Biology, Damage and Control of Bruchid Pests of Mungbean

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Abstract

Three bruchid species — *Callosobruchus chinensis* (L.), *C. maculatus* (F.) and *C. analis* (F.) — infest mungbean in the field and during storage. Major damage, however, results from the insect infestation during storage. Bruchid larvae bore into seeds and feed on the cotyledons in which they pupate. Insect feeding reduces the quality and quantity of mungbean seeds. Drying of seeds briefly at 55° to 60°C kills the bruchids inside the seeds. Drying seeds to moisture contents of below 9.5% before storage reduces bruchid infestation considerably. Coating seeds with 5 to 10 ml of vegetable oils per kg of seeds, fumigation with phostoxin, or mixing seeds with insecticides of low mammalian toxicity such as malathion, DDVP or pyrethrins protect stored seeds from bruchid infestation. Sex pheromones have a potential to monitor pest incidence, thereby enabling control measures to be taken in time to reduce further losses. One black gram and one *Vigna glabrescens* accessions are highly resistant to *C. chinensis*; however, utility of these resistance sources in breeding bruchid-resistant mungbean cultivars by conventional breeding techniques is limited due to genetic barriers. A new mungbean accession with a moderate level of bruchid resistance is now available. This is expected to hasten the breeding of bruchid-resistant mungbean cultivars.

Introduction

Among scores of species of bruchids — insects belonging to the coleopterous family Bruchidae — that infest food legumes in the tropics, three species, *Callosobruchus chinensis* (L.), *C. maculatus* (F.) and *C. analis* (F.), infest mungbean (*Vigna radiata* [L.] Wilczek) in the field and during storage. The former two species are native of Asia and Africa. Mungbean, cowpea and pigeonpea serve as their principal hosts. *C. analis*, an Asian native, is now found to be a pest of cowpea in Africa (Southgate 1978). Due to the movement of grains via trade, these pests, especially the former two, are now found in all six continents where they attack a wide range of pulses. Although the bruchids, commonly called pulse beetles or cowpea weevils, attack mungbean in the field and storage, it is the infestation of grains during storage that results in the greatest loss. In this paper, therefore, after a brief discussion of their identification and biology, a detailed account of the nature of their damage and measures to minimize storage losses incurred by them will be discussed.

Identification

Due to the lack of adequate published reports on the systemics of Bruchidae, there have been numerous misidentifications of the bruchid species in the past. However, two publications by Southgate (1958) and his colleagues (Southgate et al. 1957) have removed much of the confusion. Since certain old names are still being used in the literature, the synonymy of each of the three species that attack mungbean is summarized in Table 1 (Vazirani 1976). Certain striking morphological characters which differ in these species, and which are useful in bruchid identification, are described below.

Table 1. Synonymy of three bruchid species that infest mungbean.

Callosobruchus chinensis (L.)	*Callosobruchus maculatus* (F.)	*Callosobruchus analis* (F.)
Curculio chinensis L. 1758	*Bruchus maculatus* F. 1775	*Bruchus analis* F. 1781
Bruchus pectinicorus L. 1767	*Bruchus quadrimaculatus* F. 1792	*Bruchus jekeli* All. 1847
Bruchus rufus De Geer 1775	*Bruchus ornatus* Boh. 1829	*Bruchus glaber* All. 1847
Bruchus scutellaris F. 1792	*Bruchus vicinus* Gyllen. 1833	*Callosobruchus analis* Southgate, Howe et Brett 1957
Bruchus bistriatus F. 1801	*Bruchus ambiguus* Gyllen. 1833	
Bruchus barbicornis F. 1801	*Callosobruchus maculatus* Pic 1913	
Bruchus elegans Sturm. 1826		
Bruchus chinensis Sch. 1833		
Bruchus adustus Mots. 1874		
Callosobruchus chinensis Mukerji & Chatterji 1951		

Source: Vazirani 1976.

The shapes of antennae and the hind femur are two common characters that are used to easily distinguish the three bruchid species. In *C. chinensis* males, the fourth through apical segments are pectinate to highly pectinate whereas in females these segments are serrate. In *C. maculatus* the antennae are slightly serrate from the fourth through apical segment and in *C. analis* antennae are wholly testaceous and not serrate. The hind femur in *C. chinensis* is ventrally bicarinate with a denticle situated on each carina near the apex. The outer tooth is blunt and the inner tooth is long and straight, and rounded at the tip. In *C. maculatus* the hind femur is ventrally bicarinate, with a large blunt tooth on the outer carina and a sharp tooth of similar size on the inner carina. Both teeth are situated near the apex. In *C. analis*, the hind femur is usually ventrally bicarinate, with a large pointed tooth on the outer carina. The tooth on the inner carina is very minute or absent.

