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# Bionomics, host plant resistance, and management of the legume pod borer, *Maruca vitrata* — a review

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Legume pod borer, *Maruca (testulalis) vitrata* (Geyer) is one of the major constraints in increasing the production and productivity of grain legumes in the tropics. Screening for resistance has been carried out using natural infestation, and multi- and no-choice tests under greenhouse/laboratory conditions. Information is available on genotypic resistance to *M. vitrata* in cowpea, while such information on pigeonpea and other legumes is limited. Stem and pod wall thickness, trichomes and podding habit are associated with resistance to *Maruca*. Several natural enemies have been recorded on *M. vitrata*. Cultural practices such as intercropping, weeding, time of planting, and planting density reduce its damage in cowpea. Several insecticides have been found to be effective for controlling this insect. There is a need to generate information on insect–plant–environment interactions, screening techniques, mechanisms and diversity of resistance, genetic transformation of host plants involving Bt genes, and use of natural enemies for integrated pest management in diverse agro-ecosystems.


**Keywords:** legume pod borer; *Maruca (testulalis) vitrata*; plant resistance; resistance mechanisms; natural enemies; cultural and chemical control

## Introduction

The legume pod borer, *Maruca (testulalis) vitrata* (Geyer) is a serious pest of grain legumes in the tropics and sub-tropics because of its extensive host range, destructiveness, and distribution (Taylor, 1967; Raheja, 1974). It was reported as a pest of beans in Indonesia by Dietz (1914). Its distribution stretches from the Cape Verde Islands in West Africa to Fiji and Samoa in the far East, including the West Indies and Americas (*Table 1*). Taylor (1978) and Singh and Jackai (1988) have given information on the biology and control of this pest. As this insect is a major constraint in increasing the production and productivity of grain legumes, the major gaps in our knowledge and possible areas of research are identified in this review.

## Nature of damage and extent of losses

### Nature of damage

*M. vitrata* larvae feed on flowers, buds, and pods by webbing them. This typical feeding habit protects the larvae from natural enemies and other adverse factors, including insecticides. Moths prefer to oviposit at the flower bud stage. Larvae move from one flower to another, and each may consume 4–6 flowers before larval development is completed. Third- to fifth-instar larvae are capable of boring into the pods, and occasionally into peduncle and stems (Taylor, 1967). Moths and larvae are nocturnal (Usua and Singh, 1979). Infestation starts in the terminal shoots (21 days after planting), but later spreads to the reproductive parts (Jackai, 1981). Infestation is highest in flowers > flower buds > terminal shoots > pods. Karel (1985) also observed more larvae (52.3%) on flowers than on pods (37.8%), and leaves (9.9%). In pigeonpea, third-instar larvae prefer pods compared to flowers and leaves, and flowers over leaves (Sharma, 1998). First-instar larvae prefer flowers over pods and leaves.

### Incidence/extent of losses

Losses in grain yield have been estimated to range from 20 to 60% (Singh and Allen, 1980). In Bangladesh, pod borer damage in cowpea was 54.4% during harvest, but yield loss was estimated to be <20% (Ohno and Alam, 1989). Odulaja and Oghiakhe (1993) described a nonlinear model to assess yield loss. Dreyer *et al.* (1994) observed low seed damage despite heavy flower infestation. Seasonal variation in yield losses was shown in Nigeria, where cowpea yield loss was 72% in 1985, and 48% in 1986. A threshold of 40% larval infestation in flowers has been established (Ogunwolu, 1990).

In pigeonpea, incidence and loss in grain yield also varies between seasons and locations (Patel and Singh, 1977; Vishakantaiah and Jagadeesh Babu, 1980; Patnaik *et al.*, 1986; Dharmasena *et al.*, 1992). Plants of ICPL 88007 infested with 8 and 16 larvae resulted in 59.5 and 71.2% pod damage, and 51.8 and 66.7% loss in grain yield, respectively. Less damage has been reported in Bangladesh, where pod borers caused 0.9–6.9% damage to four varieties of country bean (Sarder and Kundu, 1987).

## Host range and host plant suitability

It has been observed to feed on 39 host plants (*Table 2*) (Akinfenwa, 1975; Atachi and Djihou, 1994). The most frequent host plants are *Cajanus cajan*, *Vigna unguiculata*, *Phaseolus lunatus*, and *Pueraria phaseoloids*. Growth indices for larvae were 4.14 on pigeonpea, 4.63 on cowpea, and 5.17 on hyacinth bean (Ramasubramanian and Sundara Babu, 1988; Ramasubramanian and Sundara Babu, 1989a). When the number of eggs laid, percentage egg hatch, growth index, and adult emergence were considered, hyacinth bean was identified as the most suitable host for culturing *M. vitrata*.

