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INSECT PESTS OF PIGEONPEA AND THEIR MANAGEMENT

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ABSTRACT

Pigeonpea (*Cajanus cajan*) is an important crop in semi-arid tropical and subtropical farming systems, providing high quality vegetable protein, animal feed, and firewood. Insect pests feeding on flowers, pods, and seeds are the most important biotic constraint affecting pigeonpea yields. This review summarizes the biology and ecology of the three most important groups of pests: flower- and pod-feeding Lepidoptera, pod-sucking Hemiptera, and seed-feeding Diptera and Hymenoptera. Recent research investigating the complex interactions among pigeonpea, its key pests, and their natural enemies is also reviewed. These relationships have implications on the pest status of individual species and on possible control strategies. Pigeonpea pest management research has focused until recently on the identification and development of resistant cultivars and on chemical control. Future research must focus on environmentally sound pest management strategies that are compatible with the needs and limitations of pigeonpea farmers. Several priority areas for research are suggested.

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INTRODUCTION

Pigeonpea (*Cajanus cajan*) is an important pulse or grain legume crop in semi-arid tropical and subtropical areas of the world. In terms of global grain legume production, it is sixth after *Phaseolus* beans, peas, chickpeas, broad beans, and lentils (21). In Asia, which accounts for approximately 90% of world production, pigeonpea is the third most important pulse crop, where India, Myanmar, and Nepal are the largest producers (57). Although Asia accounts for the bulk of production, pigeonpea is also an important crop in Africa and Latin America. In Africa, pigeonpea is primarily a subsistence crop, though several countries export significant quantities. Because of its role as a subsistance crop, and coupled with its use as a garden vegetable and intercrop, area and production figures from Africa are generally considered to be gross underestimates. It is grown in more than 33 countries, with Kenya, Malawi, Uganda, Tanzania, and Nigeria having the largest areas under production (33, 100). Countries with the largest production in the New World are the Dominican Republic, Venezuela, Ecuador, Puerto Rico, and Haiti (57).

Pigeonpea is cultivated as an annual or semi-perennial crop, usually in mixed cropping systems. Traditional cultivars/landraces are medium-to-long–duration and are harvested 6–12 months after sowing. Pigeonpea is well suited to intercropping, as it is slow growing and does not compete with shorter-season crops (3). More recently short- and extra-short–duration genotypes have been developed that mature in as few as 90 days. The shorter-duration genotypes generally have less sensitivity to photoperiod than long-duration types (4). The shorter maturity time and reduced sensitivity to daylength give these genotypes more flexibility in new cropping systems (e.g. at higher latitudes) and rotations (e.g. preceding wheat in the Indo-Gangetic Plains). The variety and complexity of cropping systems that include pigeonpea are great. In Asia, pigeonpea is frequently intercropped with sorghum or millet, while in Africa, maize is the predominant intercrop. In addition to cereals, pigeonpea is also intercropped with other legumes and with root and fiber crops (3). In contrast to the longer-duration traditional genotypes, short-duration pigeonpea is usually not intercropped. The yield advantage of short- and extra-short–duration genotypes is greatest in monocrop systems with a high plant density (4).

Pigeonpea grain is consumed in many different forms, made both from green seeds and from reconstituted dried split seeds. In the vegetarian societies of South Asia, pigeonpea is an important source of dietary protein. Studies in India have shown that in some villages, pigeonpea provides half of all protein consumed (78). In Latin America, pigeonpea is both a backyard garden crop and an export crop grown for canning green seeds (43). Pigeonpea is consumed both as green seeds and as whole dried seeds in Africa (100). Important nonfood uses are as fodder (leaves and young branches), building material, and firewood. In some areas of northern India, firewood production is as important a reason for growing pigeonpea as grain production (22). The nitrogen-fixing ability of pigeonpea makes it an important component in sustainable cropping systems, and farmers recognize and appreciate the ability of pigeonpea to "replenish" the soil when planted after a cereal crop (34, 37).

Yields of pigeonpea vary considerably among locations, cultivars, seasons, and cropping systems. In most areas, insects are the most important yield constraint and the greatest cause of yield variation. Diseases and the use of low-yielding genotypes are also cited as constraints to improving pigeonpea yields (45, 56). More than 200 species of insects have been found feeding on pigeonpea, although only a few of these cause significant and consistent damage to the crop (41). Reed & Lateef (68) presented a generalized review of pigeonpea pests and control strategies. This review emphasizes recent literature on the key pests of pigeonpea, including crop–pest–natural enemy interactions and management. Priorities for future research are also suggested.