Since larvae and pupae are always hidden, their identity require greater efforts. Vats (1974) and Begum et al. (1982) give details of distinguishing characters of bruchid larvae and these characters can be used in conjunction with those of the adult's to confirm the identity of each species. Wightman and Southgate (1982) provide very useful information on the distinguishing characters of eggs of nine bruchid species based on scanning electron microscopic (SEM) studies. Observation of the morphological characters of the adults provides the easiest form of identification. Southgate et al. (1957) and Southgate (1958) should be referred to in order to confirm the identity of the species discussed in this paper.

Biology

Several studies, mainly in the Indian subcontinent, report on the biology of *Callosobruchus* on various pulses (Rahman et al. 1943, Arora and Pajni 1957, 1959, Rajak and Pandey 1965, Raina 1970). In general, the life cycle history of all three species follows a typical coleopterous insect. There is very little difference among the three species. Raina (1970) made a detailed comparative study of the biology of the three species reared on mungbean at 30°C and 70% relative humidity (RH), a condition considered ideal for the development of the three bruchid species. The following information is extracted largely from his results.

Mating and Oviposition

Adults mate within an hour after emergence from the seed. Mating lasts 5 to 8 min in *C. chinensis*, 3 to 8 min in *C. maculatus* and 3 to 6 min in *C. analis*. Although the insects mated several times, only one mating is sufficient to ensure egg laying. Eggs are covered with a sticky substance which fastens the eggs to the seed surface (Southgate 1979). At the time of oviposition, *C. chinensis* and *C. maculatus* deposit a chemical 'oviposition marker' on the seed surface which has an ovicidal and arrestant action (Oshima et al. 1973, Yamamoto and Honda 1977, Honda et al. 1978). This chemical, a mixture of fatty acids, triglycerides and hydrocarbons, prevents the hatching of more than one or two eggs per seed and helps regulate the pest population and maximize use of the food. Yamamoto (1976) suggests that this chemical can be used as a possible oviposition inhibitor to control the bruchids. Certain edible oils (see discussion under Control Measures) give a similar ovicidal effect.

Callosobruchus chinensis laid an average of 78 eggs over a period of eight days; *C. maculatus* laid 128 eggs and *C. analis* 96 eggs over a nine-day period. Howe and Currie (1964) reported a slightly different fecundity data of the three species but this could be due to the selection of different host, cowpea, in their study.

Usually one to three eggs are laid over an individual seed although as many as five eggs in a study at AVRDC (unpublished) and seven in Raina's (1970) study were found on a single mungbean seed, when some seeds were still without eggs. The number of eggs laid was significantly correlated to the seed size (r = +0.95) in one study at AVRDC (unpublished). The average incubation period was 3.5, 4 and 5 days, respectively, for the eggs of *C. chinensis*, *C. maculatus* and *C. analis*. Egg hatching for all three species ranged between 94% and 99%.

Larval Stage

Soon after hatching the larva makes a hole in the seed coat, just underneath the spot where the egg is laid, and enters the kernal where it feeds concealed inside the seed. When the eggs are laid on the pods, as in the case of insect infestation in the field, the newly hatched larva makes a hole through the pod cover, enters the developing seed and feeds and pupates inside the developing seed. Before pupation bruchid larva gnaws a circular hole until only a thin layer or 'window' of seed coat is left intact. The combined larval and pupal period was 18.8, 20 and 23.5 days for *C. chinensis*, *C. maculatus*, and *C. analis*, respectively (Raina 1970).

Adult Stage

Adults of all three bruchid species emerge by cutting open the 'window' in the seed testa. The entire development from egg to the adult stage takes an average of 22.3, 24 and 28.5, days respectively, for *C. chinensis*, *C. maculatus* and *C. analis* at 30°C and 70% RH (Raina 1970). A similar developmental time was observed by Atwal et al. (1968) in *C. analis* on mungbean under similar environmental conditions. There was no difference in developmental time and life span between male and female in all three species and the sex ratio was 6:5, 7:6 and 1:1 males to females, respectively, for *C. chinensis*, *C. maculatus* and *C. analis*. *Callosobruchus chinensis* males and females lived an average of 7.6 and 7.4 days, *C. maculatus*, 8.2 and 7.6 days, and *C. analis*, 6.8 and 8.0 days, respectively. Developmental mortality from egg to the adult stage was 23% in *C. chinensis*, and only 9% for the remaining two species. Most of the mortality observed was in the egg and early larval instars.