## Bionomics and population dynamics

Eggs are normally deposited on floral buds and flowers, although oviposition on leaves, leaf axils, terminal shoots, and pods has also been recorded (Bruner, 1931; Wolcott, 1933; Krishnamurthy, 1936; Taylor, 1963, 1967, 1978). A female may lay up to 400 eggs (Okeyo-Owuor and Ochieng, 1981; Jackai *et al.*, 1990). Eggs are light yellow, translucent, and have faint reticulate sculpturing on the delicate chorion, and measure 0.65 × 0.45 mm (Taylor, 1967). Eggs are usually deposited in batches of 2 to 16 (Okeyo-Owuor and Ochieng, 1981). Most adults emerge between 20:00 h and 23:00 h, and 4–5 nights pairing results in highest mating percentage and oviposition. Some males mate more than once, though the majority of females mate only once (Jackai *et al.*, 1990). A one-to-one ratio (10 males:10 females) is optimum for mating and oviposition. Mating takes place between 21:00 h and 05:00 h (with a peak between 02:00 and 03:00), when temperatures range between 20 and 25°C and RH over 80%. Females live for 4–8

Table 1. Distribution of *Maruca vitrata*.

| Region | Country | Main host | Reference |
|---|---|---|---|
| Asia | Bangladesh | Country bean | Das and Islam (1985) |
| | China | Cowpea | Ke *et al.* (1985) |
| | Indonesia | Yard long bean | Dietz (1914) |
| | India | | |
| | Bihar | Legumes | Saxena (1978) |
| | Andhra Pradesh | Pigeonpea | Rao *et al.* (1986) |
| | Delhi | Legumes | Saxena (1978) |
| | Gujarat | Greengram | Venkaria and Vyas (1985) |
| | Haryana | Pigeonpea | Srivastava *et al.* (1992) |
| | Karnataka | Pulses | Krishnamurthy (1936) |
| | Orissa | Pigeonpea | Prasad *et al.* (1989a, b) |
| | Uttar Pradesh | Pigeonpea | Patel and Singh (1977) |
| | Madhya Pradesh | Legumes | Saxena (1978) |
| | Tamil Nadu | Grain legumes | Sundara Babu and Rajasekaran (1984) |
| | Japan | Adzuki bean | Katayama and Suzuki (1984) |
| | Malaysia | Long beans | Ibrahim (1980) |
| | Pakistan | Pulses | Ahmed *et al.* (1987) |
| | Philippines | Grain legumes | Rejesus (1978) |
| | Sri Lanka | Pigeonpea | Subasinghe and Fellows (1978) |
| | Taiwan | Grain legumes | Rose *et al.* (1978) |
| | Thailand | Pigeonpea | Buranapanichpan and Napompeth (1982) |
| Africa | Benin | Cowpea | Atachi and Djihou (1994) |
| | Burkina Faso | Groundnut | Traore (1993) |
| | Ghana | Cowpea | Agyen-Sampong (1978) |
| | Kenya | Cowpea | Okeyo-Owuor and Oloo (1991) |
| | Niger | Groundnut | Maiga and Issa (1988) |
| | Nigeria | Cowpea | Singh and Jackai (1988) |
| | Senegal | Cowpea | Ndoye (1978) |
| | Sierra Leone | Grain legumes | Taylor (1978) |
| | South Africa | Cowpea | Phelps and Oostihuizen (1958) |
| | Uganda | Cowpea | Nyiira (1971) |
| | Sudan | Faba bean | Siddig (1982) |
| | Zambia | Beans | Kannaiyan *et al.* (1987) |
| Australia | Australia | Adzuki bean | Turner (1978) |
| | Papua and New Guinea | Cowpea | Lamb (1978) |
| North America | USA | Grain legumes | Karel (1984) |
| South | Brazil | Grain legumes | Ruppel and Idrobo (1962) |
| America | Colombia | Grain legumes | Posada *et al.* (1970) Schoonhouen (1978) |
| | Cuba | Lima bean and other legumes | Leonard and Mills (1931) |
| | Puerto Rico | Lima bean and other legumes | Leonard and Mills (1931) |

days. Eggs hatch in 3–6.5 days (*Table 3*). There are five larval instars (Odebiyi, 1981). Larval development is completed in 8–16.3 days, and prepupal period lasts for 1–2 days. Pupation occurs in the soil in a pupal cell, and lasts for 6.4–11 days. Life cycle is completed in 18–35 days. There is no diapause in this insect, and the populations during the off season are maintained on wild hosts such as *Vigna triloba*, *Crotalaria* spp. , *Phaseolus* spp., and pigeonpea (Taylor, 1967). Development to adult stage is completed only at 22°C and 28°C, and temperatures above 34°C were lethal to the larvae (Jackai and Inang, 1992). The lower threshold temperature for pupae was 15.6–17.8°C, and upper threshold 28–34°C.

