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Insect pests of pearl millet in West Africa

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Summary

Published information on all insect pests recorded from pearl millet (*Pennisetum glaucum*) in West Africa is reviewed, with emphasis on pest status, biology and control. The major insect pests at present are the earhead caterpillar, *Heliocheilus albipunctella* (de Joannis), the millet stem borer, *Coniesta ignefusalis* (Hampson), grasshoppers and meloid and scarabaeid beetles. Many other insect pests, such as the millet grain midge, *Geromyia penniseti* (Felt), are of local importance at present but could become more damaging in future. Published sources of information on all of these pests are noted and records of natural enemies, especially parasitic Hymenoptera but also other parasitoids and predators, are tabulated. Cultural, chemical and biological control methods and the use of host plant resistance are reviewed and the preliminary development of integrated pest management programmes is noted. The general conclusion is that long-term, widely applicable control of insect pests on pearl millet in West Africa will have to be based on integrated pest management, with emphasis on plant breeding for host plant resistance, and that priority should be given to testing and evaluating current cultural methods, screening, selection and the study of resistance mechanisms, and increasing parasitoid populations through habitat manipulation.

I. Introduction

Pearl millet (*Pennisetum glaucum* L. Rich = *P. americanum*) is an important staple cereal food crop in Africa and Asia and is of particular importance in the African Sahel where it is the only cereal crop that will produce grain yields under harsh environmental conditions. 25% of the total estimated world production is produced in West Africa (Table 1), where it is grown as a rain-fed subsistence crop, especially in areas of low and erratic rainfall (250-900 mm per annum).

The main constraints on production in West Africa are drought, insect pests, diseases, weeds and birds. A Colloquium convened in Ougadougou in March 1991 to discuss crop loss in pearl millet reviewed available information on losses attributable to invertebrate and vertebrate pests and emphasised the general importance of insects [CILSS Institut du Sahel, March 1991, 'Colloque sur le profil des pertes sur le mil dans le Sahel, Ougadougou (Burkina Faso), 20-22 mars 1991']. The main conclusions of that Colloquium are noted in this review.

Most studies on pearl millet insect pests have been reported from West Africa because of the more extensive cultivation and use of the crop in this region. Prior to 1980 there was little specific information beyond general notes on the life histories and behaviour of a few target species (Risbec, 1950; Bowden, 1956, 1976; Appert, 1957, 1964; Harris, 1962; Brenière, 1970) and most of the literature was available as non-conventional publications in the form of in-country reports and regional conference papers. In recent years, the literature on insect pests of pearl millet has improved with studies on yield losses, population dynamics and pest control. Thus, Sharma & Davies (1988) published a detailed review of the insect and other pests of pearl and other millets on a world basis and their work has provided the basis for this more restricted review of the insect pests of pearl millet in West Africa. Their bibliography and tabulations are particularly useful reference sources. The long lists of insect species associated with the crop in the literature include only a limited number of major pests. Authors are prone to omit analysis of crop loss, which is the true measure of pest status. The unstable nature of the Sahelian ecosystem ensures that a pest of millet will never remain at high levels in any particular zone for more than a few years. Hence the number of species that have been reported on this crop in West Africa varies from country to country. Ndoye (1979) listed 81 insect pests in Senegal and Ajayi (1987) reported that 161 species are associated with pearl millet in Nigeria. In Niger, Guevremont (1982) has listed 84 species while from Burkina Faso and Mali the figures remain vague. Table 2 lists the species that have been reported in West Africa. These belong to several major insect orders, especially to the Lepidoptera, Diptera, Coleoptera, Hemiptera and Orthoptera. Fortunately, of the many species listed as pests or potential pests, the actual number which fall within the category of major pests of economic importance is perhaps less than a dozen. The earhead caterpillar *Heliocheilus albipunctella* (de Joannis) (= *Raghuva albipunctella*), and the millet stem borer, *Coniesta ignefusalis* (Hampson) (= *Acigona ignefusalis*), are widely distributed in the Sahel and are considered the major pests of millet (ICRISAT, 1984). Five species of midge are present in West Africa but only *Geromyia penniseti* Felt is an important pest species and is common throughout the Sahel. Several species of the Acrididae sometimes cause severe crop losses. These include the African migratory locust, *Locusta migratoria migratoriodes* (Linnaeus), the Senegalese locust, *Oedaleus senegalensis* Krauss, and *O. nigeriensis* Uvarov, plus a number of grasshopper species: *Kraussaria angulifera* (Krauss), *Hieroglyphus daganensis* Krauss, *Diabolocatantops axillaris* (Thunberg), *Cataloipus cymbiferus* Krauss and *Kraussella amabile* Krauss (Jago & Matthews, 1987). Chrysomelid beetles, especially *Lema planifrons* Weise, and armyworms, especially *Spodoptera littoralis* (Boisduval), may also reduce crop stand during the seedling stage. Species of meloid beetles, namely: *Psalydolytta fusca* (Olivier), *P. theresae* Pic, *P. vestita* (Dufour) and *Cylindrothorax westermanni* Maklin, have recently been reported to cause severe losses in some northern sahelian areas and the pyrrhocorid, *Dysdercus voelkeri* Schmidt, which appears to have recently attained major pest status, affects grain formation in early maturing varieties. In this review we have attempted to summarise available information on the economic importance, nature of damage, biology and population dynamics of the major species. The latter three sections are discussed under the subdivisions of root feeders, seedling pests, foliage and general feeders, stem borers and head pests. Although stem borer infestation often begins at the seedling stage, this group of insects is dealt with separately. A section also covers the control of millet pests.

II. Economic importance

Nowhere else is the paucity of information on millet pests more highly demonstrated than in the scanty information on crop losses caused by these insects. Actual data are still not available on crop losses in farmers' fields and in most cases the evidence provided only indicates the incidence or at best, the levels of pest infestations and not the actual losses. Among several species that are reported to attack pearl millet, field data on losses are available for only a few species and only two of these (*Coniesta ignefusalis* and *Heliocheilus albipunctella*) have been studied in detail. The FAO manual on crop loss assessment methods (Chiarappa, 1971) does not even list pearl millet nor any of its major pests.

The Colloquium held at Ouagadougou in March 1991 was the first concerted review of crop losses attributable to insect pests of pearl millet in West Africa. The general conclusion was that few objective assessments had been made, that pest status was therefore not firmly based and that much further work needs to be done. There was however overall agreement that the main pest groups (including weeds and vertebrates), in approximate order of importance in the Sahel, are grasshoppers, meloid beetles, weeds (especially *Striga*), *Heliocheilus albipunctella*, plant pathogens, *Coniesta ignefusalis*, birds, scarabaeid beetles, rodents and various other insect pests, including ants, bugs and millet grain midge. It was also noted that survey and assessment techniques had been developed, particularly in Mali and Niger.

Published information on the main insect pests is reviewed in the following sections.

2.1 Stem borer, *Coniesta ignefusalis* (Hampson)

ICRISAT conducted a series of pest surveys in 1980-83 in Burkina Faso and Niger in which observations were made on *Coniesta* and *Heliocheilus* incidence (Nwanze, 1988a). These surveys involved 379 farms in which observations were made on 2,727 millet stems and 37,689 panicles. The highest stem borer incidence was reported in Burkina Faso in the wetter Sudanian zone of Bobo Dioulasso where all the fields sampled had stem borer infestation and 72% of the stems were damaged, with a mean of 35.4% internode tunnelling (Table 3). In Niger, borer damage was most severe at Fillinque and Maradi.

Harris (1962), in Nigeria, compared the yielding capacities of individual millet stems and found conflicting results between bored and unbored stems. Usually losses were in the order of 5% except in Kano where under heavy infestation loss was projected at 15%. In Harris's experiments, bored stems yielded less than unbored stems in three cases and more in two, and in the latter case, borer attack was associated with better growth and hence higher yields. Studies by Nwanze (1989) also showed that low levels of borer infestation resulted in an increase in yield of unprotected plots over protected control plots.

2.2 Earhead Pests

2.2.1 Grain midge, *Geromyia penniseti* (Felt)

Severe infestations and crop losses often occur in the savannah areas of West Africa but these seem to be of local importance only. Rapid increases of population, and thus crop damage, are favoured by an extended flowering period which is enhanced by the diverse maturity periods of the varieties cultivated.

Studies by Coutin in Senegal (Coutin & Harris, 1968) showed severe reductions in grain yields of mid-season "Souna" millets which flowered in late September. Grain yield per head ranged from 0.7 to 12.1 g while for the later flowering "Sanio" millets the yield was 28.7 g/head, showing a yield reduction of 57.8 to 97.6%.

2.2.2 Earhead caterpillars, *Heliocheilus albipunctella* (de Joannis)

In the same surveys reported under 3.1, it was observed that *Heliocheilus* incidence was highest in the drier sahelian zone. Infestations were most severe in Niger where 95% of the fields were infested and over 30% of the panicles were damaged (Table 3). Vercambre (1978) estimated that a loss of 110,000 tonnes of grain (equivalent to 25% of production from the regions of Sine Saloum and Diourbel in Senegal) occurred in 1974. Gahukar *et al.* (1986) reported considerable variation in yield loss estimation for *Heliocheilus* in Senegal. In 1981 and 1982 losses varied from 3-82% in Sine Saloum and 15-20% in the region of Louga in 1982. Several correlations were established between egg or larval incidence, grain damage and yield loss.

In Niger, ICRISAT (ICRISAT, 1983, pp 357-373) reported a yield loss of 14.9% on CIVT, an improved cultivar, and only 0.8% on a local cultivar. Guevremont (1983), in her estimate of actual loss in grain weight, found that loss increased with grain size and that it varied between 0.4 and 1.0 g for a mean yield of 34 g per panicle. The highest yield loss recorded (6%) was on IVSP 78, a short maturity cycle cultivar. Nwanze & Sivakumar (1990) in Niger reported the highest estimated grain yield loss of 41% on HKBtif, a short cycle improved cultivar, while on the local cultivar it was 8% and 17% on CIVT. Damage was associated with crop phenology and maturity cycle.