Nature and Extent of Damage

Damage in the Field

Although bruchids attack mungbean in the field, damage to seeds *per se* is only minor. However, when infested seeds are stored, the adults emerge and lay eggs on the neighboring seeds. This secondary infestation is much more damaging. Banto and Sanchez (1972) report from 7.8% to 9.9% seed infestation by *C. chinensis* at the time of harvest. Infested seeds harbored bruchid larvae of varying stages of development.

Damage during Storage

Three aspects of bruchid damage are of particular importance: (i) the overall weight loss; (ii) changes in nutritional quality and presence of off-smelling by-products of insect infestation; and (iii) loss in seed viability.

Seed weight loss. Weight loss can be a direct consequence of bruchids feeding on the seed. It may also occur as a result of accelerated loss of moisture due to perforation by bruchids of the mungbean seed. Vimala and Pushpamma (1983a) found that the level of insect infestation, as assessed by insect count, kernal damage, frass content and weight loss, increased with the period of storage up to one year. The percentage of kernals damaged in mungbean increased from 0.53% at the beginning of storage to over 16% after one year of storage and weight loss from 0.32% to 7.22% during the corresponding period. Gujar and Yadav (1978) report a weight loss of 55.6% to 73% in individual seeds damaged by a single *C. maculatus* and 30.2% to 55.7% by *C. chinensis* in one generation. Banto and Sanchez (1972) reported total destruction of seeds when newly harvested, infested mungbean seeds (9.9% seeds damaged) were stored for three months. Infested seeds were unfit for human consumption.

Seed quality changes. Loss or denaturation of proteins and vitamins reduce the nutritional quality of pulses. In addition, the presence of insect excrement, cast larval skins, pieces of insect chitin or dead insects can have an abrassive effect on the human alimentary canal.

Vimala and Pushpamma (1983a) found up to 45 dead/alive insects per 100 g mungbean seeds after one year storage when practically no insects were present at the initiation of storage. Mungbean seeds contained from 0.39% to 0.41% frass after one year storage when practically none existed at the initiation of storage. No significant changes occurred in the grain moisture content. Uric acid, a metabolic by-product of insects which is present in insect excrement, increased from barely detectable levels at the initiation of storage to up to 31.5 g/100 g mungbean seeds. The authors reported a significant positive correlation between the number of insects and the uric acid contents of mungbean seeds. The uric acid content reached above safety level after eight months of storage and still remained above that level after one year of storage. Similarly, Singh et al. (1982) observed that free fatty acids, reducing sugars and uric acid contents increased with the increase in infestation of *C. chinensis* during a five-month period in three mungbean cultivars. The uric acid content was considerably greater in mungbean than in black gram as was the bruchid infestation. Doharey et al. (1983) also observed an increase in free fatty acids and alcoholic acidity in mungbean during 120 days of storage due to *C. chinensis* and *C. maculatus* infestation. They also reported that *C. chinensis* infestation increased protein content from 22.15% to 47.14%, and *C. maculatus* infestation increased from 22.15% to 57.55%, whereas in the check it only increased to 32.34%. No explanation for this change in protein content is offered by the authors. However, this anamoly appears to be due to the use of an inappropriate analytical method to determine the protein concentration. Doharey et al. (1983) estimated protein by analyzing total nitrogen rather than protein nitrogen (see Gujar and Yadav 1978).

Vimala and Pushpamma (1983b) found that the starch content of mungbean was decreased by 6.19% after one year of storage and certain changes were observed in the reducing and nonreducing sugars and digestibility of stored mungbean seeds. But whether this is due to bruchid infestation or a normal change during storage is unknown. Pingale et al. (1956) found a reduced concentration of thiamine in stored mungbean seed infested with *C. chinensis*. The reduction was roughly in proportion to the amount of insect damage to the seed. In addition, insect damage increased fat acidity and caused slight denaturation of protein.

Seed viability loss. Even slight feeding damage by bruchids to the embryo impairs germination. Such feeding on the cotyledon will not affect germination but the vigor of the young seedling will be reduced, as in cowpea, due to similar damage by *Acanthoscelides obtectus* (Say) (Chin 1980). In a study with three mungbean and two black gram cultivars, Singh and Sharma (1982) observed a progressive increase in seed damage and a proportional decrease in seed germination during a five-month storage period. In mungbean, the seeds damaged by *C. maculatus* varied from 42.53% to 57.77% and loss in seed germination from 47.53% to 70.60%. There was much less seed damage and less reduction in viability in black gram seeds. Significant differences were observed in seed damage and viability among both mungbean and black gram cultivars. As the level of *Callosobruchus* infestation to mungbean seed kernals increased from 4.33% to 16.67%, the loss of viability increased from 16.23% to 28.90% (Vimala and Pushpamma 1983c).

