INTERNATIONAL JOURNAL OF PEST MANAGEMENT, 2000, 46(1) 7–18

Diseases and pests of pigeonpea in eastern Africa: a review

(*Keywords:* pigeonpea, East Africa, diseases)

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Abstract. Pigeonpea is one of the major legume crops grown in eastern Africa but has been relatively neglected in terms of research and development. The peas are a rich source of protein and the crop is nitrogen-fixing and drought tolerant. It is an ideal crop for the semi-arid areas of Africa and there is great potential for it to be more widely grown. The large number of pests and diseases which attack pigeonpea in Africa (and elsewhere) is perhaps the main constraint to increased production. The most important pest worldwide is the pod borer, *Helicoverpa armigera*, but the flowers and pods are attractive to a wide range of insect pests. The most important disease in eastern Africa is Fusarium wilt (*Fusarium udum*) and considerable effort has been devoted by ICRISAT to developing wilt-resistant pigeonpeas, adapted to cultivation in the region. This paper reviews the literature on pests and diseases of pigeonpea with special reference to eastern Africa and presents some new information on distribution and damage levels for the key pests and diseases.

1. Introduction

Pigeonpea (*Cajanus cajan* (L.) Mills.) is one of the major legume crops grown in the tropics and sub-tropics, and accounts for about 5% of world legume production. The largest producer is India, where the dried pea is the favoured choice for the preparation of *dhal*. The crop is produced in many other countries in Asia, Africa and Latin America. Kenya and Malawi are the two largest producers in Africa, with production of around 20 000 tonnes but Uganda also produces a similar quantity (Nene and Sheila, 1990). It is still regarded as a neglected crop (Madeley, 1995a) in terms of the amount of research done on it, despite its many uses. It has been described as a unique crop for Africa (Madeley, 1995b) in view of its drought resistance, nitrogen-fixing capability, the ability of its deep taproot to recycle nutrients in the soil and its use as a protein-rich food and source of fuel wood. There is great potential for expansion of the crop in the semi-arid regions of Africa, where it could counteract declining soil fertility. The main constraint upon an expansion in pigeonpea production in both Africa and Asia has been its susceptibility to pests and diseases. The single most important pest world-wide is probably the pod borer, *Helicoverpa armigera* (Hub.), and several other pests that attack the flowers and pods can be damaging. In addition, the crop can be attacked by a number of serious diseases, the most widespread and destructive of which is Fusarium wilt (*Fusarium udum* Butler). Sterility mosaic disease and Phytophthora blight [*Phytophthora dreschsleri* Tucker f. sp. *cajani* (Pal *et al.*) Kannaiyan *et al.*] are important in India, and Cercospora leaf spot can cause serious losses under humid conditions in Africa and Asia.

2. Origin, history and distribution of pigeonpea in East Africa

Pigeonpea is distributed in most tropical countries of the world but the main areas of production are India, Myanmar and East Africa. There are two centres of diversity: eastern Africa and the Indian sub-continent. It is now generally accepted that pigeonpea originated in India (Vavilov, 1951; Vernon Royes, 1976) where there are several wild relatives and where the crop gene pool is most diverse (van der Maesen, 1990). Although wild pigeonpea seems to occur more commonly in Africa, there is only one close wild relative, *C. kerstingii* Harms. The other wild species is *C. scarabaeoiodes* (L.) Thouars, which, although quite widespread, is confined to coastal regions, suggesting that it is a relatively recent introduction (van der Maesen, 1979). India and Myanmar account for 16 wild species, one of which, C. *cajanifolius* (Haines) van der Maesen, could be regarded as the progenitor (van der Maesen, 1990).

The earliest record of cultivation of pigeonpea on the African continent would appear to be in Egypt (van der Maesen, 1990). In the absence of written records, it is difficult to say when the crop was first cultivated south of the Sahara. Today, the distribution of the crop (figure 1) seems to follow the patterns of immigration of Indians into Africa in the nineteenth century to become railway workers and storekeepers. It is possible that cultivation of the crop was encouraged by the Indian immigrants, even if they played no part in introducing the crop to the local inhabitants of East Africa. Pigeonpea cultivation is found all over Kenya, Tanzania, Uganda, Malawi and Mozambique, but within each of those countries, production is concentrated in certain areas. In Kenya the semi-arid areas between Nairobi and Taita Taveta are the main producing areas. In Uganda the crop is grown mainly in the north of the country, particularly in the Districts of Lango and Acholi, but it is also extensively cultivated in West Nile and to a lesser extent in Bunyoro. In Tanzania, although common right along the coast from Kenya to

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International Journal of Pest Management
ISSN 0967-0874 print/ISSN 1366-5863 online © 2000 Taylor & Francis Ltd
http://www.tandf.co.uk/journals/tf/09670874.html

Mozambique, it is grown mainly in the south (Mtwara and Lindi Districts), around Morogoro and in the dry area around Babati and Karatu in the north. In Malawi the crop is widely grown but the main areas of cultivation are probably the Shire Highlands, between Zomba and Blantyre and on the Phalombe plain. In Mozambique, the main areas of cultivation are in the north-western parts of the country.

3. Pigeonpea cropping systems

Pigeonpea is a woody perennial and as such can be grown in field margins, hedgerows or around dwellings as a shrub or small tree. It can also be used in this way in alley cropping. Because of its perennial nature it can be ratooned successfully and is often cultivated for a second season in this way. However, it is more commonly grown as an annual, intercropped with maize or sorghum and sometimes a second legume such as cowpea, groundnut or *Phaseolus* bean, may be added. In Malawi, where it is planted most often with maize, the pigeonpea is almost invisible from a distance until after the maize is harvested and the stalks cut down. During the first part of the dry season only pigeonpea remains in the fields and it becomes apparent how much of the crop is grown. In Uganda pigeonpea is traditionally intercropped with millet. In Kenya sorghum and maize are the most common intercrops with pigeonpea, while in southern Tanzania the main intercrop is cassava.