Table 2. Host range of the legume pod borer, *Maruca vitrata*

| Common name | Scientific name | Reference |
|---|---|---|
| Papilionaceae | | |
| Cowpea | *Vigna unguiculata* | Phelps and Oostihuizen (1958); Taylor (1967) |
| Green gram | *Vigna aureus* | Visvanathan *et al.* (1983) |
| Black gram | *Vigna mungo* | Taylor (1978); Das and Islam (1985) |
| Mung bean | *Vigna radiata* | Venkaria and Vyas (1985); Das and Islam (1985) |
| | *Vigna triloba* | Taylor (1967) |
| Pigeonpea | *Cajanus cajan* | Taylor (1967); Patel and Singh (1977) |
| | *Cajanus indicus* | Taylor (1978) |
| Hyacinth bean | *Dolichos lablab* | Ramasubramanian and Sundara Babu (1988) |
| Country bean | *Lablab purpureus* | Das and Islam (1985) |
| Kidney bean | *Phaseolus vulgaris* | Rejesus (1978); Taylor (1978) |
| Lima bean | *Phaseolus lunatus* | Leonard and Mills (1931); Atachi and Djihou (1994) |
| Adzuki bean | *Phaseolus angularis* | Katayama and Suzuki (1984) |
| Broad bean | *Vicia faba* | Siddig (1982) |
| Yard long bean | *Vigna sinensis* | Satsijati *et al.* (1986) |
| Fusi-sasage | *Vigna vexillata* | Oghiakhe *et al.* (1993d) |
| Long bean | *Vigna sesquipedalis* | Ibrahim (1980) |
| Winged bean | *Psophocarpus tetragonolobus* | Taylor (1978) |
| Soya bean | *Glycine max* | Das and Islam (1985) |
| Groundnut | *Arachis hypogea* | Taylor (1978); Traore (1993) |
| African yam bean | *Sphenostylis stenocarpa* | Taylor (1978) |
| | *Gliricidia sepium* | Taylor (1978) |
| Grass pea | *Lathyrus sativus* | Das and Islam (1985) |
| Field pea | *Pisum sativum* | Das and Islam (1985) |
| | *Pueraria phaseoloids* | Atachi and Djihou (1994) |
| | *Stizolobium sp.* | Taylor (1978) |
| Valvet bean | *Mucuna sp.* | Taylor (1978) |
| | *Tephrosia candida* | Taylor (1978) |
| | *Tephrosia purpurea* | Taylor (1978) |
| | *Crotalaria juncea* | Jackai and Singh (1983) |
| | *Crotalaria mucronata* | Jackai and Singh (1983) |
| | *Crotalaria incana* | Jackai and Singh (1983) |
| | *Crotalaria retusa* | Atachi and Djihou (1994) |
| | *Crotalaria amazonas* | Jackai and Singh (1983) |
| | *Crotalaria saltiana* | Jackai and Singh (1983) |
| | *Crotalaria misereniensis* | Jackai and Singh (1983) |
| Cesalpinaceae | | |
| | *Panciana* sp. | Taylor (1978) |
| Pedaliaceae | | |
| | *Sesamum* sp. | Taylor (1978) |
| Malvaceae | | |
| | *Hibiscus* sp. | Taylor (1978) |
| Mimosaceae | | |
| | *Escelerona dolabriformis* | Taylor (1978) |