Control Measures

The nature and extent of bruchid damage described above entails sound control practices in order to protect the harvest from the ravages of bruchids, especially during storage. Because of the primitive nature of the storage facilities in many of the villages where most of the mungbean crop is grown on small farms, the small volume of produce, and the fact that the grains are frequently used for consumption, the use of fumigants or other insecticides is impractical. For bruchid control, therefore, sound farming practices, good storage facilities, coupled with nonchemical control measures are necessary. These measures include, the drying of seeds before storage, use of bruchid resistant cultivars, nontoxic chemicals such as vegetable oils, sex pheromones, biological control, and as a last resort, the use of selective and safe chemicals.

Although several hymenopterous parasites have been reported to attack bruchids in the egg, larval and pupal stages, their impact on populations is insignificant. Their use in biological control of bruchids during storage is not practical.

Drying of Seeds

A seed moisture content of below 10% impairs normal activity and development of storage insects and at moisture levels below 9.5% certain of these pests do not even oviposit (Girish 1983). Besides, most insects die within 10 to 20 min at temperatures of from 55° to 60°C. The tropical sun is helpful in heating and drying the grains, thus ridding the seeds of bruchid infestation. Yoshida and Gichuki (1983) found that when adzuki bean seeds are spread in the sun in a layer of 3 cm deep, 55°C was reached in 1.5 h and maintained for 4 h and 40 min. With a layer of 1.5 cm deep, 55°C was reached within 30 min and maintained for 4 h. Sun drying of the grains before storage will thus not only reduce the risk of insects from primary infestation in the field being carried into storage, the reduction in seed moisture will minimize reinfestation from secondary sources. Low seed moisture also prolongs the effectiveness of vegetable oil and insecticide treatments which might be used to protect the seeds from storage insects (Doharey et al. 1984, Talekar and Mookherjee 1969).

Resistant Cultivars

Cultivars resistant to bruchids are yet to be developed. Due to its low cost and ease in use, coupled with the limited utility of other methods, especially chemical control, the use of bruchid-resistant mungbean cultivars has a considerable potential. Since bruchids can infest mungbean pods in the field, as well as seeds in storage, resistance either in the pod, seed or both is desirable.

Resistance in the field. Doria and Raros (1973) screened 66 mungbean cultivars for resistance to *C. chinensis* damage to the pods. None of the entries was resistant to oviposition but resistance to larval survival was evident in EG Glabrous, EG-MG-4, and EG-MG-7. Mungbean accessions UPCA 23, 25 and 325 had the least number of eggs and lowest larval survival.

At AVRDC 525 *Vigna* accessions were screened in the field. One black gram accession, VM 2011, was found to be resistant to *C. chinensis* (Talekar and Lin 1981). A confirmatory test showed that insects laid significantly fewer eggs on the pods of VM 2011 than on those of VM 2164, an accession which is resistant to bruchid in the seed, or V 2184, the susceptible check (Fig. 1). Similarly, less adults emerged from the pods of VM 2011 than the others. Careful observation of the developing, as well as mature, pods of VM 2011 revealed the presence of very high trichome density on the pods. The high trichome density hindered the movement and oviposition of bruchid adults which resulted in considerable reduction in the number of eggs laid on the pods. Since mungbean is still harvested by hand on most small farms, high trichome density on the pods is an undesirable character. Hence, this resistance source was not utilized in the resistance breeding program at AVRDC.

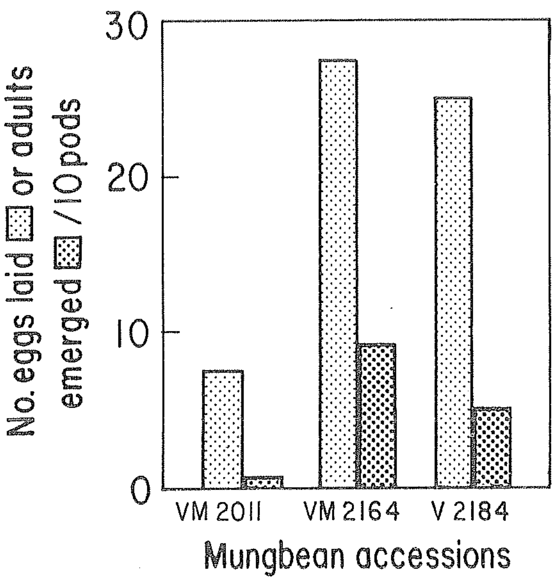

Figure 1.
C. chinensis oviposition and adult emergence from pods of three *Vigna* accessions.