THE PESTS

Insects feed on all parts of the pigeonpea plant. The most serious pests, and the primary focus of pigeonpea pest management research, are those that attack reproductive structures, including buds, flowers, and pods. Pigeonpea has a great capacity to tolerate and recover from early season losses of flowers and young pods, provided the general health of the plant is good and that sufficient soil moisture is available. Removal of all flowers and pods for up to 5 weeks after flower initiation did not reduce seed yields in 10 short- and medium-duration pigeonpea cultivars (86). Thus, only pests that are continuously present or that attack at the middle or end of the crop cycle are economically important. The key pests of pigeonpea can be grouped into three categories: flower- and pod-feeding Lepidoptera, pod-sucking Hemiptera, and seed-feeding Diptera and Hymenoptera.

Flower- and Pod-Feeding Lepidoptera

Nearly 30 species of Lepidoptera in six families feed on the reproductive structures of pigeonpea. Most of these occur at low densities and are only occasional pests or are of local importance. Basic information about the importance and the biology of individual species or groups of pests has been given in other reviews (41, 68, 92, 93). Therefore, this section focuses on the two most important species, *Helicoverpa armigera* (Noctuidae) and *Maruca vitrata* (= *testulalis*) (Pyralidae).

H. armigera is the major biotic constraint to increasing pigeonpea production (41). Annual pigeonpea losses due to *H. armigera* have been estimated at $317 million worldwide (28). 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 (24). These structures are also the most suitable for larval development. *H. armigera* larval and pupal weight were highest, larval development period shortest, and adult longevity greatest when larvae were reared on flowers or pods as compared with leaves of several short-duration pigeonpea genotypes (94).

In general, moths prefer to oviposit on plants in the reproductive growth stage (25) and are attracted to flowering crops, perhaps by the nectar, which is a carbohydrate source for adults (36). On pigeonpea, more than 80% of eggs are laid on calyxes and pods (77). 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 (see below).

In addition to its preference for feeding on reproductive structures, four features of *H. armigera* life history make it one of the most serious and widespread insect pests in the Old World: high fecundity, extensive polyphagy, strong flying ability, and a facultative diapause (24). In India, *H. armigera* has been recorded on at least 181 plant species from 45 families (45). Though highly polyphagous, *H. armigera* prefers maize and sorghum to most other host plants (25, 32, 36). In a study comparing the ovipositional response to certain host plants excluding cereals, pigeonpea was more attractive than cotton, tomato, okra, and chickpea (65). Relative to other host plants, pigeonpea is a very suitable plant for *H. armigera* development (107, 109).

The ability to feed on various plants enables *H. armigera* populations to develop continuously during the entire cropping season as they exploit a succession of different hosts (10, 58). At the ICRISAT research station near Hyderabad, India, *H. armigera* occurs on groundnut in July and feeds on sorghum and millet in August and September, and moves to pigeonpea and chickpea from October to March (10).

The biology and ecology of *H. armigera* have been extensively reviewed, and the general features do not differ when pigeonpea is used as a host (24, 36, 114). Females oviposit at night and fecundity is high, with up to 3000 eggs reported from a single female. The eggs are white and nearly spherical when freshly laid and darken with age. Eggs hatch in 3–5 days, and the number of instars, from 5 to 7, varies with temperature and host plant. The generation time of *H. armigera* is highly variable. In tropical regions it can be as short as 28 days, with up to 11 generations per year. Mean development time on six short-duration pigeonea genotypes was approximately 21 days for larvae and 15 days for pupae (94). Pupation occurs in a pupal cell 2–18 cm below ground. The prepupal stage lasts for 1–4 days. The pupal stage requires 10–14 days for nondiapausing individuals but may last several months during diapause. The variable development time on different host plants, varying number of generations per year, strong migratory ability, and co-occurrence of diapausing and nondiapausing individuals all contribute to produce overlapping generations in the field.

Extensive lists of *H. armigera* natural enemies have been published for India (73), Australia (114), and Africa (110). Detailed life table studies have been constructed for *H. armigera* on several crops in Australia and East Africa (106, 110), though only limited knowledge of the importance of natural enemies in India exists (73). In general, the impact of predators and parasitoids seems to be relatively low on pigeonpea.

M. vitrata is distributed throughout tropical and subtropical regions worldwide (92, 105). It has a wide host range but is restricted to legumes (6, 102, 104). *M. vitrata* is a serious pest of pigeonpea in India, Sri Lanka, and Africa (41), with annual losses estimated at US$ 30 million worldwide (28). During the dry season, when crop host plants are not available, *M. vitrata* feeds on wild leguminous shrubs and trees (30).