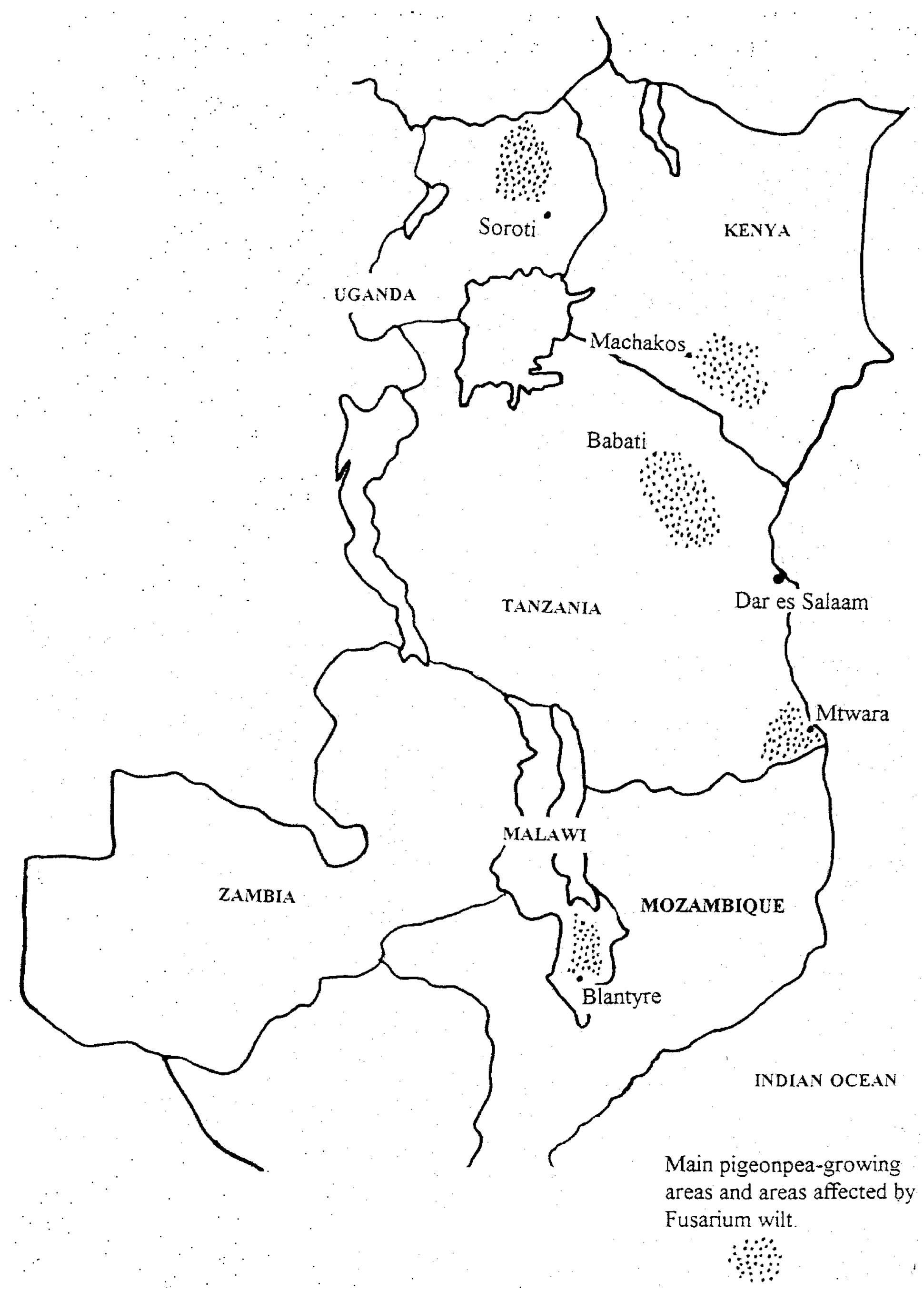

Figure 1. Sketch map of eastern Africa showing the main concentrations of pigeonpea cultivation in Kenya, Uganda and Malawi. These are also the areas where Fusarium wilt incidence is highest.

Considerable work has been done by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the National Programmes in East Africa on short season cultivars. These have great potential in areas with reliable rainfall or for farmers with irrigation who may be able to harvest three crops a year. However, the cultivars which mature in 3 – 4 months have disadvantages for subsistence growers. Their greater determinacy makes them more vulnerable to flower and pod-feeding insects and they do not provide fuel wood to the extent of the taller, long-duration types.

At present Africa grows around 6% of the 3.5 million hectares of pigeonpea grown world-wide. There is potential, particularly in eastern and southern Africa, for the area under pigeonpea cultivation to increase considerably if improved varieties with the required cooking qualities, pest and disease resistance can be made available to farmers through sustainable small-scale seed production schemes.

4. Diseases of pigeonpea

4.1. Fusarium wilt

4.1.1. Distribution. Vascular wilt disease caused by *Fusarium udum* is regarded as the most destructive disease of pigeonpea (Nene and Reddy, 1981). It was first recorded by Butler (1906) in India and has now been reported in 23 countries but is more important in India, East Africa and Malawi (Kannaiyan *et al*., 1984; Waller and Brayford, 1990; Subrahmanyam, 1994; Khonga and Hillocks, 1996; Nene *et al*., 1996). The known distribution of the disease in Africa is shown in figure 1. Fusarium wilt has also been reported on pigeonpea in Zambia, but there is no information concerning its incidence and distribution there. Ghana is also included in the distribution list but its presence in the country is unsubstantiated. There is no information on the first record of the disease in Africa. In Kenya Fusarium wilt seems to be confined to the main pigeonpea-producing area centred on Machakos (Kannaiyan *et al*., 1984; Hillocks and Songa, 1993). In Tanzania the distribution is more scattered, occurring around Babati in the north in the Southern Zone around Mtwara and along the coast near Dar es Salaam (Hillocks, unpublished) and incidences between 10 and 96% were found in Kilosa District (Mbwaga, 1994). The present distribution of the disease in Uganda is not well known due to the difficulty of travel in the main pigeonpea-growing areas towards the north of the country caused by the internal strife of the 1970s and 1980s. The most recent information is that Fusarium wilt is found in the main centre of production in the districts of Acholi and Lango (Silim Nahdy, pers. comm.). In Malawi the distribution is well known, several surveys having been conducted in recent years. The disease is found everywhere that pigeonpea is grown but incidences are particularly high in the south, in the area between Zomba and Blantyre (Kannaiyan *et al*., 1984; Reddy *et al*., 1992; Khonga and Hillocks, 1996). The annual yield loss due to Fusarium wilt alone in East Africa was estimated at US $ 5 million (Kannaiyan *et al*., 1984).