Resistance during storage. In a preliminary screening of seeds of 525 *Vigna* accessions, one black gram accession, VM 2164, was the least damaged. In a confirmatory laboratory test with seeds of VM 2164, VM 2011 and V 2184, *C. chinensis* laid relatively fewer eggs on the seeds of VM 2164 than on those of VM 2011 or V 2184. When infested seed samples were stored for up to six months, seeds of susceptible V 2184 were totally destroyed by the bruchid. The number of bruchid adults emerged from 50 g seeds were 1,200, 1,000 and 54 in VM 2164, V 2184 and VM 2011, respectively (Fig. 2). A viability test showed over 80% germination in VM 2164 as against approximately 10% and zero germination in VM 2011 and V 2184, respectively (Talekar and Lin 1981). Bruchid eggs laid on the seeds of VM 2164 do hatch but the first instar larva makes only a small shallow feeding cavity and dies.

In a breeding program to incorporate *C. chinensis* resistance of VM 2164 into superior mungbean cultivars, the progeny of straight cross showed a high level of resistance. However, when backcrosses were made to get more mungbean characters, the backcross progeny with higher levels of mungbean characters showed higher susceptiblity (AVRDC, unpublished data). Hence the resistance breeding program based on VM 2164 was discontinued.

In renewed efforts to identify sources of resistance, preferrably in *Vigna* germplasm, so that the resistance can be easily incorported to improved breeding lines, screening of eight beanfly (*Ophiomyia phaseoli* Tryon) resistant accessions resulted in the identification of one *Vigna*

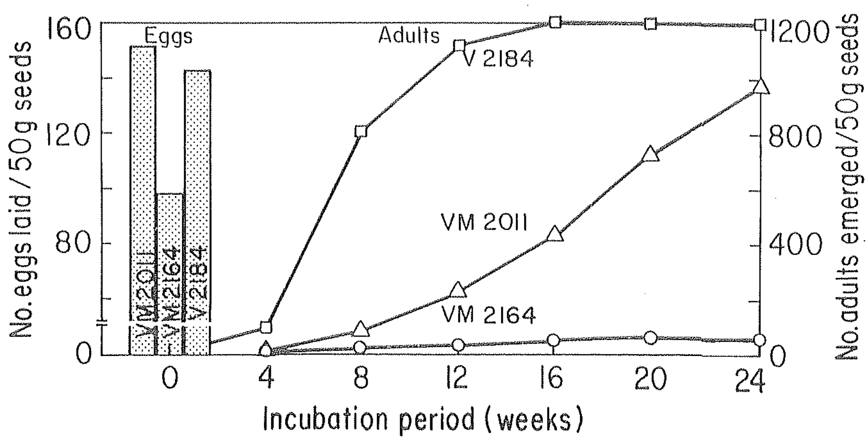

Figure 2. *Callosobruchus chinensis* oviposition and adult emergence from seeds of three *Vigna* accessions.

glabrescens accession, V 1160, that showed a high level of resistance to *C. chinensis*. Bruchids laid eggs on the seeds of this accession but the first instar larvae, in most cases, died after boring a short distance inside the cotyledons. Since *V. glabrescens* is a tetraploid, its use in a resistance breeding program will encounter a genetic barrier in transferring the resistance into mungbean by conventional breeding methods. Plans are underway at AVRDC to transfer the bruchid and beanfly resistance from this accession into mungbean by unconventional techniques. In the meantime screening of additional mungbean accessions resulted in the identification of V 2802, which was least damaged by *C. chinensis* in two preliminary tests. In a confirmatory test, the number of adults emerged and seeds damaged were significantly less in V 2802 than in the susceptible check, VC 1973A in two generations (Table 2). In fact, the insect emergence and seed damage in V 2802 was not statistically different from VM 2164, the most resistant black gram accession. V 2802 thus represents an additional source of resistance in mungbean germplasm itself to *C. chinensis*. This accession, however, has a low yield potential. The mechanism of resistance is being characterized prior to initiating a breeding program.

Table 2. Infestation of selected mungbean accessions by *Callosobruchus chinensis*.