The bionomics of *M. vitrata* has been studied in some detail, although most of this work has been with cowpea (31, 92, 102, 104). Pigeonpea and cowpea are often grown in the same areas, although the former is more common in Asia and the latter in Africa. The biology and life cycle of *M. vitrata* appear to be similar on the two host plants. Regardless of the host plant, eggs are primarily laid on buds and flowers. Fecundity of more than 400 eggs per female has been reported from laboratory studies. Eggs are usually laid in groups of 4–6, though up to 16 eggs have been found in some groups. Eggs hatch in 2–5 days and larvae pass through five instars over 8–14 days. The prepupal period lasts for about 2 days and the pupal period 6 to 9 days. Pupation may occur either on the plant or in the soil in a pupal cell made of silk and covered with debris. Generation time is typically 18–25 days, but can be as long as 57 days.

Larvae feed from inside a webbed mass of leaves, flowers, and pods. This concealed feeding complicates control as pesticides and natural enemies have difficulty penetrating the shelter to reach the larvae. Pigeonpea genotypes with determinate growth habit, where pods are bunched together at the top of the plant, are more prone to damage than genotypes with indeterminate growth habit, in which the pods are arranged along the fruiting branches (80).

A large number of natural enemies have been reported to attack *M. vitrata* (7, 61, 99, 108, 111). Life table studies on cowpea in Kenya have shown that generation mortality is about 98% (61), and that "disappearance" and diseases are the most important mortality factors. Parasitism has not been recorded from eggs or the first four instars and only low levels of parasitism were observed for fifth instars and pupae. No life table studies of *M. vitrata* on pigeonpea have been reported.

Pod-Sucking Hemiptera

A large number of Hemiptera, mainly in the families Alydidae, Coreidae, and Pentatomidae, feed on pigeonpea and are commonly referred to as pod-sucking bugs (41). Relatively few are serious pests; the most important are the coreids *Anoplecnemis*, *Clavigralla* (*Acanthomia*), and *Riptortus*. Research has focused on three *Clavigralla* species; *Clavigralla tomentosicollis* is widespread in sub-Saharan Africa, while *Clavigralla scutellaris* is found from Kenya through Yemen, Oman, Pakistan, and India (14, 15). The third species, *Clavigralla gibbosa*, is restricted to India and Sri Lanka (14). Three additional species, *Clavigralla shadabi* in western and central Africa, *Clavigralla elongata* in southern and eastern Africa, and *Clavigralla horrida* in Zimbabwe and South Africa, are also associated with pigeonpea (15, 47). *Clavigralla* spp. within a region, particularly *C. shadabi*, *C. elongata* and *C. horrida* in Africa and *C. gibbosa* and *C. scutellaris* in India, are similar in appearance and habit and are often confused in the field and in the literature. For example, nearly all of the literature on *Clavigralla* spp. in India refers only to *C. gibbosa*, although *C. scutellaris* co-occurs on pigeonpea. Only recently have *C. gibbosa* and *C. scutellaris* been differentiated in the field in India (44).

Both adults and nymphs of *Clavigralla* spp. feed on pigeonpea by piercing the pod wall and extracting nutrients from the developing seeds (11). Damaged seeds are dark and shriveled, and they are difficult to distinguish from those damaged by drought. For this reason, bug damage is frequently underestimated (68). Damaged seeds do not germinate and are not acceptable as human food (47). In Tanzania, Materu (47) 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 in Kenya, Malawi, Tanzania, and Uganda ranged from 3 to 32% and varied among locations within and between countries (52). Combined losses due to *C. gibbosa* and *C. scutellaris* in India vary among regions and occasionally exceed 50% (11, 89).

The egg to adult development of *Clavigralla* spp. reared on pigeonpea is completed in 15–40 days under ambient temperatures (11, 19, 55, 91). Both *C. gibbosa* and *C. tomentosicollis* pass through five nymphal instars before reaching the adult stage. Adult *Clavigralla* spp. can live more than 150 days (11, 19), and females occasionally lay as many as 430 eggs in clusters of varying size. Field collections of *Clavigralla* egg clusters in India showed that cluster size ranges from 2 to 62 eggs (mean = 18 eggs), with more than 70% of clusters containing 7–24 eggs (81). Similar ranges in egg cluster size have also been reported for African *Clavigralla* spp. (16, 19, 104). Longevity and fecundity of adults and egg cluster size of laboratory-reared bugs may differ significantly from field-collected bugs (11).