Disease incidence was particularly high in Malawi during the late 1980s which provided the impetus for the release of a resistant cultivar, known by its ICRISAT code, ICP 9145. This cultivar was selected at ICRISAT, Hyderabad, from material collected in Kenya, after screening in the wilt-sick plot. It was released in 1987 after further testing at Bvumbwe Research Station in Malawi. The cultivar was widely adopted and led to a considerable decline in wilt incidence during the early to mid 1990s (Babu *et al*., 1992; Reddy *et al*., 1992). Most of the local cultivars grown in Kenya and Tanzania appear to be susceptible, but pigeonpea fields are often infested with root-knot (*Meloidogyne* spp.) and reniform nematodes (*Rotylenchulus* spp.) which increase susceptibility to Fusarium wilt (Hillocks and Songa, 1993; Marley and Hillocks, 1996).

4.1.2. Disease aetiology. Fusarium wilt in pigeonpea is caused by *Fusarium udum* Butler. The fungus is soil-borne and persists in the soil for long periods in the form of chlamydospores. The host range is restricted to pigeonpea. Infection occurs through the roots, the infection becoming systemic in the vascular system. Symptoms can appear on pigeonpea plants at any stage of plant growth but susceptibility increases around the onset of flowering. Symptoms may first be noticed on the lower leaves and as the infection progresses upwards, more leaves develop chlorosis and then necrosis until the whole plant desiccates and dies. The fungus forms chlamydospores in moribund tissues which are returned to the soil in crop debris and can survive there for a number of years. There is some doubt about the ability of the wilt fungus to survive as a true soil inhabiting saprophyte, or whether its survival depends on association with organic residue. Nene and Reddy (1981) have demonstrated the ability of *F. udum* to survive for up to 3 years in buried host residues but Upadhyay and Rai (1992) state that the fungus can survive saprophytically in the soil in the absence of its host for a period of 3 – 4 years and that the fungus passes from decaying roots into the soil where it continues to grow and form spores. As the host range of *F. udum* is confined to pigeonpea, it is presumably unable to survive on the roots of secondary hosts as is common with other vascular wilt fusaria. There may be secondary hosts but this possibility has not been investigated. The pathogen can also be carried by the seed (Dwivedi and Tandon, 1975) and this may explain its widespread distribution in eastern Africa.

4.1.3. Factors affecting infection and spread. The main factors required for establishment of the wilt pathogen are a conducive soil type and a susceptible pigeonpea cultivar. The disease is favoured by soils which are neutral to slightly acid or alkaline and which have a sand content of 50% or more (Upadhyay and Rai, 1992). The disease begins in a field in a small patch which enlarges with each successive year that a susceptible crop is grown. Some soils may be suppressive to the pathogen, due either to their physico-chemical characteristics, or to active biological antagonism (Upadhyay and Rai, 1981). The main means of spread in a field is along the roots of infected plants, movement of contaminated soil, propagules carried in irrigation water, or rain water run-off and termites also act as agents of dissemination (Upadhyay and Rai, 1983). Long-distance spread may take place on contaminated seed and this would be particularly important for small-scale farmers who retain their own seed.

The susceptibility of both wilt-susceptible and wilt-resistant pigeonpea cultivars to Fusarium wilt is increased by the presence in the soil of certain nematodes. The association between Fusarium wilt and root-knot nematodes is well established (Hillocks and Songa, 1993; Marley and Hillocks, 1994, 1996). The cyst nematode, *Heterodera cajani* (Hasan, 1984; Sharma and Nene, 1989) and reniform nematode, *Rotylenchulus reniformis* (Sharma and Nene, 1990; Jain and Sharma, 1996) have also been reported to increase susceptibility to the disease in India.

4.1.4. Control. Considerable variability for resistance to Fusarium wilt exists within the genus *Cajanus*. ICRISAT has developed a number of wilt-resistant pigeonpea cultivars which have been successfully deployed in India and elsewhere. The most successfully adopted wilt-resistant cultivar in Africa was ICP 9145 which in the mid 1990s accounted for around 20% of pigeonpea production in Malawi (Babu *et al*., 1992; Reddy *et al*., 1992). The resurgence of pigeonpea wilt as a problem in Malawi, has been due to a combination of the lack of a sustainable seed production system to make ICP 9145 widely available to farmers, introgression between local susceptible types and ICP 9145, nematode-induced susceptibility and consumer preference for the cooking qualities of local, wilt-susceptible cultivars. In Kenya where ICP 9145 has also been tested, it has not shown the high level of wilt resistance expected. This may be due to a loss of resistance as a result of segregation in ICP 9145 or some other environmental factor in Kenya. However, the deployment of cultivars with resistance to Fusarium wilt or to the wilt/root-knot complex, remains the most effective means of control. There appears to be different mechanisms of resistance operating in different pigeonpea cultivars. In ICP 9145, resistance was based primarily on rapid phytoalexin accumulation (Marley and Hillocks, 1993) and the accumulation of cajanol in the invaded xylem was retarded by invasion of the roots by *Meloidogyne javanica* (Marley and Hillocks, 1994). However, with another ICRISAT line, ICP 8863, wilt resistance was unaffected by the nematode. Furthermore, it has been reported that some cultivars react to infection by *F. udum* with a ‘tolerant’ response while others show a ‘resistant’ response. This has implications for disease management, as seed infection occurred only in the crop harvested from tolerant cultivars, not from either resistant or susceptible cultivars (ICRISAT, 1987). If tolerant cultivars are made available to small-scale farmers who keep their own seed, there would be an increased risk of spreading the disease on contaminated seed. More information is required on the nature of resistance in pigeonpea cultivars from different genetic backgrounds and further quantitative data on infection levels in seed harvested from tolerant cultivars.

Effective management of Fusarium wilt requires the integration of resistant cultivars with cultural measures. Crop rotation has been shown to decrease inoculum levels and this may be particularly effective where wilt occurs together with root-knot, reniform or cyst nematodes. A 1-year break between pigeonpea crops in which sorghum or tobacco was planted, or the field remained fallow, decreased wilt by 20%, 44% and 22% respectively (ICRISAT, 1987). The choice of crops to include in the rotation would depend on which, if any, nematodes were present. Sorghum or maize might be a good choice where wilt is associated with nematodes. Most legume crops will increase populations of both root knot and reniform nematodes.

4.2. Cercospora leaf spot

4.2.1. Distribution and severity. Cercospora leaf spot is found in most countries where pigeonpea is grown. In Africa the disease has been recorded in Ethiopia, Kenya, Tanzania, Uganda, Malawi, Sudan, Zambia and Zimbabwe (Nene *et al*., 1996). Leaf spot disease was recorded by Kannaiyan *et al*. (1984) in Kenya, where pigeonpea was growing at higher altitude. In general leaf spot occurred at locations where powdery mildew did not. Leaf spot was also prevalent in Malawi but occurred at a low incidence in Tanzania and Zambia. In 1990 leaf spot was particularly severe in eastern Kenya, due to prolonged wet conditions late in the season (Songa *et al*., 1991). No data are available on yield loss in Kenya but the disease is reported to cause substantial losses where pigeonpea is grown under humid conditions with yield losses as high as 85% (Rubaihayo and Onim, 1975; Onim, 1980). Losses over 30% due to combined attack of Cercospora leaf spot and powdery mildew was estimated on short-duration pigeonpeas in Central Plateau of Malawi (Subrahmanyam, 1994).

