 2m x 3m with 50cm spacing between rows and 15cm between plants within the row (density of 13.2 plants/m^2). The medium-duration genotypes, which are taller and bushier than the above, were planted in a single plot measuring 2.5m x 4.5m with 75cm spacing between rows and 20cm between plants in the row (density of 7.7 plants/m^2). The long-duration genotypes, which are the tallest and bushiest, were planted in a single plot measuring 3.5m x 8m with 1m spacing between rows and 40cm between plants in the row (density of 2.5 plants/m^2). No fertiliser was used in all the plots.

Screening procedures

All the genotypes were screened for resistance against *C. chinensis* following deliberate infestation; a) during pod development in the field (immature green pods), b) at pod maturity (mature unshelled dry pods), and c) after harvest (mature dry seed). Only uninjured pods or seeds were infested in all treatments.

Screening was done for both oviposition (on pods) and adult emergence (on pods and seeds). To determine oviposition, egg counts were made on pods using the naked eye. In all cases percentage adult emergence was calculated from the number of eggs laid and the number of emerged adults as follows;

$$\% \text{ adult emergence} = \frac{\text{number of adults emerged}}{\text{number of eggs laid}} \times 100$$

Since the objective of the investigations was to compare resistance to damage from infestation by *C. chinensis* among as many pigeonpea genotypes as possible, no control treatments were employed.

Susceptibility to oviposition and adult emergence in immature pods, dry pods and seeds respectively, were arbitrarily classified, from infestation records of previous chapters (3 and 4), into three categories i.e. least susceptible, susceptible and most susceptible as follows;

Maturity stages	Susceptibility class					
	Most susceptible		Susceptible		Least susceptible	
	Oviposition	% adult emergence	Oviposition	% adult emergence	Oviposition	% adult emergence
Immature pods	>15.0	>15.0	5.0-15.0	5.0-15.0	≤5.0	≤5.0
Mature dry pods	>15.0	>7.0	3.3- 7.0	3.3- 7.0	≤3.3	≤3.3
Mature dry seeds	-	>70.0	-	50.0-70.0	-	≤50.0

Differences in these categories between the three maturity stages are a reflection of the general susceptibility at these developmental stages experienced in earlier chapters (3 and 4); i.e. susceptibility increased in the order; mature dry pod, green pod and dry seed.

6.3.1. Screening for resistance in immature green pods in the field

Pods of each genotype were allowed to develop until the pod-fill stage (PR-3). From 10 (replicates) randomly selected plants per genotype, a cluster of three pods were selected, labelled and caged using sleeve cages (Fig. 22). Six pairs of 48h old *C. chinensis* were introduced within each cage and left for 14 days. The cages were removed very carefully and the number of eggs laid recorded for each cluster of caged pods. The pods were re-caged until the time of harvest, to avoid field infestation.

At the end of 28 days, each cluster of harvested pods were shelled, the seeds counted and seeds from each replicate and each genotype placed in separate glass vials with perforated lids and allowed to incubate under laboratory conditions. Thereafter, at 3-day intervals, the adults that emerged from seeds were removed and counted until no more adults emerged on two consecutive observations. The data for oviposition and adult emergence were analysed using two-way analysis of variance.

6.3.2. Screening for resistance in mature dry pods

At pod maturity, 15 dry pods of each genotype were harvested from different plants and placed singly in 35 ml plastic vials with perforated lids. The pods were infested with two pairs of 48 hour old adults for 14 days and the adults carefully removed and the number of eggs laid per pod were counted and recorded. These were left to incubate for 10 days and the pods shelled and seeds of each genotype incubated under laboratory conditions until adult emergence. Thereafter, at 3 day intervals, the adults that emerged from pods were removed and counted until no more adults emerged on two consecutive observations. The data for oviposition and adult emergence were analysed using the two-way analysis of variance.

6.3.3. Screening for resistance in mature dry seeds

Before the trials, seeds of each genotype were placed in water-proof polyethylene bags and disinfested by freezing (below -10°C) in a freezer for 72 hours. After disinfestation, two sets of eight seeds of each genotype were placed in 35 ml plastic vials with perforated lids. The first set was used to pre-condition the newly emerged insects for the trials by placing the newly emerged adults in the test genotype for three days. These were then transferred to the test vials and seeds infested for 4 days (which was the time needed for females to lay more than ten eggs) with two pairs of conditioned adults. This treatment was replicated four times. After 4 days of infestation, the adults were sieved out and the number of eggs standardised to ten per replicate by gently scraping off excess eggs on seed surfaces using a scalpel. Egg scraping was done to reduce the heavy egg load on seeds to a number that could support insect development. The remaining eggs were left to hatch and thereafter, samples incubated under laboratory conditions until adult emergence. At 3 day intervals, adults that emerged from seeds were removed and counted until no more emergence was recorded on two consecutive observations. The data for adult emergence were analysed using two-way analysis of variance

6.3.4. Correlation between infestations at the various developmental stages (immature green pod, mature dry pod and dry seed) of pigeonpea

Data for oviposition (number of eggs laid per pod) and percentage adult emergence above (sections 6.3.1, 6.3.2 and 6.3.3 and presented in Appendix XIV) for the various developmental stages were subjected to correlation analysis.

6.3.5. Study of the relationship between certain physical pod and seed characteristics to *C. chinensis* infestation

In addition to screening for resistance, three pods from three randomly selected plants of each genotype were randomly harvested and measurements taken for:

- number of hairs per mm^2 of pod surface (as close as possible to mid-point of pod and always where seed development occurred),
- length and width of pods and seeds,
- thickness of pod (as close as possible to mid-point of pod and always where seed development occurred) and seed coat (at mid-point of cotyledon curvature),
- number of seeds per pod, and
- seed colour.

Pod and seed dimensions were measured using a flexible ruler and a micrometer screw gauge, respectively. Pod and seed coat thickness were measured using a micrometer screw gauge with a 2.5µm accuracy, in the case of seed, a 2-3 mm slice of testa removed from seed was used. The number of hairs on pods were recorded under a binocular microscope using an eye piece graticule. Seed colour was determined using the naked eye and were categorised into a scale of 1-5 depending on colour/colour combinations as follows:

Colour *	White to cream	Orange to light brown	Brown to dark brown	Purple	Dark purple to Black
Colour code	1	2	3	4	5

* Where seeds were speckled the predominant colour was used.

These data and data for oviposition and percentage adult emergence (section 36.3.1, 6.3.2 and 6.3.3 and presented in Appendix XIV) were subjected to correlation analysis.

6.4. Results

6.4.1. Screening for resistance in green immature pods in the field

a. Number of eggs laid (oviposition) on green pods

A significant difference ($P<0.05$) in mean oviposition by *C. chinensis* on the different immature green pods of the 262 pigeonpea genotypes screened was observed, from as high as 29.9 (most susceptible) to as low as 0.4 eggs per pod (least susceptible) (Appendix XIV). Forty one pigeonpea genotypes were considered least susceptible (≤5 eggs per pod) to oviposition by *C. chinensis* (Table 32).

Among the short-, medium- and long-duration genotypes, the overall mean oviposition on green mature pods were 10.1, 10.4 and 6.2 eggs per pod, respectively, and these means were significantly different ($P < 0.05$). The pods of the short- and medium-duration genotypes had the widest range of egg loads ranging from about 0.5 - 30 eggs per pod, while the long-duration genotypes had egg loads ranging from about 2 - 15 per pod (Fig. 48). Of these, 10 short- and 20 medium-duration genotypes, were considered the least susceptible to oviposition (≤5 eggs per pod) (Table 32). Pods of all the long-duration accessions had generally lower oviposition (always less than 15 eggs per pod) (Fig. 48) and 11 genotypes were considered the least susceptible to oviposition (≤5 eggs per pod) (Table 32).

There was some variability in egg loads (of the Ugandan *C. chinensis* biotype) on pods of genotypes from different geographic locations (Table 33). There was no significant difference ($P>0.05$) in pod oviposition between the genotypes of African and Asian (with Australia) origin with means of 10.0 and 10.6 eggs, respectively. Among the African genotypes however, there was a significant difference ($P<0.05$) between oviposition on pods of pigeonpea genotypes from West Africa (14.7 eggs) and those from East and

Southern Africa (8.8 eggs), with the latter being much less susceptible to oviposition. Oviposition on pods of pigeonpea genotypes originating from East Africa and Southern Africa were not significantly different. However, within the countries in this region, a significant difference was observed between oviposition on genotypes from Uganda and those from Tanzania, with those from the latter being more susceptible to oviposition. Oviposition on pods of pigeonpea genotypes of Asian origin were significantly more susceptible ($P < 0.05$) to oviposition than those of Australian origin, with means of 11.2 and 7.1 eggs, respectively. Within Asia, genotypes from India were significantly less susceptible than those from other countries in Asia, with means of 9.8 and 11.5 eggs, respectively.

b. Percentage adult emergence

From the 262 pigeonpea genotypes of all durations whose immature green pods were infested by *C. chinensis*, there was a significant difference ($P<0.05$) in the mean percentage adult *C. chinensis* emergence; these values ranged from 0 - 65.4% (Appendix XIV). Genotypes with low adult emergence (<5%) numbered twenty eight (Table 32).

Among the infested immature pods of the short-, medium- and long-duration maturities, the overall mean percentage adult emergence were 19.6, 18.3 and 15.2%, respectively, and these means were significantly different ($P<0.05$). Among the short- and medium-duration genotypes adult emergence ranged from 0 - 54% (Fig 49) with less than 3 and 13% of genotypes, respectively, having low adult emergence (<5%) (Fig 49) (Table 32). About 18% of the long-duration genotypes had low adult emergence (<5%), and thus were considered low in susceptibility (Table 32) (Fig. 49).

There was some variability in percentage adult emergence from pigeonpea pods of genotypes from different geographic locations (Table 34). Genotypes of African origin were significantly ($P<0.05$) more susceptible than those from Asia (with Australia), with

overall percentage adult emergence from infested green pods of 21.9 and 18.1% respectively. Among the African genotypes, those from West Africa were significantly less susceptible ($P<0.05$) than those from East and Southern Africa, with overall mean adult emergence from infested pods of 12.8% and 24.2%, respectively. Within the pigeonpea genotypes of East African and Southern Africa, those from East Africa were least susceptible, with mean adult emergence of 17.1 and 31.4%, respectively, and these were also significantly different. Among the countries in this region, a significant difference ($P<0.05$) was also observed in adult emergence, with genotypes from Uganda being the least susceptible followed by Malawi, Tanzania and Mozambique, with adult emergence of 2.7, 17.4, 31.5 and 45.3%, respectively. Percentage adult emergence on infested pods of pigeonpea genotypes of Asian and Australian origin were also significantly different ($P<0.05$), with the Asian genotypes being less susceptible than the Australian ones, with adult emergence of 17.2 and 23.5%, respectively. Genotypes from India and other countries in Asia were, however, not significantly different in adult emergence. Genotypes from Uganda showed the least susceptibility to both oviposition (7.5 eggs) and adult emergence (2.7%).

Table 32 Pigeonpea genotypes (of the 262 screened) with immature green pods of low susceptibility to oviposition and/or low adult *C. chinensis* emergence

a. Short-duration accessions

Genotype	Eggs laid per pod		% adult emergence		Genotype	Eggs laid per pods		% adult emergence	
ICPL-85035	13.9		4.8	LSAE	ICPL-83022	3.4	LSO	28.1	
ICPL-84031	11.4		4.9	LSAE	QPL-19	3.3	LSO	27.0	
ICPL-4	4.2	LSO	20.7		ICPL-208	3.3	LSO	36.8	
ICPL-86010	4.1	LSO	20.1		ICPL-84024	2.9	LSO	16.7	
ICPL-153	4.0	LSO	14.2		ICPL-84020	1.4	LSO	4.8	LSAE
ICPL-2	3.7	LSO	11.4		AI-(II-17)	1.2	LSO	47.6	

b. Medium duration accessions

PR-5089	24.6		1.6	LSAE	PI-394709	4.6	LSO	15.7	
ICPL-221	21.0		3.9	LSAE	PR-5731	4.6	LSO	5.1	
ICPL-129	20.3		4.3	LSAE	PI-398113	4.6	LSO	6.3	
RPSP-470	14.4		2.7	LSAE	PI-397679	4.4	LSO	17.8	
PI-396137	14.8		2.4	LSAE	PI-397677	4.3	LSO	17.8	
PI-397033	13.9		3.9	LSAE	PI-396995	4.3	LSO	16.8	
PI-397810	12.9		3.9	LSAE	PI-395342	4.3	LSO	21.5	
PI-397357	12.6		4.3	LSAE	CSS-16	4.2	LSO	28.9	
PI-397532	12.3		4.1	LSAE	PI-395446	4.2	LSO	24.1	
PI-398112	11.8		1.3	LSAE	PI-397748	4.2	LSO	1.4	LSAE
PI-398094	10.4		0.9	LSAE	PI-397-496	4.1	LSO	10.0	
PI-397709	9.7		4.1	LSAE	ICPL-249	4.0	LSO	0.7	LSAE
ANM-895	9.4		4.0	LSAE	IC-WL-SEL-1522	3.9	LSO	11.1	
APIO-ELINA	8.5		2.7	LSAE	PI-394739	3.8	LSO	20.4	
PI-397445	6.4		5.0	LSAE	PI-395964	3.8	LSO	3.7	LSAE
PI-398052	6.2		2.4	LSAE	PI-397763	3.0	LSO	20.7	
PI-394726	5.5		0.0	LSAE	PI-395579	2.6	LSO	10.8	
PI-396828	4.8	LSO	16.8		08-TZ	0.4	LSO	8.3	
TCP-5733-15MB	4.8	LSO	18.4						

c. Long-duration acessions

PI-394364	8.2		0.0	LSAE	3615-E1-388	4.6	LSO	3.9	LSAE
IC-SMR-SEL-5097	8.0		2.6	LSAE	IC-SMR-SEL-7942	4.4	LSO	20.3	
AGIGI	7.7		2.6	LSAE	IC-SMR-SEL-4367	3.7	LSO	19.4	
IC-SMR-SEL-7215	5.0	LSO	20.6		PI-395686	3.2	LSO	17.8	
3630	5.0	LSO	23.1		PI-395449	2.6	LSO	20.0	
IC-SMR-SEL-2003	4.9	LSO	26.1		PR-5188	2.6	LSO	4.8	LSAE
PI-394475	4.9	LSO	16.2		PI-396407	2.3	LSO	19.2	
Coefficient of variation (CV) for the 262 genotypes screened						37.3%		59.4%	
Least Significant Difference (LSD) for the 262 genotypes screened (P<0.05)						5.8		10.0	

KEY LSO = Low susceptibility to oviposition (≤ 5 eggs per pod)

LSAE = Low susceptibility to adult emergence (≤ 5% adult emergence)

Fig. 48. Frequency distribution of eggs laid by C. chinensis on immature pods of pigeonpea genotypes of different maturity groups

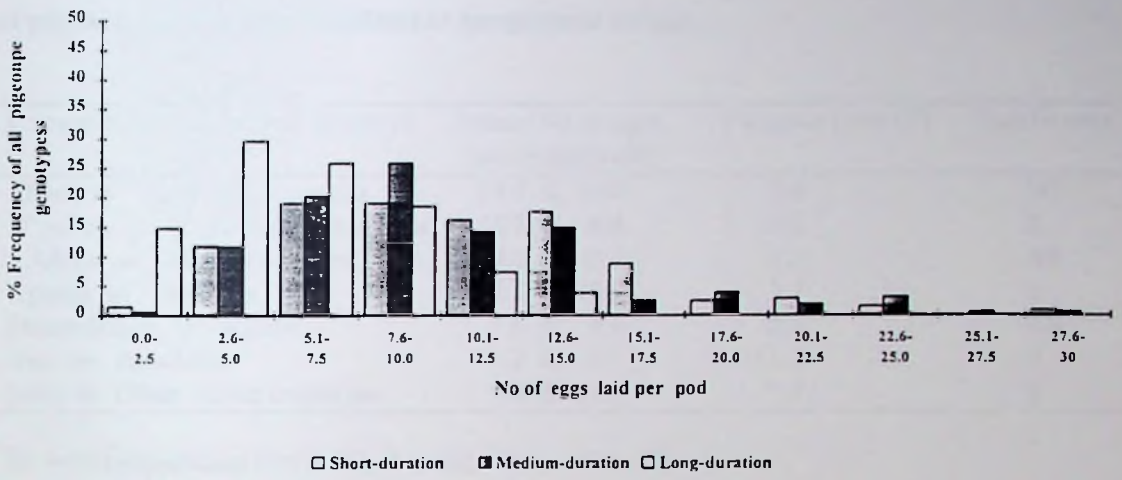


Fig. 49. Frequency distribution of percentage adult C. chinensis emergence of from infested immature green pods of pigeonpea genotypes of different maturity groups

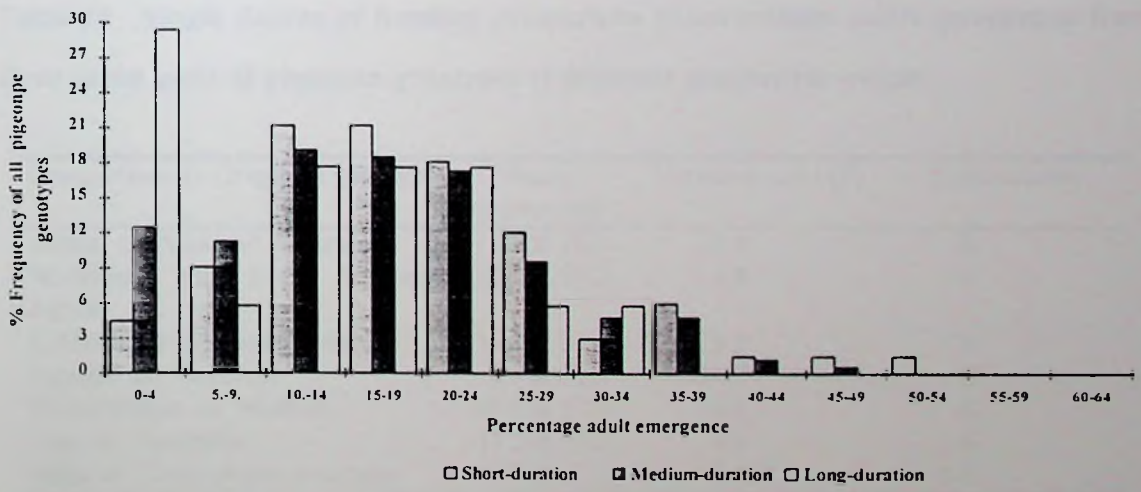


Table 33 Single degree of freedom comparison of eggs laid on immature green pods of pigeonea genotypes of different geographic origin

Comparison by Origin of genotype	Means No of eggs, laid respectively	Variance ratio (F)	Significance
Africa *vs* Asia and Australia	10.0 & 10.6	0.6	NS
W.Africa *vs* E. & Southern Africa	14.7 & 8.8	10.5	S
E.Africa *vs* Southern Africa	9.0 & 8.6	1.5	NS
Uganda *vs* Tanzania	7.5 & 10.4	3.7	S
Mozambique *vs* Malawi	7.6 & 9.6	0.6	NS
Asia *vs* Australia	11.2 & 7.1	11.3	S
India *vs* Other Asian countries	9.8 & 11.5	5.7	S

NS = Not significant (P> 0.05), S = Significant (P<0.05)

Table 34 Single degree of freedom comparison of percentage adult emergence from three green pods of pigeonea genotypes of different geographic origin

Comparison by Origin of genotype	Means, respectively	Variance ratio (F)	Significance
Africa *vs* Asia and Australia	21.9 & 18.1	31.9	S
W.Africa *vs* E. & Southern Africa	12.8 & 24.2	10.9	S
E.Africa *vs* Southern Africa	17.1 & 31.4	5.3	S
Uganda *vs* Tanzania	2.7 & 31.5	34.7	S
Mozambique *vs* Malawi	45.3 & 17.4	13.0	S
Asia *vs* Australia	17.2 & 23.5	5.9	S
India *vs* Other Asian countries	17.7 & 17.1	0.002	NS

NS = Not significant (P>0.05), S = Significant (P<0.05)

6.4.2. Screening for resistance in mature dry pods

a. Number of eggs laid on pods

Of the 262 pigeonpea genotypes screened, there was a significant difference ($P<0.05$) in the mean number of eggs laid by *C. chinensis* on the different mature dry pods. These ranged from the highest oviposition of 15.0 eggs (most susceptible), to the lowest oviposition of 0.0 eggs (least susceptible) per pod (Appendix XIV). Forty three pigeonpea genotypes had very low egg counts on pods (≤3.3 eggs per pod) and were, therefore, considered to be the least susceptible to oviposition by *C. chinensis* (Table 35).