2.2.3 Head beetle, *Rhinyptia infuscata* (Burmeister)

Infestations of chafer beetles, *Rhinyptia infuscata* in the Diourbel region of central Senegal in 1980 and 1981 affected about 40-60% of the millet heads and averaged from 1.4-15 beetles/head (Gahukar & Pierrard, 1983). In sorghum, average populations were 0.3/head in 1980 and 7.5 in 1981. Field trials at Bambey, Senegal showed yield losses of 11-16% in 1980 and up to 38% in 1981 on CE 90 sorghum cultivar. Recent studies in Niger (ICRISAT, 1990) have reported losses in the range of 37% to 57% from field sampling. Larval populations in the soil were over 20,000/ha in sole cowpea and pearl millet fields. There are no other available estimates of crop losses to other species of insect pests of millet in West Africa.

III. Pest biology

3.1 Root feeders

Larvae (white grubs) of various species of scarabaeid (chafer) beetles feed on roots of young and established crops and may kill plants in the early stages of growth. The main genera recorded in West Africa are *Rhinyptia* (= *Anomala*) and *Pachnoda* but information on the pest status and biology of the species involved does not seem to be available. Adult scarabaeid beetles are also pests of pearl millet as they feed on maturing grain (see 3.5.5.1 Chafer beetles).

Termites may also attack roots but do not seem to be of any great importance as pests of millet.

3.2 Seedling pests

3.2.1 Shoot flies (*Atherigona* spp.)

Several species of shoot flies attack young seedlings with infestations beginning as early as one week after emergence and continuing up to 5-6 weeks of crop development. Although *Atherigona approximata* Malloch has been reported as the most important shoot fly species, other species of the genus *Atherigona*, namely *A. soccata* Rondani, *A. ponti* Deeming, and *A. yorki* Deeming, have also been recorded from pearl millet (Deeming, 1971).

The characteristic damage symptom is the formation of a deadheart which results from the destruction of the central growing point by the larvae. Late infestation often triggers profuse tillering in pearl millet but may not always result in stand loss as in sorghum. Shoot fly infestation is less common in pearl millet but, unlike the situation in sorghum, this insect also causes damage to the millet earhead (Sharma & Davies, 1988).

The egg, larval and pupal stages last for a total of about 17-20 days. Infestation may occur throughout the year, especially in research stations where a crop is usually available. The highest deadheart formation has been reported in the months of July and August in Burkina Faso (ICRISAT, 1981).

Deeming (1971) also recorded three species of chloropid, *Elachiptereicus abessynicus* Becker, *Aprometopsis flavofacies* Becker and *Polyodaspis* sp., causing shoot fly damage on millet at Samaru, Zaria, Northern Nigeria as well as a number of other species causing similar damage on sorghum.

3.2.2 Leaf beetles

Lema planifrons Weise and *Chaetocnema tibialis* (Illiger) are the commonest chrysomelids attacking millet seedlings. Other common species are *L. armata* Fabricius, *Eryxia holoserica* (Klug), *Pseudocolapsis setulosa* Lefèvre and *Monolepta senegalensis* Bryant.

The beetles feed on the epidermis of young leaves, resulting in light colored spots and, in severe cases, in a bleached appearance of whole leaves. Infestations are sporadic, usually occurring in late June and July, and are associated with prolonged periods of drought during which seedling damage is severe.

3.3 Foliage and general feeders

This is probably the largest group of insect pests on millet and most are also pests of other graminaceous crops. They attack the vegetative and reproductive stages of their hosts. The most important defoliators are lepidopterous armyworms, while other lepidopterous species, as well as grasshoppers and locusts, aphids and plant bugs, also cause sporadic attacks.

3.3.1 Armyworms

The commonest species of armyworm have been reported from several countries of West Africa. Outbreaks of *Spodoptera exempta* (Walker), *S. exigua* (Hübner), *S. littoralis* (Boisduval), and *Mythimna loreyi* (Duponchel), are sporadic, sometimes localized, and may result in complete defoliation of a crop.

Outbreaks of the African armyworm, *Spodoptera exempta*, occur in the early stages of crop growth, usually in June and July. The larvae are gregarious during outbreaks, and they usually feed for 10-20 days. Outbreaks are associated with alternating wet and dry spells, and are more severe in fields where recent weeding has exposed the millet crop to the bands of caterpillars. Pupation occurs in the soil and the adults, which emerge within 5-8 days, migrate over long distances during the night.

Spodoptera littoralis larvae usually feed at night and coloration changes from light green to dark grey as larvae mature. Females lay several hundred eggs each, resulting in high larval populations which may cause complete defoliation. The adults have definite wing colorations with dark brown fore wings that are marked with light colored lines and stripes. The hind wings are whitish with dark brown margins and brown venation.

Other lepidopterous species include the hairy caterpillar, *Amsacta moloneyi* (Druce), and the leaf roller, *Marasmia trapezalis* Guenée. *A. moloneyi* is widely distributed in West Africa. The moths are silvery white, with yellow abdomens and dark stripes along the veins of the fore wings. The larvae are characterized by profuse hairs and they feed on several graminaceous species. Attacks are rarely severe. Larvae of *M. loreyi* are often found lodged in the leaf whorl and although they are voracious feeders, they seldom cause severe damage since their numbers are usually limited. Larvae of *M. trapezalis* are pale yellowish green in color and are more common on sorghum than on millet. Damage to leaves is caused by larvae feeding on the inside surface and leaves are rolled up in webs that are produced by the larvae.

3.3.2 Grasshoppers and locusts

More than 150 species of grasshopper have been reported from the sahelian zone (Launois, 1978, Launois-Luong & Launois, 1987). The species that have been recorded feeding on pearl millet in West Africa are listed in Table 2 and detailed accounts of their taxonomy, biology and distribution, with full references to the extensive published literature, are available in *The locust and grasshopper agricultural manual* (COPR, 1982).

Grasshoppers have become a constant menace to crop production in West Africa. Extensive surveillance is now in operation in the Sahel under the Programme de Recherche Interdisciplinaire Français sur les Acridiens du Sahel (PRIFAS) of CIRAD, Montpellier. Grasshoppers damage all parts of the plant, usually leaving bare stems after a severe attack. *Oedaleus senegalensis* (Krauss) and *O. nigeriensis* (Uvarov) are the most common in the Sahel and they cause severe damage to millet in this zone. Migratory species may destroy several hundreds of hectares, devouring all plant species in their path. Adults vary in colour and species variations are distinct. Usually diapause occurs in the egg stage in the soil and may last for one year, after which breeding occurs in the subsequent rainy season, coinciding with the seedling stage of several crops. *Zonocerus variegatus* (Linnaeus) is another common species in Africa. Nymphs and adults appear in groups, with only one generation occurring a year, and damage to crops is often localized.

Swarms of the desert locust *Schistocerca gregaria* (Forskål), and the African migratory locust *Locusta migratoria* (Linnaeus), often coincide in the semi-desert and tropical regions of Africa. Although these species differ during the solitary phase, their bionomics and behaviour during the gregarious phase are quite similar. Swarms travel long distances, often settling at night and devouring vegetation. Regional and international campaigns are involved in the control of locust outbreaks.

3.3.3 Aphids and plant bugs

The corn leaf aphid, *Rhopalosiphum maidis* (Fitch), is widely distributed and is active during periods of prolonged drought. Infestation causes withering of leaves, plant whorls and earheads. This aphid transmits maize streak virus disease which causes substantial yield losses (Brandes & Klaphaak, 1923). Up to 40 generations may occur annually due to rapid parthenogenetic reproduction. Nymphs and adults appear as dark green to blue clusters in the whorl leaves which become distorted due to the sucking of plant sap. Expanded leaves and developing grain are also damaged. Secondary damage occurs due to honey-dew excretion on which moulds develop.

Several species of plant bugs also attack pearl millet. The spittle bug, *Poophilus costalis* Walker causes yellowing and wilting of mature plants and death of seedlings (Bonzi, 1981). Adults are brown-grey and the greyish nymphs are usually covered by a foamy spittle. Other plant bugs, *Aspavia armigera* (Fabricius), *Callidea nana* (Herrich-Schaeffer), *Nezara viridula* (Linnaeus) and *Diploxis* sp., suck the sap of young leaves, but are otherwise of little importance since their incidence is generally low.

3.4 Stem borers

Twenty two species of Noctuidae and Pyralidae are known to infest the stems of pearl millet and of other minor millets (Sharma & Davies, 1988). In West Africa the species complex has been studied by Harris (1962), Brenière (1971), Bonzi (1977), Girling (1980), Nwanze (1981, 1989), Betbeder-Matibet (1983) and Gahukar (1990). This complex includes *Coniesta ignefusalis* (Hampson), *Busseola fusca* (Fuller), *Eldana saccharina* Walker, *Manga basilinea* Bowden, *Sesamia calamistis* Hampson, *S. cretica* (Lederer), *S. nonagrioides botanephaga* Tams & Bowden, *S. penniseti* Tams & Bowden and *S. poephaga* Tams & Bowden. Information on taxonomy, biology, host range and distribution is well documented (Tams & Bowden, 1953; Ingram, 1958; Nye, 1960; Harris, 1962, 1987a, 1987b; Usua, 1968; Girling, 1980; Nwanze, 1988b, 1989).

The importance and distribution of these stem borer species varies within West Africa: *B. fusca* is a major pest of sorghum and maize but occasionally attacks millet in the south Sudanian zone of Nigeria and Burkina Faso; *C. ignefusalis*, the major millet stem borer, is predominant in the Sahel and Sudanian zones and *E. saccharina* and *S. calamistis* are occasionally encountered in the Sudanian zone (Harris, 1962; Nwanze, 1989), especially during the dry season when *C. ignefusalis* enters larval diapause.

Damage symptoms appear within four weeks of crop emergence and are indicated by the presence of insect frass and holes on stems and the production of characteristic deadhearts in seedlings, which often results in profuse tillering and unproductive tillers. Late attack may result in extensive tunneling of the stems, the production of blasted or chaffy heads, and stem or peduncle breakages.

Although *B. fusca* is listed here as a pest of millet, it is of relatively lesser importance than other species and is not covered in subsequent sections. Studies by Harris (1962, 1985), Usua (1968, 1974), Kaufmann (1983) and Walker & Hodson (1976) provide further information on this species.