4.2.2. Aetiology. Leaf spot is caused by *Cercospora cajani* Hennings (perfect stage: *Mycovellosiella cajani* (Henn.) Rangel ex. Trotter). This is one of four species of *Cercospora* which occur on pigeonpea but the only one known from Africa. The pathogen probably survives in crop residues and perennial pigeonpea. Spores are splash-dispersed, to infect the leaves of nearby pigeonpea plants during wet weather, causing small brown spots that increase in size and coalesce. Often, only the older leaves are affected but disease development is favoured by prolonged high humidity and rapid spread is facilitated by wet conditions. Under these circumstances, younger leaves can be affected, leading to premature defoliation.

4.2.3. Control. Crop rotation may be useful in reducing the sources of primary inoculum. Fungicides such as benomyl and mancozeb have been shown to be effective in reducing disease severity and increasing yield (Onim, 1980). Onim and Rubaihayo (1976) reported a number of sources from Kenya having a high degree of resistance to Cercospora leaf spot (UCs 796/1, 2113/1, 2515/2, and 2568/1). Recently, several sources of resistance have been identified in genotypes belonging to different maturity groups in Kenya: KCCs 50/3, 60/8, 119/6, and 423/13 (early maturing), KCCs 81/3/1, 576/3, 657/1, 777, and ICPL 13081 (medium maturing), and KCCs 66, 605, 666, and ALPL 6-2 (late maturing) (Songa, 1991).

4.3. Powdery mildew

4.3.1. Distribution and severity. Powdery mildew is widespread in the semi-arid areas of India and eastern Africa (Nene *et al*., 1996). Although often present on the older leaves it is generally not regarded as a cause of crop loss and management is not considered necessary (Reddy *et al*., 1990). However, the disease was frequently encountered in Tanzania during the survey conducted by Kannaiyan *et al*. (1984) who regarded the disease as of economic importance. Powdery mildew was also moderately severe in parts of Kenya but less so in Malawi, perhaps due to the higher rainfall usually experienced in the main pigeonpea-growing areas in Malawi.

4.3.2. Aetiology. Powdery mildew is caused by *Leveillula taurica* (Lev) Arnaud (*Oidiopsis taurica*) on a wide range of crops, although isolates from one host do not always cross inoculate onto other hosts (Nour, 1958). The primary inoculum is probably the conidia. Conidia germinate on the leaf surface under a wide range of humidities. The germ-tube penetrates through the stomata and much of the subsequent mycelial development takes place within the mesophyl. Cleistothecia are formed only under cool climatic conditions and are short-lived in dry climates. The symptoms are seen on the leaf as white patches of spore-bearing mycelia. The pathogen is able to survive due to the wide host range amongst crops and weed species.

4.3.3. Control. No serious attempts have been made to control powdery mildew in Africa. Reddy *et al*. (1993) reported a high degree of resistance to powdery mildew in some Kenyan germplasm lines (ICPs 9150, 13107, 13156, and 13232).

4.4. Nematodes

Nematodes have been discussed to some extent already with respect to their association with Fusarium wilt. However, many nematodes are important pests of pigeonpea in their own right. Although nematodes are perhaps more of a problem in India, or where pigeonpea is more intensively cultivated, two nematode genera are frequently associated with pigeonpea in eastern and southern Africa. These are the root-knot nematode, mainly *Meloidogyne javanica*. and reniform nematodes, mainly *Rotylenchulus parvus* (Hillocks and Songa, 1993), and another species found in Malawi and identified as *Rotylenchulus variabilis* (Hillocks *et al*., 1995). There is no information on the host status of pigeonpea cultivars for these two *Rotylenchulus* species but *R. reniformis* severely affects crop production in Fiji (Heinlein and Black, 1983). Root-knot nematodes are reported to cause yield losses in pigeonpea of 8–35% (Bridge, 1981). Most of the cultivars presently grown in Africa are susceptible to root-knot (Hillocks and Songa, 1993; Marley and Hillocks, 1996). Lines resistant to root-knot (Thakar and Patel, 1985; Anver *et al*., 1997) and to reniform nematode (Thakar and Yadav, 1985) have been identified in India.

4.5. Other diseases

The other diseases recorded in eastern Africa (table 1) are rust (*Uredo cajani* Syd.), *Phytophthora blight* (*Phytophthora drechsleri* Tucker f.sp. *cajani* (Mahendra Pal, Grewal & Sarbhoy) Kannaiyan, Ribeiro, Erwin & Nene, and three stem canker diseases, one caused by *Macrophomina phaseolina* (Tassi)

Table 1. Occurrence and relative importance of pigeonpea diseases in selected countries in southern and eastern Africa

	Disease severity					
Disease and causal organism	Kenya	Malawi	Tanzania	Uganda	Zambia	Ethiopia
Fusarium wilt (*Fusarium udum*)	+++	+++	+++	++	+	
Root and stem rot (*Macrophomina phaseolina*)			+		+	+
Root and stem canker (*M. phaseolina*)		+				
Root rot (*Rhizoctonia solani*)				+	+	
Stem canker (*Phoma sorghina*, *Phomopsis cajani, Cercospora canescens*, *Colletotrichum crassipes*)					+	
Bacterial stem canker (*Xanthomonas campestris* pv. *cajani*)		+			+	+
Collar rot (*Sclerotium rolfsii*)					+	
Damping-off/root rot (*Dendrochium gigasporum*)	+					
Cercospora leaf spot (*Cercospora cajani*)	+	+++	++	++	++	+++
Powdery mildew (*Oidiopsis taurica*)	++	++	++	++	+++	+
Rust (*Uredo cajani*)	+		+	+		
Phoma leaf spot (*Phoma* sp.)		+			+	
Wet rot (*Rhizoctonia solani*)					+	
Cercoseptoria leaf spot (*Cercoseptoria cajanicola*)					+	
Phytophthora blight (*P. drechsleri* f. sp. *cajani*)	+					
Sclerotinia blight (*Sclerotinia* sp.)					+	
Halo blight (*Pseudomonas syringae* pv. *phaseolicola*)		+			+	+
Macrophoma leaf spot (*Macrophoma cajanicola*)			+			
Leaf blight/spot (*Alternaria* sp.)	+	+			+	
Phoma leaf spot (*Phoma* sp.)					+	
Web blight (*Rhizoctonia solani*)					+	
Leaf spot (*Phaeoisariopsis griseola*)					+	
Leaf blight (*Cladosporium oxysporum*)					+	
Cowpea mosaic (Virus?)	+					
Mosaic/ring spot (Virus?)		+			+	
Witches' broom (Mycoplasma-like organism)					+	
Root-knot (*Meloidogyne* spp.)	+	+		+	+	

+, present, but not economically important; ++, serious in some parts of the country; +++, serious and destructive in all major pigeonpea-producing areas of the country.