Accession no.	No. insects/10 g seed		Damaged seeds (%)	
	1st generation	2nd generation	1st generation	2nd generation
V 2802	7.2b	3.3b	2.88b	0.88b
VM 2164	0.0b	0.0b	0.00b	0.00b
VC 1973A	156.5a	92.0a	78.38a	12.60a

Data are means of four replicates. Means in each vertical column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Rajapakse et al. (1983) screened 11 mungbean cultivars for resistance to *C. chinensis*. Cultivars Uthong 1, H101 and CES 87 were relatively resistant as the number of insects emerging from the seeds of these cultivars were the least and *C. chinensis* required a longer period to develop from egg to adult in these cultivars. Epino and Morallo-Rejesus (1982) screened 60 mungbean accessions for resistance to *C. chinensis* in seeds. Based on the first generation bruchids that emerged, UPCA accessions 11 and 30 showed moderate to high levels of resistance. The seeds of resistant accessions adversely affected the survival, increased developmental time and reduced growth index and body weight.

Use of Vegetable Oils and Plant Products

The use of edible oils to protect stored grains, especially pulses, against insect pest damage is an ancient method of pest control in India. In addition to edible oils, extracts and plant parts of certain readily available plants, such as neem (*Azadirachta indica* Adr. Juss.) have also been utilized in villages where storage facilities are poor. In light of the adverse effects of insecticides on the environment, these methods of pest control are now attracting greater attention and research input.

In studies at AVRDC, mixing of soybean or groundnut oil at the rate of 2 to 3 ml/100 g seeds gave mungbean considerable bruchid protection for up to two months. Neither treatment affected seed germination but prolonging groundnut oil treatment to five months reduced seed germination considerably (AVRDC 1976). In a similar study Varma and Pandey (1978) utilized oils of coconut, mustard, groundnut, sesame and sunflower mixed with mungbean seeds at the rate of 0.3 g per 100 g (w/w) of seeds. Oviposition of *C. maculatus* was completely inhibited when coconut and mustard oils were used; very few eggs were found on mungbean seeds when other oils were used. Development of the adult population was prevented for at least five months, and the viability of the treated seeds was unaffected. Coconut oil was the most effective followed by mustard, groundnut and sesame. Pandey et al. (1981) used oils of cotton seed, rice bran and sal (*Shorea robusta* Gaertn. f.) at the rate of 0.3 to 0.5 g per 100 g of mungbean seeds. All three oils protected the seeds for five to six months. Neither rancidity nor free fat acidity increased significantly in the treated seeds, and there was no adverse effect on seed viability. Doharey et al. (1984) studied the utility of oils of coconut, groundnut, mustard, rice bran, safflower, sesame and taramira (*Eruca sativa* Mill.) in protecting mungbean seeds, adjusted to the moisture content of 9.6%, 10.8% and 12.8%, against *C. chinensis* and *C. maculatus*. A concentration of 1% oil (w/w) protected the seed from both species. A higher grain moisture of 12.8% significantly reduced the efficacy of safflower oil against both bruchid species. In a separate study Sujatha and Punnaiaii (1985) found that mungbean seeds can be effectively protected from *C. chinensis* by treatment with the oils of sesame, cotton seed, oil palm or neem at concentrations of 0.25% and those of groundnut or coconut at 0.5%. Treatment with all the oils at 0.125% resulted in lower infestation than the control.

In a study on the mode of action of groundnut oil, Sharma and Srivastava (1984) found a 90% reduction in oviposition by the oil treatment. Bruchid eggs affixed on the oil-treated seeds and 90% of the eggs died within 48 h as a result of coagulation of protoplasmic contents in the embryo. In the remaining eggs, the inhibition of embryonic development could be observed up to a certain extent but the embryo died soon thereafter. Singh et al. (1978), however, found that the groundnut oil treatment of cowpea seeds prevented the emergence of bruchid progeny from the seeds rather than affecting the oviposition or mortality of the bruchid adults. The oil entered the eggs of *C. maculatus* through the micropile and in 1- to 2-day-old eggs, protoplasmic movement stopped and the protoplasm coagulated. In 3- to 5-day-old eggs where the larvae are partially or fully formed, larval death occurred within minutes of the entry of the oil.