3.4.1 *Coniesta ignefusalis* (Hampson)

The millet stem borer is a major pest of the late planted crop and a close relationship exists between the growth stage of the insect and host plant phenology (Gahukar, 1984a). Eggs are laid between the leaf sheath and the stem in batches of 20 to 50 and up to 200 have been recorded from a single female (Harris, 1962). The cream yellow eggs hatch in 8-11 days and the larvae penetrate the stem directly, feeding inside the stalk and causing the characteristic deadhearts of young seedlings or complete tunneling of elongated internodes. There are 6-7 instars and development is completed in 30-40 days during the wet season. Pupation occurs in the stem and the adults emerge in 7-13 days. With the onset of the dry season, larvae enter a facultative diapause for 6-7 months. In contrast to the black-spotted, non-diapause larvae, the diapause larvae are a uniform pale yellow to creamy white. Diapausing larval populations decline during the dry season from November to May. Three distinct generations develop during the crop season at Samaru, Nigeria (Harris, 1962) while two have been recorded in the more northerly Niger and Burkina Faso (Nwanze, 1989). In Senegal, 2-3 generations have also been reported (Gahukar, 1984a, 1990).

3.4.2 *Sesamia calamistis* Hampson

This is a polyphagous cereal stem borer that is widely distributed in Africa. *S. calamistis*, the predominant species in the Savanna and Sahel zones of West Africa (Burkina Faso, Senegal, Niger and northern Nigeria) is replaced by a close relative, *S. botanephaga*, in the forest zone of Ghana, Côte d'lvoire, Nigeria and Togo. The larva of *S. botanephaga* is larger and of lighter pink coloration than *S. calamistis* and is particularly damaging to maize and sugarcane. Unlike *C. ignefusalis*, this species does not diapause in the dry season. It attacks both early and late plantings and may cause considerable yield loss, especially in irrigated dry season sorghum (ICRISAT, 1981; Nwanze, 1985). Many generations follow each other and larvae may feed on graminaceous weeds in the absence of the crop host.

Eggs are laid between the leaf sheaths and the stalk in groups of up to 400. Eggs hatch in 4-6 days and larval development is completed in 2 weeks. After hatching, early instar larvae feed inside leaf sheaths and later bore directly into the stems. Pupation occurs in the stem and lasts for about 10 days.

3.4.3 *Eldana saccharina* Walker

This stem borer occurs in most areas of Africa south of the Sahara and is a pest of graminaceous crops in West Africa. It seldom infests millet in the drier sahelian countries but can cause severe losses on maize and sugarcane in Ghana, Nigeria and Côte d'Ivoire (Girling, 1980; Betbeder-Matibet, 1983).

The young larvae feed on leaves and usually bore into the midrib of millet. Full grown larvae feed in stems and may produce deadhearts. Up to 400-600 eggs are laid in batches of up to 200. The total developmental period ranges between 33 and 80 days. Larvae of this species are easily distinguished by their dark grey to almost black coloration. Pupation occurs in the stem and moths emerge in 8-13 days.

3.4.4 *Elattocerus senegalensis* Hustache

This curculionid beetle was described by Risbec (1950). The larvae bore into millet stems and produce galleries and adults are known to be foliage feeders. Often larvae are found within the same internodes as *Coniesta*, thus making it difficult to ascertain the extent of damage caused by this beetle.

3.5 Earhead pests

A range of insect species attack pearl millet panicles from head exsertion up to harvest, often with a direct effect on yield. These species range from grain midges, head caterpillars, head beetles to head bugs and earwigs.

3.5.1 Grain midge *Geromyia penniseti* (Felt)

A number of different gall midge genera have been recorded from millet in West Africa, namely: *Geromyia penniseti* (Felt), *Contarinia sorghi* (Harris) (= *Stenodiplosis sorghi* Harris), *Lasioptera* sp., and *Lestodiplosis* sp. (a predator) (Coutin & Harris, 1968). Only *G. penniseti* is abundant and important as a pest in savanna areas and it is present across West Africa.

Although *G. penniseti* is not closely related to the sorghum midge, *Contarinia sorghicola* Coquillett, there are similarities in their biology and in the damage caused. Adults are strictly nocturnal and may thus be easily overlooked. Females lay eggs on flowering heads. The orange coloured larvae hatch in about three days, feed on developing ovaries and development is completed within a week. Pupation, which occurs beneath the glumes, lasts for about two days. With a life-cycle of about two weeks, 4-5 generations may develop in one season, with successive generations tending to overlap. Towards the end of the growing season larvae diapause in the spikelets of infested heads and remain dormant for 8-9 months. Diapause is terminated in the following rains so that the first generation coincides with early flowering "souna" varieties of pearl millet.

Severe infestations result in complete head blasting with the characteristic white pupal skins remaining loosely attached to the maturing millet heads for some days after the adults have emerged.

3.5.2 *Dicraeus pennisetivora* Deeming

This chloropid is a relatively new dipterous pest that has been reported from Burkina Faso, Nigeria and Senegal (Deeming, 1979). Larvae feed on developing grain and early infestations result in complete destruction of the ovaries. Late infestations are associated with grain lesions.

3.5.3 Earhead caterpillars.

The most important panicle-feeding insect pests of millet in West Africa are lepidopterous caterpillars and the commonest species are noctuids. *Masalia* spp., *Heliocheilus* spp., *Eublemma* sp. nr *gayneri* Rothschild, *Helicoverpa armigera* (Hübner) (= *Heliothis armigera*) and *Sathrobota simplex* Walsingham (= *Pyroderces simplex*) have been reported in the region (Schmutterer, 1969; Vercambre, 1978; Ndoye, 1979; Bhatnagar, 1984; Gahukar, 1984a; Gahukar *et al.*, 1986; and Ndoye & Gahukar, 1987).

3.5.3.1 *Heliocheilus albipunctella* (de Joannis)

Matthews (1987) published a detailed taxonomic revision of the African species that were previously wrongly assigned to the genera *Raghuva* and *Canthylidea*, which he synonymised under *Heliocheilus*. He recognised six species of *Heliocheilus*, including the main pest species, *Heliocheilus albipunctella*. Four other species (*R. vercambrei*, *R. bordati*, *R. graminivora* and *R. brenieri*) described by Laporte (1977) are now treated as synonyms of *H. albipunctella*. This work has clarified a confused taxonomic situation and, although it results in a name change for a well-known species and genus, it also stabilizes the nomenclature of this group and provides descriptions and keys for accurate identification.

Studies by Vercambre (1978) and Ndoye (1979) in Senegal and Guevremont (1982) in Niger have shown that *H. albipunctella* is the major species, making up 95-98% of the genus *Heliocheilus* captured at light traps. *H. albipunctella* has been reported across the Sahel as well as the Sudan (Vercambre, 1978). Detailed surveys in Burkina Faso, Niger and Nigeria have also delimited its occurrence between latitudes 11 N and 15 N within the southern Sahel and Sudan bioclimatic zones (Nwanze & Sivakumar, 1990).

Damage by *Heliocheilus* varies with larval age. The young larvae feed on the floral glumes, leaving whitish excreta around the flowers. Full-grown larvae cut the floral peduncles, eating their way between the rachis and flowers and pushing the damaged flowers or developing grains outwards in the process. This produces characteristic spiral mines on the earhead. Extensive damage by this pest may result in skeletonized panicles when the dislodged grain is blown off by wind.

The female moth lays about 400 eggs in batches of 20-50 on the spikelets and floral peduncles of newly exserted heads. Eggs hatch in 3-4 days and larvae complete their development in 23-39 days. Larvae are yellow to dark green with two light bands on each side. The mature prepupal larvae are pinkish in colour and descend to pupate in the soil, where the pupae diapause. Diapause lasts through the dry season and may extend well over nine months. The majority of the pupae are found at 10-15 cm deep in heavy clay/loam and at 15-25 cm in sandy soil (Vercambre, 1978; Gahukar *et al.*, 1986; Nwanze & Sivakumar, 1990). Pupal populations in the soil decline as the dry season progresses and there is considerable pupal mortality at the upper soil levels due to high temperatures (50-55°C) in April and May.

The onset and continuity of rains, favourable soil moisture and temperature are key factors in diapause termination, duration of post-diapause development and adult emergence. Peak moth emergence generally occurs in August corresponding to head exsertion in most millets of the region. However, a delay in the arrival of rains or a prolonged early season dry spell may result in a shift or an interruption of moth emergence. There is only one generation per year.

3.5.3.2 *Helicoverpa armigera* (Hübner)

The cotton bollworm (gram pod borer, tomato fruitworm etc.) is a serious pest of many crops and its biology has been studied in detail on legumes, tomato and other crops. It is a polyphagous feeder and has a wide distribution. However, on millet it is only an occasional pest although incidence has been reported to increase in varieties with compact heads (Gahukar, 1984b; Ndoye & Gahukar, 1987). Unlike *H. albipunctella*, the larvae feed on developing grains, cutting them into small bits.

Each female lays 200-300 creamy white eggs and these are deposited singly on the panicles. They hatch in 4-6 days and larvae show a wide range of colours. Development is completed within four weeks. Larvae pupate in the soil and adults emerge 2-4 weeks later.

Other species of earhead caterpillars e.g. *Eublemma gayneri*, *Pyroderces* spp. and *Celema* sp. have also been recorded on pearl millet and cause damage similar to *H. armigera*, often with associated grain webbing. Their occurrence is sporadic and, although they are often listed in the literature as head pests, very little information is available on their biology and seasonal occurrence.

3.5.4 Earhead bugs

Several species of bug infest millet heads. Their nymphs and adults feed on developing ovaries and cause distortion, shrinking and shrivelling of the grain. Damaged grains also show powdery black spots where feeding punctures are made, which also serve as entry points for grain mould. The commonest species are *Agonoscelis pubescens* (Thunberg) (= *A. versicolor*), *Nezara viridula* (Linnaeus), *Dysdercus voelkeri* (Schmidt), *D. superstitiosus* (Fabricius), *Spilostethus elegans* (Wolff), *Mirperus jaculans* (Thunberg) (= *M. torridus*), *Creontiades pallidus* (Rambur), *Aspavia armigera* (Fabricius), *Callidea nana* (Herrich-Schaeffer), *Anoplocnemis curvipes* (Fabricius) and *Oxycarenus* sp. Some of these are noted in the following sections.

3.5.4.1 *Agonoscelis pubescens* (Thunberg)

This pentatomid, referred to as the shield bug and earlier as the Sudan millet bug, was studied in detail by Sarel-Whitfield (1929) as *A. versicolor* Fabricius. It was also listed by Risbec in 1950 and briefly described by Appert (1957). The species is widely distributed in Africa. Adults are yellowish brown with numerous dark spots. Eggs are laid in clusters on leaves or inflorescences. They hatch in 3-4 days and the nymphs complete their development in 3-4 weeks. Population build-up is sporadic but under severe infestations up to 50 bugs can be found within a panicle, which is usually completely destroyed. During the dry season adults shelter in clusters in nearby shrubs, trees and bushes.