Among the short-, medium- and long- duration maturity categories, the overall mean number of eggs laid on dry mature pods were 5.9, 5.8 and 6.1, respectively, and these means were not significantly different ($P>0.05$). Although the three duration categories had similar egg distribution frequency on pods, the short-duration genotypes had a wider range of egg load ranging from 0.0 to 16 eggs on pods of the different genotypes (Fig. 50). Of these, thirteen were considered the least susceptible to oviposition (≤3.3 eggs per pod) (Table 35). Of the long- and medium-duration genotypes, 7 and 36, respectively, were considered the least susceptible to oviposition (≤3.3 eggs per pod) (Table 35). A higher proportion of the long-duration pigeonpea genotypes had very low egg loads of *C.chinensis* on their pods (Fig. 50).

There was some variability in egg loads on pods of genotypes from different geographic locations (Table 36). Pigeonpea genotypes from Africa were significantly ($P<0.05$) more susceptible to oviposition than those from Asia (with Australia), with mean egg loads on dry pods of 7.5 and 6.0, respectively. Between the African genotypes, those from West Africa were significantly less susceptible to oviposition than those from East and Southern Africa, with mean egg loads of 4.9 and 10.8 respectively. Pigeonpea genotypes from East African and Southern African origin were not significantly different ($P>0.05$) in susceptibility to oviposition, and among the countries in both regions no significant

difference was also shown. Susceptibility to oviposition on pods of pigeonpea genotypes of Asian and Australian origin were not significantly different ($P>0.05$), but those from India were significantly more susceptible to oviposition than those from other countries in Asia with mean egg loads on pods of 5.7 and 2.9 per pod, respectively.

b. Percentage adult emergence

Mean percentage adult emergence of *C. chinensis* from seeds obtained from infested pods of the 262 pigeonpea genotypes varied significantly ($P<0.05$). The range in percentage adult emergence from infested pods of the different genotypes was from 0 - 31.1% (Appendix XIV) and 73 genotypes were considered the least susceptible to adult emergence (≤3.3% adult emergence) (Table 35).

Among the infested mature dry pods of the short-, medium- and long-duration maturities, the overall mean percentage adult emergence were 9.4, 7.6 and 8.0%, respectively, and these means were significantly different ($P<0.05$). In the long-duration pigeonpea genotypes, about 31% had low adult *C. chinensis* emergence (≤3.3%), and these values were about 31 and 18% for the medium- and short-duration genotypes, respectively. The medium- and long-duration genotypes showed less susceptibility to adult emergence than the short-duration accessions (Fig. 51). In the long-, medium- and short-duration genotypes 10, 51 and 12 varieties, respectively, were considered the least susceptible to adult emergence (≤3.3%) (Table 35).

Table 35. Pigeonpea genotypes with mature dry pods of low susceptibility to oviposition and/or low adult *C. chinensis* emergence

a. Short-duration accessions

Genotype	Eggs laid per pod		% adult emergence		Genotype	Eggs laid per pod		% adult emergence	
ICPL-158	7.2		3.3	LSAE	ACG-192	2.8	LSO	4.3	
ICPL-155	6.1		1.6	LSAE	ICPL-83018	2.7	LSO	3.0	LSAE
ICPL-85053	5.6		2.5	LSAE	ICPL-86024	2.6	LSO	2.6	LSAE
ICPL-172	5.8		2.5	LSAE	ICPL-167	2.4	LSO	4.8	
QPL-23	3.9		3.0	LSAE	ICPL-84059	2.3	LSO	9.4	
ICPL-86023	3.2	LSO	2.8	LSAE	ICPL-83022	2.2	LSO	2.8	LSAE
ICPL-830	3.3	LSO	15.1		ICPL-153	1.9	LSO	3.3	LSAE
AI-(IIT-9)	3.3	LSO	4.4		AI-(II-17)	1.4	LSO	0.0	LSAE
QPL-19	3.2	LSO	8.9		ICPL-208	1.0	LSO	0.0	LSAE
ICPL-83019	3.0	LSO	6.7						

b. Medium-duration accessions

PI-395599	10.8		1.9	LSAE	PI-397505	3.6		0.0	LSAE
PI-398068	10.0		3.7		IC-SMR-SEL-3486	3.3	LSO	0.0	LSAE
ICPL-129	9.0		2.7	LSAE	PI-397763	3.3	LSO	0.0	LSAE
PR-5089	7.9		1.0	LSAE	IC-SMR-SEL-3486	3.3	LSO	0.0	LSAE
IC-SMR-SEL-3578	7.6		2.7	LSAE	ICPL-221	3.2	LSO	7.4	
PI-397457	7.6		2.7	LSAE	PI-396828	3.2	LSO	6.9	
APIO-ELINA	7.4		3.0	LSAE	PI-395342	3.2	LSO	2.8	LSAE
PI-397709	7.3		1.3	LSAE	RPSP-470	3.2	LSO	10.3	
PI-398052	7.1		2.8	LSAE	PI-397027	3.1	LSO	6.7	
ICPL-7906-10-1	7.0		0.0	LSAE	ICPL-249	3.1	LSO	9.4	
PI-397808	6.8		1.3	LSAE	PI-397744	3.1	LSO	18.1	
PI-398006	6.4		2.9	LSAE	ICP-8155-3	3.1	LSO	9.6	
PI-395446	6.2		2.8	LSAE	PI-394975	3.0	LSO	9.3	
ANM-881	6.2		1.5	LSAE	PI-395579	3.0	LSO	0.0	LSAE
IC-SMR-SEL-3576	5.7		2.7	LSAE	PI-398085	3.0	LSO	3.2	LSAE
PR-5748	5.7		2.2	LSAE	PI-398096	2.9	LSO	3.0	LSAE
PI-397496	5.6		3.0	LSAE	PI-397088	2.9	LSO	3.3	LSAE
LJR-118D	5.3		1.2	LSAE	PI-398139	2.8	LSO	9.5	
ICPL-241	5.2		1.6	LSAE	PI-396192	2.8	LSO	3.7	
PI-396137	5.2		2.7	LSAE	PI-396323	2.7	LSO	3.0	LSAE
PI-398094	5.2		1.7	LSAE	IC-SMR-SEL-7238	2.6	LSO	4.5	
PI-397102	5.0		2.1	LSAE	ICPL-245	2.6	LSO	0.0	LSAE
PI-397733	4.9		1.5	LSAE	ICPL-98	2.6	LSO	2.2	LSAE
PI-397747	4.8		1.9	LSAE	PI-397679	2.4	LSO	7.5	
PI-397357	4.8		1.4	LSAE	ANM-895	2.3	LSO	0.0	LSAE
IC-SMR-SEL-7436	4.7		0.0	LSAE	ICPL-230	2.2	LSO	3.7	
ANM-905	4.6		2.6	LSAE	IC-WR-SEL-9858	2.2	LSO	5.6	
PI-397774	4.4		2.0	LSAE	PI-395964	2.2	LSO	0.0	LSAE
PI-397208	4.3		2.6	LSAE	FAO-ACC-51-425CIT	2.1	LSO	1.3	LSAE
PI-398072	4.2		2.2	LSAE	PI-398113	2.1	LSO	19.4	

Table 35 Continued

b. Medium-duration accessions continued

Genotype	Eggs laid per pod	% adult emergence	Genotype	Eggs laid per pod	% adult emergence
PI-396120	4.1	1.5 LSAE	PI-397677	2.0 LSO	4.7
PI-397092	4.0	2.2 LSAE	PI-396040	1.8 LSO	4.2
ICPL-100	3.9	2.6 LSAE	PI-398043	1.7 LSO	10.3
PI-396087	3.8	0.0 LSAE	PI-396169	1.7 LSO	5.6
PI-397748	3.8	0.0 LSAE	PI-397501	1.6 LSO	0.0 LSAE
CSS-16	3.8	3.3 LSAE			

c. Long-duration accessions

IC-SMR-SEL-4367	9.0	3.3 LSAE	PI-396665	3.3 LSO	1.8 LSAE
AGOGI	9.0	0.9 LSAE	PI-396407	3.3 LSO	4.2
IC-SMR-SEL-8129	5.6	3.3 LSAE	PI-395686	2.9 LSO	3.3 LSAE
PI-396270	5.3	1.3 LSAE	IC-SMR-SEL-7942	2.4 LSO	0.0 LSAE
PI-395449	5.2	1.9 LSAE	3615-E1-388	2.1 LSO	0.0 LSAE
IC-SMR-SEL-8074	5.2	1.8 LSAE	PR-5069	2.0 LSO	5.7

Coefficient of variation (CV) for the 262 genotypes screened	38.2%	77.5%
Least Significant Difference (LSD) for the 262 genotypes screened (P=0.05)	3.61	10.0

Key: LSO = Low susceptibility to oviposition (≤ 3.3 eggs per pod)
LSAE = Low susceptibility to adult emergence (≤ 3.3% emergence)

Fig. 50. Frequency distribution of egg loads laid by C. chinensis on dry pods of pigeonpea genotypes of different maturity groups

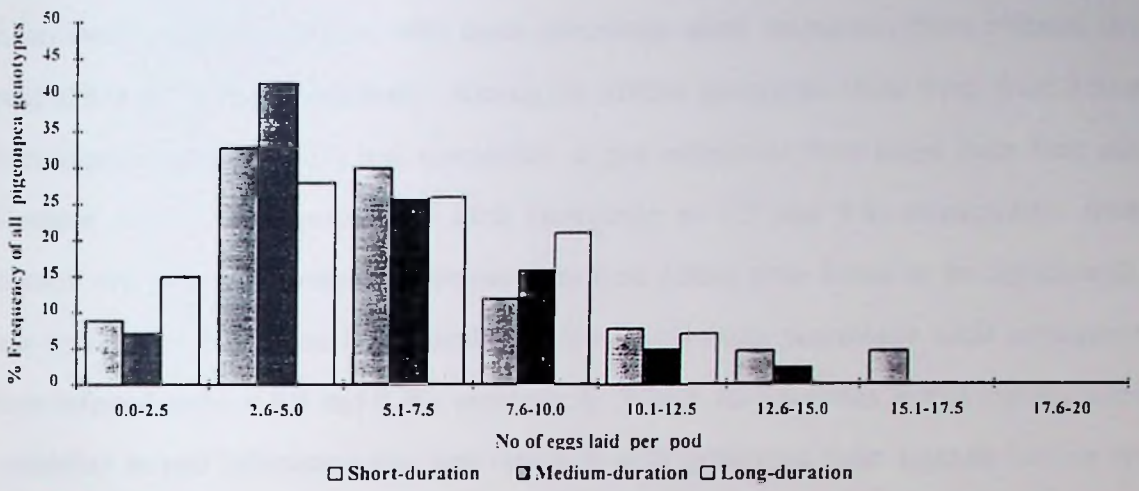
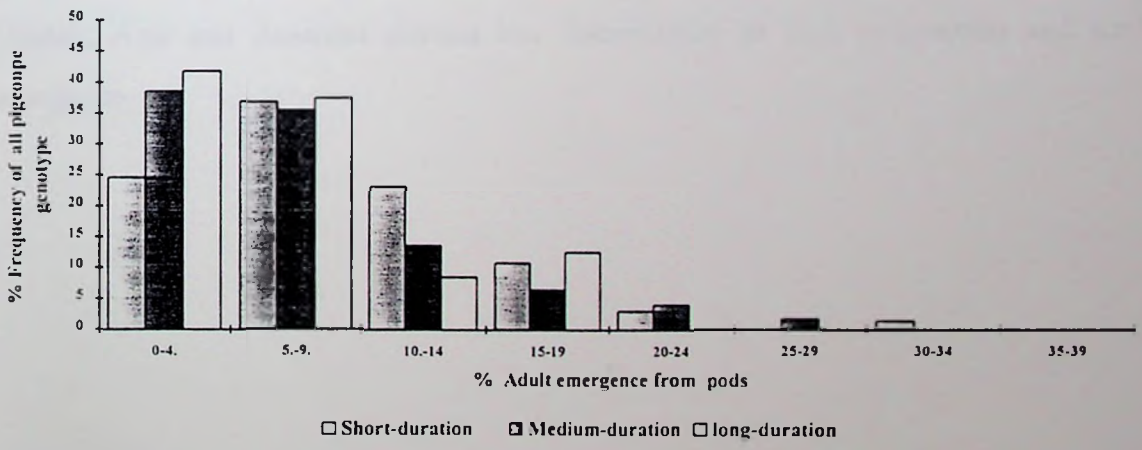


Fig. 51 . Frequency distribution of percentage adult C. chinensis emergence from infested mature dry pods of pigeonpea genotypes of different maturity groups



Percentage adult emergence from infested pods of pigeonpea genotypes from different geographic locations varied significantly ($P<0.05$) (Table 37). Globally, genotypes of African origin were significantly ($P<0.05$) more susceptible to pod infestation than those of Asian (with Australia) origin, with mean percentage adult emergence from infested dry pods of 9.0 and 8.3%, respectively. Among the African genotypes, those from West Africa were significantly ($P<0.05$) less susceptible to pod infestation than those from East and Southern Africa, with percentage adult emergence of 7.9 and 9.4, respectively, from infested dry pods. Pigeonpea genotypes from East Africa were found to be significantly less susceptible than those from Southern Africa, with mean percentage adult emergence from infested pods of 9.9 and 8.9%, respectively. Within the countries in this region, some variability in pod infestation was also observed, with genotypes from Uganda having the least pod infestation (2.0% adult emergence), followed by genotypes from Mozambique (8.4%), Malawi (9.4%) and Tanzania (17.7%), respectively. Pod infestation (% adult emergence) of pigeonpea of Asian and Australian origin were not significantly different ($P>0.05$) as well as those from India and other countries in Asia. Genotypes from Uganda, Asia and Australia showed low susceptibility to both oviposition and adult emergence.

Table 36 Single degree of freedom comparison of pigeonpea genotypes of different geographic origin for oviposition by *C. chinensis* on mature dry pods

Comparison by Origin of genotype	Means, respectively	Variance ratio (F)	Significance
Africa *vs* Asia and Australia	7.5 & 6.0	48.90	S
W.Africa *vs* E. & Southern Africa	4.9 & 10.8	12.70	S
E.Africa *vs* Southern Africa	8.5 & 7.8	1.52	NS
Uganda *vs* Tanzania	8.2 & 8.7	0.24	NS
Mozambique *vs* Malawi	7.3 & 8.2	0.35	NS
Asia *vs* Australia	7.1 & 5.5	0.33	NS
India *vs* Other Asian countries	5.7 & 2.9	4.73	S

S = Significant ($P < 0.05$)
NS = Not significant ($P > 0.05$)

Table 37 Single degree of freedom comparison of pigeonpea genotypes of different geographic origin for percentage adult emergence of *C. chinensis* on mature dry pods

Comparison by Origin of genotype	Means, respectively	Variance ratio (F)	Significance
Africa *vs* Asia and Australia	9.0 & 8.3	34.80	S
W.Africa *vs* E. & Southern Africa	7.9 & 9.4	4.50	S
E.Africa *vs* Southern Africa	9.9 & 8.9	9.20	S
Uganda *vs* Tanzania	2.0 & 17.7	31.50	S
Mozambique *vs* Malawi	8.4 & 9.4	1.28	NS
Asia *vs* Australia	8.4 & 7.2	0.33	NS
India *vs* Other Asian countries	7.2 & 8.9	0.30	NS

S = Significant ($P < 0.05$)
NS = Not significant ($P > 0.05$)

6.4.3. Screening for resistance in mature dry seeds

a. Percentage adult emergence

Of the 262 pigeonpea genotypes whose seeds were infested by *C. chinensis*, the percentage adult emergence ranged from 10 - 100%, and these differences were significant ($P<0.05$) (Appendix XIV). Of the genotypes screened, 18 had low adult emergence (≤50%) and these were, therefore, considered of low susceptibility (Table 38).

Among the infested seeds of the short-, medium- and long-duration maturities, the overall mean percentage adult emergence were 71.0, 64.2 and 74.3%, respectively, and these means were not significantly different ($P>0.05$). About 7.4 and 10% of the long- and medium-duration genotypes, respectively, had low adult *C. chinensis* emergence (≤50%), but none of the short-duration genotypes had low adult emergence (Fig. 52) (Table 38). Two genotypes from India (PI-395622 and PR-50890) showed exceptionally low adult emergence (<14%), indicating very low susceptibility to infestation.