Goid, one by *Phoma* spp. and the third a bacterial stem canker caused by *Xanthomonas campestris*pv. *cajani* (Kulkarni, Patye & Abhyankar) Dye. (Kannaiyan *et al*., 1984; Nene *et al*., 1996). Reports from Malawi and East Africa of plants suffering from stem cankers and sudden wilt seem to be increasing but is not clear if these incidences are all associated with the same pathogen (or pathogen complex) or different ones. *Fusarium* spp. and *Macrophomina* are commonly isolated from these plants but the exact cause remains to be determined (R. Hillocks, unpublished).

5. Arthropod pests

5.1. Pod-feeding Lepidoptera

Over 30 species of Lepidoptera in six families feed on the reproductive structures of pigeonpea worldwide (Shanower *et al*., 1998). The basic information about the importance and biology of individual species or groups of pests has been given in other reviews (Singh *et al*., 1978; Singh and van Emden, 1979; Lateef and Reed, 1990; Reed and Lateef, 1990). The two most important species in eastern and southern Africa are *Helicoverpa armigera* Hübner (Lepidoptera: Noctuidae), and *Maruca vitrata* (= *testulalis*) Geyer (Lepidoptera: Pyralidae). No detailed studies have been conducted on pigeonpea pod borers in the region. Results from surveys on farmers' fields in Kenya, Malawi, Tanzania, and Uganda, and on-station trials in Kenya and Malawi, indicated that pod-feeding Lepidoptera larvae accounted for 5 – 35% seed damage on different pigeonpea genotypes (Minja, 1997).

5.1.1. Helicoverpa armigera

5.1.1.1. Distribution and losses. *Helicoverpa armigera* is one of the major biotic constraints to increased pigeonpea production in the eastern and southern African region where it is found on the crop from sea level to 1800 m (Lateef and Reed, 1990; Minja, 1997). *H. armigera* is highly polyphagous and it attacks pigeonpea and other host plants in all countries from Uganda in the north to Malawi in the south of the region (Minja, 1997). The annual pigeonpea losses due to *H. armigera* have been estimated at US$ 317 million worldwide (ICRISAT, 1992).

5.1.1.2. Biology and ecology. The key pest status of *H. armigera* is due to the larval preference for feeding on plant parts rich in nitrogen, such as reproductive structures and growing tips (Fitt, 1989). *H. armigera* larval and pupal weight were highest, larval development period shortest, and adult longevity greatest, when larvae were reared on flowers or pods compared with leaves of several short-duration pigeonpea genotypes (Sison and Shanower, 1994). In general, moths prefer to oviposit on plants in the reproductive stage (Fitt, 1991) and are attracted to flowering crops, perhaps by the nectar which is a carbohydrate source for adults (King, 1994). On pigeonpea, more than 80% of eggs are laid on calyxes and pods (J. Romeis, T. G. Shanhower and C. P. W. Zabitz, unpublished). Three factors contribute to this ovipositional preference: reproductive structures are the preferred larval feeding site; long trichomes and sticky trichome exudates provide a secure substrate for the eggs; and the calyxes and pods seem to provide an enemy-free space for eggs and larvae.

Four other features of *H. armigera* make it one of the most serious and widespread insect pests in the region: high fecundity, extensive polyphagy, strong flying ability, and a facultative diapause (Fitt, 1989). Although *H. armigera* is highly polyphagous, it prefers maize and sorghum to most other hosts (Fitt, 1991; King, 1994; Jallow and Zalucki, 1996). Studies comparing ovipositional responses to certain other host plants excluding cereals, showed that pigeonpea was more attractive than cotton, tomato, okra, and chickpea (Ramnath *et al*., 1992). The ability to feed on various host plants enables the *H. armigera* population to develop continuously during the cropping season, exploiting the succession of different hosts (Bhatnagar *et al*., 1982; Nyambo, 1988).

The biology and ecology of *H. armigera* have been extensively studied and the general features do not differ when it develops on pigeonpea (Zalucki *et al*., 1986; Fitt, 1989; King, 1994). Females oviposit at night and fecundity of up to 3000 eggs has been reported for a single female. The eggs are white and nearly spherical when freshly laid, but darken with age. Eggs hatch in 3 – 6 days and the number of instars (from five to seven) varies with temperature and host plant. The larvae destroy buds, flowers, and pods. If flowers and pods are not available, they feed upon leaflets, between the veins. On pods, conspicuous holes are made by the entry of larvae. Usually developing and partly matured seed are eaten completely. At times, a portion of the seed and testa remain. The generation time is highly variable and in tropical regions it can be as short as 28 days with up to 11 generations a year. Studies on six short-duration pigeonpea genotypes showed a mean development time of approximately 21 days for larvae, and 15 days for pupae (Sison and Shanower, 1994). Pupation occurs in a pupal cell 2 – 18 cm below ground. The pre-pupal stage lasts for 1 – 4 days and the pupal stage takes 10 – 14 days for non-diapausing individuals but may last for several months during diapause. For example, larvae collected from the field in Malawi remained in the pupal stage in the laboratory for 5 months (E. Minja, unpublished).

5.1.1.3. Natural enemies: A list of *H. armigera* natural enemies has been published and detailed life-table studies have been constructed on several crops in East Africa (van den Berg, 1993). However, only limited knowledge of the importance of natural enemies exists (Romeis and Shanower, 1996; Minja *et al*., 1999). It appears that the impact of natural enemies on pigeonpea is relatively low.