3.5.4.2 *Dysdercus voelkeri* Schmidt

This species of *Dysdercus* is unusual in that it commonly breeds on sorghum and millet (Crowe, 1977). It has been confused in the past with the red cotton stainer, *D. superstitiosus* (Fabricius) and further taxonomic studies of the genus may be needed to clarify this situation. The species is widely distributed in West Africa. Adults are red with distinct black markings. The nymphs vary in colour from deep yellow to orange and red as they develop. Feeding punctures caused by both nymphs and adults show as markings on the grain. Females lay 300-400 eggs in batches in the soil, often near the stems. Eggs hatch in 4-14 days and nymphal development is completed in 25 days. Two or more generations may develop on the same crop in a season.

Up to 60 individuals may be found on a single panicle. Populations often build up on irrigated early sown millets and affect early maturing varieties. Early generations cluster in leaf sheaths and whorls, from which they move onto young developing grain. Although populations are present year round, peaks have been reported in late May and early August (Guevremont, 1982, 1983), the latter case resulting in up to 20% loss in grain formation.

3.5.4.3 *Nezara viridula* (Linnaeus)

The green stink bug has a worldwide distribution and an extensive host range and is probably one of the most studied species of pentatomid bugs (Jackai, Panizzi, Kundy & Srivastava, 1990). Adults and nymphs feed on leaves, tender shoots and developing grain of most cereal crops and on the green pods and other plant parts of grain legumes. Up to 200 eggs are laid per female and these are deposited in groups on leaves or panicles. The eggs hatch in 4-5 days and the nymphal period lasts for 4-5 weeks. Several generations may occur in a year.

3.5.4.4 *Oxycarenus* sp.

Risbec (1950) did not identify the species attacking millet. Similarly, Appert (1957) and Whitney (1977) did not refer to the particular species in their studies. However, a related species, *Oxycarenus latus* Kirby (the dusky cotton bug), is a potential pest of pearl millet in India (Sharma & Davies, 1988). In Niger, Guevremont (1980) observed *Oxycarenus* sp. within millet panicles and the axils of leaves. Their numbers were greatest during the milky grain stage, at which time up to 50 could be found per panicle.

3.5.5 Earhead beetles

The most important species belong to two families, the Scarabaeidae and Meloidae, and are generally referred to by their common names, chafer beetles and blister beetles, respectively.

3.5.5.1 Chafer beetles

Rhinyptia infuscata Burmeister was formerly referred to as *Anomala plebeja*. Adults are nocturnal and feed on the male flowers of millet while the grubs are known to feed on groundnut roots (Risbec, 1950). Infestations have been reported from Senegal, Mali and Niger. Severe infestations were reported in 1980 and 1981 in Senegal (Gahukar & Pierrard, 1983) when up to 15 beetles/head were recorded. Guevremont (1981) reported between 15-25/head in Niger in 1980 while over 800,000/ha were recorded in 1989 at Sadore, near Niamey, Niger (ICRISAT, 1990). The period of peak adult activity is from about 19 00 to 23 00 hours and at dawn they migrate from the crop to the soil near the plant base (5-10 cm deep) where they spend the day-light hours.

Pachnoda interrupta (Olivier) is often reported as an important pest of pearl millet. Adults are blackish in colour with yellow-brown or reddish brown margins on the pronotum and elytra. They feed on the developing grain, usually at the ripening stage. Grunshaw (1992) has published details of the biology and economic importance of this species in Mali. Other species of chafer beetles are listed in Table 2. Adults show a wide range of colours and patterns on their elytra. They feed mainly on the developing grain but incidence is generally low and occurs only in a few seasons.

3.5.5.2 Blister beetles

Several species of meloid beetles feed on the anthers and pollen of many plant species. In West Africa the commonest ones are: *Decapotoma affinis* (Olivier), *Cylindrothorax westermanni* (Maklin), *Psalydolytta theresae* Pic, *P. vestita* (Dufour), *P. fusca* (Olivier) and *Mylabris holosericea* Klug. The biology of these blister beetles has not been studied in detail. Adults are conspicuously bright metallic blue, green, black and red-yellow or brown. When disturbed, they produce an irritant fluid containing cantharidine - hence the name cantharids, by which they are often referred to in the Sahel. Eggs are laid in the soil in large numbers. The larvae feed on the eggs of other insects and undergo hypermetamorphosis.

D. affinis attacks both groundnuts and cowpea and on millet it is usually observed from mid July to September, when the crop is in flower, with peak numbers of 20-30/head on late maturing cultivars.

3.5.5.3 Nitidulid beetles

Kirk-Spriggs (1985) has described damage to the pistils and stamens of maturing pearl millet caused by a nitidulid beetle, *Meligethes heteropus* Gerstaecker, in N. Nigeria. Ajayi (1980) has also recorded damage by *Meligethes* in Nigeria and Khoury and Belanger (1976) have reported a *Meligethes*, possibly *M. aethiopicus*, on pearl millet in Niger. The adults are black, minute beetles and are often associated with flowering heads.

3.5.6 Storage pests

Little published information is available on the pests of stored pearl millet heads and grain in West Africa, although it is likely that losses in stores are considerable. The main species involved are *Sitophilus oryzae* (Linnaeus), *Sitophilus zeamais* (Motschulsky), *Sitotroga cerealella* (Olivier), *Rhyzopertha dominica* (Fabricius), *Plodia interpunctella* (Hübner) and *Tribolium confusum* Duval. The first three of these species are probably of greatest importance because they can attack whole grains and can establish field infestations before harvest. Study of storage pests of other cereals, especially of sorghum, will be at least partly relevant to pearl millet. Seifelnasr & Mills (1985) have reported resistance of pearl millet cultivars to *Sitophilus oryzae*, *Sitotroga cerealella* and *Rhyzopertha dominica* and Meagher *et al.* (1982) studied the development of *Sitophilus zeamais* and *Tribolium castaneum* on whole, cracked and ground pearl millet.

IV. Control methods

For the same reasons that research on pests of pearl millet has not benefited much from the scientific community, so also has there been very little effort at developing proper management of these pests. Most of the methods described in this section are mainly the results from research station trials and experiments or, at best, arguments for the possible extension of such methods to farmers' crops. Generally, the control of millet insect pests involves the use of some cultural operations that will reduce insect damage rather than their numbers, with the additional occasional use of insecticides. Unfortunately, these rare occasions often mean massive local government or international interventions to arrest an outbreak, as is currently the case in the Sahel with grasshoppers; a situation that could often be avoided where precautionary operations which require on-going routine surveillance are maintained.

The effectiveness of any large-scale control measure will depend on co-operation amongst farmers, both in the management of the crop (such as sowing date) and of the pest. Such co-operation becomes more critical when an integrated approach to the management of the pests is to be followed. But the low commercial value of millet, the small size and the scattered distribution of farm holdings and the unpredictability of rainfall in the millet growing zone of West Africa introduce both disincentives and limitations to any such co-operation. For example, farmers will be fearful of planting all at once or with one variety under the vicissitudes of the Sahel. Current research efforts to develop pest management strategies that combine all possible methods (cultural, chemical, biological and hostplant resistance) are commendable. They must however be based on the sane realities of attainable goals, given the crop, the farmer, the agro-ecosystem and the socio-political environment of a particular region or of a particular country.

4.1 Cultural methods

Cultural practices are among the oldest pest control methods and are relevant to subsistence farming in West Africa. They are convenient, often farmer-initiated, environmentally acceptable and cost-effective. These practices include choice of sowing date, intercropping, farm hygiene, crop residue destruction, soil tillage and fertilizer application.

4.1.1 Sowing date

Early planted millet suffers less stem borer damage than the late crop but the effects vary with varieties (Ajayi, 1985) and between years (Ajayi & Labe, 1990). On the other hand, early planted photo-period non-sensitive cultivars are more likely to suffer losses from *Heliocheilus* infestation, while sowing of early maturing varieties in the same areas as traditional ones favours the pearl millet midge, *G. penniseti*. Heavy incidence of the midge is often noticed on late millets (Gahukar, 1984a). But a delay in planting of short cycle millets could help to avoid the coincidence of peak moth flight and head exsertion (Gahukar *et al.*, 1986; Ndoye & Gahukar, 1987). However, such late planted crops are also at risk to early cessation of rains, especially in the Sahel. The first step a farmer takes in ensuring a crop in a particular year is to plant at the earliest possible time and sowing date in the Sahel is determined by rainfall. Thus sowing date must take into consideration the crop environment as well as the complex of pests.

4.1.2 Intercropping

Intercropping as a pest control strategy is based on the principle of increasing the diversity of the agro-ecosystem to make it less favourable for some pest species and/or more favourable for beneficial species (Lawani, 1982). However, it is crucial that the right kind of diversity be established. The feeding and searching behaviour of insects depends on certain cues (olfactory, colour, radiations etc.) that can be confounded by the presence of contradictory signals from associated crops. Studies on maize, rice and sorghum intercropped with legumes have shown significant reductions in pest numbers and damage on the cereal crop (IRRI, 1973, pp.30-31; IRRI, 1974 pp 22-24; Amoako-Atta *et al.*, 1983; Ogwaro, 1983). However, intercropping involving cereal/cereal combinations may have negative effects. Intercropping millet with sorghum or maize increased *B. fusca* damage on millet but reduced infestation of sorghum (Adesiyun, 1983). This combination did not reduce *C. ignefusalis* damage on millet, the preferred host. Millet/cowpea intercropping reduced leafhopper (*Empoasca* sp.) numbers by 50% but thrips (*Megalurothrips* sp.) numbers were not affected (ICRISAT, 1984). Similar intercropping experiments by Gahukar (1989) affected the activity of thrips on cowpea and of lepidopterous pests on millet. By planting 1 row of millet with either 10 or 30 cowpea rows infestations of *C. ignefusalis* and *H. albipunctella* were reduced.