Relatively few natural enemies have been reported for *Clavigralla* spp. The most important are hymenopteran egg parasitoids (Table 1). These parasitoids, alone or in combination, have been reported to parasitize more than 55% of available hosts on pigeonpea in India (for *C. gibbosa*, see 11, 55), Nigeria, and Benin (for *C. tomentosicollis*, see 16, 50). *Gryon clavigrallae* (Hymenoptera: Scelionidae) parasitizes up to 69% of eggs and up to 100% of *Clavigralla* egg

Table 1 Egg parasitoids reported to attack *Clavigralla* spp.

Parasitoid	*Clavigralla* species	Country	Crop[a]	Reference
EUPELMIDAE				
Anastatus ?hancocki[b]	*Clavigralla tomentosicollis*	Tanzania	C	50
Anastatus ?hemipterae[b]	*C. tomentosicollis*	Nigeria	C	50
		Benin	C	16
Anastatus sp.[b]	*C. tomentosicollis*	Nigeria	C	50
ENCYRTIDAE				
Ooencyrtus sp.	*C. tomentosicollis*	Nigeria	P	20
Ooencyrtus afer[c]	*C. tomentosicollis*	Nigeria	C	50
Ooencyrtus utetheisae	*C. tomentosicollis*	Benin	C	16
(=*Ooencyrtus patriciae*)	*C. tomentosicollis*	Nigeria	C	50
	C. tomentosicollis, Clavigralla elongata	Tanzania	C	50
SCELIONIDAE				
Baeus sp.[d]	*C. elongata*	Tanzania	—	50
Gryon sp.	*C. elongata*	Tanzania	C	50
Gryon clavigrallae	*Clavigralla gibbosa/ Clavigralla scutellaris*[e]	India	P	44, 51
Gryon fulviventre[f]	*C. elongata*	Tanzania	—	51
	C. gibbosa/C. scutellaris[e]	India	P	11, 90
	C. tomentosicollis	Benin	C, P	16
	C. tomentosicollis	Nigeria	C, P	50, 103
	C. tomentosicollis	Tanzania	C, B, D, P	48, 50
Gryon saxatile	*C. elongata*	Tanzania	—	51
Telenomus sp.	*C. elongata*	Tanzania	C	50

[a]If reported; B = *Phaseolus* beans, C = cowpea, D = *Dolichos lablab*, P = pigeonpea.
[b]*Anastatus* spp. are probably hyperparasitoids (G Mineo, personal communication in 16).
[c]Incorrectly indentified as *Ooencyrtus kuvanae* (50).
[d]Probable misidentification, as this genus is known to attack only spider eggs (A Polaszek, personal communication).
[e]*C. gibbosa* and *C. scutellaris* have been confused in the literature (see text).
[f]*Hadronotus* is a junior synonym of *Gryon*; *Gryon antestiae* and *Gryon gnidus* are synonyms of *G. fulviventre* (A Polaszek, personal communication).

clusters in India (81). Large egg clusters are more frequently attacked, probably because they are more easily located. Most of the egg parasitoids reared from *Clavigralla* spp. (Table 1) are polyphagous.

Only five other natural enemies, two parasitoids and three predators, have been recorded: *Mormonomyia argentifrons* (Diptera: Tachinidae) parasitizes adult *C. horrida* in Tanzania (48), and *Alophora nasalis* (Diptera: Tachinidae) was reared from *C. tomentosicollis* in Nigeria and Tanzania and *C. elongata* in Tanzania (49). The three predators are *Cosmolestes* sp. (Hemiptera: Reduviidae), observed feeding on *Clavigralla* nymphs in Kenya (EM Minja, unpublished data); *Antilochus coqueberti* (Hemiptera: Pyrrhocoridae), preying on nymphs and adults in India (90); and a predatory mite, *Bochartia* sp. (Acarina: Erythraeidae), which reportedly infests up to 21% of *C. gibbosa* adults and nymphs in India (67, 90).

Seed-Feeding Diptera and Hymenoptera

Two Diptera and one Hymenoptera feed on developing seeds within the pigeonpea pod. The most important is *Melanagromyza obtusa* (Diptera: Agromyzidae), the pigeonpea pod fly, which appears to be restricted to Asia. Its biology, ecology, and management have been extensively studied (83). A second agromyzid species, *Melanagromyza chalcosoma*, is a pest of pigeonpea in eastern and southern Africa (54). Though less well studied, it seems to occupy a similar ecological niche (52). Both species feed only on pigeonpea and closely related species within the subtribe Cajaninae (83).