5.1.2. Maruca vitrata

5.1.2.1. Distribution and losses. *Maruca vitrata* is distributed throughout tropical and subtropical regions (Singh and van Emden, 1979). In southern and eastern Africa, *M. vitrata* was observed on pigeonpea at altitudes ranging from sea level to 1500 m altitude and larval populations were high during summer months. Severe damage was recorded on short-duration pigeonpea genotypes in the Coast Province of Kenya up to 1000 m, in Northern Uganda, and in Southern Malawi (Minja, 1997). The pest has a wide host range but it is restricted to legumes (Atachi and Djihou, 1994). *M. vitrata* is a serious pest of pigeonpea in India, Sri Lanka, and Africa (Lateef and Reed, 1990), with annual losses estimated at US$ 30 million worldwide (ICRISAT, 1992). During the dry season when crop host plants are not available, *M. vitrata* feeds on wild leguminous shrubs and trees (Jackai and Singh, 1983).

5.1.2.2. Biology and ecology. The biology and ecology of *M. vitrata* has been studied in detail on cowpea (Taylor, 1967; 1978; Singh and van Emden, 1979; Jackai and Singh, 1991). Eggs are primarily laid on buds and flowers, irrespective of host plant. More than 400 eggs per female have been reported from laboratory studies. Eggs are laid in groups of four to six, but up to 16 eggs have been recorded. Eggs hatch in 2 – 5 days and larvae pass through five instars over a period of 8 – 14 days. The pre-pupal stage lasts for about 2 days and the pupal period 6 – 9 days. Pupation takes place in a web on the plant or on the soil surface in a silk cocoon. Generation time is 18 – 25 days, although it can be as long as 57 days.

Larvae construct webs with masses of leaves, flowers, and pods, from which they feed. This complicates control as pesticides and natural enemies have difficulty accessing the larvae. Pigeonpea cultivars with determinate growth habit, where the pods are formed in a bunch at the top of the plant, are more susceptible to damage than indeterminate genotypes, in which the pods are arranged along the fruiting branches (Saxena *et al*., 1996).

5.1.2.3. Natural enemies. Natural enemies have been reported to attack *M. vitrata* (Usua and Singh, 1978; Barrion *et al*. 1987; Okeyo-Owuor *et al*., 1991). Life table studies on cowpea in Kenya showed that the generation mortality is about 98% (Okeyo-Owuor *et al*., 1991), and that diseases are the most important mortality factors. Parasitism has not been recorded from eggs or the first four larval instars. Only very low levels of parasitism were observed for the fifth instars and pupae. No life table studies of *M. vitrata* on pigeonpea have been reported.

5.2. *Pod-sucking Hemiptera*

5.2.1. Distribution and losses. Many species of pod-sucking bugs, mainly in the families Alydidae, Coreidae, and Pentatomidae, feed on pigeonpea (Lateef and Reed, 1990). A few species are widespread and serious pests of pigeonpea, of which the most important are coreids, *Clavigralla* (*Acanthomia*) spp., *Anoplocnemis* spp., *Riptortus* spp. and *Mirperus* spp. Research efforts have been concentrated on three *Clavigralla* species: *C. tomentosicollis* Stål which is widespread in sub-Saharan Africa, *C. scutellaris* Westwood which is found from Kenya through Yemen, Oman, Pakistan and India (Dolling, 1978, 1979), and *C. gibbosa* Spinola which is restricted to India and Sri Lanka (Dolling, 1978). Three additional species: *C. shadabi* Dolling in western and central Africa, *C. elongata* Signoret in southern and eastern Africa, and *C. horrida* Germar in Zimbabwe and South Africa, are also associated with pigeonpea (Materu, 1970; Dolling, 1979). *C. shadabi*, *C. elongata*, and *C. horrida* in Africa, are similar in appearance and habit, and are often confused both in the field and in the literature (Shanower *et al*., 1998).

Adults and nymphs of pod-sucking bugs feed on pigeonpea by piercing through the pod wall and extracting nutrients from the developing seeds (Bindra, 1965). Damaged seeds are dark and shrivelled, and are often difficult to distinguish from those which develop during a drought. This results in underestimation of damage to pigeonpea seeds (Reed and Lateef, 1990). Damaged seeds do not germinate and are not acceptable for human consumption (Materu, 1970). In Tanzania, Materu (1970) reported that more than 50% of pigeonpea seeds were disfigured and unmarketable because of pod sucking bug damage. Seed damage due to pod sucking bugs on farmers' fields in Kenya, Malawi, Tanzania, and Uganda ranged from 3 to 32% and varied between seasons and among locations within and between countries. During surveys conducted in northern Uganda in 1993, *Clavigralla* spp. were the most serious pest of pigeonpea, completely destroying the crop in some fields (Silim Nahdy *et al*., 1994). In Malawi, pod sucking bugs accounted for 60% and 75% of pigeonpea seed damage on farmers' fields in 1995 and 1996, respectively. In Kenya, Tanzania, and Uganda the damage levels during the same period were between 35 and 60% (Minja, 1997).

5.2.2. Biology and ecology. A single generation of *Clavigralla* spp. reared on pigeonpea survived for 15 – 40 days under ambient temperatures (Bindra, 1965; Singh and Patel, 1968; Egwuatu and Taylor, 1977; Nawale and Jadhav, 1978). *C. tomentosicollis* has five nymphal instars and adult *Clavigralla* spp. can live for more than 150 days (Bindra, 1965; Egwuatu and Taylor, 1977). Females have been reported to lay up to 450 eggs in clusters of 2 – 62 eggs (Egwuatu and Taylor, 1977; Taylor, 1978; Dreyer, 1994). Adult longevity and fecundity, and egg mass size of laboratory-reared bugs may differ significantly from field collected samples (Bindra, 1965).

5.2.3. Natural enemies. Only a few natural enemies have been reported to be associated with *Clavigralla* spp. in eastern and southern Africa. These are mainly *Ooencyrtitus* spp. and several Scelionidae (Taylor, 1978; Matteson, 1981). Egg parasitoids alone or in combination have been reported to account for more than 50% of available *C. tomentosicollis* eggs in Benin, Nigeria, and Tanzania (Matteson, 1981; Dreyer, 1994). Most parasitoid species reared from *Clavigralla* eggs are polyphagous. Large egg masses are more frequently attacked which could be due to the high probability of being located by their enemies. Other natural enemies recorded in the region include two parasitoids and three predators of which *Mormonomyia argentifrons* Walker (Diptera: Tachinidae) parasitizes adult *C. horrida* in Tanzania (Materu, 1971), *Alophora nasalis* Bez. (Diptera: Tachinidae) was reared from *C. tomentosicollis* in Nigeria and Tanzania, and *C. elongata* in Tanzania (Matteson, 1980). Among the three predators, *Cosmolestes* sp. (Hemiptera: Reduviidae) was observed feeding on *Clavigralla* spp. nymphs in Kenya (Minja *et al*., 1999), *Antilochus coqueberti* Fb. (Hemiptera: Pyrrhocoridae) preys on nymphs and adults in India (Singh and Singh, 1987), and the predatory mite, *Bochartia* sp. (Acarina: Erythraeidae) was reported infesting up to 21% of *C. gibbosa* nymphs and adults in India (Rawat *et al*., 1969; Singh and Singh, 1987).