4.1.3 Tillage

Deep ploughing (20-30 cm) before sowing, preferably at the end of the crop season, helps to expose diapausing or soil inhabiting insects to desiccation and natural enemies. This is particularly effective in India against populations of grasshoppers and hairy caterpillars (Jotwani & Butani, 1978). In Senegal, Vercambre (1978) reported that ploughing at 20 cm depth in October reduced pupal numbers of *Heliocheilus*, although his results were not consistent in all years. Gahukar (1990) also reported that ploughing fields after harvesting the millet reduced the numbers of *H. albipunctella* pupae from 5.58 to 2.75/20 m^2. In Niger, deep ploughing (20-30 cm) reduced the number of surviving pupae at all soil depths but the effect was more pronounced in the top 10 cm of the profile. Almost three times as many pupae were recorded in the control (86 out of 128) as in the ploughed treatment (32 out of 77) (ICRISAT, 1986, p.99). The timing of this practice is crucial. When done properly and if soil moisture is adequate, it will also provide a ridged surface and reduce the effect of wind erosion on the soil. On the contrary, it could accentuate this problem. However, this practice is labour intensive and is least favourable to the subsistence farmer.

4.1.4 Farm hygiene

The removal of crop residues after harvest reduces crop damage caused by stem borers, especially those that diapause in the stems. Earlier studies by Adesiyun and Ajayi (1980) showed that partial burning of sorghum stalks after harvest can reduce the numbers of *B. fusca* larvae within stalks by 95%. Ndoye & Gahukar (1987) and Gahukar (1990) reported reductions by 61-99% of larval and 98-100% of pupal populations of *C. ignefusalis* by partially burning millet stalks. Also the simple exposure of borer larvae in stems to the full effect of high temperatures and low humidities during the long dry season reduces the diapausing population. Thus the practice of stacking stems in the shade of trees detracts from effective control and also has an added agronomic disadvantage in exposing the soil to wind erosion. But the prevention of such a practice is difficult since millet and sorghum stems are used for construction of fences and roofs, bedding for animals and fuel for cooking. A profitable approach is achieved since a considerable amount of straw and trash pass through farm animals and are redeposited as farm manure. Burning of what remains at the end of the dry season is a viable compromise.

4.1.5 Trapping

Fires have been used to attract and trap insects. A common practice in West Africa is to light fires around millet fields at night. Such practices attract blister beetles and grasshoppers which are then killed. In some parts, grasshoppers also serve as human food.

Several species of wild grasses harbour populations of lepidopterous larvae and grasshoppers as well as providing oviposition sites for some insects. Removal of these weeds improves plant development and reduces pest damage. However, weeding must be properly timed. Greater crop damage may result from poorly timed weeding where the pest population then migrates to the only available host, the crop. Studies in Burkina Faso (ICRISAT, 1982) showed higher *Spodoptera* damage on late-weeded farmers' crops compared to those that had been properly managed, and defoliation was much lower on an unweeded field.

4.1.6 Fertilizer application

In general, the application of fertilizers favours plant development and the production of healthy stalks and panicles. While this may enhance the ability of a crop to withstand pest infestation, and so reduce damage, it may also result in heavier infestations. Harris (1962) and Gahukar (1983) have associated borer attack with better crop growth. In a millet/cowpea intercrop, the application of 20 kg ha of P_2O_5 as single superphosphate and 36 kg ha of nitrogen as urea did not predispose the millet to higher borer attack. It however resulted in twice as many leafhoppers per cowpea plant in the fertilized crop than in the control (ICRISAT, 1984).

4.2 Chemical control

The use of insecticides to control pests of pearl millet is a rare practice by farmers in West Africa, not because the technology does not exist but because of current low yields, the poor cost-benefit ratio and the greater importance attached to cash crops. Very little has been done to develop insecticide spray schedules to control millet pests and those currently recommended were probably developed for such crops as cotton, tobacco and groundnut. Most of the reported studies on chemical control of millet pests have been to compare the relative control efficacies of insecticides on certain pests.

The main difficulty in using insecticides against the millet stem borer is one of timing applications to coincide with hatching of larvae. Once the first generation of larvae is established within the stems, little can be done to reduce the increase of population through subsequent generations. However, when timing is right, reasonable control of species of *Sesamia* and *Eldana*, whose larvae feed on the leaves and funnels, may be achieved. It is also known that insecticide control of low infestations of *Coniesta* results in reduced yield due to the damping effect on tillering which such infestations may trigger (Nwanze, 1989).

The situation with *Heliocheilus* is more encouraging. Insecticide applications can be timed to control this pest if applied at the egg or early larval stage. The results of 39 different studies suggest the following: endosulfan at 525-700 g a.i./ha applied once at 75% flowering or twice at the beginning of flowering and 5-7 days later (Vercambre, 1978). In earlier studies Vercambre (1976) estimated that one treatment with endosulfan was economical if a yield loss of 25% on farmers' fields or 6% loss under intensive cultivation would result. However, in other trials, chlordimeform sprays (750 g a.i./ha) reduced pest infestation but there was no significant difference in yields in control plots and those treated with endosulfan, trichlorfon, *Bacillus thuringiensis* or chlorpyrifos. In Niger, trichlorfon (Dipterex) + triflumuron 1 kg a.i./ha was the most effective against larvae of *Heliocheilus* but it failed to increase grain yields over the control (Guevremont, 1982). In yield loss trials Nwanze & Sivakumar (1990) reported that losses of 14.9% on CIVT cultivar and 41% on HKBtif cultivar can be prevented by applying four sprays of deltamethrin at 10 g a.i./ha at weekly intervals starting at head exsertion.

Coutin (1970) reported the effective control of midge with fenitrothion, although he also recommended the use of phosalone because of the phytotoxicity of fenitrothion and its harmful effects on the parasite complex.

It must however be added here that the problem with insecticide application, even when subsidised by government, is that it is still a drain on the economy and foreign exchange and this problem is compounded by the phenotype of traditional millets (which make them difficult to spray), lack of adequate and trained personnel, lack of spray equipment and the shortage of water.

4.3 Biological control

The number of parasitoids and predators that have been recorded from millet pests varies between the countries of West Africa and this is perhaps indicative of the differing extent of research that has been carried out in particular countries. Most of the reports have come from Senegal, Niger and Nigeria where studies by Risbec (1950, 1960), Harris (1962), Ndoye (1977), Vercambre (1978), Guevremont (1980, 1982, 1983), Gahukar (1981), Bhatnagar (1983, 1984, 1987), Gahukar *et al.* (1986), ICRISAT (1987), Ndoye & Gahukar (1987), and Huddleston & Walker (1988) have provided information on the species and genera involved, the biology, seasonality and efficiencies of these natural enemies. Most pest species also infest other cereals in the region and thus the natural enemy complex often consists of general feeders that do not bring about specific reductions in pest populations. Table 4 lists the parasitoids and predators recorded from millet pests in West Africa.

Risbec (1950, 1960) has published considerable information on the natural enemies of insect pests of cultivated crops in Africa, with emphasis on what was then referred to as French West Africa. Further studies in Senegal by Vercambre (1978), Gahukar (1981), Bhatnagar (1983, 1984, 1987) and Gahukar *et al.* (1986) included over 20 auxiliary parasites of *Heliocheilus. Bracon hebetor* Say (Braconidae), *Litomastix* sp. (Encyrtidae) and *Cardiochiles* spp. (Braconidae) were reported as being of major importance with parasitism of up to 48% for eggs, 62% for larvae and 8% for pupae. The biology and potential use of these species as biocontrol agents have been studied by Bhatnagar (1984). Although parasitism in the case of *Litomastix* may attain 80-90% under favourable conditions, in the field it has not exceeded 31%. *B. hebetor* appears to be a promising candidate. Towards the end of the crop season its population builds up considerably, leading to 95% parasitism in Niger (Guevremont 1983) and 64% in Senegal (Bhatnagar 1984). However, its efficacy is limited by high levels of hyperparasitism, especially by *Eurytoma* sp. (Eurytomidae) and *Pediobius* sp. (Eulophidae) which attacked up to 56% in Niger (Guevremont, 1983). Guevremont (1982, 1983) listed 22 species of insect parasitoids and predators and 21 predaceous mites and spiders on millet pests in Niger. Of these, *Orius* sp. (Anthocoridae) was the most abundant and, with *Glypsus conspicuus* (Westwood) (Pentatomidae), preyed on eggs of *H. albipunctella*. Further studies by ICRISAT (1987) reported three groups of egg parasites of *H. albipunctella* in Niger and Burkina Faso: *Trichogrammatoidea* sp. nr *lutea* (Trichogrammatidae), *Telenomus anates* Nixon (Scelionidae) and an unidentified encyrtid. The overall rate of egg parasitism was less than 10%, with a maximum of 40% being recorded at the ICRISAT research farm at Sadore. Larval parasitism was low (4%) and only two species were frequently present, namely: *B. hebetor* and *Litomastix* sp. A third species, *Goniophthalmus halli* Mesnil (Tachinidae), was also recovered from a few specimens.

The overall rate of parasitism of stem borers is low and this trend is seen not only in millet but also in sorghum and maize. Harris (1962) listed 14 primary parasitoids, one predator and four diseases that attack different stages of borers, including *C. ignefusalis*, in Nigeria. The parasitoid populations varied from year to year both in species and number, but *Tetrastichus atriclavus* Waterston (Eulophidae), *Cotesia sesamiae* (Cameron) = *Apanteles sesamiae* (Braconidae), and *Pediobius furvus* (Gahan) (Eulophidae) were the most important species on *B. fusca* towards the end of the crop season. *Syzeuctus* sp. (Ichneumonidae) was regularly found in populations of diapause larvae of *C. ignefusalis*. This species is also present in Senegal, Niger and Burkina Faso. *Goniozus procerae* Risbec (Bethylidae), a larval parasitoid of *C. ignefusalis*, has also being reported in these countries but the level of parasitism rarely exceeded 1-2%. A few pupal parasitoids of this borer have also been recorded (Table 4).

The overall rate of parasitism seldom exceeds 10% and usually attains this level only towards the end of the growing season when borer damage is well advanced. Usually the level of parasitism ranges from 2-4% although Bhatnagar (1984) claims up to 30% reduction in larval population in Senegal.

Six species of parasitoids (two ectoparasites and four endoparasites) have been reported to infest larvae and pupae of the millet grain midge, *G. penniseti*, in Senegal (Coutin & Harris 1968). *Aprostocetus diplosidis* (Crawford) (Eulophidae) was the most abundant. The other species are listed in Table 4.

Apart from these inventories of the species and the brief studies in Senegal, where a few parasitic species were evaluated for their efficiencies as biocontrol agents, there has been no concerted effort to exploit the use of natural enemies in the control of millet insect pests in West Africa.