M. obtusa females produce up to 80 eggs and lay them individually into developing pigeonpea pods. Development of the immature stages under field conditions includes 3–5 days for the egg stage, 6–11 days for the three larval instars, and 9–23 days for the pupal stage. Adults live up to 12 days when fed with honey and about half as long without food (1). The population dynamics of *M. obtusa* are governed by its narrow host range and feeding niche. In India, pigeonpea pods are available in the field from approximately October to April, and infestations increase rapidly over a relatively short period (66). 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 can be heavily damaged (38). *M. obtusa* may survive the off-season on alternate hosts such as *Rhyncosia minima*, which have been found to be infested with eggs, larvae, and/or pupae between April and November (35).

Pod fly damage has been reported from several countries. In India, the pod fly is a more serious pest in northern and central areas than in other parts of the country (40). Damage levels in farmers' fields range from 10 to 50% (39, 59, 97). In Vietnam, *M. obtusa* is the key pest of pigeonpea, causing seed losses of more than 90% (27), while damage of 43% is reported from Taiwan

(101). Seed damage of less than 1% was observed in Malawi and Tanzania, 3–5% in Uganda, and up to 15% in Kenya (52).

Parasitic Hymenoptera that attack the larval stage are the only natural enemies reported for *M. obtusa*. Shanower et al (83) listed more than 14 species, though research has focused on the two most important taxa: *Euderus* spp. (Hymenoptera: Eulophidae) and *Ormyrus* spp. (Hymenoptera: Ormyridae). *Euderus* spp. are solitary or facultatively gregarious ectoparasitoids and are found in India (96), Sri Lanka (22), and the Philippines (JA Litsinger, personal communication in 101). Parasitism rates of more than 25% have been reported for this group (2, 106). *Ormyrus orientalis* and *Ormyrus fredricki* are solitary endoparasitoids that parasitize up to 13% of hosts in India (105). Parasitism levels of up to 30% have been reported for *O. orientalis* in Sri Lanka (23).

The larvae of *Tanaostigmodes cajaninae* (Hymenoptera: Tanaostigmatidae) also feed on developing pigeonpea seeds. In addition to pigeonpea, *T. cajaninae* has been reported feeding on 13 noncrop legumes (42, 64). Female wasps lay individual eggs on the surface of flowers or young pods. The larva bores into the pod and feeds for 8–10 days on the developing seeds. Pupation, which occurs within the pod, lasts 5–7 days, and the adult lifespan is 7–9 days. Low infestation levels (<2.4% pods) have historically been reported in farmers' fields in southern India, but higher infestation levels, up to 58% of pods, were found on research stations, especially in pesticide-treated plots (42). Lateef et al (42) suggest that the more frequent use of pesticides on research stations results in higher *T. cajaninae* populations and damage owing to the destruction of its natural enemies. More recently, higher levels of pod infestation (5–11%) in farmers' fields in southern India have been observed (TG Shanower, CS Pawar & VR Bhagwat, unpublished data). The higher damage levels parallel the increasing use of pesticides by farmers (see below), lending support to the earlier hypothesis (42) that *T. cajaninae* is a secondary pest.

MULTITROPHIC INTERACTIONS

In recent years, increased attention has been given to the interactions among plants, herbivorous insects, and their natural enemies in order to optimize the efficiency of naturally occurring or released parasitoids and predators (63). Oviposition and feeding behavior of herbivorous insects are affected by both physical and chemical features of the plant (8). The plant surface plays a key role in these plant-insect interactions. Trichomes are the most well-studied plant surface structure. In several crops, trichomes have been manipulated to develop insect-resistant cultivars (62, 98). However, trichomes and their exudates are also known to reduce the efficiency of natural enemies and thus may have positive or negative effects on pest populations (13).

Five trichome types, three glandular and two nonglandular, have recently been described from pigeonpea and two wild relatives, *Cajanus scarabaeoides* and *Cajanus platycarpus* (74). One of the glandular trichomes (Type A) is multicellular with a broad base and a long tubular neck that secretes a clear, viscous fluid at its tip. The density and length of the different trichome types vary significantly among different plant structures and among *Cajanus* species (74). *C. scarabaeoides* pods have significantly higher densities of nonglandular trichomes than pigeonpea pods and generally lack the Type A trichome. On pigeonpea leaves, trichomes are generally much shorter than on reproductive structures, and the exudate-secreting Type A trichomes are rare.