Variability in percentage adult emergence (seed susceptibility) was, again, observed from pigeonpea seeds of genotypes from different geographic locations (Table 39). There was a significant variation in seed susceptibility ($P<0.05$) to *C. chinensis* infestation between the genotypes of African and Asian (including Australia) origin with mean adult emergence of 76.5 and 70.7%, respectively. Among the African collection, there was no significant difference ($P>0.05$) in seed susceptibility of genotypes from West Africa and those from East and Southern Africa and, again no significant variability was observed among those from Eastern and Southern Africa. Within the countries in the region, however, genotypes from Uganda were more susceptible than the genotypes from Tanzania. No difference was observed between genotypes from Mozambique and Malawi. A significant difference ($P<0.05$) was observed for seed susceptibility of pigeonpea genotypes of Asian and Australian origin (74.4 and 69.1%, respectively). Indian genotypes were less susceptible than those from other Asian countries with adult emergence of 66.3 and 76.0%, respectively (Table 39).

Table 38 Pigeonpea genotypes with mature dry seeds of low susceptibility to adult *C. chinensis* emergence (≤50%)

a. Medium-duration accessions

Genotype	Eggs laid per 3 pods	% adult emergence	Genotype	Eggs laid per 3 pods	% adult emergence
PR-5748	Standardised	46.7	PI-397601	Standardised	39.0
PI-398068	to 10	46.7	PI-397774	to 10	36.7
PI-397967		43.3	ICPL- 241		36.0
PI-397262		43.0	ICP-7906-10-1		33.3
PI-398052		40.0	PI-394726		33.3
ICPL-245		40.0	PI-397808		29.0
PI-396075		40.0	PI-395622		13.3
PI-397763		40.0	PR-5089		10.0

b. Long-duration accessions

PR-5069	49.9	IC-SMR-SEL-4367	50.0

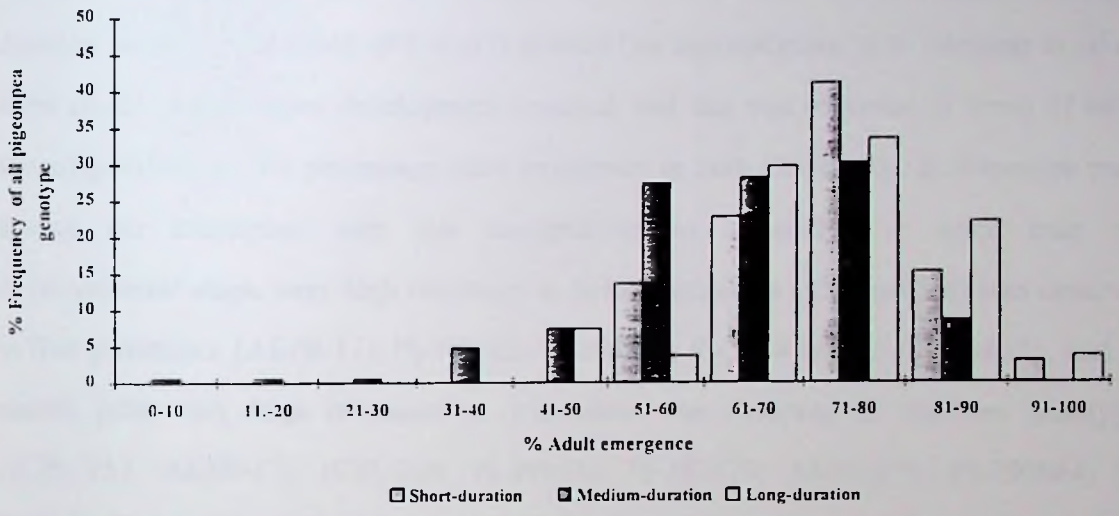
Coefficient of variation (CV) for all the 262 genotypes screened = 18.4%
Least Significant Difference (LSD) for all the 262 genotypes screened = 19.84

Table 39 Single degree of freedom comparison of pigeonpea genotypes of different geographic origin for percentage adult emergence from mature dry seeds

Comparison by Origin of genotype	Mean. respectively	Variance ratio (F)	Significance
Africa *vs* Asia and Australia	76.5 & 70.7	18.2	S
W.Africa *vs* E. & Southern Africa	78.3 & 74.6	0.7	NS
E.Africa *vs* Southern Africa	74.7 & 74.2	0.5	NS
Uganda *vs* Tanzania	85.5 & 64.4	6.9	S
Mozambique *vs* Malawi	80.7 & 73.7	2.9	NS
Asia *vs* Australia	74.4 & 69.1	5.9	S
India *vs* Other Asian countries	66.3 & 76.0	11.62	S

S = Significant ($P < 0.05$)
NS = Not significant ($P > 0.05$)

Fig. 52 . Frequency distribution of percentage adult emergence of C. chinensis from infested mature dry seeds of pigeonpea of different maturity groups



6.4.4. Genotypes showing low susceptibility to *C. chinensis* in two or more of the stages screened (immature pods, mature dry pods and mature seeds)

Of the genotypes screened, 43 showed low susceptibility to *C. chinensis* in at least two of the stages of pigeonpea development (green pods, mature dry pods and dry seeds) reflected in terms of either low oviposition or low percentage adult emergence or both (Table 40). Three medium-duration genotypes (PR-5089, PI-398052 and PI-397763) and one long-duration genotype (IC-SMR-SEL-4367) showed low susceptibility to *C. chinenis* at all the three stages of pigeonpea development screened, and this was reflected in terms of either low oviposition or low percentage adult emergence or both (Table 40). In immature pods, among the accessions with low susceptibility to infestation in more than one developmental stage, very high resistance to field oviposition (≤3eggs/pod) was observed in five genotypes {AI-(II-17), PI-397763, PI-395579, PI-395449 and PI-396407}, and on mature pods very high resistance to oviposition was observed in fourteen genotypes {ICPL-153, AI-(II-17), ICPL-208, PI-395579, PI-397679, ANM-895, PI-395964, PI-398113, PI-397677, ICPL-245, PI-395686, IC-SMR-SEL-7942, 3615-EI-388, PR-5069}. Very low susceptibility (very high resistance) to *C. chinensis* infestation (0% adult emergence) in green pods was observed in only one genotype (PI-394726), but high resistance was shown in mature dry pods in nine {AI-(II-17), ICPL-208, PI-397763, ANM-895, PI-395964, PI-397748, ICPL-245, IC-SMR-SEL-7942 and 3615-EI-7942}. Of the genotypes screened, two (PR-5089 and PI-395622) showed extraordinarily low susceptibility to *C. chinensis* in dry seeds (Table 40).

Table 40 Pigeonpea accessions showing low susceptibility to *C. chinensis* at two or more pigeonpea stages infested (immature pods, mature pods and dry seeds)*

Genotypes	Immature pods		Mature pods		Seed
	Eggs laid	% Adult emergence	Eggs laid	% Adult emergence	% Adult emergence
Short-duration					
QPL-19	3.3	27.0	3.2	8.9	
ICPL-153	3.4	28.1	2.2	2.8	
AI-(II-17)	1.2	47.6	1.4	0.0	
ICPL-208	3.3	36.8	1.0	0.0	
Medium-duration					
PR-5089	24.6	1.6	7.9	1.0	10.0
APIO-ELINA	8.5	2.7	7.4	3.0	
PI-397709	9.7	4.1	7.3	1.3	
PI-398052	6.2	2.4	7.1	2.8	40.0
PI-395446	4.2	24.1	6.2	2.8	
PI-397496	4.1	10.0	5.6	3.0	
PI-396137	14.8	2.4	5.2	2.7	
PI-398094	10.4	0.9	5.2	1.7	
PI-397357	12.6	4.3	4.8	1.4	
PI-397763	3.0	20.7	3.3	0.0	40.0
ICPL-221	21.0	3.9	3.2	7.4	
PI-396828	4.8	16.8	3.2	6.9	
PI-395342	4.3	21.5	3.2	2.8	
ICPL-249	4.0	0.7	3.1	9.4	
RPSP-470	14.4	2.7	3.2	10.3	
PI-395579	2.6	10.8	3.0	0.0	
PI-397679	4.4	17.8	2.4	7.5	
ANM-895	9.4	4.0	2.3	0.0	
PI-395964	3.8	3.7	2.2	0.0	
PI-398113	4.6	6.3	2.1	19.4	
PI-397748	4.2	1.4	3.8	0.0	
CSS-16	4.2	28.9	3.8	3.3	
PI-397677	4.3	17.8	2.0	4.7	
PI-394726	5.5	0.0			33.3
PR-5748			5.7	2.2	46.7
PI-398068			10.0	3.7	46.7
ICPL-245			2.6	0.0	40.0
PI-397774			4.4	2.0	36.7
ICPL-241			5.2	1.6	36.0
PI-397808			6.8	1.3	29.6
PI-395622			9.7	3.3	13.3
Long-duration					
IC-SMR-SEL-4367	3.7	19.4	9.0	3.3	50.0
AGOGI	7.7	2.6	9.0	0.9	
PI-395449	2.6	20.0	5.2	1.9	
PI-396407	2.3	19.2	3.3	4.2	
PI-395686	3.2	17.8	2.9	3.3	
IC-SMR-SEL-7942	4.4	20.3	2.4	0.0	
3615-EI-388	4.6	3.9	2.1	0.0	
PR-5069			2.0	5.7	49.9
L. S. D.as derived from all the 262genotypes	5.8	10.4	3.4	10.0	19.8

* Summary: Absence of data from this table indicates that the observation not shown was higher than that for the least-susceptible category. The missing information is provided in Appendix XIV.

6.4.5. Correlations between infestations at the various developmental stages (immature green pod, mature dry pod and dry seed)

There was a significant positive correlation between oviposition on immature green pods and oviposition on dry pods, indicating the possibility that genotypes with low oviposition on immature pods would also show low oviposition on dry pods and *vice versa* (Table 41). The correlations between oviposition on immature green pods and percentage adult emergence from both infested green pods and dry pods were also significant and positive (Table 41), indicating similarity in the infestation trends. Between oviposition on mature dry pods and percentage adult emergence, on both infested green pods and infested dry pods, significant and positive ($P<0.05$) correlations were observed, again indicating similarity in the infestation trends. No significant correlation was, however, observed between oviposition on immature or mature pods and percentage adult emergence from infested dry seeds (Table 41).

Significant ($P<0.05$) and positive correlations were observed between percentage adult emergence from infested immature green pods and adult emergence from infested mature dry pods, as well as mature dry seeds. Significant and positive correlation was also observed in percentage adult emergence from infested dry pods and from mature seeds. These significant positive correlations (and especially those with $r > 0.100$) indicate that those genotypes with low susceptibility to *C. chinensis* on immature pods tend to show low susceptibility on mature pods, and low adult emergence from seeds (and *vice versa*).

Table 41. Correlation coefficients between oviposition on green immature pods (OGP), oviposition on mature dry pods (ODP), % adult emergence from infested green pods (% EGP), % adult emergence from infested dry pods (%EDP) and % adult emergence from infested dry seeds (%EDS)

Parameter and point of resistance measured	ODP	% EGP	% EDP	%EDS
OGP	0.152 ***	0.095 *	0.084 *	0.055 NS
ODP	_	0.081 *	0.234 ***	0.021 NS
% EGP	_	_	0.084 *	0.157 ***
% EDP	_	_	_	0.231 ***

Significance : NS = Not significant, * = Significant at $P < 0.05$,

** = Significant at $P < 0.01$, *** = Significant at $P < 0.001$

Degrees of freedom = 784

6.4.6. Study of the relationship of certain physical pod and seed characteristics to *C. chinensis* infestation

a. Density of hairs on pods (hairs/mm^2)

The mean density of hairs on pods screened was 38.3 hairs/mm^2, these ranged from 63.9 to 3.3 hairs/mm^2 of pod surface among the 262 genotypes screened (Appendix XIV). There was a negative correlation between the density of hairs per mm^2 of pod surface on the one hand, and each of oviposition and percentage adult emergence from infestation from pods on the other. The correlations were significant ($P<0.05$) for oviposition on both immature green pods and mature dry pods (Table 42), but for percentage adult emergence it was significant only for mature dry pods and not significant ($P>0.05$) for immature green pods. The strongest negative correlation coefficient was observed between pod hair density and oviposition on dry pods followed by percentage adult emergence from dry pods, indicating a strong negative influence of pod hair density on both pod infestation and subsequent adult emergence.

b. Pod dimensions and pod wall thickness

Of the pigeonpea genotypes screened, the mean length and width of the pods were 47.3 and 7.3 mm, respectively (Appendix XIV). A significant ($P<0.05$) but slight positive correlation between pod length and % adult emergence from immature pods was observed. Similar correlations were observed between pod and width, and percentage adult emergence from infested green immature pods, but no correlation was detected with infested mature dry pods (Table 42). This low level of correlation may indicate the minor role pod dimensions may have on infestation.

The mean pod wall thickness of the pigeonpea genotypes screened was 0.178 mm and the range was from 0.111 to 0.246 mm (Appendix XIV). There was a significant ($P<0.05$) and negative correlation between pod thickness and percentage adult emergence in mature dry pods (Table 42). The high correlation level in dry pods between pod wall thickness and

percentage adult emergence indicate the importance of pod thickness in reducing infestation by *C. chinensis*.

c. Seeds per pod, seed dimensions, seed coat thickness and seed colour

The mean number of seeds per pod for the genotypes screened was 3.8 (Appendix XIV). Significant ($P<0.05$) but slight positive correlations between the number of seeds per pod and oviposition as well as percentage adult emergence in both immature green and mature dry pods were recorded (Table 42).

The mean seed length, width and seed coat thickness of screened pigeonpea were 5.51, 4.80 and 0.116 mm, respectively. From infested dry seeds, there were significant ($P<0.05$) though slight correlations between seed width (positive) as well as seed coat thickness (negative), and percentage adult emergence. In all cases there was no significant ($P>0.05$) correlation between seed colour and all parameters measured in all pigeonpea stages screened. The low values of correlation coefficients recorded among these seed characteristics and infestation probably indicates the minor role they play in reducing infestation.

Table 42 Correlation coefficients between certain physical pod and seed characteristics of pigeonpea genotypes and C. chinensis oviposition and percentage adult emergence

Developmental stage	Parameters measured	Hairs on surface	Pod length	Pod width	Pod thickness	Seeds/pod	Seed length	Seed width	Seed coat thickness	Seed colour
Immature green pods	Egg count	-0.174 ***	-0.015 NS	-0.092 *	NA	0.081 *	NA	NA	NA	NA
	% adult emergence	0.064 NS	0.103 **	0.111 **	0.039 NS	0.113 **	0.043 NS	0.048 NS	0.010 NS	-0.026 NS
Mature dry pods	Egg count	-0.725 ***	-0.007 NS	0.035 NS	NA	0.092 *	NA	NA		NA
	% adult emergence	-0.289 ***	0.061 NS	0.070 NS	-0.166 ***	0.084 *	0.035 NS	0.008 NS	0.020 NS	0.020 NS
Mature dry seed	Egg count	NA	NA	NA	NA	NA	NA	NA	NA	NA
	% adult emergence	NA	NA	NA	NA	NA	0.064 NS	0.078 *	-0.122 **	0.064 NS

NA = Not applicable

Significance: NS = Not significant, * = Significant at $P < 0.05$, ** = Significant at $P < 0.01$, *** = Significant at $P < 0.001$

Degrees of freedom = 784

6.5. Discussion

6.5.1. Screening for resistance in green immature pods, mature dry pods and mature dry seeds

a. Oviposition and percentage adult emergence

From the current investigations, there appears to be a very wide variability in susceptibility to oviposition and percentage adult emergence by *C. chinensis* on immature green pods in the field among the various pigeonpea genotypes. Among the stages screened, it was found that most of the genotypes are susceptible to oviposition and to infestation in the field and only about 16% of genotypes had low ovipositional susceptibility and 10% low susceptibility to adult emergence, respectively. Unlike in the immature green pods, on mature dry pods there appears to be less variability in the range of susceptibility to oviposition, and especially percentage adult emergence, by *C. chinensis* among the various pigeonpea genotypes. A high proportion of genotypes with low susceptibility were observed on dry pods, these were recorded at about 20% and 28% for the genotypes with low oviposition and low adult emergence, respectively. On mature dry seeds, wide variability was again recorded, but with most genotypes being highly susceptible to infestation and only 6.1% of the genotypes screened showing low susceptibility to dry seed infestation. These results indicate that greatest resistance to infestation occurs at the dry mature pods stage, less resistance at the immature green pod stage, and least resistance for dry seed, respectively.

Investigations by other workers, on both pod and seed resistance of several legume species to various bruchids have been made and in varying degrees, similar observations to the above findings have been made. In their studies on cowpea, Fitzener *et al.* (1985) found that some genotypic diversity in the suitability of dry cowpea pods and seeds to oviposition by cowpea weevils exists. Talekar and Lin (1981), studying resistance to *C. chinensis* in

mung bean, observed that, among the 14 accessions screened varying degrees of susceptibility were reflected in both dry pods and dry seed stages. Varying degrees of resistance to *Bruchus dentipes* has also been observed on pods of faba beans in the field (Tahhan and van Emden, 1989). In Kenya (Warui, 1983) it was found that variability to *C. maculatus* resistance in the field are expressed both among local and introduced genotypes. In dry seeds of grain legumes, Ahmed *et al.* (1989) reported variability among fourteen genotypes of chickpea to *C. maculatus.* Ofuya (1987) compared the susceptibility of some *Vigna* species to infestation by *C. maculatus* and found high infestation in some varieties and low in others.

These variabilities in resistance can probably be explained through plant/pest interaction. In the study of plant/insect interactions, the central dogma is that plants utilise natural products to defend themselves against herbivorous insects (Rosenthal and Janzen, 1979). The basic modes of plant defence are two:

- either where insects are adversely affected because of physical/chemical properties of the defence and/or,
- where the insects are affected due to the biologically interactive properties of defence i.e. toxicity, repellence and anti-nutritive qualities (Duffy, 1986).

Irrespective of the mode of defence, it is apparent that in the course of evolution many of the plant defence systems against insects may have evolved out of complex and varying degrees of pressures exerted on the plant by the insect. For example, according to Jeffree (1986), the diversity and extent of plant surface structure is a reflection of the diversity and extent of environmental pressures encountered by plants. Though in an evolutionary perspective most of these defence attributes are ephemeral, diverse defence mechanisms either acting singly or in synergy have evolved.