The two major pest species of millet, *Heliocheilus* and *Coniesta*, diapause over the long dry season, thus breaking the pest-parasitoid association. The rate of parasitism of diapause pupae in the case of *Heliocheilus* and of larvae in the case of *Coniesta* are either not known or are rather low. In most cases, alternative host species providing carry-over populations of the parasitoids are also not known.

4.4 Host plant resistance

In the preceding sections we have noted various methods that are either in use or that have the potential to control millet pests. Each method has several limitations. Adherence to age-old traditions, labour requirements, conflict of interest in the use of crop residues and soil conservation factors make cultural practices less easily acceptable. Chemical insecticides are unlikely to play a major role in millet subsistence farming in West Africa. Although there is an abundance of natural enemies of millet pests, the species involved are apparently inefficient in controlling their hosts (stem borers) or have not been adequately exploited, as in the case of *H. albipunctella*. The use of resistant varieties is therefore of relevance in this crop. A major advantage of this method is that it requires practically no input from the farmer although he faces a major draw-back in the lack of adequate seed production programs in the region.

4.4.1 Identification of resistance

Screening for resistance against the insect pests of pearl millet suffers from the lack of screening techniques for uniform and optimum infestation of test material. Several studies on varietal resistance have been conducted in West Africa under natural infestation. Consequently the results obtained have been unreliable and need re-evaluation. Another pre-requisite for a successful screening program is access to a broad and variable germplasm collection and an infrastructure for the multilocational testing of identified resistance source material.

Currently available data on varietal resistance studies in pearl millet are restricted to *Coniesta* and *Heliocheilus*. Studies conducted by ICRISAT in Niger and Burkina Faso (ICRISAT 1982, 1983, 1984, 1987; Lukefahr, 1989) under natural infestation show considerable variability in varietal performance under stem borer and *Heliocheilus* infestations. In 1983, under severe stem borer infestation, the following entries from Nigeria were reported to have low levels of borer damage: INMB 106, INMB 218 and INMB 155. In subsequent trials all test entries showed high levels of susceptibility to *Coniesta* except the local entries (CIVT and Sadore local) which, in spite of borer attack, tillered profusely and gave good yields.

Vercambre (1978) first indicated that certain varieties of millet appeared resistant to *Heliocheilus*. Subsequent studies in Senegal, Niger and Mali have resulted in the identification of genotypes that show low levels of infestation. The local genotype Souna, 3/4 HK-78, IBV 8001 and ICMS-7819 were rated resistant in Senegal (Ndoye & Gahukar, 1987). In preliminary evaluation in 1983 in Niger the following genotypes were also retained: IBMV 8302, INMG1-1, INMG 52, ITMV 8001 (ICRISAT, 1984). The local entries Souna (Mali), Haini Kirei and Toriniou (Niger) were also rated as promising. Several genotypes have also been selected in other studies in Senegal (Gahukar, 1981, 1983, 1984b), Niger (Guevremont, 1983; Maiga, 1984) and Mali (Doumbia *et al.*, 1984).

4.4.2 Mechanisms of Resistance

Studies on the mechanisms of resistance in millet to *Coniesta* and *Heliocheilus* have been limited. Most of the explanations given so far are based on conjectures derived from field observations on varietal performance with little investigative and analytical data to support them. Some of these will be discussed here to underline the need for increased activity in this domain.

4.4.2.1 Tillering capacity

Local genotypes have been reported to tiller profusely under low to moderate levels of borer attack and to maintain reasonable yields. Tillering is a general adaptive form of tolerance of native grasses to stem injury and, as an aspect of varietal resistance, may result in an overall increase in head production and yield (Nwanze, 1985). Studies by Harris (1962) and Nwanze (1989) have also indicated higher yields of millet under low borer infestation, presumably as a function of extra tiller production.

4.4.2.2 Pseudo-resistance

Infestations of *Heliocheilus* result in severe panicle damage and yield loss when peak moth emergence coincides with panicle exsertion. Thus very early or late maturing varieties of millet may escape infestation. This phenomenon is referred to as pseudo-resistance. The latter case is common in local photoperiod-sensitive genotypes. It has been shown that crop damage is directly related to crop maturity ($r = -0.83$) and particularly to the period of head exsertion ($r = -0.69$) (ICRISAT, 1984; Guevremont, 1982, 1983).

Plant escape (pseudo-resistance) is an adaptive crop characteristic which may have evolved in parallel with an insect species or an adverse environment and is common in several millet landraces. Such genotypes make it possible either to evade peak pest populations or shortfalls in rainfall.

4.4.2.3 Non-preference

Other sets of studies have shown that in some millet genotypes, although head exsertion coincides with *Heliocheilus* moth emergence, panicle damage is low (ICRISAT, 1983, 1984). It has been suggested that this situation may have arisen due to either non-preference for oviposition and/or antibiosis against larval feeding. Non-preference to oviposition may be related to involucral bristles - their density and variations in length and orientation. Bristle length is one of the few characters associated with *Heliocheilus* attack that have been studied (Guevremont, 1982).

4.4.2.4. Anti-biosis

Anti-biosis in plant resistance may be expressed in many ways: prolonged or incomplete progeny development, reduced progeny size and numbers, reduced adult fecundity and viability, and mortality. These may arise from mechanical or physical factors and may result in the inability to use the host for food or shelter, resulting in starvation, disruption in its metabolic processes or exposure to biotic and abiotic population-reducing factors.

In stem borers, differences were reported to exist in the initial levels of infestation between varieties, and infestation was observed to shift with crop age and phenology (ICRISAT, 1982). Such changes were attributed to differences in both biophysicial and chemical constituents between varieties at different physiological growth stages and may play a role in affecting pest populations. It has also been suggested that stem size, thickness and hardness may also affect progeny development. Ndoye (1977) also suggested that in the local cultivar, Zongo, a secretion in the galleries where the larvae are lodged may be a resistance mechanism.

Some panicle characters associated with *Heliocheilus* attack have been investigated. Vercambre (1978) reported lower levels of damage on long and compact panicles and this was not affected by number and length of floral peduncles. Further studies by Gahukar (1984b) and Guevremont (1983) investigated the relationships between *Heliocheilus* damage and bristle length and position, panicle length, compactness and diameter. Correlation existed only between compactness - measured by the number of florets - and pest damage (r = 0.81)

4.5 Integrated pest management

Ajayi (1990) assessed the possibilities for integrated control of the millet stem borer, *Coniesta ignefusalis*, in Nigeria. He concluded that destruction of infested millet stems before the beginning of the rainy season is a very important control measure against this pest as it is a cheap and effective way of reducing carry-over populations of larvae. He also noted that carbofuran seed dressing and natural enemies do not provide effective control; that systemic insecticides, particularly granular carbofuran, gave better control than contact insecticides, such as carbaryl; that infestation and damage was strongly influenced by date of planting and by rate and timing of nitrogenous fertilizer application; and that no resistant varieties are available, although different levels of susceptibility have been detected. Nwanze (1985) examined the constraints on successful implementation of an integrated pest management programme against *Heliocheilus albipunctella* and *Coniesta ignefusalis* in the Sahel. He concluded that chemical control is not feasible, mainly because of lack of cash, water, trained personnel and delivery systems. He noted that cultural practices, including destruction of crop residues, end-of-season ploughing and synchronized early planting, could be used to reduce carry-over populations of larvae but require farmer education and changes of traditional practices. Natural enemies may be practically effective on *H. albipunctella*, but not on *C. ignefusalis* and incorporation of identified host plant resistance into germplasm sources with desirable agronomic characters has yet to be achieved. The basis for development of integrated pest management must therefore be multi-disciplinary and the resources available in the Sahel for development of national programmes, for training research workers, for farmer education and for individual motivation and orientation of objectives need to be developed in the contexts of overall crop management and technology transfer.

Gahukar (1989) has also reviewed the management of insect pests of millets and concluded that research on pest management needs to be intensified. He also noted that a combination of cultural practices and resistant cultivars had proved effective, but this statement must relate more to India than Africa.

V. Conclusions

The pearl millet crop almost certainly originated around the southern edges of the Sahara desert over the past 10,000 years and, as a result of that long period of natural and human selection, has been well adapted to survive the harsh conditions in which it has been traditionally cultivated in West Africa. The key pests that attack it are also indigenous to this part of Africa and are also well adapted to survival in the dry climate of the Sahel. Of these pests, some of the most important species, such as *Coniesta ignefusalis*, *Heliocheilus albipunctella* and *Geromyia penniseti*, are probably almost entirely dependent on the crop for their survival in some areas, although in other locations they may also survive on alternative grass hosts. The period during which their populations actively increase is restricted to the few months of the rains during which the crop grows and they spend substantial parts of their annual cycles in diapause in crop residues and/or in the soil. They are therefore susceptible to control by the use of cultural methods to reduce carry-over populations from one season to the next but there are sociological and organisational problems that may prevent the widespread and effective use of techniques that rely on co-ordinated removal and destruction of crop residues and the effective cultivation of infested soils. Existing information on the biology and ecology of these species could be used to devise some methods of cultural control although it is also true that insufficient information is available for some other pest groups, such as the earhead beetles.

Chemical control has been attempted in experimental trials against stem borers and against earhead caterpillars and seed-dressings have been used to protect against soil pests during the early stages of crop development, but widespread use of chemical control in pearl millet farming systems seems to be neither appropriate to the economic circumstances of the farmers nor desirable in such fragile ecosystems.

Biological control has been suggested as a possible alternative approach but, although some of the possibilities merit further investigation, may be a difficult technique to apply in the critical climate of the sahelian zone.

It therefore seems that long-term, widely applicable methods of pest control will have to be based on plant breeding for resistance. This requires for its basis the conservation of the existing genetic diversity of the crop which, because of its relatively long interaction with the main pest species, may well include useful levels of resistance or tolerance. This preliminary stage of development has already been achieved by the establishment of germplasm collections at ICRISAT Center in India, where over 19,000 accessions are maintained under long term cold storage. Similar facilities are envisaged in the near future at the ICRISAT Sahelian Center in Niamey, Niger, where work on screening and selection is already in progress for resistance/tolerance to *Heliocheilus* and *Coniesta* (Lukefahr, 1989). Similar studies are also being conducted by national programs of the region. Although resistant/tolerant cultivars have been reported, resistance mechanisms have not been properly studied. This is an area that would require considerable emphasis in the future.

VI. Acknowledgements

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Table 1. Pearl millet: estimated grain production, 1989 ('000 metric tonnes)
Based on 'FAO Crop Production for 1989'

Africa		9,302
W. Africa	7,723	
North, Central and Southern Africa	1,579	
Asia		17,112
S. America		50
Europe		26
Australia		21
USSR		4,000
Total world production		30,511

Table 2. Insect pests of pearl millet in West Africa[1]

ORDER/Family	Genus/species	Common name	Plant part/ stage damaged
ISOPTERA			
Termitidae	*Microtermes* sp.	termite	roots
DIPTERA			
Cecidomyiidae	*Geromyia penniseti* (Felt)	pearl millet midge	developing grain
Chloropidae	*Aprometopsis flavofacies* Becker		seedling
	Dicraeus pennisetivora Deeming		developing grain
	Elachiptereicus abessynicus Becker		seedling
	Polyodaspis sp.		seedling
Diopsidae	*Diopsis macrophthalma* Dalman	stalk-eyed fly	seedling
	Diopsis collaris Westwood	stalk-eyed fly	seedling
Muscidae	*Atherigona approximata* Malloch	pearl millet shoot-fly	seedling
	Atherigona soccata Rondani	sorghum shoot-fly	seedling
	Atherigona ponti Deeming	shoot-fly	seedling
	Atherigona yorki Deeming	shoot-fly	seedling
LEPIDOPTERA			
Arctiidae	*Amsacta moloneyi* (Druce)	hairy caterpillar	foliage
Cosmopterygidae	*Sathrobota simplex* Walsingham [= *Pyroderces simplex*]	head caterpillar	developing grain
Eupterotidae	*Janomima mesundulata* Strand	defoliator	foliage
Hesperiidae	*Pelopidas mathias* (Fabricius)	defoliator	foliage
Noctuidae	*Adisura affinis* Rothschild	defoliator	foliage
	Adisura callima Bethune	head caterpillar	earhead
	Busseola fusca (Fuller)	maize stem borer	stem, foliage

Table 2. Continued

ORDER/Family	Genus/species	Common name	Plant part/ stage damaged
	Eublemma sp. nr *gayneri* Rothschild	head caterpillar	earhead
	Heliocheilus albipunctella (Joannis) [= *Raghuva albipunctella, R. bordastei* etc.]	head caterpillar	earhead
	Heliocheilus confertissima (Walker)	head caterpillar	earhead
	Helicoverpa armigera (Hübner) [= *Heliothis armigera*]	bollworm	earhead
	Manga basilinea Bowden	stem borer	stem
	Masalia nubila (Hampson)	head caterpillar	earhead
	Masalia terracottoides (Rothschild)	head caterpillar	earhead
	Mythimna loreyi (Duponchel)	armyworm	foliage
	Nola spp.	head caterpillar	developing grain
	Poecopa mediopuncta Bowden	stem borer	stem
	Sesamia calamistis Hampson	pink stem borer	stem
	Sesamia cretica (Lederer)	pink stem borer	stem
	Sesamia nonagrioides botanephaga Tams & Bowden	pink stem borer	stem
	Sesamia penniseti Tams & Bowden	stem borer	stem
	Sesamia poephaga Tams & Bowden	stem borer	stem
	Spodoptera exempta (Walker)	armyworm	foliage
	Spodoptera exigua (Hübner)	armyworm	foliage
	Spodoptera littoralis (Boisduval)	cotton leaf worm	foliage
	Timora senegalensis (Guenée)	head caterpillar	earhead
Notodontidae	*Antheua ornata* (Walker)		
Pyralidae	*Achyra massalis* (Walker)	stem borer	stem
	Chilo orichalcoeciliella (Strand) [= *Chilotraea argyrolepia*]	spotted stem borer	stem
	Coniesta ignefusalis (Hampson) [= *Acigona ignefusalis*]	pearl millet borer	stem
	Eldana saccharina Walker	sugarcane borer	stem
	Marasmia trapezalis Guenée	leaf roller	foliage
COLEOPTERA			
Alleculidae	*Synallecula* sp.		earhead
Buprestidae	*Anthaxia binotata* Chevrolat	leaf beetle	foliage
	Sphenoptera sp.	leaf beetle	foliage
Chrysomelidae	*Chaetocnema tibialis* (Illiger)	flea beetle	foliage
	Dactylispa nigritula (Guérin-Méneville)	leaf beetle	foliage
	Eryxia holoserica (Klug)	leaf beetle	foliage
	Lema armata Fabricius	leaf beetle	foliage
	Lema planifrons Weise	leaf beetle	foliage
	Monolepta goldingi Bryant	leaf beetle	foliage
	Monolepta senegalensis Bryant	leaf beetle	foliage
	Podagrica sp.	flea beetle	foliage
	Pseudocolaspsis setulosa Lefèvre	leaf beetle	foliage
Coccinellidae	*Epilachna similis* (Thunberg)	coccinellid beetle	foliage
Corylophidae	*Arthrolips senegalensis* Matthews		earhead
Curculionidae	*Dereodus marginellus* (Boheman)		
	Elattocerus senegalensis Hustache		
	Myllocerus decorsei Hustache	grey weevil	roots/foliage
	Pachytychius elongatus (Gyllenhal)		
	Siderodactylus saggitarius (Oliver)		
	Tanymecus discolor Gyllenhal		
Meloidae	*Cyaneolytta* spp.	blister beetle	inflorescence
	Cylindrothorax westermanni (Maklin)	blister beetle	inflorescence
	Decapotoma affinis (Olivier)	blister beetle	inflorescence
	Epicauta albovittata Gastro	blister beetle	inflorescence
	Mylabris bifasciata (De Geer)	blister beetle	inflorescence
	Mylabris holosericea Klug	blister beetle	inflorescence
	Mylabris pallipes Olivier	blister beetle	inflorescence
	Psalydolytta aegyptiaca (Maklin)	blister beetle	inflorescence
	Psalydolytta fusca (Olivier) [= *Psalydolytta flavicornis*]	blister beetle	inflorescence
	Psalydolytta theresae Pic	blister beetle	inflorescence
	Psalydolytta vestita (Dufour)	blister beetle	inflorescence
Melyridae	*Idgia terminata* Castelnau		earhead
	Melyris abdominalis (Fabricius)		developing grain

Table 2. Continued

ORDER/Family	Genus/species	Common name	Plant part/ stage damaged
Nitidulidae	*Carpophilus* sp.		developing grain
	Meligethes heteropus Gerstaecker		inflorescence
Scarabaeidae	*Anomala senegalensis* Blanchard	chafer beetle	inflorescence
	Anomala tibialis Lansberge	chafer beetle	inflorescence
	Leucocelis nitidula (Olivier)	chafer beetle	inflorescence
	Pachnoda interrupta (Olivier)	chafer beetle	inflorescence
	Polybaphes sanguinolenta (Olivier)	chafer beetle	earhead
	Pseudoprotaetia burmeisteri Arrow	chafer beetle	inflorescence
	Rhabdotis sobrina (Gory & Percheron)	chafer beetle	earhead
	Rhinyptia infuscata Burmeister	chafer beetle	inflorescence
	Schizonycha africana (Castelnau)	chafer beetle	inflorescence
HEMIPTERA: HETEROPTERA			
Alydidae	*Mirperus jaculans* (Thunberg)		earhead
	[= *Mirperus torridus*]		
Coreidae	*Anoplocnemis curvipes* (Fabricius)		developing grain
	Cletus fuscescens Walker		developing grain
	Fabrictilis australis (Fabricius)		foliage/
	[= *Leptoglossus membranaceus*]		developing grain
Lygaeidae	*Aspilocoryphus fasciativentris* (Stål)		developing grain
	Dieuches armipes (Fabricius)		developing grain
	Oxycarenus sp.	dusky cotton bug	developing grain
	Spilostethus spp. (??)		developing grain
Miridae	*Creontiades pallidus* (Rambur)	head bug	developing grain
	Eurystylus bellevoyei (Reuter)	head bug	developing grain
	Taylorilygus vosseleri (Poppius)	mirid bug	developing grain
Pentatomidae	*Agonoscelis pubescens* (Thunberg)	sudan millet bug	developing grain
	[= *Agonoscelis versicolor*]		
	Afrius figuratus (Germar)	stink bug	developing grain
	Aspavia armigera (Fabricius)	stink bug	developing grain
	Carbula difficilis (Westwood)	stink bug	developing grain
	Carbula trisignata Germar	stink bug	developing grain
	Carbula pedalis Bergroth	stink bug	developing grain
	Nezara viridula (Linnaeus)	green stink bug	developing grain
Pyrrhocoridae	*Dysdercus superstitiosus* (Fabricius)	red cotton stainer	developing grain
	Dysdercus voelkeri Schmidt	pyrrhocorid bug	developing grain
Scutelleridae	*Alphocoris* sp.		grain
	Callidea nana (Herrich-Schaeffer)	blue bug	grain
HEMIPTERA: HOMOPTERA			
Aleyrodidae	*Neomaskellia bergii* (Signoret)	spotted white fly	foliage
Aphididae	*Rhopalosiphum maidis* (Fitch)	corn leaf aphid	foliage
Aphrophoridae	*Poophilus costalis* Walker	spittle bug	foliage
Cercopidae	*Locris rubra* (Fabricius)	cercopid bug	foliage
Cicadellidae	*Recilia mica* Kramer	leaf hopper	foliage
Pseudococcidae	*Heterococcus nigeriensis* Williams	mealybug	foliage
HYMENOPTERA			
Formicidae	*Messor barbarus* Linnaeus	ant	grain
ORTHOPTERA			
Acrididae	*Acrotylus blondeli* Saussure	grasshopper	foliage
	Acrotylus patruelis Herrich-Schaeffer	grasshopper	foliage
	Aiolopus thalassinus (Fabricius)	grasshopper	foliage
	Cataloipus cymbiferus Krauss	grasshopper	foliage
	Catantops spp.	grasshopper	foliage
	Chrotogonus homalodemus (Blanchard)	grasshopper	foliage
	Diabolocatantops axillaris (Thunberg)	grasshopper	foliage
	Gastrimargus africanus Saussure	grasshopper	foliage
	Harpezocatantops stylifer (Krauss)	grasshopper	foliage
	Hieroglyphus daganensis Krauss	grasshopper	foliage
	Kraussaria angulifera (Krauss)	grasshopper	foliage
	Kraussella amabile (Krauss)	grasshopper	foliage
	Locusta migratoria (Linnaeus)	migratory locust	foliage
	Morphacris fasciata (Thunberg)	grasshopper	foliage
	Oedaleus nigeriensis Uvarov	grasshopper	foliage
	Oedaleus senegalensis (Krauss)	grasshopper	foliage
	Schistocerca gregaria (Forskal)	desert locust	foliage
Pyrgomorphidae	*Pyrgomorpha cognata* Krauss	grasshopper	foliage
	Zonocerus variegatus (Linnaeus)	grasshopper	foliage

Table 2. Continued

ORDER/Family	Genus/species	Common name	Plant part/ stage damaged
DERMAPTERA			
Forficulidae	*Forficula senegalensis* Serville	earwig	grain
THYSANOPTERA			
Thripidae	*Haplothrips sorghicola* Bagnall	thrips	foliage
ACARINA			
Tetranychidae	*Oligonychus* sp.	spider mite	foliage

[1]This tabulation is based on Table 2 in Sharma and Davies (1988), which includes references to published records. The pest status of many of the species included here has not been adequately established. Stored products pests are not included in this Table but are dealt with in section 4.5.6 of the text.