Table 3. Development of legume pod borer, *Maruca vitrata* on different host plants

| | Development period (days) | | | | | |
|---|---|---|---|---|---|---|
| Host plant | Egg | Larval | Pre-pupal | Pupal | Total | Reference |
| Cowpea | 5 | 8–14 | 2 | 7 | 18–35 | Taylor (1967); Booker (1965); Akinfenwa (1975) |
| | 3 | 8–14 | 1 | 5–14 | 25–27 | Okeyo-Owuor and Ochieng (1981) |
| | 3.1 | 13.9 | 1.8 | 6.9 | 25.7 | Ramasubramanian and Sundara Babu (1988, 1989a) |
| Pigeonpea | 3.1 | 12.7 | 2.1 | 8.7 | 26.5 | Vishakantaiah and Jagadeesh Babu (1980) |
| | 2.9 | 13.3 | 1.5 | 6.4 | 24.1 | Ramasubramanian and Sundara Babu (1988, 1989a) |
| | 3–4 | 11–14 | 1–2 | 8–11 | 21–23 | Sharma (1998) |
| Country bean | 6.5 | 16.3 | – | 7.4 | 30.2 | Das and Islam (1985) |
| Hyacinth bean | 3.1 | 12.9 | 1.5 | 7.5 | 24.5 | Ramasubramanian and Sundara Babu (1988, 1989a) |

Larvae of *M. vitrata* are dispersed randomly on flowers of cowpea (Firempong and Mangalit, 1990). Initial infestation on cowpea in Nigeria occurs when adults emerge from alternate hosts (Taylor, 1967). Peak infestation occurs on the early sown crop in June–July. The first generation adults on cowpea emerge in July, and the second between July and September. Adults have been observed in light traps in most months, although the catches are low during the off-season. The insects possibly migrate from South to North associated with movements of the inter-tropical convergence zone, and moving South in November–December. Adults have been caught in light traps between 18:40 and 00:45 h, with a peak between 20:00 and 21:00 h (Akinfenwa, 1975). Okeyo-Owuor *et al.* (1983) reported that in Kenya, pod borer populations are lower during the short rainy season, but infestation is continuous unless flower and pod production ceases. Atachi and Ahohuendo (1989) observed maximum larval density 40 DAP (days after planting) on four cultivars, and 47 DAP on six cultivars (4–17 larvae per 20 flowers) in Benin. Highest infestation of flowers was recorded on the same sampling date on all cultivars (20–70%).

At ICRISAT Center, moth catches were greatest between early November to mid-December in the light traps (Srivastava *et al.*, 1992) with a peak during November (in 46 and 47 standard weeks). At Hisar, maximum moth activity has been observed from mid-September to mid-October. Akhauri *et al.* (1994) observed that the larval density increased from mid-October to the end of November at Dholi, Bihar, India on early pigeonpea. The peak in larval density occurred in the last week of November. In Sri Lanka, Saxena *et al.* (1992) observed a high larval density in the crop planted in mid-October. Alghali (1993a) observed three peaks of pod borer infestation in cowpea. Significant relationships were observed between pod borer incidence and cumulative rainfall, and number of rainy days between crop emergence to flowering.

## Mass rearing

Ochieng *et al.* (1981) developed a procedure for mass rearing, which allows production of over 75 000 eggs per month. Jackai and Raulston (1982), Jackai and Raulston (1988) and Ochieng and Bungu (1983) attempted rearing of *M. vitrata* on an artificial diet, but the performance of the laboratory reared insects declined after a few generations. Onyango and Ochieng-Odero (1993) developed a diet on which the fecundity of the females increased with advancing generations: adult emergence ranged between 70 and 90%, one litre of diet produced nearly 400 adults, and a female laid > 200 eggs.

## Screening for resistance

### Field screening techniques

Screening for resistance to pod borers can be carried out during March–April and August–September in Nigeria, when pod borer density is high. Planting infester rows 2 weeks earlier than the test cultivars, and uprooting the infester rows running parallel to the test material after 6 weeks (Jackai, 1982), spraying experimental plots at the flower bud stage to suppress thrips and hemipterans, and keeping the greenhouse or the field plots moist (Singh and Jackai, 1988) helps to improve the efficiency of screening for resistance to the pod borer. An infestation level of two larvae per plant was enough to detect differences in flower and pod damage, and grain yield between infested and uninfested plants (Echendu and Akingbohungbe, 1989). Flower, pod and seed damage (Jackai, 1982; Valdez, 1989), larval population in flowers and ratio of grain yield under protected and unprotected conditions (Wooley and Evans 1979), and pod evaluation index (ratio of pod load to pod damage) (Oghiakhe *et al.*, 1992a) have all been suggested as criteria to select for resistance to pod borer.