The most detailed knowledge of pigeonpea–herbivore–natural enemy interactions is for *H. armigera* and its *Trichogramma* (Hymenoptera: Trichogrammatidae) egg parasitoids. Plant volatiles, trichomes, trichome exudates, and surface chemicals affect the behavior of both *H. armigera* and *Trichogramma* spp. In the laboratory, volatiles from pigeonpea leaves attract *H. armigera* and stimulate oviposition (26, 69, 70). Olfactometer studies with *Trichogramma chilonis* have shown that females are repelled by volatiles from pigeonpea plants in the reproductive growth stage and by pods alone (75, 76). Because the parasitoids show no response to plants in the vegetative stage, different volatiles appear to influence the behavior of *H. armigera* and *T. chilonis*. The infochemicals that repel *T. chilonis* are unknown but do not derive from Type A trichome exudates; washed pods and pods of *C. scarabaeoides* that generally lack this trichome type also repel the parasitoids (76). Another parasitoid, *Eucelatoria bryani* (Diptera: Tachinidae), which attacks *Helicoverpa*/*Heliothis* larvae, is attracted by volatiles from pigeonpea leaves, buds, flowers, and hexane extracts of flowers (46). However, the relative importance of pigeonpea volatiles during host selection and oviposition behavior by *H. armigera* or the host location process of its parasitoids in the field is not known.

More than 80% of *H. armigera* eggs on pigeonpea are found on calyxes and pods (77). Differences in the length and distribution of trichome types among different pigeonpea plant structures may contribute to this ovipositional preference. Trichomes play an important role in the ovipositional behavior and host selection process of *H. armigera* (25, 36, 114). In addition, they have been identified as an important resistance factor in wild relatives of pigeonpea, as they prevent small *H. armigera* larvae from reaching the pod surface (84). But on pigeonpea reproductive structures, the long trichomes and sticky trichome exudates inhibit the movement of *Trichogramma* spp. (76). Egg parasitism levels therefore vary widely on different plant structures. Romeis et al (77) found 41% of eggs on leaves were parasitized, while fewer than 4% of eggs on pods and calyxes were attacked.

The oviposition behavior of *Callosobruchus chinensis* (Coleoptera: Bruchidae) is also affected by trichomes. In no-choice experiments, *C. chinensis* laid more eggs on pigeonpea pods with trichomes removed or on pods with low trichome density than on pods with a high density of trichomes (88). High trichome density also prevented small bruchid larvae from reaching the pod surface. There is no information on the effects of pigeonpea trichomes on other important pests. However, trichome density and orientation are important resistance factors against *M. vitrata* and *Clavigralla* spp. on cowpea (29, 60).

Surface chemicals from pods of pigeonpea and wild *Cajanus* species also affect the behavior of *H. armigera* larvae and *T. chilonis*. A filter paper feeding test showed that an acetone extract from the surface of pigeonpea pods contains *H. armigera* feeding stimulants (84). The same response to surface extracts was detected in *C. platycarpus* pods, but not in extracts from pods of *C. scarabaeoides* that lack Type A trichomes. These results suggest that the feeding stimulants are contained in the trichome exudate. Apolar chemicals on the plant surface also stimulate oviposition behavior of *H. armigera* (12). *M. obtusa* may also respond to pigeonpea surface chemicals because significantly more eggs were found in water-washed pods than in unwashed pods of the same cultivar (95). In a filter paper bioassay, *T. chilonis* was deterred by pod surface extracts from pigeonpea, *C. scarabaeoides*, and *C. platycarpus* (76). The compounds responsible for this effect are therefore not present in the Type A trichome exudates.

Generalist predators may also be deterred from searching on pigeonpea. Several major taxa of predators including chrysopids, coccinellids, anthocorids, and spiders are more common on sorghum than on pigeonpea in sorghum-pigeonpea intercrops (18). *Orius tantillus* (Hemiptera: Anthocoridae) attacks eggs and first instars of *H. armigera* more effectively on sorghum than on pigeonpea. The lower efficacy on pigeonpea relative to sorghum is attributed to differences in plant chemistry and architecture (87). A predatory ant, *Paratrechina longicornis* (Hymenoptera: Formicidae), removes more than 50% of *H. armigera* eggs from leaves but less than 17% of eggs from buds and pods (72). The long trichomes and sticky exudates on pigeonpea reproductive structures interfere with movement and searching ability. Thus it appears that the pigeonpea plant growth stage and plant structures most preferred by *H. armigera* for oviposition and larval feeding are the most unsuitable for *Trichogramma* egg parasitoids and other natural enemies.