Since the initial interface between the plants and their enemies, including storage pests, is in the field, the pod in this case appears to have evolved a wider array of functions

including defence mechanisms to protect the seeds within. In the case of pigeonpea, the initial storage pest infestations are mostly of field origin and as such it is on the pod that the first line of defence would be. It appears that pod defence mechanism develops as the pod matures so that at the dry pod stage maximum protection is afforded to the mature seeds within. The seed within, on the other hand, is more functionally adapted towards reproduction and would expend less effort to attributes suited to defence. Since pods appear to have a more diverse array of defence mechanisms than the seed, they may thus have wider sources of resistance.

Among the various maturity duration groupings, variability in *C. chinensis* infestation (oviposition and percentage adult emergence) was also observed (Figs 48, 49, 50, 51 and 52) on immature green pods, mature dry pods and mature dry seeds. In immature green pods, the long-duration genotypes had the highest percentage of genotypes with medium to low susceptibility to infestation (low oviposition and low adult emergence) by *C. chinensis*. On mature dry pods, both the long- and medium-duration genotypes had higher percentage of genotypes with medium to low susceptibility to infestation (low oviposition and low adult emergence) by *C. chinensis* than the short-duration ones. On dry seeds, again, most of the least susceptible genotypes belonged to the medium- and long-duration maturities, respectively.

Although these differences may have been due to the unequal number of genotypes screened from each duration category, it is, however, highly likely that man's manipulation had some effect on susceptibility to *C. chinensis*. Man's genetic manipulation through years of selection and breeding may have increased the attractiveness of some plants and plant materials to both man and pests. Through these manipulations and selections, a number of defence attributes have most likely been overlooked in the past, and their occurrence in bred plants most often are incidental than purposeful. In the case of the pigeonpea, where wide diversity in susceptibility to *C. chinensis* infestation was observed in this study, extensive research and selection only started in the 1970s (Swindale, 1990) and as such a

great diversity in defence attributes still occurs which may also include defence against *C. chinensis* infestation.

The focus for most of the recent research on pigeonpea has been towards high-yielding, short-duration varieties and hybrids with wide adaptability to various ecological zones (Swindale, 1990). Due to this emphasis, and particularly on short-duration varieties, the long-duration genotypes have had least manipulation from scientists and as such they appear to have retained many of their defence attributes (in this case showing least susceptibility to field infestation by *C. chinensis* on the pod). The medium- and short-duration genotypes on the other hand show more or less the same trends in susceptibility frequency to infestation (Figs 48 and 49) (which in this case is mostly of medium susceptibility to infestation), this is probably due to the fact that these genotypes have been developed only recently and have a narrow genetic base (Said Silim, personal communication).

In the immature green and mature dry pods, as well as dry seeds, variability in infestation was also observed due to geographic origin of the genotype, with Asia having the largest collection of genotypes with low infestation by *C. chinensis*.

Variability in susceptibility to infestation due to geographic origin is probably due to the amount and extent of man's manipulation of the various genotypes from their point of origin or the sample size, which in this case contained a very wide collection of materials from India and few from elsewhere, which did not offer a large enough population for comparison. The large number of long-duration genotypes screened from Asia may have also contributed to some variability in infestation.

6.5.2. Correlation between infestations at the various developmental stages (immature green pod, mature dry pod and mature dry seed) of pigeonpea

The significant and positive correlation observed between the various parameters measured during pod development is probably an indication of the synergetic action of factors that confer field resistance (Table 41). For example, the significant correlation between oviposition on immature green pods on the one hand and oviposition on dry pods may be a result of one pod attribute or a combination of several occurring through these developmental stages. This resistance may have been due to non-preference of the host due to some physical pod attribute, or repellence, or due to some mechanical barrier(s) to oviposition, or a combination of any of these factors.

The significant correlation in percentage adult emergence between immature and mature dry pods also probably points to the similarities or multiplicity in the attributes that confer resistance during pod development. Such resistance is initially probably manifested in reduced oviposition on the pod surface and eventually manifested in reduced adult emergence possibly due to one or several additional pod attributes. These resistance attributes may be due to the physical pod texture or pod toxicity or non-penetration by larvae or nutritional inadequacy of the pod.

The positive correlation between oviposition on pods (both immature and mature) and percentage adult emergence from both immature and mature pods is probably attributable to a combination of several anti-ovipositional and anti-developmental factors on pods acting in synergy in defence against all stages of pest infestation.

Correlation between adult emergence on pods (both immature and mature) and adult emergence from infested seeds indicate that resistance to *C. chinensis* may occur in synergy with certain seed attributes probably combining with pod factors to afford a wider degree of resistance that neither the pod nor seed alone could offer.

6.5.3. Study of the relationship between some physical pod and seed characteristics to *C. chinensis* infestation

a. Pod characteristics

i. Hairs (trichomes) on pods

Investigations on host/plant interactions in respect to hair density on pod surface and degree of infestation showed a negative correlation between these two factors in the two developmental stages (immature and mature pods) and in the two parameters measured (oviposition and percentage adult emergence). These correlations were all highly significant ($P<0.001$) except for percentage adult emergence in immature green pods which were insignificant ($P>0.05$). The highest negative correlations were recorded between pod surface hairs and infestation which is a confirmation of earlier studies which indicated that the pod and more specifically, the density of pod surface hairs provides the greatest defence mechanism against *C. chinensis* infestation in the field.

According to Duffy (1986), the defensive mechanism of plant surface hairs (trichomes) arises from a diversity of causes and effects such as a highly trichomatous state; (1) presenting a physical barrier thereby conferring resistance, to attack due to reduced ability of the insect to gain access to the plant surface and thus feed, seek shelter, and/or oviposit; (2) conferring resistance because of the ability of trichomally contained chemicals to poison the insect by contact, ingestion, and/or inhalation; (3) conferring resistance because of the ability of insect-fractured trichomes to exude gummy, sticky, or polymerising chemical mixtures that severally impede the insect's ability to feed, move and/or survive. Although the types of trichomes were not distinguished in the current study, Reddy (1990), established three distinct types of hairs on pigeonpea pod wall, *viz.* simple and globular secretory hairs that contain yellow oil, and a third type of hair that has secretory cells towards the base and along the tubular neck. It therefore appears that, apart from acting as a physical barrier to oviposition and first instar larval penetration (Chapter 4),

trichomes on pod surfaces may also be able to exude chemicals which could increase egg mortality as well as repel or impede adult movement. On immature pods, the lower significance in correlation between adult emergence and the surface hair density is probably due to two opposing factors, the surface hairs on the one hand impeding oviposition but the softness of the young pod wall facilitating pod penetration by the first instar larvae.

The results of the current study are similar to observations made by Talekar and Lin (1981) on the mode of mung bean pod resistance to *C. chinensis* where it was found that resistance was mostly attributed to pod hairiness. Studies by Tahhan and van Emden (1989) on resistance of faba beans to *B. dentipes*, however, found that only phenological resistance was present, whereby pests are avoided by the rate of development and time and duration of maturity.

ii. Pod dimensions and pod wall thickness

Only in immature pods was a significant correlation observed between oviposition (width) and percentage adult emergence (length and width) on the one hand and pod dimensions; the correlation coefficient was negative for the former and positive for the latter. It is probable that in larger pods, the pods may have, on the average, been more mature and thus with stiffer and longer trichomes than the smaller pods, or it could also be that the larger pods produce more exudates which may produce more repellent or ovicidal activity, which all combine to reduce oviposition. The positive correlation with adult emergence may be due to, again, the maturity stage of the pod which is more conducive to development, or the fact that there may be more of the large seeds in bigger pods, which affords more nutrients and opportunities for development than smaller pods. Pod size by itself, therefore, appears to be of little consequence in relation to resistance.

Pod wall thickness appears to affect adult emergence only from mature dry pods and not immature green pods (Table 42). The negative coefficient of correlation observed on dry

pods is likely to be due to the pod physical attribute as a mechanical barrier to larval penetration; in thicker pods, larval penetration would be more difficult than in thinner pods. In immature pods, pod thickness may have no significant effect on larval penetration as the walls are still soft and easy to penetrate. Mechanical resistance to *C. chinensis* due to pod thickness has also been observed in some varieties of faba beans and this has been attributed solely to difficulties encountered by hatching larvae and by the emerging adult in penetrating the surfaces (Nwanze and Horber, 1976).

b. Seed characteristics

i. Seeds per pod, seed dimensions (length and width), seed coat thickness and seed colour

Correlations between the number of seeds per pod and oviposition and adult emergence in both immature and mature dry pods were significant and positive (Table 42). These significant correlations are all likely to be linked to the greater array of opportunities for both oviposition and larval development, as a result of the bigger surface area offered for oviposition and greater number of seeds for development in the bigger pods, with more seeds than the smaller pods with less seeds. The number of seeds per pod by itself thus appears to be of little practical value as a defence mechanism against *C. chinensis*.

Significant correlations were observed on dry seeds between seed dimensions as well as seed coat thickness on the one hand and percentage adult emergence; these were positive for seed dimensions and negative for seed coat thickness. Talekar and Lin (1981) and Regupathy and Rathnaswamy (1979) also observed reduced infestation on smaller seeded legumes by bruchids, and Nwanze and Horber (1976) stated that seed infestation may be affected, among other things, by seed size.

The observed correlations discussed above are most likely a result of seed physical attributes, which, in the case of bigger seeds, affords better opportunities for development than in smaller seed. As in case of the pod wall thickness, a thicker seed coat acted as a physical barrier to larval penetration which reduced the eventual number of emerged adult

and thinner seed coats offered less barrier to larval penetration. The correlation between seed coat thickness and larval penetration has also been observed with faba bean seed coats in relation to resistance to *A. obtectus* (Thiery, 1984). In mung bean, however seed resistance to *C. chinensis* in some genotypes was attributed to seed hardness (Talekar and Lin, 1981). In cowpea, resistance to *C. maculatus* was attributed to rough seed coat, which was due to the arrangement of the macrosclereids of the epidermal layer of the seed coats.

In Uganda, traditionally, pigeonpea seeds are boiled both whole and after splitting. Although thicker seed coats may increase cooking times, in split seeds this would not make any difference, and in whole seeds, traditionally cooking times are long anyway, and thus thick seed coats are unlikely to be less acceptable to consumers.

6.5.4 General considerations

In pod infestation, the high correlation shown between resistance to *C. chinensis* for both oviposition and adult emergence on the one hand, and pod hair density and pod wall thickness on the other (Table 42) was also reflected in the majority of genotypes with very high resistance to field infestation (Appendix XIV). Most genotypes with pods of very high resistance to both oviposition and adult emergence had high pod hair density and/or thick pod walls. Although there was a significant correlation between pod resistance to *C. chinensis* infestation (oviposition and % adult emergence) and the number of seeds per pod, this was not necessarily reflected in genotypes with the highest resistance (Appendix XIV). Likewise, the correlation exhibited between some pod dimensions and infestation was not reflected in data for the most-resistant genotypes in Appendix XIV. For the purpose of selection for resistance, the suggested pod ideotype as a criterion for selection would, therefore, be a pod hair density of more than 35 hairs/mm^2 and a pod-wall thickness greater than 0.18mm. The use of pod dimensions and the number of seeds per pod is, however, not suggested for selection purposes.

In seeds, although there was a significant correlation between resistance to seed infestation (% adult emergence) and seed coat thickness, examination of the data in Appendix XIV showed that the genotypes most resistant to infestation and damage by *C. chinensis* did not necessarily show the greatest seed coat thickness. Likewise, the significant positive correlation between seed width and seed infestation was not reflected in data for the most-resistant genotypes in Appendix XIV. Accordingly it would not be desirable to select genotypes for seed resistance (i.e. in storage) to *C. chinensis* solely on the basis of seed coat thickness and seed width, and in that sense no seed ideotype is suggested as a criterion for selection; other factors are probably at least as important.

From the foregoing discussions it is apparent that the pod offers the best array of defence mechanisms against *C. chinensis* infestation. Some of these pod defence attributes, especially pod hairiness combined with pod thickness, would form the best measure for field resistance. These attributes could therefore form the basis for future selection and breeding for low susceptibility to field infestation by *C. chinensis.*

From the results of this screening exercise, the following genotypes showed the highest overall resistance and had a combination of a number of desirable attributes that confer resistance:

Medium-duration				
PR-5089	APIO-ELINA	PI-397709	PI-395964	PI-396137
PI-398094	PI-395579	ANM-895	PI-397748	PI-394726
PI-397774	ICPL-241	PI-397808	PI-395622	

Long-duration	
AGOGI	3615-EI-388

These genotypes and their attributes could probably be utilised as a reference point for any future selection for resistance to *C. chinensis.*

CHAPTER 7. GENERAL DISCUSSION

Objectives of the study

The major objective of this study was to improve pigeonpea storage through an integrated pest management strategy. This, therefore, involved, as a first step, the diagnosis of the pest problems of obvious or economic importance, identification of the causative agents and the quantification of the losses. The second step involved the study of the total complex of organisms and their interaction in the crop area, together with all aspects of the environment as modified by the various agricultural, social and human activities. And the third step was to develop the management strategy using multiple tactics, with the goal of reducing pest numbers to tolerable levels.

7.1 Diagnosis of the pest problem

Past records in Uganda showed that the three bruchid species which commonly infest pigeonpea in storage are *C. chinensis, C. maculatus* and *B. atrolineatus* (Davies, 1960). In the current study, the three bruchid species found infesting pigeonpea were *C. chinensis. C. maculatus* and *A. obtectus. C. chinensis* was, however, found to be by far the most predominant, with infestations starting from the field and continuing throughout the post-harvest system with heavy consequent damage in storage. *B. atrolineatus* which has been reported to infest pigeonpea in Uganda (Davies, 1960) was not found in the current study.

7.2. Infestation patterns

In the field, it was shown that various pod characteristics, both induced and inherited, affect the degree of pigeonpea infestation. Of the induced characteristics, the degree of physical pod damage either due to shattering/cracking or to certain field pests such as *H. armigera* were positively correlated with field infestation by *C. chinensis*. Among the inherent pod characteristics, factors related to the stage of pod development as well as pod hairiness and hardness and/or thickness were the most important. The induced characteristics increased infestation only due to their effect on the accessibility of *C. chinensis*, to the vulnerable seeds within the pods. In contrast, the inherited characteristics affected oviposition, larval penetration, bruchid development and adult emergence.

Because of the differences, both biotic and abiotic, in which infestation occurs in field and under storage conditions, *C. chinensis* appear to have developed dimorphic forms, the flight and flightless forms, respectively (Chapter 4). These differ in a number of physical, and biological characteristics (elytral colour, wing span, body size, eye size, fecundity, longevity, etc.) which are thought to be adaptations to conditions in the different environments they occupy. In the case of the flight forms, the observed differences are well suited for survival and reproduction under the harsh field conditions, where there are fewer mating partners, scattered and more difficult ovipositional substrates, and hostile environments for development and survival. In the case of the flightless forms, the observed differences are well suited to the easier life under storage conditions, with easily accessible and plentiful ovipositional surfaces for development and less hostile environments for development and survival and thus the main pre-occupation would be the production of the progeny. The flightless morph form which appears to be adapted to storage conditions, is probably a neoteny (Kennedy, 1956; Utida, 1972) of the flight form whose occurrence and predominance in storage is triggered by certain favourable storage conditions, probably the dryness of seeds, to take advantage of the abundant oviposition and development sites.

7.3. Pest management

Since polymorphism in *C. chinensis* is an adaptation to survival under differing conditions, management strategies have to be two pronged, aimed at reducing populations of the flight forms in the field and the flightless forms in storage. This would probably help in breaking the infestation cycle from the field to storage and *vice versa*.

My investigations showed that a number of management strategies may have potential for adoption by farmers in order to break or reduce the field to storage infestation cycle and *vice versa*.

7.3.1. Management of field infestation of *C. chinensis*

Under field conditions, management options against *C. chinensis* infestations that may be recommended to the farmers are the utilisation of host plant characteristics to reduce infestations and the application of chemicals.

a. Utilisation of host -plant characteristics

Under the pigeonpea cropping systems in most parts of Africa and Asia, long-duration pigeonpea genotypes are grown and intercropping is practised due to growth compatibility in which the initial slow growth of pigeonpea is needed to benefit the fast-growing cereals such as millet and sorghum (Lawn and Treadson, 1990). Under such cropping systems, yields are usually low (Chauhan, 1990), but field pests are often reduced (Labeyrie and Maison, 1957) and security is afforded by growing more than one crop in the same field (Chauhan, 1990). In such a system, to reduce pod infestation, a combination of strategies

will be necessary, both in the short- and long-term. The short-term strategies would involve management practices attainable within the limited resources available to the farmers and that would fit within the existing practices. Since the long-duration crop is too tall and bushy for field spraying, and moreover the use of insecticide is unsustainable in the long-term, the alternative management strategies should focus on utilising a combination of host-plant characteristics and a knowledge of pest biology.

It was shown in Tables 14-16 and 41 that, in Uganda the two landraces grown (Agogi and Apio-elina) show high resistance to pod infestation. Even where pod infestation occurs, adult emergence is mostly internal (Fig. 31, Page 77; Table 16, Page 73). From the biology of *C. chinensis*, it was shown that, in storage development takes about 38 days (Howe and Currie, 1964) and for the flight morphs 57 days (Fig. 28C). Given that the maximum longevity of the flight morph form is about 15 days and even shorter for the flightless forms (Fig. 42), this would mean that any internally occurring infestation of field origin would have died within at least 72 (57 + 15) days of initial infestation, if pods are not shelled. Such pod infestation may have occurred in any of the developmental stages from PR-1 to PR-5 but not PR-6 and PR-7 stages (Table 13). Since it takes about 12 days, at least for Apio-elina, for pod development from stage PR-6 to PR-7, i.e. to harvest (Fig. 24), assuming that the crop was harvested in time, it is therefore expected that 60 days (72-12 days) after harvest, infestation of field origin will have died, if pods are not shelled. It was also shown that pod storage was very effective in controlling infestation (Table 25). From this knowledge, it is possible to drastically reduce infestation of field origin by either continued pod storage, as is practised in Gulu, or holding on to the harvested crop (whole plant harvest) for at least 2 months before threshing (which is already practiced in Lira and Apac, but for shorter durations). Where part of the crop is needed for food or for sale, threshing to meet specific needs may be appropriate.

b. Chemical application

Where semi-commercial cultivation is being practised, as in some parts of East Africa. a monocrop of the medium-duration genotype would be recommended, especially since the variety cultivated would have been bred for high yield and earlier maturity than the long-duration ones. Since these maturation types are shorter and less bushy than the long-duration genotypes, field application of insecticides would be possible. In this study, using the pesticide commonly used in controlling field pests (cypermethrin), at the same recommended application rate and frequency, a high degree of *C. chinensis* management was achieved (Table 22). Field insecticide application (by any recommended insecticide for field pests) has the advantage of controlling both infestation by field pest and storage pest in the field. In addition, control of field pest damage alone, especially damage by *H. armigera*, would reduce storage pest infestation (Table 15).

Field spraying using the applied concentration and frequency in this study may, however, not be able to eliminate all forms of infestation. This is because, not all developmental stages of the insects are destroyed due to the insidious nature of infestation. Before field pesticide application is recommended more studies may, therefore, be required to investigate the most effective dosage rate, or application frequency, or to investigate other insecticides, which combine both contact and systemic characteristics and which are effective on field pests and also on *C. chinensis* both on the surface of the pod and internally.

7.3.2 Management of storage infestation of *C. chinensis*

a. Cultural pest management

Of the cultural management strategies against *C. chinensis* infestation investigated in stored seeds, the use of the traditional sealed-storage "tua", pod-storage and solar disinfestation were found to be the highly effective in controlling *C. chinensis* infestation: seed splitting was effective only for longer periods of storage.

i. Traditional sealed storage "tua"

Sealed containers have been shown by several workers to reduce infestation by storage pests in grains (Caswell, 1974; Storey, 1981; Vincente *et al.*, 1972). Previous recommendations on hermetic storage were based on the use of steel drums (Caswell, 1975) or polyethylene bags (Vincente *et al.*, 1972). These technique are, however, based on the use of materials which are either too expensive (steel drums) for the peasant farmers in Africa, or using weak materials (polyethylene) which are unsuitable for long term storage. These materials are, in addition, not easily available throughout much of Africa nor are they compatible with the storage systems typical in Africa. Their acceptance as effective management techniques have, therefore, not met with wide acceptance, if at all.

Sealed storage "tua" investigated in this study has been shown to be very effective in eliminating infestation by *C. chinensis*. The sealed storage "tua" described in this study is made entirely from locally available materials (clay soil and straw) and its construction requires minimal training and therefore, any farmer could make his own structure to satisfy his own storage needs. It is also long-lasting and is compatible with most storage systems in use in the Sub-Saharan Africa and is, indeed, already in use by some farmers in Uganda. The technique, in addition doubles both as a storage structure and for pest management. It is therefore recommended for pigeonpea storage and for the management of *C. chinensis* in stored seed.

ii. Pod-storage

Pod-storage for cowpea has been reported in several countries (Booker, 1967; Caswell, 1968; Silim *et al.*, 1990). In pigeonpea, however, pod-storage is only recorded in Uganda (Chapter 2). Although no comparisons were made in this study on pigeonpea and cowpea pod infestation and damage, it appears that in pigeonpea, pod-storage is a more effective control technique for *C. chinensis* infestation than pod-storage in cowpea for *C. maculatus*

infestation. This is further confirmed by farmers in Gulu (Chapter 2) who reported minimal storage damage on pod-stored pigeonpea, although high damage and infestation figures by *C. maculatus* reported on pod-stored cowpea in farms in West Africa (Caswell, 1975). This is most likely a result of the presence of numerous trichomes on the pigeonpea pod surface which offer protection against oviposition in addition to protection afforded by pod-wall thickness and hardness. In cowpea for example, only pod-wall thickness and hardness have been implicated in resistance to bruchids (Caswell, 1975). Pod-storage as practiced in Gulu would therefore, be highly recommended as an effective management option for *C. chinensis* infestation control.

It may, however, be necessary to determine pod surface hair density (should be $\leq 35/mm^2$) and pod wall thickness (should be $\leq 0.180mm$) on pigeonpea genotypes grown before the technique is recommended widely; i.e., the approach is only likely to be sufficiently effective for such genotypes.

iii. Solar disinfestation

Solar disinfestation of infested stored grains, though with doubtful efficacy, is routinely practiced by most farmers in East and Central Africa (Giga *et al.*, 1992). This is done by simply spreading infested grains on a smooth surface in the heat of the sun for some time. This technique, however, is only partially effective as grain temperatures are not high enough to be lethal to larvae and pupae within the seeds. The effect of the sun would only expel most adults due to the heat and glare from the sun (Nahdy, unpublished). To kill both the adults and hidden infestation within the grains, the solar heater shown in Fig. 45 was found to be very effective. Since the materials used are cheap and reusable, and even cast off clear polyethylene may be used, solar disinfestation may be easily adaptable in a number of situations. The solar disinfestation technique is easy to use and in addition, it is applicable to any grain and may thus have wider acceptability.

Because solar disinfestation reduces seed viability, it may therefore only be used as described in Chapter 5, on pigeonpea meant for food; farmers should be informed about this limitation. Before this method can be used for seed disinfestation as well, more investigations will be needed to determine optimum solarisation conditions that give total pest kill but preserve seed viability.

iv. Seed splitting

In this study, it was shown that with time (3 months), *C. chinensis* infestation dies off in split seeds of pigeonpea. Although some *C. chinensis* infestation on split seeds is initially expected (Table 26), after three months of storage the grain remains free from infestation. In Uganda pigeonpea is split if and when needed and is therefore not stored for long in this form. This is probably due to the technique used in seed splitting, under two grinding stones, which is labour intensive and very difficult. Splitting of large quantities for storage is therefore not possible. In commercial or semi-commercial decorticators however, seed splitting may be used as a form of bruchid management; this could preferably, be combined with oil treatment which acts as an ovicide (Credland, 1992) and gives the grain a good sheen (Varma and Pandey, 1978). This practice, like that used in Asia would find wider acceptance in the rural setting if simple and affordable post-harvest packages are introduced with the aim of, among other things, reducing the labour requirement during seed splitting.

Overall, however, it has to be noted that some cultural practices are entrenched within very strong traditional and cultural practices. Their dissemination to areas of dissimilar traditions and cultures may not, therefore, be easy but with well laid out on-farm trials with a strong farmer participatory approach and especially where the benefit of the technique are demonstrated well, some of these methods could be adaptable to different areas.

b. Plant and plant products

Various plants and plant products have been reported as useful in controlling storage pest infestation in various grains (Gill and Lewis, 1971; Teotia and Tiwari, 1971; Pandey *et al.*, 1981). In East Africa some of the materials tested in this study are already in use by some farmers to protect grains against storage pests (Giga *et al.*, 1992).

In this study, a number of plant parts and plant products were found effective against *C. chinensis* infestation in stored pigeonpea seeds. Among these, those with the highest potential for use against *C. chinensis* infestation in stored pigeonpea seeds were found among materials which were effective at very low concentration, i.e. 0.5g/200 (tephrosia, fire-cured tobacco and wood ash, respectively), and those which were effective but showed a strong dose response (burly tobacco, water hyacinth and Mexican marigold).

The plant with the highest potential, however, is tephrosia which grows, or is capable of growing in most agro-ecological zones in East Africa where pigeonpea is grown. Since it grows very easily and propagates very well, farmers would not have problems in growing it. The preparation procedure for the admixture is also very simple involving plucking the leaves and drying them in the sun before finally grinding the leaves to smaller particles ready for use. The effective dose is also small (0.5g/200g) and would therefore not adversely affect marketing of grains. It is therefore recommended for on-farm trials for *C. chinensis* management.

Mexican marigold, although slightly less toxic to *C. chinensis* than tephrosia, but like tephrosia, it grows in most agro-ecological zones in the region, propagates very easily (it is actually a weed) and would be just easy to use. It is therefore also recommended at 0.5g/200g for on-farm trials.

Water hyacinth, which is a serious water weed, though effective, is less readily available, occurring only in the major waters in Uganda (Lake Victoria, Lake Kyoga and River Nile)

and may therefore not find ready use in the pigeonpea growing areas far from these waters. The plant may also be recommended, but with caution, as its widespread use by small farmers may spread it to other smaller water bodies with dire consequence to the ecosystems in these waters.

Other materials such as tobacco and ash although recommended may, however, compete for other commercial uses (tobacco) or may taint the grain with either undesired smell (tobacco) or colour (ash). Ash is, however, ideal for seed storage because the ash coating on seed does not matter.

For some of the above plants, however, before final recommendations are given more investigations may be needed to understand the mode of action of the various treatments, and in some cases the active ingredients and their mammalian toxicity.

c. Use of resistant genotypes

Most of the management techniques described above need to be reinforced with long-term strategies. For long-term sustainability, an integrated management strategy has to be adopted to include some of the above techniques, but reinforced by methods that exploit inherent host plant characteristics to suppress, both field and storage infestations. Since the pod is, in a way, a protective mechanism for the seed, it appears to have the greatest array of defence mechanisms which affords diverse methods of resistance. The seed, on the other hand, has fewer defence attributes. Pods therefore, have wider defence mechanisms which, if exploited, could greatly reduce field infestation and thus the consequent storage infestation and damage. The most obvious pod attribute that affords resistance to *C. chinensis,* on both immature and dry pods, appears to be the density of surface hairs on the pod and to some extent the thickness of the pod. Where total resistance to infestation in the field was observed, this was associated with heavy hair density combined with thicker pods. This combination of pod attributes could therefore be taken as an indicator of pod

resistance to *C. chinensis* infestation and could be used as an easy screening parameter in breeding and selection programmes.

Because the current pigeonpea breeding programmes do not take in to account field and storage infestation and damage by *C. chinensis* as a parameter for selection (Swindale, 1990), it is likely that most selected cultivars would end up being increasingly more susceptible to bruchid infestation. This tendency was observed in this study in short-duration accessions (bred for early-maturity) which showed more susceptibility to infestation (Figs 48-52). Long term strategies for the management of pod infestation by *C. chinensis* are therefore recommended, especially now that several of the important pod attributes that confer resistance have been identified in this study. It is recommended that, in addition to breeding and selecting for shorter-duration, higher-yielding and widely-adaptable hybrids, as a matter of routine, in any future breeding programmes pod attributes such as high pod hair density (>35 hairs/mm^2) and thick pod walls (>0.180mm) should be included among the criteria for selection. This should, of course, take into account other desired traits such as seed colour and seed size, because consumers prefer creamy-coloured and medium-seeded pigeonpea (Fig. 16). It is also important to avoid varieties that may have a higher tendency to shatter either in the field when dry or during pod storage, as shattering has been shown to increase pod infestation (Table 15).

In this study, 16 genotypes showed high resistance to *C. chinensis*, either in the pod- or seed-form (section 6.5.5). In dry seeds the two genotypes, PI-395622 AND PR-5089 showed exceptional resistance to *C. chinensis*. These genotypes may therefore be used as a reference point for any future selection and breeding exercise.

There may, however, be other factors affording resistance to *C. chinensis* infesting both pod and seed, and these need to be investigated. More accessions will also need to be screened because the screening reported here involved only 262 genotypes. The screening should concentrate on the medium- and long-duration genotypes since these showed a larger

proportion of accessions with more resistance to *C. chinensis* than the short-duration genotypes. Wild accessions, if available, should also be screened so as to widen the search for the desired attributes that confer resistance.

7.4. Future work

Having arrived at a set approaches which could be put into integrated pest management packages as discussed above, future work in the East and Central African pigeonpea network in general, and Uganda in particular, should focus on demonstrating and conducting on-farm trials using some of these techniques, using the farmer participatory approach, to control storage infestation of pigeonpea by *C. chinensis*.

It is, in addition, hoped that follow-up work on resistance to *C. chinensis* on pigeonpea will continue and breeding programmes will in future incorporate resistance to *C. chinensis* as one of the parameters for pigeonpea selection.

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APPENDICES

Appendix I. Some dietary composition of pigeonpea (by dry matter)

Constituent	Composition
Proteins	20.50%
Lysine	6.80*
Threaonine	3.80*
Methionine	1.00*
Cystine	1.20*
Carbohydrates	64.20%
Fats	3.80%
Fibre	5.00%
Ash	4.20%
Calcium	296.00**
Iron	6.70**
Thiamine	0.63**
Riboflavin	0.16**
Niacin	3.10**

Key, * = $100g^{-1}$ protein; ** = $100mg^{-1}$ dry matter

Source: Faris and Singh (1990)

Appendix II. Maturity classification of pigeonpea when sown at the beginning of the rainy season (June/July), ICRISAT Centre, India

Maturity group	Days to 50% flowering	Reference Cultivars	Description
0	< 60	Pant A3	Photoperiod insensitive
I	61 - 70	Prabhat, Pant A2	Extra early
II	71 - 80	UPAS 120, Baigani	
III	81 - 90	Pusa Ageti, T21	Early
IV	91 - 100	ICP 6	
V	101 - 110	No. 148, BDN 1	Medium
VI	111 - 130	ICP 1, ICP 6997, ST 1, C11	
VII	131 - 140	Hy 3C, ICP 7035	Late
VIII	141 - 160	ICP 7065, ICP 7086	
IX	> 160	NP(WR) 15, Gwalior 3, NP 69	

Source: ICRISAT, 1978; Sharma *et al.*, 1981.

Appendix III. Some important and widespread pests of pigeonpea

Order/Scientific name	Family	Portion of plant attacked	Countries reported from	Reference
Coleoptera				
Callosobruchus analis	Bruchidae	P, DS	India	Nair, 1975
C. chinensis	Bruchidae	P, DS	India, Caribbean	Srivastava, 1964 Bridwell, 1918
C. maculatus	Bruchidae	P, DS	India, Caribbean	Davies and Lateef, 1975 Bridwell, 1918
C. theobromae	Bruchidae	P, DS	India	Davies and Lateef, 1975
Mylabris amplectens	Meloidae	F	Tanzania, Kenya	Le Pelley, 1959 Khamala *et al.*, 1978
M. farquharsoni	Meloidae	F	Kenya Nigeria	Khamala *et al.*, 1978 Egwuatu and Taylor, 1977
M. pustulata	Meloidae	F	Asia	Davies and Lateef, 1975
M. seminigra	Meloidae	F	E. Africa	Le Pelley, 1959
Epilachnoda cordata	Scarabaeidae	F	Nigeria	Egwutu and Taylor, 1977
Diptera				
Melanagromyza chalcosoma	Agromyzidae	P	E. Africa Nigeria	ICRISAT, 1982 Singh and Taylor, 1978
M. obtusa	Agromyzidae	P	Asia	Davies and Lateef, 1975
Hemiptera				
Anoplocnemis curvipes	Coreidae	P	Nigeria	Egwuatu and Taylor, 1977
Clavigralla gibbosa	Coreidae	F, P	Asia	Davies and Lateef, 1975
C. scutellaris	Coreidae	F, P	India	Srivastava, 1964
C. tomentosicollis	Coreidae	F, P	E. Africa Nigeria	Le Pelley, 1959 Egwuatu and Taylor, 1977
Cletus signatus	Coreidae	F, P	India	ICRISAT, 1976
C. fusescens	Coreidae	F, P	E. Africa	Khamala *et al.*, 1978
Dolycoris indicus	Pentatomidae	F, P	India	Davies and Lateef, 1975
Lepidoptera				
Blasmopalpus rubedinellus	Phycitidae	P	Carribbean	Joplin, 1974
Exelastis atomosa	Pterophoridae	F, P	Asia E. Africa	Davies Lateef, 1975 Le Pelley, 1959
Grapholita critica	Tortricidae	L, F, P	Asia	Davies and Lateef, 1975
Helicoverpa armigera	Noctuidae	L, F, P	Asia, Africa Australia	Lateef and Reed, 1990
H. punctigera	Noctuidae	F, P	Australia	Reed *et al*, 1989
H. zea	Noctuidae	L, F, P	N. and C. America	Lateef and Reed, 1990
Heliothis virescens	Noctuidae	F, P	C. America	Lateef and Reed, 1990
Maruca testulalis	Pyralidae	L, F, P	Asia, Africa, C. America	Lateef and Reed, 1990
Nordavene virgulana	Noctuidae	P	E. Africa	Le Pelley, 1959

Key: F = Flower, P = Pod, DS = Dry Seed, .

Appendix IV. Known world distribution of the stored products Bruchidae

The bruchid	Asia	Europe	Africa	North America	South America	Australia
C. maculatus	ID	IT	ID	IT	IT	IT
C. chinensis	ID	IT	ID	IT	IT	IT
C. analis	ID		IT			
C. rhodesianus			ID			
C. subbinnotatus			ID		IT	
C. phaseoli	ID		ID	IT	IT	
A. obtectus	IT	IT	IT	ID	ID	IT
Z. subfasciatus	IT	IT	IT	ID	ID	
Caryedon serratus	ID		ID		IT	I

Key: ID = indigenous species, IT = introduced species

After Southgate (1978)

Appendix V. Pigeonpea post-harvest survey questionnaire

1. General Information

(a) District ----------

(b) County ----------

(c) Sub-county ----------

(d) Village ----------

(e) Farmer No ----------

2. General cropping patterns

(a) Main crops grown by order

	Cassava	01	S/potato	10
	Millet	02	Millet/P'peas	11
	Sorghum	03	G.nuts/P'pea	12
	Maize	04	Beans/Sorghum	13
	Simsim	05	Bananas	14
	G/nuts	06	Others	15
	Beans	07		
	Pigeonpea	08		
	Soybean	09		

3. Pigeonpea production systems

(a) Was pigeonpea grown this season?

	Yes	01	No	02

(b) Varieties planted?

	Early maturity	01	Medium maturity	03
	Late maturity	02		

(c) Local names ----------

(d) How many acres per variety? ----------

(e) Characteristics of varieties grown?

	Early maturity	01	Medium maturity	02	Late maturity	03
	High yield	04	Medium yield	05	Low yield	06
	Cooks easily	07	Difficult cooking	08		
	Brown colour	09	White colour	10	Mixed colour	11
	Large sized	12	Medium sized	13	Small sized	14
	Long storage	15	Poor storage	16	Others	17

(f) Source of seed

(g) Have you ever tried new varieties ?

	Yes	01	No	02

(h) What characteristics would you consider important in accepting new varieties ?

	High yield	01	Early maturity	02	White colour	03
	Brown colour	04	Large size	05	Small size	06
	Cooking time	07	Storability	08		

4. Planting

(a) How many times do you plant pigeonpea in one year ?

	Once	01	Twice	02

(b) Are all varieties planted at the same time?

	Yes	01	No	02

(c) When is each variety planted?

Variety			Jan.	01	Feb.	02
Month			March	03	April	04

5. Inter-cropping patterns

(a) Do you inter-crop pigeonpea with other crops?

	Yes	01	No	02

(b) If yes, what do you inter-crop with?

	Millet	01	G/nuts	02	Simsim	03
	Cassava	04	Sorghum	05	Others	06

(c) If yes, why inter-crop?

---

6. Crop rotation

(a) Do you usually grow pigionpea after a particular crop?

☐ Yes 01 No 02

(b) If yes, what with?

☐	Cotton	01	Sorghum	02	Millet	03
☐	Simsim	04	Beans	05	Cassava	06
☐	S/potato	07	G/nuts	08	Others	09

(c) What is the reason for such rotation?

---

7. Pests and diseases

(a) What are the major pests of pigeonpea?

1 ---------- 2 ---------- 3 ----------
4 ---------- 5 ---------- 6 ----------

(b) According to you what level of damage is usually caused by each of the pest?

		Level of damage			
Pest	☐☐☐☐☐	Slight	01	Medium	02
Damage level	☐☐☐☐☐	Heavy	03		

(c) Does field damage levels have any effect on eventual storage losses?

☐ Not noticed ☐ Yes 01 No 02

(d) If yes, how does it affect eventual storage damage?

☐ < damage 01 >damage 02

8. Post harvest

(a) What is your yield (bags) per acre per variety?

Variety
Bags

Yield

<1 01
1-2 02
3-4 03
>4 04

(b) What is the end use?

Food only 01
Both 04
Cash only 02
Seed only 03

(c) How do you harvest pigeonpea?

---- --- --- ---- -- -- ---- -- --

(d) How do you store pigeonpea?

Pod form 01
Seed form 02

(e) Where do you store pigeonpea?

(f) If stored, for how long? (months)

<3 01
4-6 02
7-9 03
10-12 04
>12 05

(g) Do you have storage concern?

Yes 01
No 02

(h) If yes, list major concerns

(i) If bruchids are the major concern, to what extent, over time is the severity? (months)

<3
4-6
7-9
>9

Slight 01
Medium 02
Severe 03

(j) How do you contain storage problems, if it is bruchids? (list)

(k) Have you ever heard of any other methods other than the ones you are using?

[ ] Yes [01] No [02]

(l) If yes, name them

---------- ---------- ---------- ----------

(m) Reasons for not using method(s)

Methods	1_____	2_____	3_____	4_____
Reasons	----------	----------	----------	----------
	----------	----------	----------	----------
	----------	----------	----------	----------
	----------	----------	----------	----------
	----------	----------	----------	----------

9. Marketing

(a) Indicate the proportion of pigeonpea normally sold

[ ] 0 [01] 25% [02] 50% [03] 75% [04] 100% [05]

(b) Where is it normally sold?

[ ] In village market [01] In town market [02] Others [03]

(c) How soon after harvest is pigeonpea usually sold off?

[ ] Immediately after harvest [01] <3 months after harvest [02]
3-6 months after harvest [03] 6-9 months after harvest [04]
Just before next harvest [05]

(d) Why does the household sell at the above times?

01	02	03	04	05
----------	----------	----------	----------	----------
----------	----------	----------	----------	----------

(e) Is there price differences during sales at the various times of the year?

[ ] Yes [01] No [02]

(f) If yes, what are the reasons for such differences?

At early sale	Medium term sale	Late sale
----------	----------	----------
	----------	----------

(f) If yes, what are the reasons for such differences?

At early sale	Medium term sale	Late sale
----------	----------	----------
----------	----------	----------

(g) Apart from the above factors, are there any other parameters that could affect prices especially at mid and late season selling times?

	Yes	01	No	02

(h) If it is insect damage, to what extent does it affect prices? If they are weeviled as follows: (show sample)

<5%		31-35%		None	01	By 10%	02
5-10%		36-40%		By 20%	03	By 30%	04
11-15%		41-45%		By 40%	05	By 50%	06
16-20%		46-50%		By >50%	07	Not marketable	08
21-25%		>50%					
6-30%							

(i) If pigeonpea is too damaged for marketing what is usually done with it?

	Thrown away	01	Given to neighbour	02	Given to animals	03
	For food (split)	04	For food (whole)	05	For seed	06
	Sold in village	07	Sold in town market	08	Mix old+new and sell	09

(j) Does household at times run out of reserved pigeonpea just before harvest?

	Yes	01	No	02

(k) If yes, what do you normally do to solve the problem?

	Buy from market	01	Borrow from friends	02	Work for food	03
	Substitutes used	04	Barter	05	Harvest green	06

(l) If obtained from other sources what factors are considered before purchase? (In priority)

	Seed colour	01	Bruchid damage	02	Origin of seed	03
	Seed size	04	Price	05	Others	06

At the end of the questions request for a 250 gm sample of pigeonpea in exchange for improved variety. Label and record origin, age variety and storage condition.

Appendix VI Main crops grown by order and rank of importance in the three study districts

Crops	District ranking			Total score	Mean rank
	Apac	Gulu	Lira		
Millet	11	9	13	33	11
Sorghum	8	4	6	18	7
Maize	6	8	8	22	8
Simsim	2	7	4	13	4
Groundnuts	4	3	7	14	6
Beans	1	9	2	12	3
Pigeonpea	11	11	13	35	13
Cowpea	9	13	9	31	10
Cassava	7	1	5	13	4
Sweet potatoes	4	2	3	9	1
Millet/Pigeonpea	3	5	1	9	1
Groundnuts/Pigeonpea	10	6	12	28	9
Beans/Sorghum	11	14	11	36	15
Bananas	11	12	10	33	11
Groundnuts/Maize	11	11	13	35	13
Others	11	13	16	40	16

Appendix VII. Varieties planted and area (hectares) with pigeonpea per household

(a) Varieties planted (according to maturity period)

Maturity period	District percentages			Mean %
	Apac	Gulu	Lira	
Medium maturity only	100	0.0	33.3	44.4
Late maturity only	0	88.8	0.0	29.6
Both	0	11.1	66.6	25.9

(b) Area planted with pigeonpea (hectares)

	Districts			Mean %
	Apac	Gulu	Lira	
Acres planted	0.52	0.36	0.48	0.44

Appendix VIII. Inter-cropping patterns

(a) Is Inter-cropping of pigeonpea practiced?

	Districts(percentage)			Mean %
	Apac	Gulu	Lira	
Yes	100	100	100	100
No	0	0	0	0

(b) What pigeonpea is inter-cropped with

	Districts (percentage)			Mean %
	Apac	Gulu	Lira	
Millet	100	100.0	100	100.0
Groundnuts	10	88.8	8	35.6
Simsim	0	0.0	0	0.0
Cassava	0	44.4	0	14.8
Sorghum	0	0.0	0	0.0
Others	0	11.1	33	14.7

Respondents gave positive answers to more than one crop

Appendix IX. Crop rotation patterns

(a) Is crop rotation involving pigeonpea and other crops practised?

	Districts (percentage)			Mean %
	Apac	Gulu	Lira	
Yes	100	100	100	100
No	0	0	0	0

(b) Crops often rotated with pigeonpea

Crop	District ranking			Total score	Rank
	Apac	Gulu	Lira		
Cotton	4	9	2	15	5
Sorghum	5	3	4	12	2
Millet	1	4	8	13	3
Simsim	5	2	3	10	1
Beans	3	10	6	19	7
Cassava	5	1	7	13	3
Sweet potatoes	5	7	8	20	8
Groundnuts	5	5	7	17	6
Millet/Pigeonpea	15	15	1	31	10
Groundnuts/Pigeonpea	15	8	15	38	11
Others	2	6	5	23	9

Appendix X. Desired characteristics for pigeonpea by farmers (according to priority ranking)

	District (rank)			Total score	Rank
	Apac	Gulu	Lira		
High yield	1	1	1	3	1
Early maturity	2	2	2	6	2
White colour	3	4	7	14	5
Brown colour	9	6	8	23	7
Large seeded	7	6	6	19	6
Small seeded	9	6	8	23	7
Cooking time	4	5	3	12	3
Storability	4	3	5	12	3
Taste	8	10	10	28	9
Others					

Appendix XI. Source of pigeonpea seeds

Source of seed	Districts (percentage)			
	Lira	Gulu	Lira	Mean
Own seed only	30	39	22	30.4
From neighbour only	0	0	0	0.0
From market only	0	0	0	0.0
Own seed and neighbour	31	27	22	26.6
Own seed and market	21	20	27	23.0
All the above	17	15	29	20.0

Appendix XII. Places where farmer normally sells pigeonpea

	Districts (percentages)			
	Apac	Gulu	Lira	Mean %
In village markets only	70	67	57	64.7
In town markets only	0	0	0	0
Both	30	33	43	35.3
Others	0	0	0	0

Appendix XIII. Are there price differences during sales at various times of the year?

	Districts (%)			Mean (%)
	Apac	Gulu	Lira	
Yes	100	67	83	83
No	0	33	17	17

(a) Reasons for differences in selling price at various marketing times

Reason for price differences at different times of sale	Districts, periods of marketing and percentage of respondents			Mean %
	Apac	Gulu	Lira	
Early sale:	Nov.- Mar.	Jan. - Apr.	Nov. - Mar	
Flooded market	0	100	0	33
Less pigeonpea in market	44	0	50	32
High demand for pigeonpea	56	0	50	35
Medium term sale	Apr. - Jun.	Jun. - Aug.	Apr. - Jun.	
Flooded market	55.5	0	35.5	30.3
Less pigeonpea in market	44.4	80	41.6	55.3
High demand for pigeonpea	0.0	20	33.3	17.8
Late sale	Jul. - Sep.	Sep. - Dec.	Jul. - Sep.	
Flooded market	0.0	0	0.0	0.0
Less pigeonpea in market	11.1	0	41.6	17.6
High demand for pigeonpea	88.8	100	58.3	82.4

NB. Percentages exceeding 100% indicates positive response to more than one answer to the same problem or question by respondents.

Percentages of less than 100% indicates lack of positive response by some respondents.

Appendix XIV. Relative infestation (mean number of eggs laid per pod and/or percentage adult emergence) by C.chinensis on immature green pods, dry pods and dry seeds of pigeonpea accessions of different maturity groups and measurement of some of the pod and seed characteristics.

Short-duration genotypes

NOTYPES	ORIGIN	GREEN PODS		DRY SEEDS		SEEDS	Hairs/	Seeds/	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)			Seed
		Eggs/pod	% ADE	Eggs/pod	% DE	% ADE	mm^2	pod	L	W	PWTH	L	W	TTH	colour
III-5)	12	10.8	10.6	16.5	22.3	90.0	7.3	3.3	47.0	7.7	0.195	5.4	4.3	0.117	3.0
-173	1	25.0	26.9	13.4	14.1	63.3	10.2	3.7	50.7	7.3	0.181	5.0	4.2	0.113	3.0
-86013	1	21.9	20.1	12.6	11.4	70.0	22.6	4.0	43.3	7.3	0.165	4.8	4.8	0.110	1.0
-289	1	15.6	11.6	12.3	11.8	63.3	17.8	3.7	43.3	7.0	0.140	4.8	3.9	0.105	3.0
-314	1	13.6	17.0	11.1	12.4	80.0	31.1	4.3	56.7	9.4	0.197	5.1	4.3	0.117	3.0
-85054	1	19.7	17.8	11.0	16.6	83.3	24.9	4.3	55.0	9.5	0.195	5.7	4.8	0.109	3.0
-83013	1	14.0	15.3	10.2	19.7	70.0	24.9	4.0	53.7	8.1	0.183	4.9	4.0	0.114	3.0
PL-164	1	10.8	35.4	10.1	14.1	56.7	27.1	3.7	52.3	8.3	0.188	5.1	4.3	0.120	3.0
PL-84031	1	11.4	4.9	9.2	9.4	56.7	24.2	4.0	53.0	8.3	0.182	5.7	4.3	0.111	3.0
URVAI	1	11.8	18.2	9.0	13.3	66.7	30.1	2.3	27.3	7.0	0.185	5.0	4.1	0.121	3.0
CPL-184	1	5.8	35.8	8.9	16.8	76.7	27.9	3.7	48.3	7.6	0.196	4.9	4.0	0.114	3.0
CPL-174	1	11.7	20.9	8.9	7.2	63.3	25.2	3.7	48.7	7.5	0.195	5.5	4.5	0.116	3.0
CPL-177	1	7.8	31.6	7.9	12.2	60.0	28.5	3.7	55.0	9.4	0.195	5.4	4.2	0.116	3.0
CPL-88	1	14.4	16.6	7.8	15.0	63.3	29.0	3.7	39.3	7.0	0.153	4.5	3.8	0.098	3.0
CPL-86021	1	11.7	25.2	7.7	12.4	76.7	35.0	3.7	54.3	7.6	0.189	5.2	4.1	0.114	3.0
-30	1	5.3	20.0	7.7	15.7	66.7	33.1	3.7	41.7	7.4	0.181	5.3	4.4	0.119	3.0
CPL-830213	1	9.8	24.7	7.4	7.8	83.3	32.0	3.7	50.3	8.2	0.183	5.4	4.4	0.124	3.0
CPL-158	1	13.1	19.2	7.2	3.8	66.7	32.9	3.7	49.3	8.7	0.186	5.6	4.8	0.097	3.0
CPL-143	1	10.2	15.5	7.2	7.4	63.3	36.5	3.7	42.7	7.1	0.189	4.8	4.0	0.119	1.0
CPL-83008	1	14.0	19.4	7.0	6.3	83.3	27.0	4.0	57.7	8.6	0.191	5.8	5.2	0.097	4.0
CPL-287	1	7.2	24.8	7.0	4.4	76.7	32.2	4.0	52.7	7.7	0.195	5.1	4.1	0.121	3.0
QPL-49	12	10.0	12.2	6.8	8.4	73.3	34.3	4.0	51.7	8.0	0.192	4.9	4.1	0.126	3.0
CPL-183	1	8.4	9.8	6.8	8.4	76.7	36.6	3.0	40.0	7.2	0.191	5.0	4.3	0.124	3.0
CPL-84045	1	17.4	18.5	6.7	20.0	100.0	27.5	3.7	51.0	7.9	0.192	5.1	4.3	0.121	3.0
CPL-176	1	12.9	14.9	6.2	13.2	83.3	34.0	3.7	41.3	7.3	0.190	5.6	4.4	0.121	3.0
CPL-86002	1	15.6	14.0	6.2	10.0	73.3	34.2	3.7	46.7	7.5	0.172	5.5	4.7	0.115	3.0

Appendix XIV. Short-duration (continued)

GENOTYPE	ORIGIN	GREEN PODS		DRY PODS		SEEDS	Hairs/	Seeds/	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)			Seed
		Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE	mm^2	pod	L	W	PWTH	L	W	WCTH	colour
PL-155	I	12.2	8.8	6.1	1.6	63.3	37.3	3.0	43.7	7.6	0.191	5.4	4.6	0.112	1.0
L-84052	I	6.9	21.9	6.0	14.6	76.7	37.9	3.7	47.7	7.5	0.211	5.1	4.1	0.110	3.0
-85014	I	17.2	22.5	5.9	18.5	40.0	38.0	3.7	51.3	7.3	0.190	4.9	4.1	0.114	3.0
379	II	8.0	9.0	5.7	10.4	60.0	37.9	3.7	53.3	7.0	0.196	4.9	4.3	0.105	1.0
-94	I	7.9	10.0	5.7	9.4	100.0	44.5	3.3	47.3	8.6	0.185	5.2	4.1	0.123	3.0
	I	20.6	14.4	5.7	5.4	60.0	36.6	3.7	50.0	7.4	0.195	4.8	4.1	0.112	3.0
85053	I	17.9	8.2	5.6	2.5	76.7	52.2	3.7	50.3	8.0	0.188	5.2	4.2	0.113	3.0
84018	I	5.6	9.4	5.6	31.1	83.3	36.5	3.3	51.0	8.0	0.184	5.3	4.3	0.110	3.0
85014	I	17.2	22.5	5.4	18.5	40.0	38.0	3.7	51.3	7.3	0.190	4.9	4.1	0.114	3.0
839	I	10.0	10.7	5.4	11.7	56.7	34.3	3.7	49.4	7.2	0.201	4.7	3.9	0.104	3.0
-172	I	5.4	20.6	5.3	2.5	73.3	34.9	3.7	50.7	8.2	0.196	5.1	4.3	0.119	3.0
-85010	I	5.9	28.1	5.3	6.5	80.0	41.1	3.7	42.7	7.0	0.201	5.2	5.2	0.113	3.0
-86014	I	11.2	16.7	5..4	6.8	56.7	39.7	3.3	39.0	6.9	0.190	4.7	4.7	0.109	3.0
-145	I	7.2	21.5	5.0	9.4	73.3	41.8	3.7	52.0	8.1	0.182	5.6	4.5	0.113	3.0
L-85035	I	13.9	4.8	4.8	6.5	70.0	42.0	4.3	49.9	7.6	0.197	5.2	4.2	0.120	3.0
PL-4	I	4.2	20.7	4.7	7.9	60.0	33.2	4.0	44.7	7.5	0.178	4.8	4.8	0.113	3.0
PL-84020	I	1.4	18.2	4.7	13.3	53.3	40.3	4.0	46.0	8.1	0.196	6.0	4.9	0.106	1.0
CPL-86006	I	10.0	28.0	4.7	8.6	83.3	40.2	3.7	49.7	7.6	0.185	5.6	4.5	0.090	3.0
-3(II-16)	12	12.0	27.7	4.6	12.2	70.0	36.5	4.0	46.0	9.1	0.172	5.2	5.0	0.128	3.0
ICPL-86012	I	13.7	18.1	4.4	6.3	63.3	38.6	4.0	46.7	6.4	0.184	5.0	4.1	0.105	2.0
ICPL-146	I	7.8	18.2	4.3	11.8	73.3	43.2	3.3	48.3	7.5	0.182	5.4	4.1	0.111	1.0
ICPL-86010	I	4.1	20.1	4.3	5.3	76.7	41.2	3.7	52.3	7.9	0.185	5.2	4.2	0.112	3.0
ICPL-141	I	10.2	31.9	4.1	5.2	76.7	45.7	3.7	48.3	7.3	0.199	5.3	4.2	0.109	3.0
ICPL-2	I	3.7	11.4	4.1	11.6	83.3	44.2	3.7	46.0	7.7	0.179	5.4	4.1	0.125	3.0
ICPL-84023	I	7.3	18.4	4.0	5.1	80.0	44.7	4.0	55.7	7.4	0.191	5.2	4.2	0.111	3.0
QPL-23	12	6.7	26.1	3.9	3.0	63.3	42.1	3.7	49.0	6.9	0.199	4.8	4.1	0.130	3.0
AI-(III-9)	12	5.8	13.1	3.3	4.4	60.0	45.5	4.0	55.3	9.6	0.200	5.2	4.2	0.125	3.0
ICPL-830	I	8.7	12.7	3.3	15.2	76.7	39.3	3.7	42.3	6.2	0.163	4.9	4.4	0.111	3.0
ICPL-86023	I	8.8	9.6	3.2	2.7	63.3	50.2	4.0	53.0	7.9	0.197	4.9	4.1	0.129	3.0
QPL-19	12	3.3	27.0	3.2	8.9	83.3	41.7	4.0	56.0	9.1	0.197	5.6	4.1	0.120	3.0

Appendix XIV. Short-duration (continued)

GENOTYPE	ORIGIN	GREEN PODS		DRY PODS		SEEDS	Hairs/ mm^2	Seeds/ pod	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)			Seed colour
		Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE			L	W	PWTH	L	W	SCTH	
PL-83019	1	8.3	11.0	3.0	6.7	66.7	45.7	3.7	49.0	7.9	0.196	5.4	4.2	0.119	3.0
L-85053	1	16.9	8.2	2.8	2.5	40.0	52.2	3.7	50.3	8.0	0.188	5.2	4.2	0.113	3.0
G-192	1	7.0	50.3	2.8	4.3	90.0	49.0	3.7	45.7	7.8	0.183	5.0	5.0	0.110	3.0
-83018	1	6.1	40.8	2.6	3.0	73.3	52.7	3.3	51.0	8.5	0.184	5.6	4.5	0.118	3.0
-84024	1	2.9	16.7	2.6	2.6	73.3	52.7	3.7	44.7	7.6	0.175	4.8	4.8	0.110	3.0
-167	1	8.9	36.6	2.4	4.8	76.7	59.2	3.7	42.3	6.6	0.168	4.2	4.2	0.115	1.0
-84059	1	6.9	14.2	2.3	9.4	76.7	51.1	3.3	53.3	7.5	0.206	4.9	4.0	0.139	3.0
-83022	1	3.4	28.1	2.2	2.8	76.7	50.1	3.7	43.0	5.0	0.202	5.0	4.0	0.106	3.0
-153	1	4.0	14.2	2.2	3.3	66.6	57.6	3.7	42.0	7.0	0.209	4.8	4.1	0.107	3.0
-17)	12	1.2	27.0	1.4	0.0	73.3	63.9	4.0	55.0	9.6	0.200	5.7	4.9	0.120	3.0
-208	1	3.3	25.5	1.0	0.0	76.7	62.5	4.3	55.0	7.6	0.183	5.3	4.2	0.109	1.0

Appendix XIV. Medium-duration genotypes

OTYPE	ORIGIN	GREEN PODS		DRY PODS		SEEDS	Hairs/ mm2	Seeds/ pod	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)			Seed colour
		Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE			L	W	PWTH	L	W	SCTH	
TZ	11	18.4	37.7	14.3	7.6	64.4	18.4	5.0	69.7	10.4	0.196	5.6	4.7	0.122	1.0
-TZ	11	15.2	36.6	13.3	21.8	60.0	20.0	5.0	73.9	8.9	0.190	5.7	4.6	0.122	1.0
-397532	1	12.3	4.1	13.0	9.4	66.7	11.0	3.3	44.0	5.6	0.118	5.3	4.6	0.105	2.0
CWR-3753	1	13.9	14.7	12.6	7.7	70.0	15.8	3.7	38.7	5.3	0.130	5.7	4.7	0.115	2.0
PI-398062	1	11.2	9.6	12.3	12.9	60.0	15.7	3.7	45.0	6.3	0.154	5.3	4.8	0.130	2.0
PI-394833	1	10.1	26.6	11.1	13.9	80.0	13.7	4.0	43.0	5.5	0.119	4.4	4.1	0.119	2.0
PI-395599	1	14.8	5.2	10.8	1.9	53.3	30.2	3.3	41.7	6.1	0.159	5.5	4.4	0.120	2.0
PI-397121	1	7.0	24.2	10.8	6.4	70.0	17.6	3.7	36.0	5.8	0.165	4.9	5.1	0.116	2.0
RPM- 116	2	8.8	30.2	10.2	6.3	83.3	22.5	4.0	41.0	5.8	0.125	5.7	4.9	0.106	2.0
PI-395780	1	13.8	22.3	10.2	7.3	76.7	25.7	3.3	38.0	6.1	0.163	6.1	4.3	0.103	2.0
IC-SMR-SEL-3678	1	7.1	6.3	10.2	19.6	76.7	26.8	5.0	33.3	7.0	0.111	5.3	4.7	0.084	2.0
PI-397774	1	12.9	8.4	10.1	3.2	46.7	28.8	3.7	39.7	5.7	0.170	4.8	4.3	0.118	2.0
6-TZ	11	9.6	39.2	10.0	12.5	75.5	5.0	31.8	74.3	9.4	0.191	6.2	5.2	0.122	1.0
PI-394704	1	13.4	19.5	9.9	9.3	86.7	3.3	24.8	38.3	6.0	0.129	5.7	5.2	0.112	2.0

Appendix XIV. Medium-duration genotypes (continued)

ENOTYPE	ORIGIN	GREEN PODS		DRY PODS		SEEDS	Hairs/	Seeds/	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)			Seed
		Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE	pod	pod	L	W	PWTH	L	W	SCTH	colour
98113	1	17.4	19.5	9.9	4.7	60.0	23.7	4.0	42.3	8.3	0.182	5.3	4.5	0.142	4.0
6187	1	9.4	16.5	9.9	7.9	70.0	10.8	3.3	42.4	5.7	0.176	5.7	4.8	0.119	3.0
566	1	10.4	16.2	9.8	13.6	56.7	19.4	3.7	41.0	6.2	0.137	5.5	4.6	0.125	5.0
6	4	12.6	26.4	9.7	12.3	73.3	19.5	3.7	38.7	6.6	0.151	5.3	4.4	0.105	1.0
22	1	13.3	19.2	9.7	5.6	13.3	21.0	3.7	50.3	6.5	0.162	5.4	4.7	0.095	2.0
32	1	12.4	32.8	9.6	8.0	63.3	30.5	3.0	36.3	6.7	0.140	5.4	4.9	0.157	2.0
	11	14.1	38.7	9.6	19.5	82.2	35.9	5.3	67.0	8.4	0.191	5.7	5.2	0.122	1.0
98	1	17.7	20.2	9.1	16.2	90.0	31.3	3.7	43.7	6.6	0.148	5.7	4.6	0.091	3.0
LINA	9	9.6	39.2	9.0	12.5	75.5	31.8	5.0	74.3	9.4	0.191	6.2	5.2	0.128	1.0
29	1	20.3	4.8	9.0	2.7	50.0	20.7	3.3	37.3	7.6	0.172	5.7	4.9	0.115	2.0
	11	9.1	29.1	8.7	12.5	64.4	34.6	5.0	66.7	9.9	0.191	5.6	4.8	0.132	1.0
507	1	17.1	37.1	8.6	7.1	83.3	23.9	3.7	43.7	6.7	0.129	5.4	4.8	0.106	2.0
985	1	9.1	17.9	8.4	8.9	50.0	35.4	3.3	36.0	5.8	0.143	5.6	4.2	0.101	2.0
879	1	7.7	22.2	8.3	14.8	83.3	23.5	2.3	38.3	6.1	0.155	6.0	4.0	0.135	3.0
	11	7.8	35.9	8.2	19.7	84.4	34.2	5.7	87.7	11.4	0.198	7.1	5.8	0.120	1.0
6157	1	11.9	34.2	8.2	9.9	60.0	23.1	4.3	45.0	4.3	0.130	5.3	4.6	0.130	2.0
-615	5	6.6	17.4	8.2	11.4	66.7	24.1	4.0	44.0	6.3	0.149	5.2	4.2	0.109	2.0
97490	1	6.9	17.3	8.0	7.1	56.7	26.1	2.7	27.7	5.9	0.148	4.9	4.6	0.102	4.0
397601	1	7.8	6.1	8.0	13.4	39.3	25.5	3.7	41.0	6.5	0.157	5.1	4.6	0.128	2.0
396995	1	4.3	16.8	8.0	8.1	10.0	20.9	3.3	40.7	6.4	0.138	6.1	4.9	0.110	2.0
398112	1	11.8	1.3	7.9	5.5	56.7	25.8	3.7	40.7	5.9	0.151	5.7	4.9	0.104	2.0
CWR-SEL-1522	1	3.9	11.1	7.9	12.9	60.0	10.4	3.3	37.7	6.1	0.189	5.8	4.5	0.100	3.0
PR-5089	4	24.7	1.6	7.9	1.0	63.3	25.8	3.3	53.0	9.3	0.199	5.6	5.2	0.117	4.0
PI-394980	6	7.3	37.6	7.8	10.3	93.3	28.6	3.7	41.3	5.7	0.136	5.1	4.6	0.116	2.0
FAO-ACC-51-426 CIT	3	19.4	13.5	7.8	14.5	80.0	27.4	4.0	42.3	6.1	0.142	5.7	4.4	0.125	2.0
PI-397925	1	5.9	7.9	7.7	5.3	66.7	13.9	3.7	40.3	5.9	0.176	5.7	4.9	0.163	2.0
PI-398080	1	18.7	13.5	7.7	6.0	56.7	49.1	3.7	41.0	6.2	0.157	6.2	4.9	0.108	2.0
ICPL- 232	1	11.3	20.8	7.7	11.8	76.7	35.0	3.3	39.7	6.2	0.153	4.8	4.2	0.118	2.0
PI-396051	1	19.0	20.7	7.6	26.5	63.3	27.3	3.3	40.7	5.8	0.137	5.5	4.8	0.108	2.0
IC-SMR-SEL-3578	1	10.7	11.8	7.6	2.7	50.0	38.6	3.7	36.3	6.7	0.184	5.2	4.7	0.114	2.0

Appendix XIV. Medium-duration genotypes (continued)

ENOTYPES	ORIGIN	GREEN PODS		DRY PODS		SEEDS	Hairs/	Seeds/	POD DIMENSIONS (mm)			SEEDS DIMENSIONS (mm)			Seed
		Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE	pod	pod	L	W	PWTH	L	W	SCTH	colour
96834	I	8.8	0.9	7.6	4.1	50.0	23.4	4.0	44.7	7.6	0.179	6.3	4.8	0.114	3.0
7773	I	18.0	24.8	7.4	16.2	80.0	39.5	3.7	42.0	6.3	0.143	5.5	4.8	0.083	3.0
7709	I	9.7	4.1	7.3	1.3	56.7	26.3	3.3	54.3	8.2	0.194	5.6	4.2	0.110	4.0
967	I	5.9	14.3	7.3	5.7	43.3	38.3	3.3	42.3	6.0	0.161	6.3	5.1	0.129	3.0
R-SEL-2098	I	14.3	12.2	7.2	5.2	76.7	29.3	3.7	41.7	7.7	0.161	5.3	4.4	0.105	3.0
052	I	6.2	2.4	7.1	2.8	40.0	27.5	3.0	40.0	6.4	0.142	5.4	4.7	0.112	2.0
765	I	7.6	23.1	7.1	15.9	76.7	37.9	3.3	39.5	6.6	0.149	5.4	4.9	0.102	2.0
389	I	9.8	22.1	7.1	9.5	70.0	30.5	4.3	44.0	5.7	0.156	5.8	4.1	0.099	2.0
794	I	13.2	7.2	7.1	4.0	56.7	36.5	3.7	40.0	5.4	0.130	5.5	4.8	0.120	2.0
06-10-1	I	10.4	38.2	7.0	0.0	33.3	27.6	3.3	41.3	8.4	0.193	5.0	5.2	0.103	2.0
419	I	13.4	13.0	6.9	16.8	56.7	29.3	2.7	44.0	5.8	0.133	5.9	5.1	0.096	2.0
808	I	14.9	19.5	6.8	1.3	30.0	32.0	4.0	52.3	6.2	0.186	5.2	4.3	0.124	2.0
	II	0.4	8.3	6.7	21.0	84.4	42.9	5.3	90.3	9.9	0.194	6.5	5.3	0.128	1.0
5895	I	7.6	29.5	6.6	18.6	76.7	40.5	3.7	36.3	5.6	0.121	5.8	4.8	0.095	2.0
Z	II	11.0	26.7	6.6	13.0	77.8	45.3	4.7	67.7	9.8	0.191	6.4	5.2	0.121	1.0
8006	I	8.0	11.6	6.4	2.9	53.3	39.6	4.0	54.0	10.3	0.191	6.0	6.8	0.140	3.0
98105	I	6.9	65.4	6.3	26.1	83.3	35.7	4.0	47.3	7.2	0.190	5.3	4.6	0.122	1.0
395702	I	14.0	11.7	6.3	10.2	70.0	33.6	4.3	43.0	5.6	0.147	5.6	4.7	0.086	2.0
395170	I	9.2	20.7	6.2	5.4	73.3	32.2	4.0	35.3	5.3	0.160	5.3	4.4	0.104	2.0
NM-881	I	6.2	18.6	6.2	1.5	63.3	30.2	4.3	50.3	6.8	0.181	5.3	4.7	0.107	1.0
I-307150	I	6.1	14.2	6.2	9.3	60.0	40.6	3.7	37.7	5.8	0.147	5.2	5.4	0.114	2.0
PI-395446	I	4.2	24.2	6.2	2.8	60.0	40.1	4.0	38.3	5.4	0.138	5.9	4.4	0.108	2.0
ICPL-295	I	9.0	11.7	6.2	7.1	70.0	33.4	3.3	34.7	6.3	0.148	5.2	4.3	0.085	2.0
PI-390317	I	7.9	10.2	6.1	6.0	70.0	33.6	3.3	41.7	6.0	0.161	5.5	4.4	0.113	2.0
PI-397488	I	9.3	27.3	6.1	4.8	83.3	36.5	3.7	46.3	6.6	0.187	5.8	5.5	0.105	4.0
PI-398109	I	8.7	22.4	6.1	7.7	66.7	42.1	3.7	41.7	6.4	0.166	5.4	4.6	0.096	2.0
PI-394794	I	18.0	20.6	6.0	9.6	60.0	41.4	3.3	41.7	6.2	0.162	5.4	4.4	0.116	2.0
PI-395504	I	5.0	13.3	6.0	5.3	83.3	29.3	4.0	52.3	5.3	0.159	4.9	4.4	0.114	2.0
PI-397246	I	9.1	10.8	5.9	11.0	90.0	35.4	4.0	44.3	6.4	0.167	5.5	4.6	0.128	2.0
PR-5731	I	4.6	5.1	5.8	5.9	63.3	32.7	3.3	41.3	6.2	0.197	5.9	5.2	0.112	2.0
PI-398095	I	23.0	19.1	5.8	10.3	70.0	27.7	3.6	45.0	7.2	0.166	5.3	4.3	0.120	3.0
PR-5748	I	6.6	14.7	5.7	1.8	46.7	35.3	4.7	42.7	7.6	0.172	5.3	4.7	0.142	3.0

Appendix XIV. Medium-duration genotypes (continued)

NOTYPE	ORIGIN	GREEN PODS		DRY PODS		SEEDS	Hairs/	Seeds/	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)			Seed
		Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE	pod	pod	L	W	PWTH	L	W	SCTH	colour
MR-SEL-3576	I	5.3	14.9	5.7	2.7	63.3	37.8	4.0	50.0	7.0	0.223	5.1	4.2	0.141	1.0
-496	I	4.1	10.0	5.6	3.0	56.7	38.2	4.0	45.0	7.0	0.188	5.1	5.0	0.153	3.0
42-8	I	10.8	15.7	5.6	8.1	63.3	36.2	4.0	38.3	5.9	0.123	5.4	4.6	0.095	2.0
26	I	5.5	0.0	5.6	9.4	33.3	25.3	3.7	42.3	6.2	0.155	5.8	4.9	0.153	2.0
71	I	7.2	14.1	5.3	15.1	63.3	33.8	3.0	49.7	5.4	0.142	5.1	5.7	0.117	2.0
3D	I	5.8	26.7	5.3	1.2	63.3	34.9	3.3	50.3	7.0	0.189	5.2	4.6	0.112	1.0
36	I	9.4	24.4	5.3	8.8	80.0	35.5	4.0	47.7	5.7	0.135	5.6	4.3	0.105	2.0
	I	6.7	15.5	5.2	6.6	6.7	38.0	3.7	39.3	5.4	0.120	5.2	4.2	0.127	2.0
4	I	10.4	0.9	5.2	1.7	50.0	38.9	4.0	47.7	7.1	0.189	4.9	3.9	0.132	4.0
37	I	14.8	2.4	5.2	2.7	63.3	33.6	3.7	39.7	6.1	0.162	5.7	4.6	0.102	3.0
1	I	7.8	10.6	5.2	1.6	30.0	36.0	3.3	39.7	5.9	0.237	6.1	4.7	0.116	4.0
45	I	6.4	5.0	5.1	7.5	60.0	38.6	3.3	39.3	6.1	0.157	4.9	4.3	0.095	2.0
02	I	8.2	23.8	5.0	2.1	60.0	50.0	4.0	50.0	7.0	0.188	5.3	4.3	0.120	3.0
KNOWN	I	7.8	21.8	5.0	5.1	63.3	38.2	3.3	45.7	6.3	0.144	6.2	5.0	0.104	2.0
	II	7.7	29.8	5.0	25.2	64.3	42.7	6.3	86.0	11.4	0.183	5.8	5.1	0.135	1.0
241	I	20.7	18.4	5.0	5.5	56.7	40.1	3.7	47.3	6.4	0.159	6.4	5.1	0.133	2.0
7733	I	12.0	11.5	4.9	1.5	56.7	44.8	4.0	43.0	7.0	0.250	5.2	4.5	0.099	2.0
06075	I	6.7	26.5	4.9	3.7	40.0	39.0	3.7	57.0	8.4	0.190	5.3	4.5	0.117	2.0
96865	I	9.2	16.2	4.9	7.3	73.3	41.8	3.3	34.3	5.5	0.161	5.5	4.8	0.090	2.0
895083	I	8.8	15.8	4.9	10.0	70.0	34.7	3.3	39.7	6.9	0.158	5.4	5.6	0.090	2.0
395399	I	14.2	10.9	4.9	9.7	63.3	39.7	3.3	39.3	5.9	0.140	5.5	4.2	0.096	3.0
R-119	I	23.1	14.9	4.9	27.6	73.3	36.8	3.3	37.3	6.6	0.133	5.5	4.8	0.116	2.0
I-397357	I	12.6	4.3	4.7	1.4	66.7	39.5	4.0	42.7	6.5	0.171	5.6	4.7	0.094	2.0
09-TZ	II	10.6	32.3	4.7	15.9	51.1	46.7	5.3	80.0	10.7	0.185	5.1	5.7	0.129	1.0
PI-397747	I	10.6	22.6	4.7	1.9	76.7	46.5	3.7	39.3	6.4	0.144	5.2	4.9	0.106	2.0
IC-SMR-SEL-7436	I	6.9	20.5	4.7	0.0	53.3	39.6	4.3	44.7	7.2	0.168	5.3	4.2	0.109	2.0
ANM-905	I	7.4	8.3	4.6	2.6	63.3	39.5	4.0	43.7	6.9	0.157	5.2	4.1	0.112	1.0
PI-394439	I	11.6	14.6	4.6	4.4	73.3	46.2	3.7	43.3	5.7	0.137	5.3	4.6	0.120	3.0
PI-397490	I	10.1	8.3	4.6	4.1	76.7	35.9	3.3	41.7	6.2	0.139	6.0	4.8	0.129	3.0
PI-394709	I	4.7	15.7	4.6	5.6	70.0	37.2	3.3	39.3	5.8	0.156	5.9	4.2	0.123	2.0
ICP-5733-15MB	I	4.7	18.4	4.6	4.2	56.7	47.6	3.7	43.3	6.3	0.147	5.3	4.4	0.100	2.0