Jotwani et al. (1968) mixed 0.5, 1 or 2 g of crushed neem seeds with 100 g of mungbean seeds and observed the damage by *C. maculatus* in storage over several months. At the end of eight months, only 9.8% of the seeds were damaged in 2 g, 11.9% in 1 g and 18.8% in 0.5 g neem treatments, whereas in the control 59% seeds were infested by bruchids. In a second experiment, the authors found that treatment with up to 2.5 g crushed neem seed per 100 g mungbean seeds reduced the bruchid oviposition considerably over a period of four months. Neem apparently repelled the adults from laying eggs on the treated seeds. In similar experiments, Yadav (1985) applied 2 to 50 mg neem seed oil per 10 g mungbean seeds and confined adults of *C. analis*, *C. chinensis* or *C. maculatus* over the treated seeds. Treatment of 50 mg neem oil prevented oviposition of *C. maculatus* as against 40 mg in the remaining two species. Dosages of 30, 10 and 20 mg neem seed oil suppressed adult emergence in the three species, respectively. This was due to the toxic action of neem oil against the bruchid eggs (Yadav 1985). Rajasekaran and Kumaraswami (1985) obtained complete control of *C. chinensis* when extracts of karanj

(*Pongamia glabra Vent.*) and neem were coated on mungbean seed at the rate of 0.6% v/v and 0.8% w/w, respectively. In a series of laboratory tests in India, Qadri (1985) showed that neem extract synergized the toxicity of custard apple (*Anona* sp.) extract, and garlic extract synergized the toxicity of oleoresin obtained from chrysanthemum, to *C. chinensis*.

In a series of experiments, scientists at USDA's Stored Products Insects Research and Development Laboratory found that oils of several citrus fruits, extracts of black pepper (*Piper nigrum* L.), dill (*Anethum graveolens* L.), Chinese cinnamon (*Cinnamomum cassia* Nees ex Blume) are toxic to several insect pests including *C. maculatus* (Su et al. 1972, Su 1978, 1985a, 1985b). Similarly, Chander and Ahmed (1983) obtained good protection of mungbean against *C. maculatus* by mixing the powders of rhizomes of *Acorus calamus* L. (1%) and *Cucuma zedoaria* (Christm.) Roscoe (5%) and seeds of *Carum roxburghianum* Benth. Pranata (1984) found turmeric (*Curcuma longa* L.) powder extract to be toxic to the adults of *C. maculatus* when the extract was mixed with mungbean seeds. In one case vapors of *Acorus calamus* extract showed chemosterilant effect on *C. chinensis*. Exposure of adult females to the vapors reduced fecundity and caused regression in the terminal folicle at the vitellarium (Bhaskar et al. 1976).

Sex Pheromones

Utilization of sex pheromone chemicals represents the safest form of pest control. Although this approach has not been used in the control of any of the three bruchid species which attack mungbean, recent studies have pointed out the existence of sex pheromone in bruchids and their potential, especially for pest monitoring purposes. In a laboratory study at AVRDC (1976) which utilized virgin females and unmated males, blowing of air over virgin females placed in an olfactometer attracted large number of males towards the virgin females. One- to two-day-old females attracted a greater number of males than the older ones. The males showed characteristic excitatory behavioral response including rapid antennal movement and extension of wings. Similar observations were made for *C. maculatus* by Rup and Sharma (1978) and Qi and Burkholder (1982). The chemical properties of *C. chinensis* sex pheromone have been isolated and described (Honda and Yamamoto 1977, Tanaka et al. 1982). The pheromone consists of a mixture of callosobruchusic acid [(E)-3, 7-dimethyl-2-octenedioic acid] and several hydrocarbons. Neither the acid nor the hydrocarbons are active alone, their effect is synergistic.

Burkholder and Ma (1985) give details of the use of pheromones for monitoring various storage pests. The presence of a single bruchid in a trap indicates initiation of infestation and at such time suitable treatments can be utilized to reduce further loss. Bruchid pheromones can be utilized in the field in a similar fashion to monitor primary infestation of bruchids. The presence of bruchids in the pheromone-baited traps will indicate initiation of infestation of pods. At this time the whole crop can be sprayed with a suitable chemical to prevent further spread of the pest or the seeds from the infested field can be dried thoroughly to reduce grain moisture to below 9%. The heat of the drying will also kill the larvae, pupae and possibly adults inside the seeds and a reduced grain moisture level will considerably reduce the secondary infestation during storage.

Chemical Control

The appropriate insecticide when used properly gives assured and immediate control of insect pest during storage as it does in the field. However, the use of insecticides to protect mungbean in storage has serious limitations on small farms. Firstly, the grains are stored for short duration, in most cases from season to season. During this period the seeds are often used for family consumption. Under such conditions mixing grains with insecticides, even of relatively low persistence, is not advisable. Secondly, the use of fumigants is not practical because of the small sized produce and special precaution and training required to handle fumigants. Also in most cases mungbeans, along with other grains, are stored in living quarters where the use of fumigants poses hazards. Thirdly, mungbean is still a low priced low input crop and use of insecticides may be uneconomical. Under such circumstances alternative methods, such as use of vegetable oils, clean cultivation, storing seeds after thorough drying in a clean storage space, will assure protection from bruchid attack.