5.3. *Seed-feeding Diptera*

5.3.1. Distribution and losses. The pigeonpea pod fly, *Melanagromyza chalcosoma* Spencer (Diptera: Agromyzidae) feeds on developing seeds within the pigeonpea pod in eastern and southern Africa (Minja *et al*., 1996a; Minja, 1997; Shanower *et al*., 1998). A second species, *M. obtusa* Malloch, appears to be restricted to Asia. Both species feed only on pigeonpea and closely related species within the subtribe *Cajaninae* (T. G. Shanower, S. S. Lal and V. R. Bhagwat, unpublished). Pod fly damage has been reported from several countries. In eastern and southern Africa, seed damage due to *M. chalcosoma* ranged from 0 to 4% in Malawi, 0 to 7% in Tanzania, 0 to 13% in Uganda, and 0 to 46% in Kenya. The pest causes most damage on pigeonpea maturing during cool weather and pigeonpea planted at altitudes higher than 500 m above sea level (Minja, 1997).

5.3.2. Biology and ecology. Extensive studies have been conducted on *M. obtusa* in Asia (T. G. Shanower, S. S. Lal and V. R. Bhagwat, unpublished). Although *M. chalcosoma* has not been studied as extensively, it seems to occupy a similar ecological niche (Minja, 1997). *M. obtusa* females produce up to 80 eggs and lay them individually into the developing pigeonpea pods. The egg stage takes 3 – 5 days, the larval stage takes 6 – 11 days to pass through three larval instars, and the pupal stage lasts for 9 – 23 days. Adults live for almost 12 days when fed with honey and about 6 days without food (Ahmad, 1938). Major differences observed between *M. chalcosoma* and *M. obtusa* are that it was rare to find a single *M. chalcosoma* developmental stage in pod locules, and up to 40 larvae/pupae were recorded per pod with an average of five seeds in Kenya (Minja and Shanower, 1999).

The population dynamics of *M. obtusa* are governed by its narrow host range and feeding niche. In India, pigeonpea pods are available in farmers' fields from October to April, and infestations increase rapidly over a relatively short period (Rangaiah and Saghal, 1986). Fewer eggs are laid in December and January when temperatures are low, and populations increase as temperatures rise. Long duration pigeonpea crops mature in March or April and may suffer heavy damages (Lal *et al*., 1981). While the population of *M. obtusa* increases as the temperatures rise, that of *M. chalcosoma* increased with decrease in temperatures in eastern Africa, coinciding with the reproductive period of the long-duration pigeonpea genotypes in the region from June to September (Minja, 1997).

More than 14 species of hymenoptera parasitoids have been reported to be associated with *M. obtusa*. T. G. Shanower, S. S. Lal and V. R. Bhagwat (unpublished) listed more than 14 species, although focus has been on two most important taxa: *Euderus* spp. (Hymenoptera: Eulophidae) and *Ormyrus* spp. (Hymenoptera: Ormyridae). Surveys conducted in farmers' fields in eastern and southern Africa (Minja and Shanowa, 1999; Minja *et al*., 1999) revealed a *Bracon* sp. near *celer* Szepligeti, (Hymenoptera: Braconidae) [A.K.Walker (IIE) det.] causing 0 – 5% larval parasitism in *M. chalcosoma*.

5.4. Storage pests

The legume bruchids, *Callosobruchus* spp., have been reported as pests of pigeonpea in eastern Africa (Le Pelley, 1959; Mphuru, 1978). *Callosobruchus chinensis* (Coleoptera: Bruchidae) was reported as the most important storage insect pest of pigeonpea in Uganda (Silim Nahdy and Odong, 1994). Surveys in farmers' fields in Tanzania showed that at crop maturity but before harvest, *Callosobruchus* spp. infestation reached 2% in southern Tanzania (Minja, 1997). The species identified in Tanzania were *C. chinensis*, *C. maculatus*, *C. rhodesianus* and *C. analis* with *C. chinensis* the most widespread (Mphuru, 1978). In Uganda *C. chinensis* was again the most widespread and damaging species although *C. maculatus* was also found on pigeonpea together with the bean bruchid, *Acanthoscelides obtectus* (Davies, 1960; Silim Nahdy, 1995).

Bruchid damage to stored pigeonpea in Uganda has been estimated at 4 – 7%. Various management methods have been advocated. Insecticides and fumigants, although very effective, are rarely affordable by small-scale producers and may be hazardous to consumers if incorrectly applied. Some success has been achieved with alternative control measures such as the use of neem extracts and vegetable oils (Schmutterer, 1990), hermetic storage (Srivastava *et al*., 1991), solar heating and various physical methods (Silim Nahdy, 1995).

5.5. Other arthropod pests

The other insect pests on pigeonpea in eastern and southern Africa (table 2) include other Lepidoptera pod and seed borers (*Etiella zinkenella* Treitschke, *Exelastis crepuscularis* Meyrick, *Lampides boeticus* Linnaeus), termites (*Microtermes* sp., *Odontotermes* sp.), flower thrips (*Megalurothrips sjostedti* Trybom, *Frankliniella schultzei* Trybom), other sucking bugs (*Nazara viridula Linneaus*, *Oxycarenus* sp., *Taylorilygus*sp.), blister or flower/pollen beetles (*Mylabris* spp., *Coryna* spp.), aphids (*Aphis craccivora* Koch), leafhoppers (*Jacobiasca* spp.), groundnut hopper (*Hilda patruelis* Stål), scale insects (*Ceroplastes* spp. and *Icerya purchasi* Mask.), stem flies (*Ophiomyia* spp.), stem borers (*Alcidodes* sp., *Sphenoptera* sp.), and spider mites (*Tetranychus* spp.) (Le Pelley, 1959; Bohlen, 1978; Reed *et al*., 1989; Minja, 1997).