Appendix XIV. Medium-duration genotypes (continued)

ENOTYPE	ORIGIN	GREEN PODS		DRY PODS		SEEDS	Hairs/	Seeds/	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)			Seed
		Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE	pod	pod	L	W	PWTH	L	W	SCTH	colour
95181	1	17.9	15.3	4.4	11.7	73.3	32.9	3.0	35.3	5.9	0.142	5.2	4.8	0.113	2.0
5498	1	5.2	8.8	4.4	5.3	70.0	48.6	3.3	39.7	5.9	0.173	5.2	4.6	0.106	2.0
7492	1	12.2	26.2	4.4	4.3	83.3	33.1	3.3	43.7	8.6	0.168	6.3	5.5	0.106	2.0
7774	1	11.4	15.5	4.4	2.0	36.7	48.6	3.7	40.0	6.1	0.170	5.7	5.2	0.109	1.0
543	1	8.1	48.3	4.4	9.7	73.3	50.3	3.7	35.3	6.3	0.124	4.9	4.8	0.094	2.0
457	1	12.8	23.2	4.4	2.2	60.0	48.9	3.3	47.3	6.1	0.161	5.9	4.5	0.115	2.0
-54X2EB	1	8.3	32.4	4.4	6.9	73.3	43.3	4.0	47.0	6.7	0.160	5.4	4.6	0.124	2.0
208	1	19.9	19.0	4.4	2.6	60.0	46.9	3.7	58.0	7.6	0.198	5.0	3.9	0.119	4.0
447	1	6.6	24.3	4.3	3.9	66.7	41.9	4.0	46.7	5.8	0.164	5.8	4.8	0.107	2.0
107	2	14.2	60.4	4.3	6.5	80.0	36.0	5.0	61.0	10.7	0.203	5.5	5.8	0.120	5.0
	1	8.0	13.2	4.2	10.9	70.0	47.7	3.7	38.0	5.5	0.149	5.1	4.5	0.103	1.0
8072	1	14.2	21.4	4.2	2.2	73.3	42.6	4.0	49.7	5.7	0.151	6.2	4.5	0.116	2.0
7776	1	24.7	8.7	4.2	6.3	76.7	49.4	3.3	37.3	5.9	0.169	5.2	4.2	0.104	2.0
96120	1	6.9	27.8	4.1	1.5	56.7	50.3	4.7	41.7	8.9	0.185	4.9	4.2	0.118	2.0
94739	1	3.4	20.4	4.1	11.9	80.0	40.7	4.0	36.3	5.9	0.170	4.8	4.6	0.132	2.0
397810	1	12.9	3.9	4.1	4.9	56.7	37.6	3.3	40.0	6.2	0.152	5.4	4.6	0.114	2.0
397092	1	6.0	7.2	4.0	2.2	53.3	37.1	3.3	43.3	7.5	0.176	6.3	5.2	0.145	2.0
395748	1	5.1	15.9	3.9	21.3	83.3	32.0	3.3	38.7	6.2	0.151	5.7	6.1	0.138	2.0
PL-100	1	6.3	11.3	3.9	2.6	50.0	46.2	4.3	49.3	6.7	0.188	5.0	4.5	0.122	2.0
PI-398002	1	8.3	6.3	3.9	6.5	63.3	50.8	3.7	40.0	5.3	0.133	5.2	4.3	0.118	2.0
PI-397262	1	7.0	12.5	3.9	8.0	43.3	45.8	4.3	41.3	7.9	0.172	5.4	4.8	0.118	2.0
PI-397748	1	4.2	1.4	3.8	0.0	56.7	47.9	3.7	50.0	6.8	0.224	6.0	5.0	0.118	2.0
PI-395562	1	12.3	17.4	3.8	9.6	63.3	46.4	3.3	41.0	6.2	0.157	5.6	4.5	0.103	2.0
PI-396087	1	13.6	20.7	3.8	0.0	73.3	42.0	3.7	47.3	6.6	0.188	5.7	4.2	0.101	2.0
PI-397013	1	6.2	29.8	3.8	11.4	83.3	47.1	4.0	41.3	7.9	0.174	6.1	5.8	0.101	2.00
CSS-16	1	4.2	28.9	3.8	3.5	73.3	48.5	3.7	49.0	5.3	0.153	5.7	5.3	0.121	2.0
PI-397033	1	13.9	3.9	3.6	6.7	56.7	45.3	3.3	41.0	5.9	0.155	5.9	4.8	0.126	3.0
PI-397363	1	29.9	24.1	3.6	8.5	70.0	50.2	3.7	48.7	6.5	0.190	5.6	4.8	0.145	4.0
PI-397505	1	10.9	20.4	3.6	0.0	60.0	51.5	3.7	53.3	9.2	0.200	5.7	4.6	0.113	2.0
D-O TYPE	1	8.6	12.1	3.6	5.0	60.0	49.4	3.3	36.3	5.4	0.123	6.0	4.7	0.124	2.0
PI-397763	1	3.0	4.4	3.3	0.0	40.0	44.8	3.3	38.7	5.7	0.150	5.2	4.5	0.120	2.0

Appendix XIV. Medium-duration genotypes (continued)

ENOTYPE	ORIGIN	GREEN PODS		DRY PODS		SEEDS	Hairs/ mm^2	Seeds/ pod	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)			Seed colour
		Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE			L	W	PWTH	L	W	SCTH	
SMR-SEL-3486	1	14.0	21.9	3.3	0.0	56.7	50.3	3.3	49.3	6.0	0.238	6.1	4.8	0.132	4.0
95342	1	4.3	21.5	3.2	2.8	70.0	50.5	3.3	40.7	6.0	0.172	5.3	4.9	0.106	2.0
-470	8	14.4	2.7	3.2	10.3	60.0	50.9	4.0	54.0	7.0	0.178	5.3	5.1	0.129	3.0
221	1	21.0	4.0	3.2	7.4	80.0	51.4	4.0	53.3	7.8	0.188	5.1	4.3	0.124	3.0
828	1	4.8	16.8	3.2	6.9	70.0	49.5	4.0	43.3	7.0	0.155	5.3	5.1	0.122	2.0
027	1	25.9	8.1	3.1	6.7	83.3	51.0	4.0	36.0	5.7	0.155	5.5	4.7	0.101	2.0
249	1	4.0	0.7	3.1	9.4	50.0	48.2	3.3	43.0	5.3	0.133	4.7	4.4	0.119	1.0
744	1	7.1	33.3	3.1	18.1	80.0	47.2	4.0	41.0	6.5	0.164	5.6	5.1	0.099	2.0
55-3	1	9.4	37.2	3.1	9.6	83.3	52.8	4.0	40.3	6.7	0.181	5.3	4.5	0.100	2.0
085	1	7.6	9.5	3.0	3.2	50.0	50.1	3.0	40.3	5.9	0.238	5.3	4.8	0.124	3.0
975	7	11.3	19.6	3.0	9.3	76.7	45.5	5.0	56.7	5.5	0.192	5.1	4.4	0.105	2.0
579	1	2.6	10.8	3.0	0.0	53.3	49.2	3.7	36.0	5.6	0.161	5.2	4.6	0.113	2.0
088	1	23.6	24.8	2.9	3.3	70.0	50.4	4.0	48.7	6.7	0.153	5.9	5.0	0.120	2.0
096	1	5.2	16.2	2.9	3.0	56.7	50.7	3.7	41.7	7.0	0.187	5.0	4.3	0.153	3.0
6192	1	7.9	14.7	2.8	3.7	73.3	51.5	4.0	43.3	6.9	0.155	6.2	5.1	0.127	3.0
3139	1	15.0	21.0	2.8	9.5	56.7	49.3	4.0	52.0	6.9	0.188	5.3	4.6	0.118	1.0
06323	1	6.6	25.9	2.7	3.0	50.0	52.3	4.0	55.7	8.5	0.192	5.0	4.4	0.118	3.0
MR-SEL-7238	1	9.2	34.7	2.6	4.5	56.7	52.9	4.0	39.7	6.6	0.149	5.3	5.3	0.126	2.0
-98	1	18.8	15.4	2.6	2.2	56.7	51.6	3.7	60.7	9.1	0.217	5.4	4.6	0.135	3.0
PL-245	1	9.1	10.8	2.6	10.9	90.0	35.4	4.0	44.3	6.4	0.167	5.5	4.6	0.128	2.0
397679	1	4.4	18.0	2.4	7.5	66.7	52.4	3.7	40.0	5.3	0.147	5.5	4.9	0.107	3.0
NM-895	1	9.4	4.0	2.3	0.0	56.7	52.2	4.3	64.3	9.1	0.217	5.2	5.4	0.117	2.0
CPL-230	1	7.8	18.9	2.2	3.7	66.7	55.6	4.0	55.3	8.5	0.193	5.6	4.7	0.112	5.0
C-WR-SE-9858	1	15.7	8.7	2.2	5.6	66.7	49.9	3.7	40.3	5.5	0.149	4.4	4.1	0.116	2.0
PI-395964	1	3.8	3.7	2.2	0.0	53.3	55.0	4.0	42.0	5.5	0.141	5.6	4.8	0.100	2.0
FAO-ACC-51-425	3	10.0	12.2	2.1	1.3	76.7	56.4	3.7	56.7	9.1	0.216	5.2	5.2	0.103	2.0
PI-398113	1	4.4	6.3	2.1	19.4	66.7	55.4	4.3	45.3	6.8	0.159	5.4	5.2	0.108	2.0
PI-397677	1	4.3	17.8	2.0	4.7	70.0	54.8	3.3	39.0	6.1	0.132	5.4	4.4	0.111	2.0
PI-396040	1	6.0	14.0	1.8	4.2	73.3	57.5	3.3	37.0	6.0	0.125	5.8	5.0	0.090	2.0
PI-398043	1	9.8	32.5	1.7	10.3	83.3	57.2	3.7	43.7	5.7	0.156	5.6	4.5	0.105	2.0

Appendix XIV. Medium-duration genotypes (continued)

GENOTYPE	ORIGIN	GREEN PODS		DRY PODS		SEEDS	Hairs/	Seeds/	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)			Seed
		Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE	mm^2	pod	L	W	PCTH	L	W	TTH	colour
PI-396169	I	5.9	25.0	1.7	5.6	80.0	57.3	4.0	45.0	6.4	0.158	5.1	4.4	0.104	4.0
PI-397501	I	8.0	43.7	1.6	0.0	53.3	55.4	4.0	45.0	6.2	0.164	6.0	5.1	0.114	2.0

Appendix XIV. Long-duration genotypes

PR-5188	I	2.6	4.9	12.0	20.1	83.3	22.0	4.0	52.0	8.0	0.172	6.0	5.2	0.113	5.0
PI-394475	I	4.9	16.2	11.0	17.4	66.7	26.0	4.0	62.3	10.3	0.177	6.1	5.3	0.124	4.0
AGOGI	9	7.8	30.9	10.0	16.0	86.4	34.2	5.7	87.7	11.4	0.198	7.1	5.7	0.120	1.0
3613	10	6.9	11.6	9.7	10.0	83.3	31.7	4.7	54.3	9.7	0.190	6.0	6.0	0.099	1.0
IC-SMR-SEL-4367	I	3.7	18.4	9.0	4.3	50.0	27.3	3.7	50.0	9.9	0.219	6.0	5.2	0.138	3.0
IC-SMR-SEL-2003	I	4.9	22.1	8.9	17.3	80.0	37.0	4.0	50.3	10.1	0.159	6.7	5.5	0.105	2.0
JM-3085	I	5.8	9.8	8.6	17.0	75.3	32.0	4.0	49.3	7.9	0.154	5.9	5.0	0.106	4.0
IC-SMR-SEL-8151	I	6.2	13.7	8.3	17.0	93.3	32.3	3.7	49.7	9.5	0.180	6.2	5.0	0.095	4.0
PI-395449	I	2.6	20.0	7.8	16.2	70.0	40.3	4.0	50.3	8.9	0.180	6.7	5.5	0.150	4.0
PI-394364	I	8.2	0.0	7.7	13.0	84.3	37.3	3.3	50.3	10.2	0.164	7.0	6.3	0.112	1.0
3630	10	5.0	20.1	7.7	5.0	80.0	40.3	3.7	47.3	8.1	0.172	7.1	5.8	0.103	3.0
SCG-2-3	I	8.1	30.3	6.1	6.1	76.7	38.0	4.3	54.3	10.6	0.168	6.4	4.6	0.110	5.0
IC-SMR-SEL-7215	I	5.0	20.6	6.0	7.5	70.0	35.3	3.3	36.0	11.9	0.197	7.2	7.0	0.121	5.0
IC-SMR-SEL-8129	I	5.7	20.2	5.6	3.3	90.0	43.7	4.0	55.7	10.4	0.237	5.8	5.7	0.098	1.0
3651-1-S3X-2EB	I	7.2	31.1	5.4	7.3	76.7	39.3	4.0	62.0	8.1	0.213	5.8	6.3	0.110	4.0
PI-396270	I	11.3	11.9	5.3	1.3	70.0	39.6	5.0	54.6	8.2	0.213	6.0	6.0	0.128	5.0
IC-SMR-SEL-8074	I	6.8	12.5	5.2	1.8	73.3	41.6	4.0	62.3	11.9	0.223	6.8	6.3	0.115	4.0
PI-395013	I	9.7	6.1	4.7	7.0	76.7	45.6	5.0	62.6	10.6	0.243	7.1	6.5	0.118	3.0
IC-SMR-SEL-8074	I	6.8	20.1	4.4	6.7	63.3	45.0	4.0	62.3	11.8	0.174	7.0	6.3	0.108	4.0
IC-SMR-SEL-5097	I	8.0	2.6	4.3	7.8	70.0	45.3	3.6	69.0	11.4	0.184	4.7	4.7	0.131	3.0
IC-SMR-SEL-5733	I	9.6	13.4	4.1	5.0	75.7	44.3	4.6	43.3	9.0	0.170	7.2	6.3	0.123	3.0
PI-396665	I	14.8	13.2	3.3	1.7	86.7	48.0	3.3	64.3	8.1	0.210	7.0	6.1	0.099	2.0

Appendix XIV. Long-duration genotypes (continued)

GENOTYPE	ORIGIN	GREEN PODS		DRY PODS		SEEDS	Hairs/	Seeds/	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)			Seed
		Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE	mm^2	pod	L	W	PWTH	L	W	TTH	colour
PI-396407	1	2.1	14.2	3.3	2.2	70.0	48.6	4.0	51.6	10.6	0.220	6.0	5.9	0.131	2.0
PI-395686	1	3.2	14.8	2.9	3.3	60.0	57.0	4.0	53.3	8.1	0.176	6.8	6.3	0.131	1.0
IC-SMR-SEL-7942	1	4.4	20.3	2.4	0.0	66.7	60.0	3.0	36.0	6.3	0.246	4.8	4.7	0.134	2.0
3615-E1-388	1	4.4	2.9	2.1	0.0	80.0	49.3	4.3	59.6	8.6	0.239	5.0	4.5	0.108	1.0
PR-5069	1	10.6	13.8	2.0	3.6	49.9	56.6	3.3	53.3	12.8	0.225	5.4	5.5	0.141	1.0
Least Significant Difference =		5.8	10.4	3.4	10.0	19.8									

Mean recordings for results above

DURATIONS OF	GREEN PODS		DRY PODS		SEEDS	Hairs/	Seeds/	POD DIMENSIONS (mm)			SEED DIMENSIONS (mm)		
GENOTYPES	Eggs/pod	%ADE	Eggs/pod	%ADE	%ADE	mm^2	pod	L	W	PWTH	L	W	TTH
Short-duration	10.1	19.6	5.9	9.4	71.0	37.7	3.7	48.6	7.7	0.189	5.2	4.3	0.114
Medium-duration	10.4	18.3	5.8	7.6	64.2	37.9	4.1	45.0	6.9	0.170	5.5	4.9	0.117
Long-duration	6.2	15.2	6.1	8.0	74.3	42.3	3.9	55.6	8.9	0.199	6.2	5.7	0.118
Overall mean	7.9	18.31	5.9	8.1	67.0	38.3	4.0	47.3	7.3	0.178	5.5	4.8	0.116

Key %ADE=% Adult emergence, L=Length W=Width, PWTH=Pod wall thickness, SCTH=Seed coat thickness

Origin; 1=India, 2=Mozambique, 3=Nigeria, 4=Nepal, 5=Malawi, 6=Pakistan, 7=Burma, 8=Thailand, 9=Uganda, 10=Bangladesh, 11=Tanzania, 12=Australia