### Greenhouse/laboratory screening techniques

Field screening is often difficult due to low or unknown levels of insect infestations. Artificial infestation of the test plants under field/greenhouse conditions can be used to overcome this problem. Expression of cowpea resistance to *Maruca* is affected by plant growth stages (Dabrowski *et al.*, 1983). Plants with five to seven shoots are most suitable for resistance screening prior to flowering. Using five eggs per plant at this stage, it was possible to differentiate between the resistant and susceptible lines, but 10 eggs per plant is optimum. Echendu and Akingbohungbe (1990), using free- and no-choice techniques, confirmed the results obtained under field conditions. Jackai (1991) used a dual-choice arena test (DCAT) for 72 h, and calculated the relative resistance of a test line compared with either the susceptible or resistant check using a feeding index. In the second assay (intact pod test, IPT) — a no-choice test was conducted in a screenhouse for 2 weeks. Using this test, conclusive information on seed damage could be obtained after 72 h of feeding exposure. In this test, TVNu 72 showed resistance similar to that determined by the DCAT. The two assays are complementary and provide useful information on antixenosis and antibiosis components of resistance, and can be used in sequence. Infesting pigeonpea plants with 10 first-instar larvae, and covering with a cloth bag placed around a wire-framed cage (40 cm in diameter, 45 cm long) can be used to screen for resistance to the pod borer (Sharma, 1998). The plants may be evaluated for insect damage 15 days after infestation. This technique can be used to confirm the resistance observed under field conditions, and determine resistance levels in different cultivars.

## Sources of resistance

### Cowpea

Several genotypes showing moderate to high levels of resistance to *Maruca* damage have been identified

(*Table 4*). TVu 946, showing high levels of resistance across seasons and locations, can be utilized in breeding programs (Jackai, 1981). Oghiakhe and Odulaja (1993a) used principal component analysis to study the variation patterns in 18 cowpea cultivars developed for resistance to *M. vitrata* based on seven developmental parameters of the pest on floral buds, flowers, and sliced pods. Percentage pupation, adult emergence, and growth index were important for the grouping of the cultivars. Growth index had the highest factor score. Using cluster analysis, Oghiakhe and Odulaja (1993b) found that MRx 6-84F has wider adaptability in the presence of *Maruca* infestation. TVu 946 performed best, and was in a single cluster. Mokwa, MRx 2-84F, MRx 5-84F, MRx 6-84F, MRx 54-84M, MRx 8-84F, MRx 49-84M, and MRx 50-84F were grouped together. Expression of resistance to the pod borer is influenced by variety and environment (Suh and Simbi, 1983), and intercropping (Gethi *et al.*, 1993). Resistance of TVu 946 was reduced when intercropped with maize. This has been attributed to increase in pod and peduncle length, and a significant reduction in the number of branches. Intercropping also resulted in significant differences in temperature, R.H., and a reduction in photosynthetic activity. Wooley and Evans (1984) have described a methodology to breed for resistance to pod borer in cowpea.

### Pigeonpea

Low to moderate levels of resistance have been observed in pigeonpea genotypes against pod borer damage (*Table 4*). Early maturing pigeonpea varieties suffer greater damage than the late maturing varieties (Sahoo and Patnaik, 1993). Indeterminate type lines are in general less damaged than the determinate types (Lateef and Reed, 1981; Saxena *et al.*, 1996).

## Mechanisms of resistance

### Antixenosis

Ramasubramanian and Sundara Babu (1989b) observed that hyacinth bean was preferred for oviposition, followed by cowpea and pigeonpea. Maximum number of eggs were laid 3 days after mating on the preferred host, while on cowpea and pigeonpea, the highest number of eggs were laid on the fourth day after mating. Cowpea cultivar TVu 946 exhibits

Table 4. Sources of resistance to *Maruca vitrata* in pigeonpea and cowpea

| Genotype | Remarks | Reference |
|---|---|---|
| Pigeonpea | | |
| ICPL 81, Pusa 33, and H 76-208 | Less susceptible compared to ICPL 1 and ICPL 151 | Patnaik *et al.* (1986) |
| Pusa 855 | Low pod damage compared to T 14 and ICPL 106 over two seasons | Prasad *et al.* (1989a) |
| MTH 8, Phule T 17, and MTH 9 | Lower pod damage than BR 65 | Prasad *et al.* (1989b) |
| MPG 359, MPG 531, MPG 532, and MPG 566 | Suffered a damage rating of <3, and are determinate types | Saxena *et al.* (1996) |
| MPG 537, MPG 664, MPG 665, MPG 359, ICPL 88034, ICPL 89038, MPG 662, ICPL 87115, ICPL 90037, ICPL 89016, ICPL 85045, and ICPL 86020 | Yielded greater than ICPL 2 and suffered 10–25% pod borer damage. Tolerant to pod borer damage | Saxena *et al.* (1996) |
| ICP 809 and T 21 | