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INSECTS OF FOREST SEED

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1. INTRODUCTION

Insect damage to fruit and seed crops causes heavy losses of seed every year. Destruction of seed crops may be caused either by insects directly infesting the reproductive structures (flowers, fruits and seeds) or by insects attacking other parts of the tree, e.g. defoliators, which cause exhaustion of nutrient reserves, which in turn may diminish nutrient allocation for seed production (Koerber 1989). Only insect problems of the former type will be dealt with in this note.

Some insects attack flower buds or flowers and may thus cause complete failure of fruit setting. Other species attack during the later phase of seed development, but before the seeds mature. Still others are able to attack after maturity and continue both feeding and infestation after harvest provided the external environment is suitable, e.g. temperature. Whenever the attack takes place, a heavy infestation may cause almost complete seed-crop destruction and certainly make seed collection inefficient and uneconomical. Seed predation or infestation rate varies from species to species, from location to location and from year to year. It is often correlated with seed-crop size in the way that small seed crops are heavily attacked while the percentage of infested seeds in large crops is significantly smaller.

Infestation before fruit harvest, i.e. in the field, is difficult to control. Chemical treatment e.g. by spraying flowers or fruit-bearing branches, a method applicable in agriculture and horticulture, is usually practically impossible or too expensive for forest trees, except in some seed orchards. Injection of certain systemic pesticides under the bark is technically possible and sometimes effective, but the expenses involved are usually high. Hence, **for most seed sources pest management becomes a matter of collecting seeds with the lowest possible field infestation and preventing damage after harvest**. Early collection (possibly with subsequent after-ripening) and collection from heavy crops are usually the most effective preventive measures in order to reduce loss caused by seed insects in the field. Early elimination of insect-infested seed during processing plus storage under conditions unfavourable to insect development can further reduce risk of damage during storage, including possible secondary infestation. Although chemical treatment takes up several pages of this Technical Note and may be necessary in some instances, e.g. to completely eliminate pests from seed lots for export, **much chemical treatment can be avoided by appropriate preventive measures.**

Determining preventive measures as well as assessing necessity for and type of chemical treatment usually imply that the type of insect pest can be identified. Identification (at least to genus level) and knowledge of mode of attack (time and stage of infestation, generation turnover, and host-species range) are often necessary to design the best control measures. For example, insects that are able to infest mature seed (and possibly other species) under storage conditions may need radical treatment to be eliminated whereas there may be little gain by using chemical treatment where insects do not re-infest under storage conditions. The number of insect species is exorbitant and their life cycles are often unknown or only superficially known. Exact identification of insects normally requires entomological expertise, **but many practical seed-insect problems may be overcome by current observations of insect behaviour**.

Most seed insects belong to five orders which are very distinct, and families are relatively easy to identify by some key characteristics. For practical purposes identification to family or genus level often suffices. Key characteristics are described in appendix 1.

2. INSECT DAMAGE TO SEEDS

For the individual seed, the effect of infestation depends on how much and which part of the seed is affected. Small damage to the endosperm or cotyledons may have little or no effect; and even where part of the cotyledons has been eaten by larvae or sucking adults, the seed may survive and the seedling fully recover, albeit usually with some delay due to shortage of food reserve. Many insects consume only a minor part of the seed contents. However, even minor damages to the vital part of the embryo like the radicle or hypocotyl may rapidly cause the death of the seed (Lamprey *et al.* 1974).

Damage to the seed coat alone does not affect viability directly but may sometimes impair storability e.g. by serving as entry points for infecting pathogens, especially under ambient conditions. On the other hand, in hard-seeded legumes, insect damages to the seed coat may help to overcome physical dormancy. Infestation in dry fruits and cones, where the insects leave webs or galls or cause damage to the natural fruit-opening mechanism, may cause secondary damage by impairing seed extraction.

Damage to harvested seed lots depends on (1) the initial infestation i.e. how many percentages of the seed contain insects at the time of collection, (2) the rate of destruction of infested seed during a certain period under the prevailing storage conditions, and (3) the ability of emerging adult insects to re-infest seeds in the seed lot. In connection with (3) the multiplication rate, which in tum is dependent on generation turnover and reproductive success, becomes important. Where secondary infestation is possible and conditions are favourable for development, the whole seed lot may be lost.

3. LIFE CYCLES OF INSECTS

Insects undergo a metamorphosis, i.e. a dramatic change from juvenile to adult, which for most groups occurs during a pupal stage (complete metamorphosis). In few others, e.g. true bugs, a gradual (or incomplete) metamorphosis occurs with interim nymph stages. In insect species with complete metamorphosis, seeds are most often exclusively fed upon by the larvae, while adult insects typically feed on more easily digestible material such as flowers or nectar. In species with gradual metamorphosis, e.g. plant bugs like *Dysdercus* spp., both adults and nymphs feed on the seed.

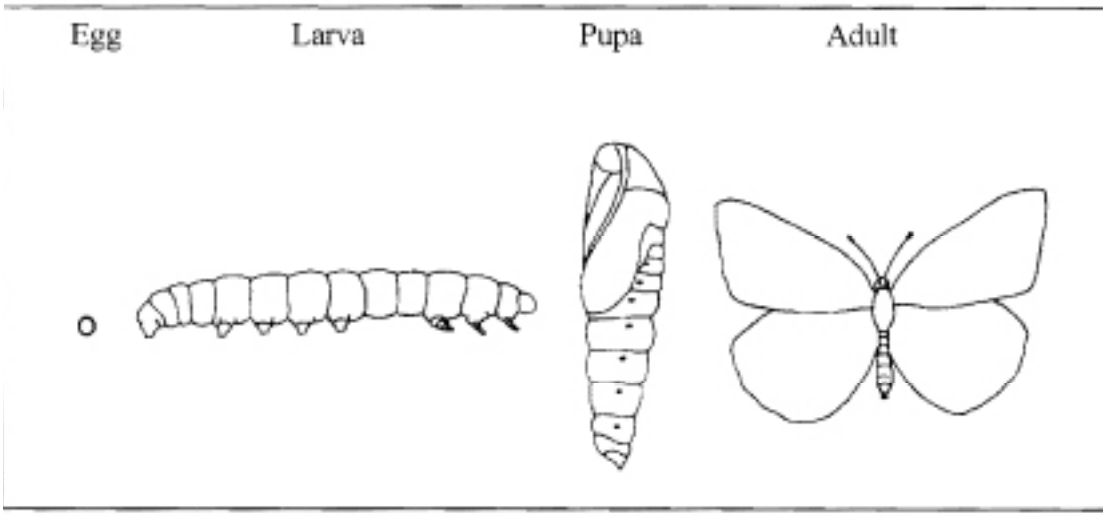


Figure 1. Complete metamorphosis. (After Hilje *et. al.* 1991).

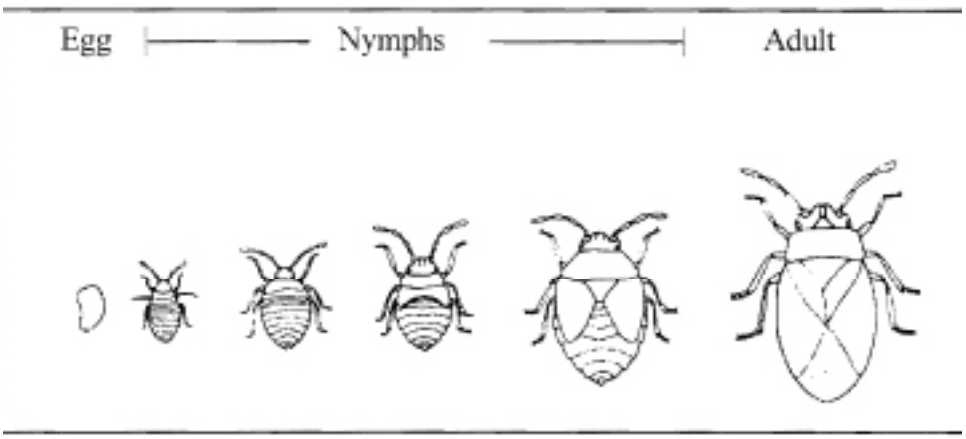


Figure 2. Gradual or incomplete metamorphosis. (After *Hilje et. al.* 1991).

As an example of an insect life cycle, the cycle of a bruchid beetle is illustrated in figure 3.

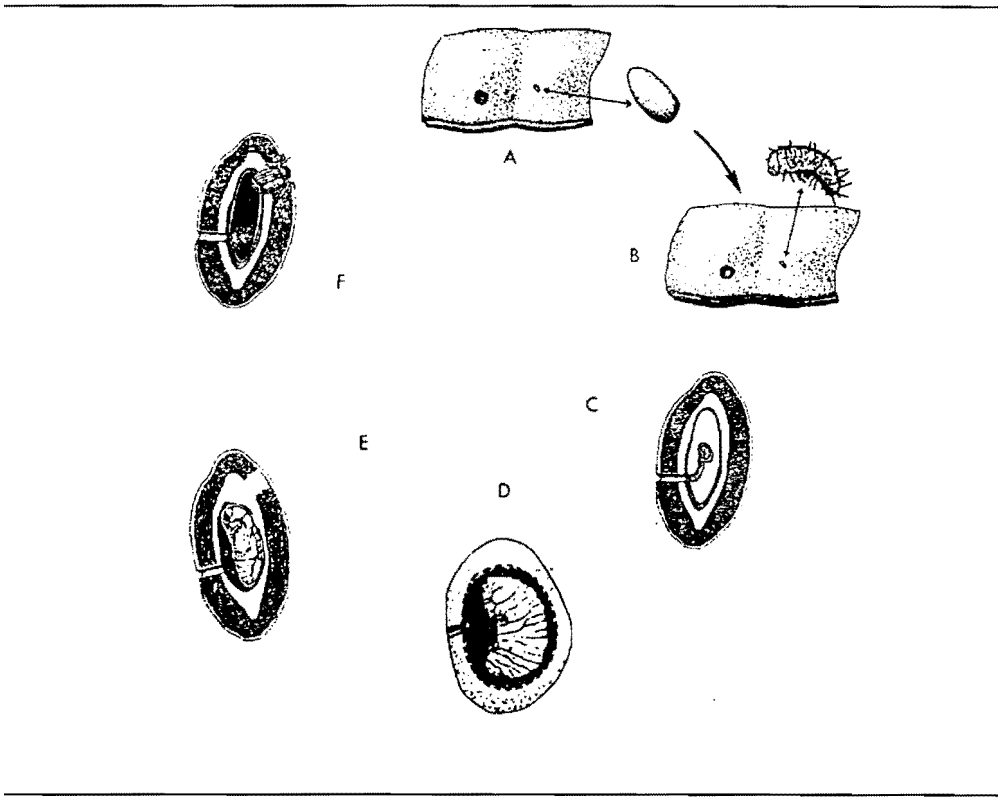


Figure 3. Life cycle of bruchid beetle, here on *Prosopis sp.* (A) Eggs glued to pod surface or laid in cracks in pod or in emergence holes of an adult bruchid (round holes). (B) Entry holes of the first-stage larvae that have burrowed through pod wall, and first-stage larva enlarged to show hairs, spines and legs which are modified for entering seeds. (C) Cross section of pod and seed showing the burrow made by the entering first-stage larva. (D) Later-stage larva inside cavity chewed in seed. (E) Pupa inside larval feeding chamber. The larva penetrates the testa except for a thin 'window' before it pupates. (F) Adult emerging through hole prepared by last-stage larva. (From Johnson 1983; partly redrawn).

Some variation occurs between different species. For example, pupation within the seed is most frequent, but in some large species like *Caryedon spp.* the larva leaves the seed after completion of its development

and pupates in the soil or, in the case of seed stores, outside and adhering to the seeds (Southgate 1983, El Atta 1993). This feature can be used in insect control since both pupae and empty seeds can be separated from non-infested seeds during processing, e.g. by sifting, blowing and/or flotation.

The duration of generation turnover or life cycle depends on species and environment. Under favourable environmental conditions some species may complete their life cycle in less than a month while others may take several months. Insect species having several generations per year (multivoltine species) emerge quickly after pupation while those with only one generation per year (univoltine) stay dormant as pupae inside the cocoon for several months, i.e. typically until next seed season. Univoltine behaviour is accordingly typical for the group of species which only infests green pods or immature seeds in species with synchronized and short fruiting season. In multivoltine species the insect mates and re-infests seeds shortly after their emergence. The adult stage is normally very short (< 2 weeks).

Species of bruchids infesting green pods only may cause considerable loss of seeds in the field, but as their damage is limited to the seeds already infested at the time of collection, the total loss is smaller and storage conditions are less critical for these seeds than for those where reinfestation may continue during storage. However, as the pupae may survive in the seeds, there is a risk that surviving insects may spread with the seed if exported into areas where the species are not originally present (phytosanitary problems, Lecture Note C-12; Willan 1991). Species which infest seed right up to full maturity can generally not be avoided by early collection (Southgate 1983).

4. SPECIES SPECIFICITY

The life cycle of seed insects is closely connected to the reproductive phenology of the host tree. This is especially crucial in species where host susceptibility is of short duration and where the insect has a pronounced host specificity. Survival conditions for the seed insect outside the infestive period is often crucial for the infestation rate. A heavy infestation presupposes a large population of adult individuals that can lay their eggs in/on the flowers, fruits or seeds. And a large population of adults presupposes a successful previous infestation plus a good survival rate of the juvenile stage. Therefore, infestation rate in good seed years following poor seed years is often low because the insect population is low; infestation rates after good seed years are high because the insect population has increased during the good seed year (Wagner *et al.* 1991).

For this reason, insect problems may often be more severe in seed orchards with annual abundant seed production compared to populations with large fluctuations from year to year, and where insect population is starved between good seed years. In tree species with prolonged fruiting seasons, insect populations may build up through the season. With a life cycle of only 20-30 days, *Apion* species may complete four generations within a fruiting season of *Triplochiton scleroxylon* (Wagner *et al.* 1991). The later part of the fruit crop is likely to be heavily infested and unsuitable for collection.

Except the relatively few tree species with diffuse flowering and fruiting, most plant species only bear fruits during a short period of the year, and periodic species only at long intervals. Hence, insects must adjust to the reproductive cycle of their host plants, be able to survive periods where fruits and seeds are not available, and detect a reproductive event sufficiently early to take the full opportunity to infest the maturing fruits. Seed insects may survive the interim period between two seed crops in various ways e.g.:

1. A prolonged dormant pupal stage, inside or outside the seed.
2. An adult stage in which the insect is dormant or feeds on other food sources, e.g. flowers.

3. A period where the insect feeds on seeds in soil seed banks, or in established seed stores.
4. A shift in predation to other species where seeds are available at different times of the year or in years where the main host species has poor seed production.

Species with a narrow host range (pronounced host specificity) with a relatively short infestive period often have a long dormancy period (diapause) between infestations. For example, many bruchid species spend a dormant stage as pupae, but some species that can infest mature seeds have a rapid generation turnover if seeds are abundant. The seed weevil *Sitophilus (Calandra) rugicollis*, which attacks seeds of *Shorea robusta*, *Syzygium cumini*, *Dipterocarpus allatus* and *Polyalthia longifolia* in India, survives as dormant adult in the forest floor and emerges with the first monsoon rain which coincides with the commencement of seed fall (Khatua and Chakrabarti 1990).

Life cycles and species specificity are closely connected in the sense that the more host specific the insect, the more tightly it must be connected to the life cycle of the host. Some insects have adapted closely to one host. In some Latin American forests *Sterculia apetala* is attacked primarily by the bug *Dysdercus fasciatus* which in turn is not known from any other tree species (Janzen 1972). *Hypsipyla* species which, in addition to their destructive infestation of mahogany shoots also attack their seeds, are exclusively predators on species of this family (Meliaceae). Another insect closely associated with Meliaceae is *Catopyla dysorphaea* which attacks *Khaya* and *Entandophragma* species in W. Africa (Wagner *et al.* 1991).

A high degree of host specificity is prevalent in bruchids attacking seeds of legumes. *Pseudopachymerina spinnipes* attacks almost exclusively *Acacia farnasiana* and *A. caven* (Southgate 1983). *Bruchidius albosparsus* is commonly associated with *Acacia tortilis* subsp. *raddiana*, and *Caryedon serratus* with *Acacia gerradii* ssp. *negevensis* in Israel (Halevy 1974). From some regions in Latin America, Africa and India it was found that more than half of the bruchid species have only one host species and only few have many hosts (Labeyrie 1981, Janzen *et al.* 1977, Janzen 1980, Singh and Bhandari 1988).

Some bruchid species do, however, have a wider host range. *Caryedon gonagra* has been found in several species of *Acacia*, *Albizia*, *Prosopis* and *Cassia* plus *Tamarindus indica* (Singh and Bhandari 1988). Sometimes seed insects show preference for one species but may shift to other species if the number of main hosts is insufficient. In other cases species specificity is less pronounced in areas where several susceptible hosts occur. For example, the above mentioned *Caryedon serratus* has a wider host-species range in India including e.g. *Acacia tortilis*, *A. nilotica* and *Albizia lebbeck* (El Atta 1993), and in Thailand the species feeds on both *Bauhinia* and *Cassia* species (Eungwijarnpanya and Hedlin 1984).

An illustrating example of the host - insect specificity is given by Ernst *et al.* (1990): in Botswana *Bruchidius uberatus* is the only bruchid species affecting seeds of *Acacia nilotica* although several other species of bruchids occur in the area; in the Sudan *B. uberatus* is the prime infesting species but several other species also attack seeds of *A. nilotica*. In Botswana *A. nilotica* is the main host species of *B. uberatus*, but in other parts of Africa the bruchid attacks several other *Acacia* species. In a storage-infesting experiment in Botswana *B. uberatus* showed a strong preference for *A. nilotica* seeds (75% infestation), but also attacked seeds of *A. tortilis*, *A. mellifera*, *A. burkei*, *A. erioloba*, *A. hebeclada* and *A. robusta* (all less than 25%). Some other species were not attacked at all. The example shows that host-insect specificity is sometimes not absolute. An account of host - insect specificity of the *Prosopis* - bruchid association in the Americas is given by Johnson (1983).

Despite the above mentioned non-absolute nature of infection patterns, plus the inevitable problem that the full host range can rarely be proven, the knowledge of such host-predator relations is very useful in seed-source management and seed handling. For example, seed insects with a wide host range are more

likely to spread from one species to another during storage than host-specific species. Further, where one main seed pest prevails, it is easier to take preventive measures to avoid infestation in the field, e.g. treatment during a specific flying time.

Occasionally host specificity gives problems when species are introduced into new areas. Australian acacias are generally not susceptible to attack by African bruchids. Some Australian acacias (*A. melanoxylon* and *A. saligna*) have become weed in parts of S. Africa because of absence of their natural seed predators (*Melanterius spp.*) and non-susceptibility to local seed beetles. *Melanterius spp*. do not attack indigenous African acacia species and in the particular case the Australian predator has been introduced into Africa as a control measure (Plant Prot. Res. Inst. 1987).

Seed beetles (Coleoptera) are by far the most numerous seed predators. In an investigation from Pakistan it was found that 86% of the seed-infesting insects belonged to the order Coleoptera, the others were Lepidoptera and Hymenoptera (Wali ur Rehman 1995). Coleoptera is also the group with the most pronounced host specificity, whereas Hymenoptera and Lepidoptera are more general feeders (Auld 1991).

5. EXAMINATION OF INSECT INFESTATION OF SEEDS AND FRUITS

Different types of insect leave different types of trace of their activity. There are three principal modes of assessing infestation rate: (1) visual examination of the fruit or seed exterior, (2) cutting test to examine hidden insect stages directly, and (3) X-radiography by which interior seed is examined without cutting seed or fruit.

5.1 Visual Examination

Some types of infestation can be detected on the seed surface, e.g. where parts of the seed coat has been consumed or exit holes are present. Seed beetles lay their eggs on the surface of the fruit or seed, and after hatching the larva enters the seed through a small entry hole. Entry holes are, however, very small and extremely difficult to see, especially on a rough seed coat. Once the larva has started feeding inside the seed, their presence can sometimes be detected by some discolouration of the seed coat. Where pupation takes place inside the seed, the larva gnaws through most of the seed coat before pupation, leaving a small 'window', through which the adult insect will leave the seed. The 'window' is easily visible on the surface. Where either the larva or the adult has left the seed, a distinct exit hole is visible. Exit holes are also reliable indications of e.g. cone-borer attack in conifers. Seed chalcids (*Megastigmus spp.*) spend most of their life inside the seed and infestation is not immediately visible on the surface until the insects leave as adults after pupation (Barbosa and Wagner 1989). Such infestation can only be revealed by X-radiography or cutting test.

Damage caused by e.g. plant bugs are not immediately visible on the exterior of the seed, since the insect does not enter the seed but is able to eat the inside of the seed through a stylet. Some discolouration may be visible if large parts of the interior have been consumed. Discolouration of fruits or cones in patches, spots or other localized parts of fruits often indicates localized dehydration which in turn is often caused by infestation. Moth and butterfly larvae feed from the outside of seeds and leave traces of removed tissue readily visible on extracted seeds. However, early attack on young fruits or cones may be barely visible since the larvae are hidden in tunnels inside the fruit or cone. A heavily attacked crop is often detected by web or frass (dry larval faeces) on the surface.

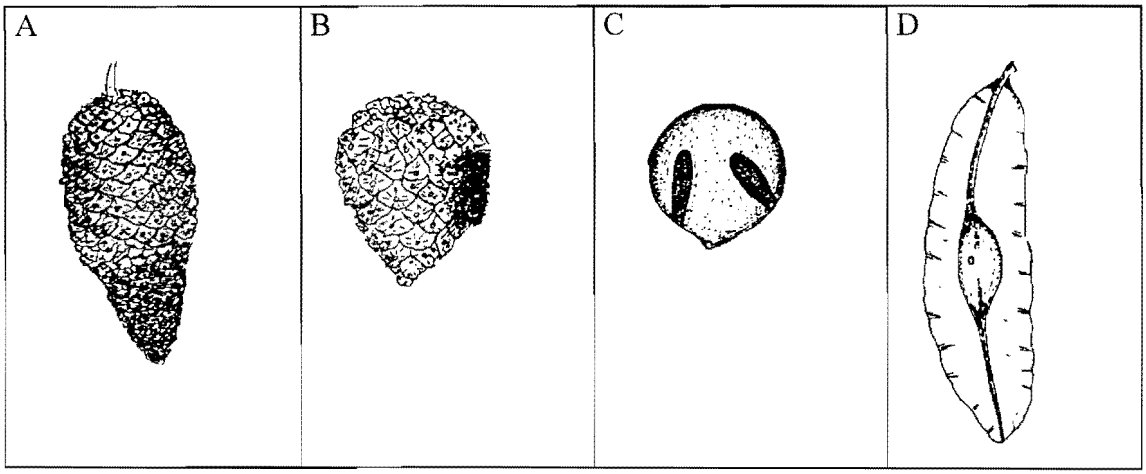


Figure 4. Evidence of insect attack apparent on the surface of fruit and seed. (A) Discolouration and deformation of a cone. (B) Frass left on the surface of a cone. (C) Discolouration of an acacia seed infested by bruchid. (D) Exit hole of a *Nanophyes sp.* on *Teminalia ivorensis* fruit.

5.2 Cutting Test

Cutting of cones, fruits or seeds usually reveals possible infestation at least where damages are large and advanced. Smaller localized attacks may, however, be overlooked. The applicability of the method implies that the insect or traces of it are present on the cut surface; a larva lying at one side of a fruit or seed may hence easily be overlooked. Cutting may be used as verification of visual surface traces, e.g. cutting through a discoloured area to see if it contains larvae. Cutting test is especially applicable to medium to large size fruits and seeds while it is difficult to carry out on small seeds, especially those with a hard seed coat. Sharp secateurs are useful for cutting medium to large seed, nail clippers or other small tools for smaller seeds.

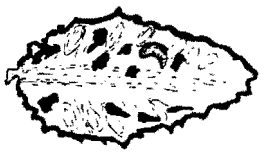


Figure 5. Infestation by cone worm (*Dioryctria*) revealed by cutting test. Redrawn from Hedlin *et al.* 1981.

5.3 X-radiography

X-radiography is a versatile method of examining the interior of fruits and seeds without cutting and thus destroying them. X-radiographs reveal distinct pictures of the embryos, thus also any damage exerted by insects. The method is especially useful for estimating infestation rate of a seed lot of relatively small-seeded species such as bruchid infestation in legumes or chalcid infestation in pines.

Young stages of seed beetles or chalcids with only minor consumption of the interior of the seeds may only be visible in X-radiographs. X-radiographs may also reveal damage caused by bugs, i.e. where the insect has fed from outside the seed through a stylet (Hemiptera, appendix 1) (Hedlin *et al.* 1981). The test is carried out on a representative sample. Because of the equipment involved, X-radiography is a relatively expensive assessment method.

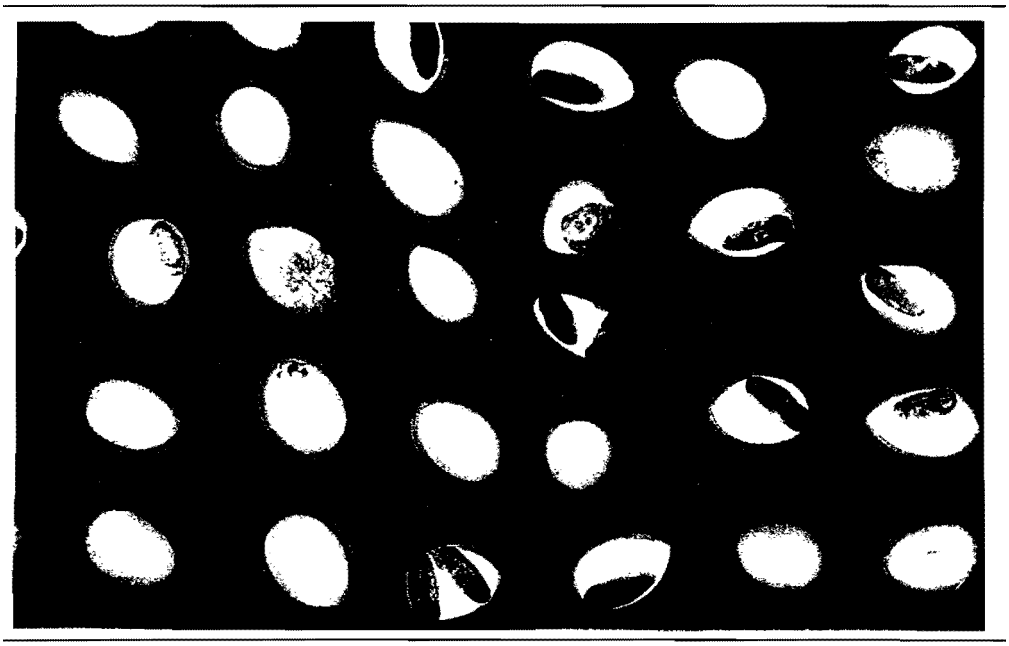


Figure 6. X-radiograph ofbruchid infested *Albizia procera* seeds (From Saelim *et al.* 1996).

6. INSECTS IN SEED STORAGE

Insect larvae that have infested seeds in the field may continue their predation during storage. However, only species able to breed and re-infest seeds in storage can be considered true storage pests. Most storage pests belong to the two coleopteran families Bruchidae and Curculionidae, but only a minor part of seed insects of the two families occurs as storage pests. **Most insects are unable to re-infest seeds because of failure of the adult insect to survive and mate under storage conditions, or the larvae may be unable to penetrate the seed coat of mature, dry seeds**. However, despite the hard seed coat of legumes, a small group of bruchids are able to re-infest seeds during storage and pass several generations until the whole seed lot is destroyed, provided temperature is conducive to their survival and continuous activity. The adult of these bruchids need no food intake for reproduction (Southgate 1983).

Some species are field pests as well as storage pest. An example is *Caryedon gonagra* which attacks young developing seeds on the growing plant as well as stored seeds (Singh and Bhandari 1988). *C. serratus* showed a relatively low field infestation rate on *Acacia nilotica* in the Sudan (ranging from 10% on standing trees to 17% on the forest floor), but the infestation increased to 90% after 3 months' storage. The speed of seed destruction during storage depends on the multiplication rate of the insect, which in turn is determined by generation turnover and reproductive success. El Atta (1993) gives the following example of a life cycle for *Caryedon serratus* under storage conditions:

1. Egg incubation period (i.e. from oviposition to hatching) was 7-16 days.
2. Larval feeding: 4 larval stages (‚instars') were recognized with average durations of 12.4, 11.5 and 7.2 days respectively, i.e. a total feeding period of approx. 42 days.
3. Metamorphosis and pupal stage, 10-15 days.
4. Emergence and mating, 1 day
5. Time from mating to new oviposition, 2-3 days.

Total life cycle for this species under the given conditions is thus 63-76 days. The average number of eggs per female in the investigation was 93 ofwhich some 80% hatched. However, as 12-25 eggs were laid per seed by this bruchid species, each female may have infested on an average only 5-6 seeds. If the initial infestation rate is low, it will require several generations to infest all seeds in a seed lot. Hence, short-term storage even under ambient conditions may not cause serious damage and thus not justify chemical treatment.

The life cycle of 2-2½ months in the example is under optimal conditions of insect activity. A much longer duration of life cycle is expected where temperature and moisture content are low. The activities of insects during low temperatures vary with their environmental adaptation. Many tropical insect species show little activity below 10°C, while subtropical and high-altitude species may be active at temperatures down to a few degrees above zero. Moisture content may be limiting for feeding, but there is large variation also in this respect. While a moisture content below 10% is limiting for many field insects, several storage insects remain active at lower moisture content. However, though the activities of some insects may not be stopped altogether at a given storage condition, any reduction of temperature and moisture content below the physiologically optimal will delay their development. For example, the duration of the above cycle may be doubled or tripled under conditions of reduced temperature. Storage conditions also have an impact on the reproductive success. For example, the theory has been proposed that insects lay more eggs in dark and damp stores than in light dry ones (Singh and Bhandari 1988).

Some insect species have very short life cycles and are able to destroy a seed lot within short time under conditions optimal for their activity. A fruit weevil (*Menechamus sp.*, Family Curculionidae) attacking seeds of *Guarea cedrata* in Ghana has a life cycle of about 4 weeks and caused complete destruction of a seed lot in three months. Although this species can infest seeds in storage, fully dried seeds were not attacked (Kudler 1970, in Wagner *et al.* 1991).

Seed-infesting organisms metabolize much more intensively than the seed itself at low moisture content. During their metabolism, water and heat are released both of which are conducive to their development and activity.

Storage insects may also cause indirect damage to seeds by destroying storage bags, and thus exposing the seeds to ambient air humidity. Orthodox seeds are typically stored at low moisture content in sealed polythene bags that prevent them from absorbing moisture from the atmosphere. Bags perforated by insects permit humid air to enter into the bags and moisture content may increase. For recalcitrant seeds, lowering of the moisture content is critical. An example has been reported from Brazil where desiccation damage was encountered for seeds of *Carapa procera* and *C. guianensis* after insects had destroyed the plastic storage bags (Ferraz and Sampaio 1996).

7. CONTROL OF INSECT INFESTATION OF SEEDS

Several methods are available for minimizing destruction by seed insects. Generally, the earlier the control measure, the smaller the destruction. However, as insects may attack at any time during seed handling, a low initial infestation rate does not guarantee that the seed lot remains free from insects. Control measures must thus be observed throughout the seed handling process.

7.1 Control of Seed Infestation in the Field

A lot of work can be saved by collecting fruits and seeds which are free from infestation or only have a small percentage of infested seeds. Usually heavy crops and early crops are much less attacked than small and late ones. Where infestation takes place relatively late during development and where seeds can be after-ripened, collection few weeks before natural fruit fall is applicable. For example, seed infestation of mahogany (*Swietenia mahagoni*) in Florida only takes place after the fruits dehisce and the seeds become exposed (Howard and Giblin-Davis 1997). Collection just before the fruits open would in this case prevent infestation. Several insects attack fruits during a long maturation period, and in tree species with long fruiting season combined with insect species with short life cycles, the insect population and hence the infestation rate may build up during the fruiting season (cf. example of *Apion* in chapter 4). Consequently, the earlier the collection, the smaller the number of infested fruits and seeds. Where fruits and seeds are already infested, early collection may still save the seeds if the young and small stages of larvae are killed or their development stopped before the seeds are irreversibly damaged. A minor attack by e.g. bruchids, where only small parts of the cotyledons are affected, is not fatal unless the infested place is used as entry point for fungal infection.

Protection against seed insects by physical shielding of individual fruit-bearing branches with nets has been used in *Acacia spp.* but is very labour intensive and applicable only on a small scale e.g. in seed orchards or for research (Southgate 1983).

Various types of chemical protection are available. In India, field infestation has been controlled by spraying individual fruit-bearing branches or trees with 0.25% endosulfan or fenitrothion water emulsions, or 0.05% monocrotophos or dichlorvos water emulsion (Singh and Bhandari 1987). Several problems and limitations are, however, connected to the use of chemical spraying:

1. Spraying is only applicable to accessible fruits, i.e. relatively low trees and shrubs, unless aerial spraying is pertinent (Singh 1976).
2. The effect of chemical treatment cannot be limited to the target pest, but will frequently affect harmless or beneficial organisms, e.g. seed-pest predators or pollinators. Birds feeding on treated seeds or insects may also be affected.
3. Spraying cannot be applied in seed sources with public access where seeds or fruits are used for consumption. For example, spraying of *Acacia nilotica* pods was dissuaded in areas where the pods are used for local medicine or fodder for domestic animals (El Atta 1993).
4. It is difficult to apply the chemical in a dosage where it is effective over a longer period.
5. Chemicals may have detrimental side effects to the tree as well as to the surrounding environment, cf. 2.

Where chemical treatment is used in the field, timing of application is crucial both to achieve the optimal effect of the treatment (and hence the best economical result) and to avoid harmful side effects. For insect-pollinated species, insecticide application during flowering should be avoided, as it may kill pollinators (Johnson 1983). Insect larvae that have already entered the interior of seeds may not be affected by chemical treatment on the outside of fruits or cones. Appropriate timing is especially difficult in insect-

pollinated species with prolonged flowering and where insects attack at an early stage of development, e.g. bruchid beetles in *Acacia spp*.

Timing is less crucial for the use of systemic pesticides with long-acting effect. In North America, two serious pests affect seed production of Douglas-fir (*Pseudotsuga menziesii*): the cone worm (*Dioryctria reniculelloides*) attacks the cones directly; an indirect effect on seed production is exerted by the bud worm (*Choristoneura occidentalis*) by its destruction of tree foliage. Repeated defoliations by the latter deplete the nutrient reserves and render the trees unable to produce cones and seeds. Implantation of capsules containing 0.875 g acephate insecticide into the sapwood every 10 cm around the tree bole one meter above the ground has proven to be an effective field treatment against both pests (Koerber 1989, Stein *et al.* 1988). **Generally, chemical insect control in the field is only applicable in seed orchards.**

7.2 Insect Elimination or Reduction during Seed Processing

Elimination or reduction of infestation is appropriate, e.g. in cases where the insects are able to continue destruction and re-infestation of seeds under storage conditions. Even if the seed lot cannot be totally free from seed insects, a reduction of their population will greatly limit reinfestation. Seeds infested by field insects only, may not be a serious problem in storage but such seeds are preferably removed in order to increase the general quality of the seed lot; damaged, non-viable seeds are at the best redundant to store, at the worst they may harbour infective fungi which can spread to other seeds. **Seed insects may be eliminated either by removing infested seeds or by killing the insects inside the seeds.**

During extraction procedures where fruits are exposed to high temperatures, e.g. kiln drying, any stage of insects, whether adult, pupa, or larva, present inside the fruit or seed is normally killed. In other words, species normally extracted by high temperature, e.g. serotinous cones, are normally insect free after processing. In tree species where seeds are tolerant to a brief high temperature exposure, the method may be used as a treatment. A quick dip in hot water (80-100- 13°c) may be effective in some species and not in others. The efficiency of the method depends on temperature tolerance level of seed and insect and transmission of heat within the fruit or seed.

1. Seed embryos of some species are temperature sensitive. For example, *Cassia* seeds are often killed by temperatures under boiling point, whereas several *Acacia* species tolerate several minutes' boiling. Tolerance also depends on moisture content of the seed, which influences both metabolic activity and heat transmission through the seed. Seeds with high moisture content are thus much more sensitive to high-temperature damage than dry seed.

2. Actively feeding larvae are killed by a brief high-temperature exposure while pupae are much more resistant i.a. because of the insulating effect of the cocoon.

Low temperatures may also be effective in killing insects inside infested seeds. In Argentina a cold treatment of -18°C for 10 days was effective to kill all stages of bruchids in infested seeds of *Prosopis chilensis* (Mazzuferi *et al.* 1991). Also low-temperature treatment must be given with due consideration to seed tolerance: seeds with high moisture content are more sensitive. Because recalcitrant seeds do not tolerate desiccation and temperature extremes, temperature treatment for insect control is not applicable to these seeds. However, prolonged storage at safe minimum temperature and moisture content may gradually kill insects inside these seeds or at least delay their development.

Insect-infested seeds may be eliminated from sound seeds during the seed-cleaning process if their physical properties differ. For example, where insects have consumed most of the interior of seeds, these

are normally lighter than intact seeds and may be removed by **winnowing, blowing or flotation**. Which method is efficient (or sufficient) depends on the physical variation within the seed lot and the difference between infested and non-infested seed. If seeds vary in size, separation is facilitated by initially grading the seeds into several size fractions by screening. Each fraction is then sorted by e.g. blowing or flotation. Special derivations of the flotation method have been developed for separating infested seeds from uninfested seeds, e.g. PREVAC and IDS (Bergsten and Sundberg 1990, Bergsten and Wirklund 1987).

For chemical treatment during processing, see chapter 8.

7.3 Seed Insects Controlled by Storage Conditions

Storage conditions should aim at preventing any development of insect stages present inside the seeds and exclude any new infestation during storage. Seeds from a previous seed lot or insects (typically adults or pupae) left in cracks, corners, old containers etc. may carry a potential source of seed destruction for a new seed lot in storage. Thorough cleaning and possible disinfection of store rooms, bags and containers are measures to prevent transmission from previous seed lots (Singh and Bhandari 1988). Where seeds are stored at ambient temperature, mechanical barriers, such as plastic sheets or insect nets, may prevent entrance of flying insects and hence infestation (Howe 1972). However, while e.g. polyethylene sheets may be effective in preventing insects entering into the bags, escaping insects may easily penetrate the sheets upon departure.

The most efficient way of reducing insect damage during storage is by **appropriate drying and subsequent storing at low temperature**. Although some storage insects are able to feed on and infest seed at low moisture content, the activity of most species is reduced in very dry seed, and infestation through a dry seed coat is low. Any reduction in temperature is likely to reduce insect activity. For most tropical species there is little activity below about 10°C, but even a small temperature reduction may lower both general activity and development. A temperature of 5°C was able to delay the development of bruchids in *Prosopis chilensi*s but did not kill the insects (Stoyanova 1984). Reproduction and thus re-infestation is usually limited by a smaller temperature reduction than necessary to impose metapauses of larvae. However, whenever the insects metabolize, they produce heat and water. They may thereby improve the microenvironment in their immediate vicinity which in turn may promote their activity (Singh and Bhandari 1988). **Ventilation** in connection with low temperature helps to avoid favourable local microclimate sites.

Seed may be stored safely in an atmosphere of CO_2; see further in paragraph 8.2.

8. SEED TREATMENT WITH CHEMICALS

Chemical treatment of seed lots to control seed insects may be necessary where (1) pests cannot be eliminated during processing, (2) where there is a risk that insect predation may continue or accelerate during storage or (3) where complete freedom from insect pests is required for phytosanitary reasons.

Several methods of control are available. Choice of method depends e.g. on seed type (species), infestation type, quantity of seed to be treated, available material and trained staff.

8.1 Fumigation

Fumigation denotes application of a gas that is toxic or inhibits the insects' metabolism. The method is used in other connections of plant propagation, e.g. sterilization of nursery soil. The advantages and

disadvantages of fumigation, as compared to other seed treatments, such as insecticide powders, pertain to their volatile nature:

1. Gases have high penetration efficiency and will usually reach the target organism, unless it is deeply hidden within the seed.
2. The gases do not adhere to the seeds, therefore there is no residual pesticide left on the seed after treatment.
3. The effect is short and restricted to the duration of treatment; the gases have normally no effect after they have escaped from the seeds.
4. Insects absorb gases through the cuticle. The greater the metabolic activity, the greater and quicker the effect. Accordingly, fumigation has larger effect on adult stages and feeding larvae than on eggs and pupae; and the effect increases with temperature within the physiological limits.
5. Seeds must be treated in containers impermeable to gases.
6. The gases are often invisible and without smell, so it is important that their possible toxicity to humans is not ignored (cf. chapter 9).

Several fumigants with proven effect on seed-insect control are available. The most common ones are ethylene bromide, hydrocyanic gas, a mixture of carbon disulphide and carbon tetrachloride, phosphine and pirimiphs (Willan 1991). For bruchid beetles in *Acacia tortilis*, fumigation with carbon disulphide, aluminium phosphide or chlorosal (a mixture of three parts ethylene chloride and one part carbon tetrachloride) has been used in India (Singh and Bhandari 1987). The above fumigants are all toxic to humans and should be handled with the utmost care, and only by authorized staff using safety protection. Further, most of the fumigants are phytotoxic, so prolonged exposure of the seed should be avoided (Singh and Bhandari 1988).

8.2 Treatment with CO_2

CO_2 is a non-toxic gas which has been used successfully for seed treatment of many species of orthodox seeds. CO_2 is a product of aerobe respiration. In normal atmosphere it makes up some 0.03% while, in comparison, O_2 makes up some 20%. CO_2 is non-toxic to the insects at its normal atmospheric concentration, but when present in large concentrations in proportion to oxygen, it blocks some physiological pathways of the respiration system. Since seeds are not metabolically active at low moisture content, CO_2 is harmless to the seeds whereas living insects are killed in an atmosphere of high CO_2 and low O_2 content. Adult and larval stages with relatively high metabolic rate are easier to kill. Pupae have active metabolism during their metamorphosis, but may also be dormant and then more resistant. Because CO_2 is harmless to dry seeds, seeds can be stored in plastic bags with the gas for prolonged periods (Sary *et al.* 1993). Seeds with high moisture content and hence metabolism, e.g. recalcitrant seeds, do not tolerate prolonged exposure to CO_2 fumigation. In Australia a maximum of 10 days' exposure to CO_2 is recommended for recalcitrant seeds (ATSC 1996).

CO_2 is available at most places of the world since it is extensively used for e.g. fire extinguishing and thin-plate welding. It is available in refillable metal bottles from approx. 6 kg and larger. Stored under pressure of approx. 40 atmospheres (bars), CO_2 is liquid. The pressure in the bottle decreases as the CO_2 is used. An adjustable pressure-reduction valve must be connected to the bottle to reduce the pressure of the outlet and allow a steady flow of the gas. The most convenient type is a flowmeter in which the pressure of the outlet can be adjusted quite exact, which makes it easier to determine the time it takes to fill a bag with CO_2. A hose is fitted to the flowmeter/reduction valve at one end and a blowing pistol for pressurized air at the other. All connections should be provided with gaskets and closely fit to avoid leaking of the gas. When all joints are fitted, the pressure of the bottle is released by opening the main valve. Possible leaks

may be checked by applying a thin layer of soap water or thin oil to fittings with a paint brush; escaping gas will be detected as bubbles blown in the liquid.

Seed to be fumigated with CO_2 is placed in heat-sealable plastic bags with low permeability to CO_2. Laminated plastic material consisting of an outer layer of approx. 0.03 mm thick polyamide (nylon, low CO_2 permeability) and an inner layer of approx. 0.07 mm low-density polythene (ordinary plastic, heat-sealable) is suitable. An alternative laminate has aluminium foil instead of the outer polyamide layer. Bags less than 4 litres are preferred as larger bags are more difficult to fill and they tend to puncture easily.

During filling, the bag is kept upright with its opening as flat as possible, yet allowing the air to escape as CO_2 is introduced. CO_2 is introduced through a tube into the bottom of the bag (see fig. 6). Because CO_2 is heavier than atmospheric air, it will flush out the air while filling the bag. It is recommended to flush the bags with twice the volume of the empty bag, e.g. 8 litres of CO_2 flushed into a bag of 4 litres. Flowing rate at a given pressure can be read directly on the flowmeter. Where a pressure-reduction meter is used, the flowing rate per minute is initially checked by filling an empty bag of known volume.

For larger bags it is advisable to seal the major part of the opening and only leave space for inserting the filling tube. Immediately after filling the bag is sealed with an electric heat sealer. Special heat sealers make a broad tight seal and allow adjusting of temperature and sealing time to the particular material thickness. It is important that the temperature and time are adjusted so that the two sides melt together without melting holes in the material. During sealing, the bag is kept upright and the sealing site kept clean. (For further information on CO_2 fumigation, see Sary et al. 1993)

Since CO_2 is absorbed by the seed, a vacuum will develop within the bag. Initially the sealed bag must be stored at room temperature for about 8 weeks in order to assure a sufficiently high metabolic rate of the insects to increase the effect of CO_2.

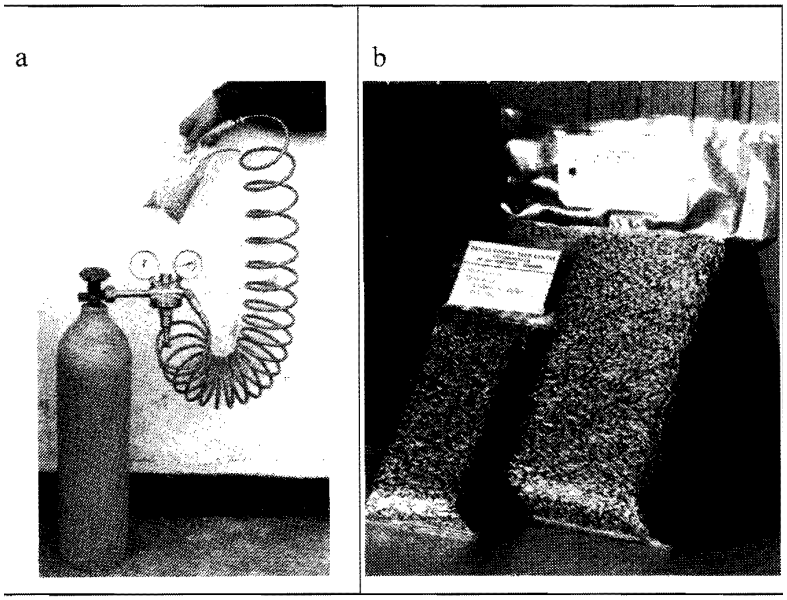


Figure 7. Fumigation with CO_2, (a) Application of CO_2 to bag with dry seeds. CO_2 is heavier than atmospheric air, and when the gas is placed at the bottom of the bag, it will replace normal air and fill the inter-seed air space of the bag. (b) Bags of seeds after fumigation; because the seeds absorb CO_2, a vacuum is created. These bags were only filled to about 3/4 of the capacity and sealed so that space was left above the seeds to insert a label. The bags were sealed a second time at the top to keep the label in place.

8.3 Insecticides

Chemical treatment with insecticides should be minimized as much as possible, but may be imperative at heavy attacks, and where preventive measures or CO_2 fumigation is not applicable. Seeds containing dormant or hidden stages of insects, which easily escape CO_2 fumigation, and which are subsequently stored at ambient temperature may typically require use of insecticides. A number of insecticides are effective against seed insects. Most products are developed for and have their main use in agricultural or horticultural seeds, their use in forestry being secondary and in quantity of minor importance.

The commonly used insecticides in forest seeds are grain protectants where the remedy is incorporated in and mixed with the seeds after processing. These are typically contact pesticides where the target organism dies after absorption of the poison through the skin. Systemic pesticides are occasionally used in seed orchards to prevent or control an attack. Here the chemical is either sprayed on green leaves and fruits and then taken up by the plant, or it is implanted under the bark of the stem. In both cases the insecticide is translocated within the tree and thus also to the fruit and seed prone to attack.

The basic requirements of insecticides are:

1. Efficacy
2. Minimum risk to user
3. Environmental safety

Re. 1. Efficacy concerns the ability to kill, or prevent attack from, the target insect i.e. efficiency. The typical pattern is a high efficacy at the time of application which gradually wears off during a shorter or longer period. The type of pesticide used depends on predator pattern. Where fruit maturation is synchronized and insect attack in the field is concentrated within a short period, spraying with a momentarily efficient and rapidly degrading contact pesticide is applicable (provided spraying is practically possible e.g. in low seed-orchard trees). Such products are little effective against insects attacking fruits at different development stage, and where fruit maturation takes place over a prolonged period of time. Here the most effective insecticides are systemic ones with a long efficacy period.

Since some resistant individuals in an insect population usually escape treatment without being killed and pass genes for resistance to their offspring, resistant populations are continuously formed. The problem is frequent in agriculture (e.g. malathion resistance) but less so in forest seeds where the selection pressure is less. Where resistance occurs, alternative products must be used.

Re. 2. All insecticides are poisonous to humans, but their toxicity varies. Although strict rules and prescriptions on safety measures aim at reducing safety risk during handling, failure to comply with these rules plus inevitable accidents cause both injuries and deaths. While toxicity through inhalation of gaseous compounds and ingestion are usually recognized as potential dangers, dermal toxicity (absorption through the skin) is often overlooked. Where a particular pesticide can be replaced by a safer one with the same effect, it is usually advisable.

Re. 3. A dilemma often exists between the ability to assure long-term efficacy, i.e. to protect the seed from attack for a prolonged period, and at the same time be degradable and harmless once it is no longer needed. Long-acting pesticides are naturally the ones with slowest degradability. Residual pesticides may leave seeds poisonous during a prolonged period after application, during which special care must be taken during seed handling. Of more concern is, however, their long-term environmental impact. Compounds relatively harmless when used in small dosages for insect control may accumulate in the food chain e.g. seeds → insects → insect-eating birds → birds of prey. The last link in the chain may

suffer seriously from accumulated toxins. A well documented example of this is DDT, a formerly widely used insecticide. Slow degradable pesticides or their residuals may also find their way to ground water or wells, from where they directly or indirectly may contaminate human food or drink.

New insecticides are currently being manufactured and marketed. The appearance of new products pertains to the above three points. New products are marketed if they are (l) more efficient, e.g. against which resistance has not (yet) developed; (2) safer for humans than other equivalent products, and (3) environmentally safer. The environmental concern has eliminated a number of formerly commonly used pesticides, primarily chlorinated hydrocarbons and products containing heavy metals.

Pesticides consist of an active ingredient or compound which is the one with direct impact on the insect, plus a number of additives such as carrier and emulsifier which make the product stable and facilitate application. The state in which the insecticide is sold is called its formulation e.g. soluble, dust or wettable powder. The same pesticide may be sold in different formulations dependent on its potential use. Dust is the most frequent formulation for application to dry seed in storage. The same product may be sold under different trade names according to manufacturer. Labels on product container will indicate active ingredient or common name.

Combined pesticides in the form of mixed fungi-and insecticides are available. Where chemical treatment or protection against both fungi and insects (and possible others) is necessary, mixed commercial products are recommendable rather than mixing different pesticides before treatment. However, mixed products often imply unnecessary use of part of the compound. For example, insecticides are only occasionally necessary while treatment with fungicides may be much more imperative.

Dust formulations are mixed with the seeds and/or applied to gunny bags or containers. In India, phorate or pyrethin dust is mixed with seeds (Singh and Bhandari 1988), and in Australia a light dusting of low toxicity insecticide (malathion, pyrethrin or hexachloride) is recommended for long-term storage of susceptible seeds stored under ambient conditions (Cremer 1990). Insecticides with fumigant action (toxic gas gradually being released from solid particles) may be applied as granules or pellets mixed with the seeds.

Most insecticides are classified according to the chemical structure of their active ingredient, their mode of action and/or the source of manufacturing. Synthetic pesticides encompass chlorinated hydrocarbons, organic phosphates, carbamates and pyrethroids (synthetic equivalents to the natural compounds in pyrethrum flowers). Extracts (crude or refined) from plants with insecticidal efficacy, mainly *Chrysanthemum cinerariaefolium* (pyrethrum) and *Azadiracta indica* (azadiractin) form a transition to traditional and biological methods, where various parts of plants or inorganic products are used to kill or repel insects. Among the synthetic products organic phosphates and pyrethrum are by far the most important, mainly because chlorinated carbohydrates are being excluded from most countries for environmental reasons. A brief description of some of the main insecticides is found in appendix 2.

8.4 Biological Methods

Traditional grain protectants are becoming increasingly popular along with the growing concern about adverse effects of insecticides in nature. Apart from being environmentally safer, traditional grain protectants are usually safer to human beings and cheap compared to commercial insecticides. A list of some plants with insecticidal effect (botanical pesticides) is given in table 1.

Table 1. Plant and plant parts used for insect control in storage, particularly for bruchids (Golob and Webley 1980, quoted in Johnson 1983).

Plant species	Plant part or extract used
Azadirachta indica	leaves, kernels or seed oil
Chrysanthemum cinerariaefolium	whole plants or flower heads
Capsicum	pepper chilis
Cactus spp.	stem powder
Anona reticulata	custard apple seed powder
Mundulia sericca	stem bark powder
Piper nigrum	black pepper powder, extract
Madhura latifolia	stem bark powder
Acorus calamus	rhizome powder, oil
Thevetia nerifolia	powder of drupes
Adhatoda vasica	leaf powder
Ipomea cornea	leaf powder
Derris elliptica	oil
Pogostemon heyneanus	pachouli oil
Nigella sativa	black cumin oil
Phaseolus vulgaris	bean oil
Allium cipa	oil
Allium sativum	oil

Among the many plants with all edged insecticidal or insect-repellant effect, two plants, *Chrysanthemum cinerariaefolium* (pyrethrum) and *Azadirachta indica* (neem) have gained major importance for insect control, including seed pests. Both plants have been and can be used with little processing where they are locally available. A number of commercial insecticides are being manufactured from extracts of the two plants (pyrethrum products are mentioned above).

Traditional use of neem grain protectants includes both leaves, crushed seeds and sawdust. The concen-

tration of the prime active ingredient, azadirachtin, is apparently higher in the seeds but it occurs in other parts of the plant as well. These neem plant parts are simply mixed with seeds during storage. This is a widely used practice in for instance rice storage (Soon and Bottrell 1994), and the protection potential ranges from 3-8 months. Commercial azadiractin insecticides are manufactured from neem kernel oils or other seed extracts. The insecticidal effect of neem products is broad. It rarely kills the insects instantly but delay or inhibit their development e.g. by preventing moulting, inhibiting reproduction or interfering with their feeding (Soon and Bottrell 1994). Jute sacks treated with neem oil or neem extract prevent entry of weevils into the grain (NRC 1992) which suggests a repellent effect. In some species the effect is merely delayed development while other insect species are killed by the treatment. Although there is little documentation to support possible insecticidal effect of related species, it is reported that *Azadirachta excelsa* and *Melia azedarach* have similar properties.

Traditional use of pyrethrum includes the entire plant. The concentration of active ingredient is higher in the flower heads which are also the parts from which commercial pyrethrum products are manufactured. Pyrethrum kills most insects upon direct contact with the active chemical, while the effect is mainly repellent when pyrethrum is used as unrefined mix of plant parts with seeds.

Several traditionally used plant protectants release a strong odour which is apparently avoided by insects; others have a direct insecticidal effect. Although the efficacy of most traditional plants needs to be thoroughly investigated and documented, it is likely that a large potential exists. In addition to plants and plant extracts, several minerals with alleged insect-repellent or insecticidal effects have been listed by Golop and Webley (1980, quoted in Johnson 1983). These include diatomite, termite mound soil, kaolin and lime. A more recently developed method of biological insect control is establishing insect traps, where the insects are attracted by pheromones. The practical application of the method has not been documented for seed insects. There also seems to be a largely unused biological potential in the use of seed-insect predators or parasitoids (Southgate 1983).

9. SAFETY PRECAUTIONS DURING HANDLING OF PESTICIDES

Use of pesticides in seed handling should be limited to the absolutely necessary. Where pesticides are used, they must be handled with due respect, and the seed handler must comply with the safety precautions prescribed by the manufacturer. Any toxic chemical should be provided with a label from the manufacturer indicating toxicity, e.g. in classes A, B, C, or I, II, III. The system varies although there are some widely accepted standards e.g. in U.S and E.U. Each toxicity class implies a standard set of precautions. Highly toxic pesticides should only be handled by authorized personnel under observation of strict safety rules throughout handling. Some general rules and precautions are listed here (a more detailed discussion on safety measures is found in Bohmont 1990, and CABI/BCPC 1998):

1. Read instruction from the manufacturer carefully and handle the remedy accordingly.
2. Use the concentration prescribed by the manufacturer.
3. Never make experiments of mixing different chemicals.
4. Prepare pesticide mixtures in a well ventilated place.
5. Always use gloves during preparation and application; in the case of liquid remedies, water-proof rubber gloves should be used.
6. Use masks and protective glasses when applying toxic fumigants, sprays and dust.
7. Check and repair any leak from containers and equipment. Replace worn gaskets in equipment used for fumigation and spraying.
8. Do not leave pesticides unattended. Have a locked up room or cabinet specially for pesticides and application equipment.
9. Never store food or drink together with pesticides. Never fill pesticides into containers normally used for food and drink, e.g. coke bottles.
10. Dispose any left-over remedy safely.
11. Be prepared for accidents; the universal emergency agent is water which should always be available within reach.
12. Keep pesticides out of reach of children, - and keep children far away from pesticides.
13. Only personnel having received appropriate instruction and training should be allowed to handle pesticides.

Seeds which have been surface treated or mixed with a long-acting toxic pesticide should be handled with similar precaution measures as during treatment. Accidental intake of treated seeds, inhalation of pesticide dust or direct skin contact with seeds treated with pesticides with dermal toxicity may cause health hazards. These factors are often overlooked but imply on one hand that treatment should be well documented e.g. shipment papers (type, toxicity class etc.) and on the other hand that safety precautions are taken, e.g. use of gloves, masks and, if necessary, safety glasses.

10. REFERENCES

Arguedas, M. 1997

Plagas de semillas forestales en America Central y el Caribe. Seria Técnica. Manual Técnico no. 25. CATIE, Turrialba, Costa Rica.

ATSC 1996

Operation manual. Australian Tree Seed Centre, CSIRO, Australia.

Auld, T.D. 1991

Patterns of predispersal seed predators in the Fabaceae of the Sydney Region, south-eastern Australia. Australian Journal of Zoology, 39:5, 519-528.

Barbosa, P. and Wagner, M.R. 1989

Insects that attack seeds and cones. Chapter 12 in: Introduction to forest and shade tree insects. Academic Press, pp 277-290.

Bengston, M. 1986

Grain protectants. In: Pesticides and Humid Tropical Grain Storage Systems (Champ, B.R. and Highley, eds). Proceedings of an international seminar, Manila, Philipppines 27-30 May 1985. ACIAR Proceedings No. 14, pp. 277-289. Canberra.

Bergsten, U. and Sundberg, M. 1990

IDS sedimentation of *Cupressus lusitanica* seeds. In: Tropical tree seed research (Turnbull, J.W. ed.). Proceedings of an international workshop held at the forestry training centre, Gympie, Qld., Australia, 21-24 August 1989. pp. 99-102.

Bergsten, U. and Wirklund, K. 1987

Some physical features conditions for removal of mechanically damaged *Pinus sylvestris* L. seeds by using the PREVAC method. Scandinavian Journal of Forest. Research, 2:3,315-323.

Bohmont, B.L. 1990

The standard pesticide user's guide. Prentice Hall.

CABI/BCPC 1998

The UK pesticide guide (Whitehead, R.. ed.). CAB International/British Crop Protection Council, U.K.

Cremer, K.W. 1990

Trees for rural Australia. Inkata Press, Melbourne and Sydney.

El Atta, H.A. 1993

The effect of *Caryedon serratus* Oliver (Col., Bmchidae) on viability and germination of seeds of *Acacia nilotica* (L.) Willd. ex Del. in the Sudan. For. Ecol. Management 57: 169-177.

Eldridge, K., Davidson, J., Harwood, C. and Wyk, C. van. 1993

Eucalypt domestication and breeding. Oxford Science Publ.

Ernst, W.H.O., Decelle, J.E., Tolsma, D.J. and Verweij, R.A. 1990

Lifecycle ofthe bruchid beetle *Bruchidius uberatus* and its predation of *Acacia nilotica* seeds in a tree savanna in Botswana. Entomol. Exp. Appl. 57: 177-190.

Eungwijarnpanya, S. and Hedlin, A.F. 1984

Studies on insects of some forest trees. The Embryon, 1: 1, 48-55.

Ferraz, I.D.K. and Sampaio, R. de T.B. 1996

Metodos simples de armazenamento das sementes de andiroba (*Carapa guianensis* Aubl. e *Carapa procera* D.C. Meliaceae). Acta Amazonica, 26:3, 137-144.

Golob, P. and Webley, DJ. 1980

The use ofplants and minerals as traditional protectants of stored products. Report of the Tropical Products Institute G138.

Halevy, G. 1974

Effects of Gazelles and seed beetles (Bruchidae) on germination and establishment of *Acacia* species. Isr. Jour. Bot., 23: 120-126.

Hedlin, A.F. , Yates III, H.O., Tovar, D.C., Ebel, B.H., Koerber, T.W. and Merkel, E.P. 1981

Cone and seed insects of North American conifers. Canadian For. Serv., For. Serv. U.S. Dept. Agric., and Secreataria de Agricultura y Recursos Hidraulicos, Mexico.

Hilje Q., Luko, Araya F., Carlos, Scorza R., Felix and Viquez C., Manuel. 1991

Plagas y enfermedades forestales en America Central. Serie Técnica, Manual Técnico No.3. CATIE, Turrialba, Costa Rica.

Holmes, P.M. and Rebelo, A.G. 1988

The occurrence of seed feeding *Zulubius acaciophagus* (Hemiptera, Alydidae) and its effect on *Acacia cyclops* seed germination and seed banks in S. Africa. South African Jour. Bot. 54: 4, 319-324.

Howard, F.W. and Giblin-Davis, R.M. 1997

The seasonal abundance and feeding damage of *Hypsipyla grandella* (Lepidoptera: Pyralidae) in seed capsules of *Swietenia mahagoni* in Florida. Florida Entomologist, 80: 1, 34-41.

Howe,R.W. 1972

Insects attacking seeds during storage. In: Kozlowski, T.T. (ed.): Seed Biology. Vol. III. AP.N.Y. and London. pp. 247-297.

Janzen, D.H. 1972

Escape in space by *Sterculia apetala* seeds from the bug *Dysdercus fasciatus* in a Costa Rican deciduous forest. Ecology, 53:2, 350-361

Janzen, D.H. 1980

Specificity of seed-attacking beetles in a Costa Rican deciduous forest. Journal of Ecology, 68: 929-952.

Janzen, D.H., Juster, H.B. and Bell, E.A. 1977

Toxicity of secondary compounds to the seed eating larvae of the bruchid beetle, *Callosobruchus maculatus*. Phytochemistry, 16: 223-227.

Johnson, C.D. 1983

Handbook of seeds of *Prosopis* species. FAO, Rome

Johnson, C.D., Zona, S. and Nilsson, J.A. 1995

Bruchid beetles and palm seeds: recorded relationship. Principes 39:1, 25-35.

Khatua, A.K. and Chakrabarti, S. 1990

Life history and seasonal activity of sal seed weevil, *Sitophilus* (*Calandra*) *rugicollis* Casey (Coleoptera: Curculionidae). The Indian Forester, 116:1, 63-70.

Koch, C.K. and Campos, S. 1978

Biocenosis del tamarugo (*Prosopis tamarugo* Philippi.) con especial referencia de los artrópodos fitófagos y sus enemigos naturales. Zeitschrift fur angewandte Entomologie 85: 86-108.

Koerber, T.W. 1989

Spring and fall trunk-implanted acephate for protection of Douglas-fir from defoliation by western spruce budworm. In: Miller, G.E. (ed.): Proceedings of the 3rd cone and insect working party conference, working party S2. 07 -01. June 26/39, 1988. IUFRO. pp. 220-223.

Labeyrie, V. 1981

Ecological problems arising from weevil infestation of food legumes. Series Entomologica, 19: 1-15.

Lamprey, H.F., Halevy, G. and Makacha, S. 1974

Interaction between Acacia, bruchid beetles and large herbivores. E. Afri. Wildl. J. 12: 81-85.

Mazzuferi, V.E., Cragnolini, C. and Argello, J.A. 1991

Cold treatment as a method of insect control and its effect on germination and vigour in *Prosopis chilensis*. Seed Sci. & Technol. 19: 435-438.

NRC 1992

Neem, a tree for solving global problems. National Research Council. National Academic Press, Washington D.C.

Plant Prot. Res. Inst. 1987

Beetle release to curb the spread of blackwood. Plant Protection News No 8:3. Plant Protection Research Institute, South Africa.

Rees, A.A. and Phillips, D.H. 1986

Detection, presence and control of seedborne pest and deceases of trees with special reference to seeds of tropical and subtropical pines. Technical Note No. 28. Danida Forest Seed Centre.

Saelim, S., Pukittayaacamee, P., Bhodthipuks, J. and Wang, B.S.P. 1996

X-radiography Testing for Viability of Tropical Forest Tree Seed. Proceedings of an ASEAN training course on rapid viability testing of tropical tree seed. Muak-Lek, Thailand. February 1994.

Sary, H., Yameogo, C.S. and Stubsgaard, F. 1993

The CO_2 method to control insect infestation in tree seed. Technical Note No. 42. Danida Forest Seed Centre.

Singh. K.D. 1976

Timber seed pests. Seed Technology in the tropics. 1976: 47-51.

Singh, P. and Bhandari, R.S. 1987

Insect pests of *Acacia tortilis* in India. The Indian Forester 113:11, 734-743.

Singh, P. and Bhandari, R.S. 1988

Insect pests of leguminous forest tree seed and their control. The Indian Forester 114:12, 844-853.

Snelson, IT. 1987

Grain protectants. ACIAR Monograph No.3. Canberra, Australia.

Soon, L.G. and Bottrell, D.G. 1994

Neem pesticides in rice, potential and limitations. International Rice Research Institute (IRRI). Philippines.

Southgate, B.J. 1983

Handbook on seed insects of Acacia species. FAO, Rome.

Stein, J.D., Koerber, T.W. and Frank, C.L. 1988

Trunk-implanted acephate to protect Douglas-fir seed crops on individual trees in northern California. Journal of Economic Entomology, 81:6, 1668-1671.

Storer, T.I., Stebbins, R.C., Usinger, R.L. and Nybakken, J.W. 1979

General Zoology. McGraw-Hill Book Comp.

Stoyanova, A. 1984

Seed desinfection using low temperatures. Plant Science XXI: 3, 91-96.

Wagner, M.R, Atuahene, S.K.N. and Cobbinah, J.R. 1991

Pest of flowers, fruits and seeds. In: Forest entomology in West Tropical Africa: Forest insects in Ghana. Kluwer Ac. Publ. pp. 89-102.

Wali ur Rehman 1995

Studies of seed insect pests of forest trees. Pakistan Jour. For. 43:1, 27-31.

Willan, R.L. 1991

Phytosanitary problems in seed procurement. DFSC Lecture Note No. C-12. Danida Forest Seed Centre.

11. GLOSSARY

ADI (Acceptable daily intake). The maximum dose of a substance that is anticipated to be without risk to humans when taken daily.
Active ingredient(s). The chemical(s) in a product responsible for the desired effect. Apart from the active ingredient(s), formulations consist of other ingredients e.g. emulsifiers, solvents or carriers.
Biological control. Control of pests by means of predators, parasites, and disease-producing orgamsms.
Botanical pesticide. A pesticide produced by and extracted from plants e.g. pyrethrum and azadiractin.
Chlorinated hydrocarbon. Organic chemical compound consisting of carbon, hydrogen and chlor. A wide range of chlorinated carbons are used in chemical industry e.g. as pesticides. Gradually being replaced by other compound because of their slow degradation in nature.
Carcinogen. A chemical capable of producing cancer.
Carrier. The liquid or solid that is used to dilute the active ingredient in manufacturing a pesticide formulation.
Contact pesticide. A pesticide that is absorbed through the skin of the pest organism after which the insect is killed.
Cumulative pesticide. Chemical that tends to accumulate or build up in the tissues of individuals, in the food chain (i.e. in predators) or in the environment (soil, water).
Degradability. The ability of chemical compounds to decompose or break down into less compound complex compounds or elements.
Dermal toxicity. Poisoning caused by pesticides passing through the skin of humans. Dermal toxicity is especially pronounced for many organophosphates.
Diapause. A spontaneous state of dormancy during development. May occur during any stage of the life cycle thus not necessarily restricted to the transition period during metamorphosis.
Dust. A formulation consisting of and applied to the seed as dry powder pesticide.
Emulsifiable concentrate. A concentrated pesticide formulation usually consisting of a pesticide dissolved in an organic solvent and a surface-active agent that permits dispersion of the total formulation in water.
Emulsifier. A chemical that is used to form a stable mixture between two liquids that would usually not mix, e.g. oil in water. The emulsifier helps one liquid to form tiny droplets that can remain mixed in the other liquid.
Entomology. The studies of insects.
Formulation. The type of pesticide product when sold, e.g. dust. solution or wettable powder. The formulation consists of the active ingredient(s), the carrier plus other additives required to make it ready for sale.
Fumigant. A substance applied as a gas, vapour, fume or smoke to kill the target organism. Fumigants may be volatile liquids, solids or gases.
Galls. On plants, growths caused by insects; size usually few mm to few cm. Larvae grow inside the galls.
Host specificity. The degree to which a predator or parasite is specialized to one or several host species. Host-specific insects may attack only one or a few (then often related) tree species, as opposed to generalists, which may attack a wide range of species, sometimes without taxonomic relation.
Infestation. Invasion by an exterior organism. In pathology, distinguished from infection where the latter refers to invasion by endoparasites i.e. micro-organism living inside the host organism e.g. a seed. In insect terminology, referring to any attack where the insect (larva, nymph or adult) lives inside the organ (e.g. fruit or seed) or together with these e.g. in a seed lot.
Insecticide. The type of pesticide applied for control of insects.

Instar. Stage of an insect between moults. Commonly used for progressively developing larval stages in species with complete metamorphosis, larval instars.
Metamorphosis. The period or the process of rapid transformation from juvenile to adult form.
Complete metamorphosis. Metamorphosis with a distinct juvenile form, larva, which is very different from the adult stage, imago. Transformation takes place during a resting stage, pupa. Found e.g. in butterflies, bees and flies.
Incomplete (gradual) metamorphosis. Metamorphosis in which the young, nymph, resembles the adult though without wings and without mature sexual organs. Transformation takes place through several more or less distinct nymph stages which appear progressively more like adults. Found in e.g. true bugs and grasshoppers.
Moult (molt). The cast or shed of outer coverings like skin or hair. Occurs e.g. in connection with gradual (incomplete) metamorphosis from one nymph stage to the next.
Nymph. A juvenile form of insects with incomplete metamorphosis, see above.
Oviposition. Egg laying by insects.
Ovipositor. Organ for egg laying, positioned on the terminal end of female insects. In some insects extended into a long sharp or pointed organ by which the insect penetrates e.g. bark, fruit or cones to insert its eggs. In sterile 'worker' bees and whasps modified to a sting.
Parasite. An organism living on or with an individual of a different species (the host) and from which it derives its food during a prolonged period without killing the host.
Pathogen. A disease-producing micro-organism.
Pest. An organism, e.g. an insect, causing damage or destruction of a host or prey organism. Also referring to the damage or destruction itself. Often distinguished from damage caused by micro-organisms, e.g. 'pests and diseases' or 'pests and pathogens'.
Pesticide. Collective term of all substances intended to kill or control pests, pathogens and weed. Pesticides are usually classified according to their specific target-group organism e.g. herbicides (weed), insecticides (insects), fungicides (fungi), nemacides (nematodes) and rodenticides (rodents).
Phytotoxic. Injurious or lethal to plants.
Predator. An organism that destroys or kills another organism or organ for food, e.g. seed predators. There is a gradual transition from parasitism to predation where the former refers to a prolonged deprivation of food from a host during which the host may be weakened but not necessarily killed; during predation the entire food source (whether part of or the entire organism) ceases to function and eventually dies after a short period; for some types of attack death is instantaneous.
Pupa. In complete metamorphosis, the stage between larva and adult insect. During pupal stage, the transformation occurs while the insect appears dormant and does not feed.
Radiograph. Image created on a film or photographic paper after radiation e.g. by X-rays
Residual pesticide. Pesticide remaining on the seed or in the soil after a specific period of time. The level of residual pesticide relates e.g. to natural degradation and possible prolonged toxicity.
Resistance. The ability of an organism to suppress or retard the injurious effects of e.g. a pesticide.
Seed treatment. The application of a pesticide to seeds in order to protect them from attack by pests and pathogens.
Serotinous. Of fruits and cones that remain closed and usually on the tree for a long period after maturity. Extraction of seeds from such fruits and cones normally requires heating.
Systemic pesticide. Pesticides which are absorbed by and then distributed within the plant or seed, where they will kill e.g. insects feeding on the plant. Ant. non-systemic pesticides which need direct

physical contact with the target organism e.g. contact pesticides.

Target organism. The type or species of organism against which a control measure is directed. The target organism of an insecticide may be a particular insect, e.g. bruchid in legume seed. Non-target organisms are organisms against which the pesticide is not aimed but which may be affected by it.

Univoltine. Having one generation per year. Ant. multivoltine.

Wettable powder. Formulation of finely ground, dry powder that can be readily suspended in water for application by spray equipment.

Key Characteristics for Identification of Seed Insects

Identification of seed insects is generally far more complicated than identification of plants because the number of insects is vast and identification literature scarce. However, most seed insects belong to five orders which are very distinct, and families are relatively easy to identify on some key characteristics. Identification to genus or species level often requires entomological expertise. For practical purposes, identification to family or genus level often suffices. Most identification keys require adult specimens and where only insect eggs, larvae or pupae are available inside or on the seeds, adult stages may be reared e.g. by incubating the seed under controlled conditions until adult stages emerge. Where e.g. bruchid-infested seeds are placed in a plastic bag at room temperature, adult beetles will usually emerge within a few days. The morphology of a generalized insect with key terminology is shown in figure 7.

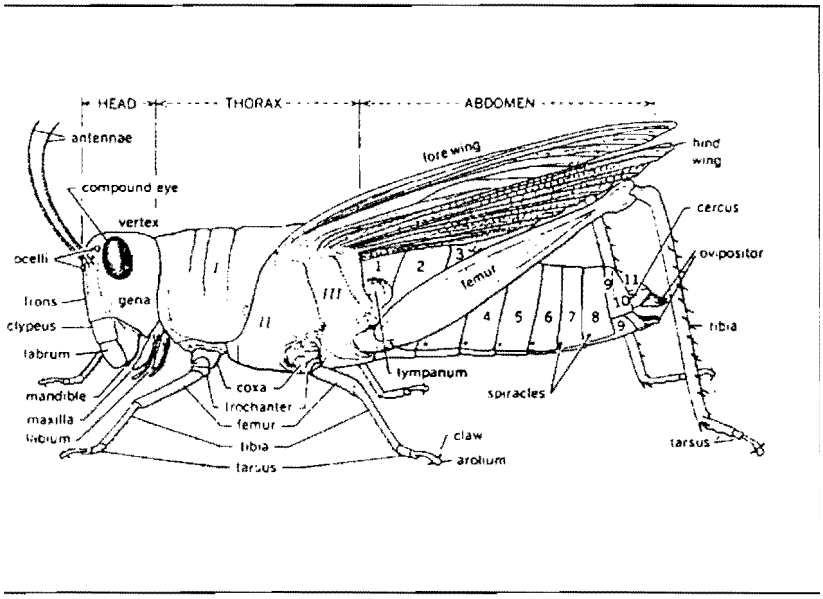


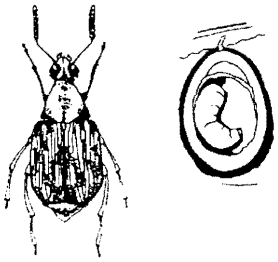
Figure 7. Morphology of a generalized insect (from Storer et al. 1979).

The majority of seed pests belong to the following five orders:

1. Coleoptera (Beetles)

Beetles have thick, hard, leathery fore wings which meet along the middorsal line. Hind wings are membranous, used for flight and folded under the fore wings during rest. Antennae usually 11-jointed. Larvae wormlike with distinct head capsule and usually thoracic legs. Both adult and larva have chewing mouth parts. Metamorphosis is complete. Pupa resembles the adult.

The three most important families of seed beetles are:
Bruchidae (bruchids) are relatively small (usually 3-8 mm) with oval body, somewhat truncated at both ends. Most species with large compound eyes, with a deep 'U'-shaped cleft opening towards the front, from which the thin antennae appear. Fore wings almost square, usually only slightly longer than wide. Legs with well developed claws. 56 genera of which the most com-



Bruchid (from Southgate 1983).

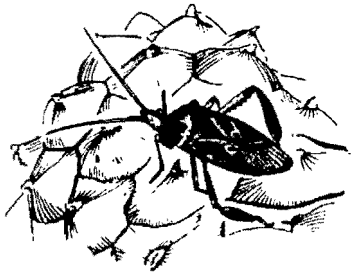
mon are *Brunchus, Brunchidius, Tuberculobruchus, Conicobruchus, Caryedon, Callosobruchus and Acenthoscelides*. Bruchids are the prevalent pest in Leguminosae such as *Acacia, Prosopis, Albizia, Brachystegia*, *Dalbergia spp.*, but are also found in e.g. Cordia
alliodora, some *Eucalyptus spp*. and palms. Species of the subfamily Pachymerinae feed almost exclusively on palm seeds in America (Johnson et al. 1995). Bruchid species have been found in 32 plant families (Johnson 1983).

Curculionidae (weevils or snout beetles) are small to large (to 50mm) hardshelled, often roughsurfaced; snout prolonged; antennae often elbowed; femora often swollen. Larvae legless. An important genus is Nanophyes which occurs throughout the tropics infesting e.g. *Terminalia ivorensis* in West Africa and dipterocarps in Malaysia. *Alcidodes dipterocarpi* attacks *Shorea spp*. in Thailand (Eungwijarnpanya and Hedlin 1984), and *Apion spp.* feed on *Triplochiton scleroxylon* in West Africa (Wagner *et al.* 1991).

Scolytidae (bark beetles) are short, cylindrical with clubbed antennae. Most species feed under the bark of trees but some attack fruits and seeds. The most common genus is Conophteorus, which causes vast destruction ofNorth American pine cones (Hedlin et al. 1981).

2. Hemiptera (Plant bugs)

True bugs have leathery fore wings with membranous tips which are crossed at rest; hind wings membranous and shorter than fore wings and folded under them at rest. The wings lie flat over the abdomen; triangular scutellum (small shield) between wing bases. The mouthparts consist of a bundle of needle-like stylets within a segmented sheath which forms a beak or tube-like structure (proboscis). During feeding, the bug inserts its proboscis into the food material; salivary fluid dissolves the food which is then sucked up through the duct of the proboscis. Metamorphosis is gradual with nymph stages which resemble the adults in form and feeding habit.



Leptoglossus sp.
(from Hedlin et al. 1981)

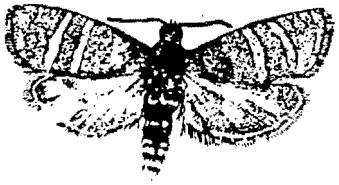
Dysdercus spp. attack mainly species of the plant order Malvales (Sterculiaceae, Malvaceae, Bombacaceae, Tiliaceae). *Zulubius acaciaphagus* causes heavy attack on *Acacia cyclops* in S. Africa (Holmes and Rebelo 1988), and *Leptoglossus spp*. are major pests of conifers in N. America (Hedlin *et al.* 1981).

Lepidoptera (Moths and butterflies)

Adults with four membranous wings almost wholly covered with minute overlapping scales. Antennae long, thread or feather-like; eyes large. Body scaly or hairy. Mouthparts of adults of most species consist of a long proboscis, coiled up when not in use. Adults usually feeding on flower nectar are important pollinators. Larvae (caterpillars) usually cylindrical with three pairs of thoracic legs and up to five pairs of abdominal legs. Well developed heads with chewing mouthparts. Larvae produce silk cocoons. Pupae compact with appendages fused to the body.

There are two major families with members causing seed damage.

Olethreutidae. This family of moths contains a large number of cone insects. Species of the genera *Barbara*, *Eucosma*, and *Laspeyresia* cause great damage to conifers in North and Central America (Redlin *et al.* 1981). *Ofatulena spp.* feed on *Prosopis* flowers and fruits. *Cryptophlebia carpophagoides* is a South American species that attacks the pods and



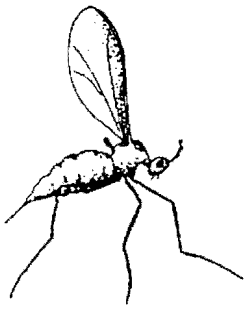
Laspeyresia sp.
(from Hedlin et al. 1981)

causes heavy loss in leguminous species such as *Enterolobium contortisiliquum* in Argentina and *Prosopis tamarugo* and *P. juliflora* in Chile (Koch and Campos 1978, quoted in Johnson 1983). *Leptotes trigemmatus* feeds on *P. tamarugo* in Chile.

Paralidae (snout moths). The main genus attacking conifers is *Dioryctria* (coneworms), which infests cones and seeds as well as flowers and young shoots. It occurs both in the temperate and tropical region. *Dichocrocis punctiferalis* infests seed of *Tectona grandis* in Thailand (Eungwijarnpanya and Redlin 1984). *Agathiphaga* is a moth that infests cones and seeds of *Agathis spp.* (Willan 1991). *Hypsipyla grandanella*, best known from its great damage to mahogany shoots, also attacks their seeds (Roward and Giblin-Davis 1997). In W. Africa *H. robusta* attacks *Khaya*, *Entandophragma* and *Carapa* species.

4. Diptera (true flies)

Adults have a single pair of membranous fore wings, hind wings are reduced. Mouthparts modified for piercing and sucking, often in the form of a proboscis. Body division distinct. Abdomen of 4-9 visible segments. Complete metamorphosis. The larva is legless with head retracted into the thorax.

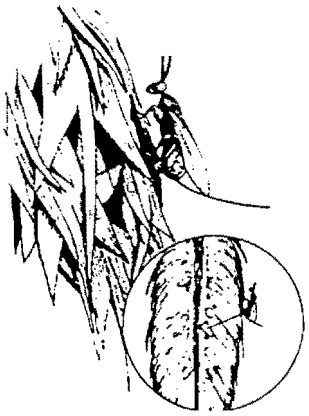


Contarinia sp.
(from Hedlin et al. 1981)

Cecidomyidae (gall gnats or midges) are minute, mosquito-like with antennae with whorled hairs. Many produce galls in which larvae are reared. The shape and size of the galls on the plants may help to identify the insect. Others are predaceous or parasitic. Members of the families **Anthomyiidae** (root maggot flies) and **Lonchaeidae** cause destruction of cones in North American and Central American conifers (Redlin et al. 1981, Arguedas 1997).

Hymenoptera (wasps, sawflies and seed chalcids)

Adults have four membranous wings, the hind wings being distinctly smaller than the fore wings. Wing venation is sparse. Body division distinct ('wasp waist'). Mouthparts of the chewing type. Female with ovipositor for sawing, piercing or stinging. Metamorphosis complete. Larvae are variable; head capsules and legs are present in some families, absent in others. Pupa, frequently encased in a cocoon, resembles the adult. A single genus Megastigmus in the family Torymidae comprises a number of seed pests. Megastigmus species are quite specialized with regard to host species, method of attack and feeding habit (Hedlin *et al.* 1981). Their main hosts are conifers in which they are often a serious pest, but they also attack e.g. *Eucalyptus spp.* (Eldridge *et al.* 1993), *Casuarina spp.* (Arguedas 1997) and *Sesbania grandiflora* (Eungwijarnpanya and Hedlin 1984). The female insect has a long ovipositor brood by which it penetrates the fruit and seed coat to lay its eggs within the developing seed. Number of eggs varies from one to several per seed. The larvae feed inside the seed and pupation also takes place within the seed. Infestation can thus not normally be recognized on the outside of the seed. The adult insect emerges via a round exit hole, which it chews through the seed coat and sometimes through the fruit as well.



Megasligmus sp.
(from Hedlin et al. 1981)

APPENDIX 2

Brief Description of Some of the Main Insecticides

A. Chlorinated Hydrocarbons

Also called organochlorines or organochlorine insecticides. These are organic compounds containing chlorine and were formerly the most commonly used seed treatments. Most compounds are, however, now either banned or have restricted use, and are gradually phasing out and being replaced in e.g. Europe and Unites States. The diminished use is partly due to observed resistance in some insect groups, partly due to slow degradation and, for some compounds, their tendency to accumulate in the food chain causing sterility or other adverse effects in higher animals. Few chlorinated hydrocarbons are used and available in Europe, United States and Australia, but they are still being manufactured, sold and used in a number of tropical countries with less strict environmental laws.

Lindane is a broad-spectrum insecticide with good penetration action. It is formulated as emulsifiable concentrate, dust, smoke pellets and wettable powder. Effective against most seed pests including internal infestations such as bruchids. Application rate about 10 mg per kg seed. Toxicity moderate to high. The insecticide remains effective for long periods after application (2.5 years, Snelson 1987). It has restricted use or is terminated in many countries and is generally phased out together with the other chlorinated hydrocarbons. However, a derivative, gamma-HCH, is still produced and used both as a separate insecticide and in combination with fungicides (CABI/BCPC 1998).

DDT. [Di-chlor di-phenyl trichlorethan]. Formulations wettable powder, dust and solution. Formerly widely used insecticide, now only available in a few countries in Asia, S. America and Africa. DDT is toxic to humans, but its main danger is through accumulation in the tissue of higher animals through gradual increasing concentration in the food chain, causing sterility and other irreversible disorders. The remedy has an extremely long degradation time in nature. Because of these effects it should no longer be used. Other chlorinated hydrocarbons formerly used in seed treatment but now restricted or terminated in most western countries are **Aldrin, Chlordane, Dieldrin, Endrin, Heptachlor, Methoxychlor, and Toxaphene**.

B. Organic Phosphates

Also called organic phosphorous insecticides. These are synthetic compounds derived from phosphoric acid. Organic phosphates are primarily contact insecticides, i.e. absorbed through the skin of the insects rather than consumed. Their efficacy is relatively short and they are decomposed relatively fast by water, pH extremes, high temperature and micro-organisms, thus with smaller environmental effects than e.g. chlorinated hydrocarbons. Toxicity to humans ranges from highly toxic for e.g. parathion to low for malathion. Toxicity is oral, dermal and through inhalation.

Dichlorvos [Vapona, Nuvan, Mafu]. Contact pesticide with fumigant and penetrant action. Specially effective against moths. Formulated as emulsifiable solutions, solutions, aerosols, and resin based slow-release strips. It has a short residual life. Because of its good penetration ability, the insecticide is effective against internal infestations e.g. larval stages of seed beetles. Application rate for wheat 6-12 mg /kg at 30°C and 55%RH may serve as a guideline. Acute oral and dermal toxicity high.

Malathion. Formerly widely used grain protectant in agriculture, now gradually being replaced by other products because of resistance. For forest seeds still one of the most widely used insecticides. Formulated

as emulsifiable concentrates, dust and wettable powder. The insecticide has little penetrant action but emergent insects will be killed when they come in contact with treated seeds. Application rate: 8mg/kg grain for 9 months' protection of wheat in Australia at 30°C and 55%RH may serve as a guideline (Bengston 1986). Low toxicity but protection gloves and shield should be used when mixing concentrate.

Parathion. Formerly a widely used insecticide in agri- and horticulture. Formulated as solutions and wettable powder. It is highly toxic but with relatively low residual toxicity.

Diazinon. Broad-spectrum insecticide albeit with little use as seed protectant. It has some fumigant action in the sense that its vapour penetrates the treated seed lot. It is, however, little effective against internal infestations, but kills the emerging insects.

Phenitrothion (**fenitrothion**) [trade names: **Sumithion, Folithion, Cytel** and others]. Broadspectrum insecticide, effective against most insect species. Formulated as emulsifiable solutions, wettable powder and dust. Oral toxicity moderate, dermal toxicity low (Bengston 1986). The insecticide is variable according to producer. For most tree species, application rate in the range of 5-12 mg per kg dry seed is suitable. This dose gives protection for some 9-12 months. Sometimes used in connection with pyrethrum insecticides. The insecticide degrades reasonably fast in nature but is restricted in use because of its toxicity (Bohmont 1990). In India, dusting of gunny bags with 5% folithion dust for short term storage and 10% for long term storage was recommended for control of bruchid beetles in *Acacia tortilis* seed in storage (Singh and Bhandari 1987).

C. Carbamates

This group of pesticides encompasses both herbicides, fungicides and insecticides. In connection with seed insects the two main carbamates are **Bendiocarp** (**Bencarbate**) and **Carbaryl**. Formulations are dust, wettable powder or granules, and the products are often traded combined with other pesticides. Carbamates resemble organic phosphates in terms of toxicity and environmental impact. Toxicity may be caused by inhalation, swallowing or through the skin.

D. Pyrethrum

This is a complex group of insecticides consisting of extract from pyrethrum flowers (*Chrysanthemum cinerariaefolium*) or synthetic equivalents (pyrethroids). The term 'pyrethrum' refers to both the flower, the whole plant, and the crude, concentrated or refined extract. Pyrethrin is the active ingredient. Pyrethrum is insoluble in water. It is formulated as solutions and emulsifiable concentrates. Pure pyrethrum formulations are not stable and easily lose their efficacy. Therefore most pyrethrum formulations are added piperonyl butoxide, an anti-oxidant, to enhance their effects and prolong their insecticidal activity. Pyrethrum is effective against a wide range of insects, both adults and larvae. They have a low both oral and dermal toxicity, but unrefined extracts may produce allergic reactions. Pyrethrums degrade rapidly in nature and have thus no long-term adverse environmental impact.

Because the products are safe for humans and the environment, they are very useful insecticides. Their main limitation is their unstable nature. Both light, high temperature and high humidity enhance degradation and thus shorten the effective protective period. However, in dry grain, pyrethrum formulations containing piperonyl butoxide are capable of giving protection for up to 12 months (Snelson 1987).