There is also indirect evidence that pigeonpea affects the host location process of natural enemies of other pest insects. Egg parasitism of *Clavigralla* spp. is strongly influenced by the host plant on which eggs are laid. In Africa, *Gyron fulviventre* attacked 6% of *C. tomentosicollis* eggs on *Phaseolus* beans, 11% of eggs on pigeonpea, and 24% of eggs on *Dolichos lablab* (48). Dreyer (16) reported two *C. tomentosicollis* egg parasitoids on cowpea, *G. fulviventre* and *Ooencyrtus utetheisae*. Only one of these, *G. fulviventre*, was found in more than 12,000 eggs sampled from pigeonpea. In addition, both parasitoids attacked *C. tomentosicollis* eggs on potted cowpea plants in a pigeonpea field, but *O. utetheisae* did not parasitize eggs on pigeonpea plants exposed in a cowpea field. Similarly, Egwuatu & Taylor (20) reported that *Ooencyrtus* sp. attack *C. tomentosicollis* eggs on pigeonpea at very low levels (<0.1%).

MANAGEMENT

Pigeonpea pest management is complicated by several factors. The crop is attacked by at least three key pest groups with very different biologies. These differences include host range (oligophagous to highly polyphagous), apparency (feeding on the plant surface versus concealed feeding), and feeding mode (chewing versus piercing and sucking). The pests also have highly variable population dynamics between years and locations, and at least one, *H. armigera*, has developed high levels of resistance to several insecticides. The key pests are all direct pests, feeding on the portion of the crop most valued by humans, and each is capable of completely destroying a crop. Economic thresholds have not been developed for any pest of pigeonpea. Given the variety of pests, the long reproductive phase and compensatory ability of the crop, and the socio-economic constraints of farmers in most pigeonpea-producing countries, it is doubtful if useful or practical economic thresholds could be developed. Another obstacle to progress in pigeonpea pest management is that pigeonpea has been considered a marginal crop or is the neglected component of a mixed cropping system and is thus given less attention by farmers, crop protection specialists, and policy makers.

The primary focus of pigeonpea pest management has been on *H. armigera* and *M. obtusa*, with emphasis on chemical control and host plant resistance (68). A major change in farmers' pest management practices has been the widescale adoption of synthetic pesticides as the primary method of pest control in some areas (85). In India, calendar sprays are recommended and followed, with the first application at 50% flowering and second and third applications at 15-day intervals (79). Farmers in southern India now apply pesticides 3–6 times per season (82). This change has occurred over a period of about 10 years, and there are indications that pigeonpea farmers in Africa may follow a similar trend (53). In Asia, *H. armigera* has developed high levels of resistance to organophosphates and synthetic pyrethroids (5). This has resulted in control failures and a lack of confidence in insecticides (71). The rapid increase in pesticide use on pigeonpea is alarming and emphasizes farmers' concern with insect pests. The trend also highlights the need for safe and effective management strategies.

The difficulty in managing insecticide-resistant populations of *H. armigera* has given impetus to the development and use of alternative insecticides such as plant-derived products [e.g. neem (*Azadiracta indica*)] and insect pathogens, particularly the *Helicoverpa* nuclear polyhedrosis virus (NPV). These products are generally considered to be safer for humans and the environment and have less negative impact on beneficial organisms than conventional insecticides. Neem products have traditionally been used to protect stored grain in India. Commercially formulated neem products are available in many countries, although results on pigeonpea have been inconsistent (82). The use of NPV to control *H. armigera* has received much attention, particularly in India, though reliable control on pigeonpea has not been obtained (82). Both neem and NPV products suffer from poor and highly variable quality and a more limited distribution network than conventional insecticides. These problems must be overcome before these products can be considered effective and practical alternative control methods. The possibility of farmers or farmer cooperatives producing and using plant-derived or insect pathogen products on a local scale has attracted the attention and resources of a number of nongovernmental organizations.

The development of insect-resistant and/or -tolerant pigeonpea cultivars has been a high priority in both national and international research programs for many years. Two problems have hindered progress: highly variable pest populations (within and across seasons) and the high degree of out-crossing in pigeonpea. The first problem was addressed by developing an open-field screening methodology to compare the performance of genotypes at different locations and across years (68). The key to this system is that material is evaluated in groups with similar flowering and maturity times, and any entry more susceptible than standard checks is rejected. Over a period of several years, only lines showing consistently superior performance relative to the checks are advanced (68). Isolating material and vigilantly removing off-types minimizes the effect of out-crossing. Limitations of land, labor, and financial resources make this approach difficult for many national programs to follow rigorously .