In community storage and large-scale commercial storage facilities, insecticides can be applied by mixing with seeds, spraying the surface of bulk storage or stacks and by fumigation to protect mungbeans from bruchids.

Insecticide dusts or sprays. Initially the storage space can be disinfested by spraying the area with suitable chemicals such as fenitrothion or chlorpyrifos methyl at the rate of 1 g a.i./m^2 (COPR 1981). Subsequent risk of reinfestation can be reduced by spraying the surfaces of loosely stored grains or bags at intervals of about eight weeks with the same chemicals. In the past mixing seeds with lindane or pyrethrin dusts was suggested to control bruchids. However, due to the availability of chemicals such as malathion, DDVP, fenitrothion, pirimiphos methyl, which are less toxic to mammals and less persistent than lindane but more persistent and cheaper than pyrethrum, use of lindane and pyrethrum are no longer recommended. These chemicals can be mixed at the rate of 5 ppm with grains meant for long storage. Among the synthetic pyrethroids Duguet and Wu (1986) applied deltamethrin at the rate of 0.75 and 1.00 ppm to artificially infested cowpea in storage. This treatment protected the grains against *C. maculatus* for up to six months, when pirimiphos methyl dust applied at the rate of 10 ppm was effective for only three months. In China spraying of mungbean seeds with deltamethrin plus piperonyl butoxide at the rate of 0.25, 0.50 and 1.00 ppm protected the seeds against *C. chinensis* for up to 228 days (Duguet and Wu 1986). Synthetic pyrethroids, which are as selective for their less toxic effect on mammals but higher toxicity to insects as natural pyrethrins, but which are more persistent than the natural pyrethrins, have promise in protecting mungbean seeds in storage. However, their dosages should be carefully chosen to give protection for only the intended length of storage so that it will not leave excessive residues.

Recently, Davis et al. (1984) found that exposure of adults of *C. chinensis* and *C. maculatus* to the dust of tricalcium phosphate, a commonly used fertilizer, causes complete mortality in 6 to 8 h. When insects were exposed to the compound mixed with snapbean (*Phaseolus vulgaris* L.) seeds at 0.01% to 0.25% concentrations, the number of F_1 adults of *C. chinensis* that emerged was greatly reduced. Similar results were obtained when *C. maculatus* adults were exposed to cowpea seeds treated with tricalcium phosphate and, in fact, at doses of 0.1% and above no F_1 adults emerged. Tricalcium phosphate is readily available and relatively inexpensive. However, its mode of action and possible health hazards associated with mixing with grain need further study before this treatment can be suggested to small-scale producers.

Fumigation. Like the above-described insecticide treatments, fumigation of mungbean is practical only in large-scale storage facilities. The greatest advantage of fumigation is the property of the fumigant to penetrate through the layers of grain and reach the target insect. Fumigants also penetrate through the feeding holes and oviposition windows in the seed and kill the larvae and pupae which are not reached by conventional insecticide application. In addition fumigants are capable of penetrating cracks and crevices which might harbor insects from the previously infested grains. Fumigation treatment does not leave persistent toxic residues and treated grains can be utilized after one to two days of aeration.

Several fumigants have been tested for their effectiveness against bruchids infesting various legumes and a few have proved to be more effective than the others (Singh and Srivastava, 1980, 1983, Mundhe and Pandey 1980, El Sayed and Kamel 1978, Tsuruta and Tadauchi 1983, Abu and Muthu 1985, Sadomov 1984). The adult stage is the most susceptible and the pupal the most resistant to fumigant action. The species of the host food legume does affect the susceptibility but such influence is of minor significance. Among the fumigants tested, phosphine is the most effective and convenient to use, especially for small-scale storage. The chemical is available in convenient pellet or tablet forms. Quantities of mungbean can be packed into jute bags with polyethylene liners into which pellets or tablets are placed. The bags are then sealed and left for four to five days during which the phosphine gas penetrates through the layers of grains and kills the bruchids. Usually 1 to 1.5 g tablet per cubic meter space is a suitable dose to achieve complete disinfestation. If kept sealed, the phosphine treatment will also prevent insect reinfestation.

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