Table 3. Crop infestation of pearl millet by *Coniesta ignefusalis* and *Heliocheilus albipunctella* in farmers' fields in Burkina Faso and Niger, West Africa. 1980–1983[1]

Species	Location				
			Burkina Faso[2] (region)		
	North	South	Central	East	West
Stem Borers					
% infested fields	100.0	100.0	100.0	100.0	–[3]
% infested stems	51.0	72.0	66.3	44.6	–
% tunnelled internodes	27.1	35.4	22.3	19.7	–
% frequency of borer species					
C. ignefusalis	100.0	81.4	99.7	100.0	–
E. saccharina	0.0	14.0	0.3	0.0	–
S. calamistis	0.0	4.6	0.0	0.0	–
Heliocheilus albipunctella					
% infested fields	80.0	0.0	6.7	0.0	0.0
% infested panicles	17.9	0.0	3.5	0.0	0.0
Mean damage score[4]	3.5	0.0	2.0	0.0	0.0
			Niger[5] (districts)		
	Niamey	Dosso	Tahoua	Maradi	Zinder
Stem borer					
(*Coniesta ignefusalis*)					
% infested fields	67.0	100.0	94.0	100.0	89.0
% infested stems	35.2	69.1	48.2	58.0	61.5
% tunnelled internodes	17.1	33.4	16.9	25.3	28.6
Heliocheilus albipunctella					
% infested fields	52.9	12.0	77.4	70.1	60.0
% infested panicles	30.7	4.2	7.5	30.5	16.8
Mean damage score	3.2	1.0	1.5	2.8	2.0

[1]Adapted from Nwanze (1988a)
[2]Surveys conducted in 1980 and 1981
[3]Insufficient data
[4]Measured on a 1–5 scale where 1 = zero to low damage and 5 = severe damage
[5]Surveys conducted in 1982 and 1983

Table 4. Natural enemies recorded on insect pests of pearl millet in West Africa[1]

Host species	Natural enemy	Order/Family	Type/stage attacked
Rhopalosiphum maidis	*Ischiodon aegyptium* (Wiedemann)	Diptera: Syrphidae	Predator/nymph-adult
	Cheilomenes propinqua vincina (Mulsant)	Coleoptera: Coccinellidae	Predator/nymph-adult
	Exochomus troberti Mulsant	Coleoptera: Coccinellidae	Predator/nymph-adult
	Micraspis striata (Fabricius)	Coleoptera: Coccinellidae	Predator/nymph-adult
Lema planifrons	*Chlaenius boisduvali* Dejean	Coleoptera: Carabidae	Predator/larva
Coniesta ignefusalis [= *Acigona ignefusalis*]	*Goniozus procerae* Risbec	Hymenoptera: Bethylidae	Parasitoid/larva
	Cotesia sesamiae (Cameron) [= *Apanteles sesamiae*]	Hymenoptera: Braconidae	Parasitoid/larva
	Euvipio fascialis Szepligeti	Hymenoptera: Braconidae	Parasitoid/larva
	Euvipio rufa Szepligeti	Hymenoptera: Braconidae	Parasitoid/larva
	Glyptomorpha sp.	Hymenoptera: Braconidae	Parasitoid/larva-pupa

Table 4. Continued

Host species	Natural enemy	Order/Family	Type/stage attacked
	Rhaconotus sudanensis Wilkinson	Hymenoptera: Braconidae	Parasitoid/larva
	Hyperchalcidia soudanensis Steffan	Hymenoptera: Chalcididae	Parasitoid/pupa
	Pediobius furvus (Gahan)	Hymenoptera: Eulophidae	Parasitoid/pupa
	Tetrastichus atriclavus Waterston	Hymenoptera: Eulophidae	Parasitoid/pupa
	Dentichasmias busseolae Heinrich	Hymenoptera: Ichneumonidae	Parasitoid/pupa
	Chasmias sp.	Hymenoptera: Ichneumonidae	Parasitoid/pupa
	Syzeuctus sp.	Hymenoptera: Ichneumonidae	Parasitoid/larva-pupa
	Platytelenomus hylas Nixon	Hymenoptera: Ichneumonidae	Parasitoid/egg
	Sturmiopsis parasitica (Curran)	Diptera: Tachinidae	Parasitoid/larva-pupa
	Pyemotes ventricosus (Newport)	Acarina: Pyemotidae	Parasitoid/diapause larva
	Metarhizium anisopliae Sorokin	Fungus	Disease/larva
Sesamia calamistis and other *Sesamia* species	*Cotesia flavipes* (Cameron)	Hymenoptera: Braconidae	Parasitoid/larva
	Cotesia sesamiae Cameron	Hymenoptera: Braconidae	Parasitoid/larva
	Mysosoma chinensis (Szepligeti) [= *Bracon chinensis*]	Hymenoptera: Braconidae	Parasitoid/larva
	Brachymeria feae Masi	Hymenoptera: Chalcididae	Parasitoid/pupa
	Pediobius furvus (Gahan)	Hymenoptera: Eulophidae	Parasitoid/pupa
	Pediobius sp. nr. *hirtellus* Masi	Hymenoptera: Eulophidae	Parasitoid/pupa
	Tetrastichus atriclavus Waterston	Hymenoptera: Eulophidae	Parasitoid/pupa
	Norbanus sp.	Hymenoptera: Pteromalidae	Parasitoid/larva-pupa
	Sturmiopsis parasitica (Curran)	Diptera: Tachinidae	Parasitoid/larva
Geromyia penniseti	*Aprostocetus diplosidis* (Crawford) [= *Tetrastichus diplosidis*]	Hymenoptera: Eulophidae	Parasitoid/larva-pupa
	Tetrastichus sp.	Hymenoptera: Eulophidae	Parasitoid/larva-pupa
	Eupelmus popa (Girault)	Hymenoptera: Eupelmidae	Parasitoid/larva-pupa
	Eupelmus sp.	Hymenoptera: Eupelmidae	Parasitoid/larva-pupa
	Aphanogmus sp.	Hymenoptera: Eupelmidae	Parasitoid/larva-pupa
	Platygaster sp.	Hymenoptera: Platygasteridae	Parasitoid/larva-pupa
Heliocheilus albipunctella [= *Raghuva albipunctella*]			
	Goniozus sp.	Hymenoptera: Bethylidae	Parasitoid/larva
	Apanteles sp.	Hymenoptera: Braconidae	Parasitoid/larva
	Bracon hebetor Say	Hymenoptera: Braconidae	Parasitoid/larva
	Cardiochiles sahelensis Huddleston & Walker	Hymenoptera: Braconidae	Parasitoid/larva
	Copidosoma obscurum (Nikolskaya) [= *Litomastix* sp.]	Hymenoptera: Encyrtidae	Parasitoid/larva
	Barylypa sp.	Hymenoptera: Ichneumonidae	Parasitoid/larva
	Pristomerus sp.	Hymenoptera: Ichneumonidae	Parasitoid/larva
	Trichogramma sp.	Hymenoptera: Trichogrammatidae	Parasitoid/egg
	Trichogrammatoidea sp. nr. *lutea*	Hymenoptera: Trichogrammatidae	Parasitoid/egg
	Telenomus anates Nixon	Hymenoptera: Scelionidae	Parasitoid/egg
	Thyridanthrax sp. nr *kappa* Bowden	Diptera: Bombyliidae	Parasitoid/pupa
	Goniophthalmus halli Mesnil	Diptera: Tachinidae	Parasitoid/larva
	Orius sp.	Hemiptera: Anthocoridae	Predator/egg-larva
	Glypsus conspicuus (Westwood)	Hemiptera: Pentatomidae	Predator/larva
	Ectomocoris fenestratus (Klug)	Hemiptera: Reduviidae	Predator/larva
	Katanga etiennei Schoutedon	Hemiptera: Reduviidae	Predator/larva
	Chlaenius boisduvalii Dejean	Coleoptera: Carabidae	Predator/larva
	Chlaenius dusaultii (Dufour)	Coleoptera: Carabidae	Predator/larva
	Pheropsophus sp. nr. *laferti* Arrow	Coleoptera: Carabidae	Predator/larva
	Hexamermis sp.	Nematoda: Mermithidae	Parasitoid/larva

Table 4. Continued

Host species	Natural enemy	Order/Family	Type/stage attacked
	Aspergillus flavus Link	Fungus	Pathogen/larva
	Aspergillus sp. (*ochraceus* gp.)	Fungus	Pathogen/larva
	Bacillus thuringiensis Berliner	Bacterium	Pathogen/larva
Poophilus costalis	*Asarkina ericetorum* (Fabricius)	Diptera: Syrphidae	Predator
Dysdercus voelkeri	*Phonoctonus lutescens* (Guerine & Percheron)	Heteroptera: Reduviidae	Predator/nymphs-adults

[1]This tabulation is based on Table 4 in Sharma and Davies (1988), which includes references to published records, including Harris (1962), Coutin and Harris (1969), Guevremont (1983), Bhatnagar (1984), Gahukar *et al.* (1986), and Ndoye and Gahukar (1987) with the addition of Huddleston and Walker (1988). The status and host relationships of many of the species listed here have not been adequately established.

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