Pigeonpea lines with resistance to either or both *H. armigera* and *M. obtusa* have been reported, but little progress has been made in incorporating resistance in cultivars that are acceptable to farmers. No insect-resistant pigeonpea genotypes are widely cultivated by farmers. Frequently, the resistant lines are less preferred in terms of taste, seed color, and/or size and are often susceptible to wilt, sterility mosaic virus, or other diseases (82).

Traditional pigeonpea landraces are medium-to-long–duration and may have been selected to avoid peak pest attack (68). Delaying planting to avoid high pest populations has been an effective strategy in research station trials but has not been widely adopted (112, 113). Selecting companion crops or cultivars has also been investigated as a means of minimizing pest damage (41). 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 risks of insect or other losses. But the companion crop(s) is usually harvested before pigeonpea flowers when medium- and long-duration pigeonpea cultivars are used. Thus, when pigeonpea is most attractive to the key pests, it is functionally a monocrop, and there is seldom any reduction in pest damage relative to sole-cropped pigeonpea (9). Recently developed shorter-duration pigeonea genotypes, which mature in less than 4 months, may offer new opportunities for cultural or agronomic manipulations to minimize insect damage.

Improving the impact of natural control agents is perhaps the most neglected area of pigeonpea pest management research. Although a large number of natural enemies have been recorded from the key pests of pigeonpea (31, 73, 83), little is known of their effect on pest population dynamics. No reliable or comprehensive life table study that evaluated the role and impact of natural enemies of any insect pest on pigeonpea has been published. An attempt was made to increase the impact of natural enemies on short-duration pigeonpea by intercropping with short-duration sorghum (17). The mechanism behind this strategy was that synchronized flowering times would facilitate the transfer of natural enemies from sorghum to pigeonpea. Though initially successful, the impact of natural enemies in this intercrop system has not been consistently greater than in sole-cropped pigeonpea (77). A number of pigeonpea plant characters that inhibit natural enemies have been identified. Developing genotypes that lack these characters would be a practical approach to improving natural enemy impact.

Another possibility for improving natural control would be to investigate the potential for exchanging natural enemies. For example, *H. armigera* eggs are attacked by *Telenomus* spp. in Africa and Australia, while only a single unconfirmed record of this genus in India is available (73). Species of *Clavigralla* and *Melanagromyza* are other promising targets either for classical biological control or for trying new associations of natural enemies from closely related species. Much more needs to be known of the pests and natural enemies of pigeonpea, particularly in Africa, before the feasibility of this idea can be determined.

FUTURE NEEDS

Insect pests are a major constraint to pigeonpea production, yet there has been relatively little research investment, particularly outside of India, into the biology, ecology, and management of pigeonpea pests and their natural enemies. Research has concentrated almost exclusively on *H. armigera* and *M. obtusa,* with little attention given to other pests. Knowledge of the impact, dynamics, and ecology of the pests and their natural enemies is essential before effective control strategies can be developed. These studies must focus on the cropping system, as pigeonpea is frequently one component of a complex farming system. Other tropical legumes are particularly important because they share a number of pests and natural enemies with pigeonpea.

Pigeonpea farmers in some parts of India and Africa have rapidly adopted the use of pesticides as the primary means of pest management. Past experience in developing countries has shown that pesticide use is often inappropriate and unsafe and that farmers frequently fall into a cycle of increasing the amounts and/or frequency of pesticide applications. To avoid this "pesticide treadmill," pigeonpea farmers need effective alternative pest management practices. There is no shortcut or magic bullet to reduce losses due to insect pests immediately. Progress will be incremental, and in the short term, the greatest impact may come from improving insecticide application. This would involve enhancing the skills needed to scout fields and properly mix and apply insecticides and providing unbiased information on the relative risks and benefits of different insecticides. A strategy for the medium term should concentrate on developing improved cultivars that combine high yield and disease and insect-resistance into backgrounds with consumer-preferred agronomic characters. The identification of specific resistance mechanisms, such as increasing the density of nonglandular trichomes on pods, would be a good start. A longer-term solution to insect pest problems in pigeonpea must focus on ways to enhance natural control processes, either by the introduction of exotic natural enemy species or by enhancing the effectiveness of endemic species.

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