6. Insect pest management

Pigeonpea pest management is complicated by a number of factors. At least three major insect groups with different biologies attack the crop. The differences include host range (oligophagous to highly polyphagous), mouth parts (chewing versus piercing and sucking), feeding habit (exophagus versus endophagus), and variable population dynamics between years and locations. Each of the key pests is capable of destroying the whole crop, for they feed on the harvestable portions of pigeonpea. Recent work conducted in southern and eastern Africa showed that major pod borer pests on pigeonpea are more destructive during summer months, pod sucking bugs are destructive at any time of the year, and pod fly causes severe seed damage under cool temperatures (Minja, 1997). Economic thresholds have not been developed for any pest on pigeonpea (Shanower *et al*., 1998). The socio-economic constraints of farmers in most pigeonpea-producing countries, the variety of pests, the long reproductive phase and compensatory ability of the crop, all contribute to the difficulties of developing practical economic thresholds. Progress in pigeonpea pest management has also been hindered by the fact that it is considered as a marginal crop or the neglected component in mixed cropping

Table 2. Major insect pests on pigeonpea in farmers' fields in Kenya, Malawi, Tanzania and Uganda

		Pest status			
ORDER/Scientific name	Family	Kenya	Tanzania	Malawi	Uganda
COLEOPTERA					
Alcidodes sp.	Curculionidae	*	*		*
Callosobruchus chinensis Linnaeus	Bruchidae	***	***	–	***
Callosobruchus spp. (Probably *C. rhodesianus)*	Bruchidae	–	***	–	–
Coryna spp.	Meloidae	**	**	**	**
Mylabris spp.	Meloidae	**	**	**	**
Sphenoptera sp.	Buprestidae	*	*	*	*
DIPTERA					
Melanagromyza chalcosoma Spencer	Agromyzidae	***	***	*	***
HEMIPTERA					
Aphis craccivora Koch	Aphididae	*	*	*	*
Ceroplastes sp.	Coccidae	*	*	*	*
Clavigralla tomentosicollis Stål	Coreidae	***	***	***	***
Icerya purchasi Maskell	Margarodidae	*	*	*	*
Jacobiasca lybica de Beryeven	Cicadellidae	*	*	*	*
ISOPTERA					
Microtermes sp.	Termitidae	**	**	**	*
Odontotermes sp.	Termitidae	**	**	**	*
LIPIDOPTERA					
Etiella zinkenella Treitschke	Pyralidae	**	**	**	**
Helicoverpa armigera Hübner	Noctuidae	***	***	***	***
Maruca vitrata (testulalis) Geyer	Pyralidae	***	***	**	***
THYSANOPTERA					
Frankliniella schultzei Trybom	Thripidae	**	**	*	**
Megalurothrips (Taeniothrips) sjostedti Trybom	Thripidae	**	**	*	**

***Serious, widely distributed, causes heavy economic losses; **Common, causes widespread concern; *Occasionally serious, sporadic or of local importance; –Not observed.

systems. Thus, less attention is paid to pigeonpea by farmers, crop protectionists and policy makers.

Pest management efforts on pigeonpea have been focused mainly on *H. armigera* with emphasis on chemical control and host plant resistance (Reed and Lateef, 1990). In Asia, *H. armigera* has developed high levels of resistance to organophosphates and synthetic pyrethroids (Armes *et al.*, 1996). Farmers in southern India now apply pesticides three to six times per season (Shanower *et al.*, 1997). This development has occurred over a period of about 10 years and there are indications that insecticide use on pigeonpea is increasing now in Africa (Minja *et al.*, 1996b). This situation highlights the need for safe and effective management strategies (Shanower *et al.*, 1998).

In Asia, the development and use of alternative insecticides has become necessary as a result of insecticide resistance in *H. armigera*. Such alternatives include plant-derived products, for example neem (*Azadiracta indica*) and insect pathogens, particularly Helicoverpa nuclear polyhedrosis virus (NPV) and *Bacillus thuringiensis* Berl. [Bt]. These products are generally considered to be safe for humans and the environment, and have less impact on beneficial organisms than conventional insecticides (Shanower *et al.*, 1998). Preliminary results in Kenya showed that neither neem extract or *B. thuringiensis* were as effective as the conventional insecticides. This is mainly due to their delayed mode of action; *H. armigera* will have damaged the crop by the time mortality occurs. Furthermore, the larvae feed with their heads inside the pod, making them a more difficult target for Bt-based pesticides.

The development of insect-resistant and/or tolerant pigeonpea cultivars has been of high priority both at national and international research levels (Reed and Lateef, 1990). Pigeonpea lines with resistance to either or both *H. armigera* and *Melangromyza* spp., and *M. vitrata* have been reported, but little progress has been made in incorporating resistance in cultivars acceptable to farmers. There are no insect-resistant pigeonpea genotypes that are widely cultivated by farmers. Frequently the resistant lines are less preferred in terms of taste, seed colour, and/or size, and are often susceptible to diseases (Shanower *et al.*, 1997a).

Most traditional pigeonpea landraces are medium to long duration and may have been selected to avoid pest attack (Reed and Lateef, 1990). The widespread practice of intercropping the longer duration pigeonpea genotypes with one or more companion crops may have evolved through farmers' desire to reduce the risk of insect or other losses. However, companion crops are usually harvested before pigeonpea flowers. Pigeonpea is therefore exposed to its pests as a maturing monocrop, and there is seldom any reduction in pest damage, relative to sole-cropped pigeonpea (Bhatnagar and Davies, 1981). Recently developed shorter duration pigeonpea genotypes, which mature in less than 4 months, may offer new opportunities for cultural or agronomic manipulations to minimize insect damage (Shanower *et al*., 1998).

Natural enemies could play a key role in the management of pigeonpea pests. However, only limited attention has been paid to this area of pest management on pigeonpea. Although a large number of natural enemies has been recorded from key pests of pigeonpea (Romeis and Shanower, 1996; Shanower *et al*., 1998; Minja *et al*., 1999), little is known of their effect on pest population dynamics. No reliable or comprehensive life table study has been published that evaluated the role and impact of natural enemies of any pest on pigeonpea.

Natural control could be improved by investigating the potential for exchanging natural enemies. For example, *H. armigera* eggs are attacked by *Telenomus* spp. in Africa and Australia, whereas only one unconfirmed record of this genera is available in India (Romeis and Shanower, 1996). Species of *Clavigralla* and *Melangromyza* are other promising targets for either classical biological control or trying new associations of natural enemies from closely related species. Much more information is required on pests and natural enemies of pigeonpea, particularly in Africa, before the establishment of the role of natural enemies in pest management on pigeonpea in the region.

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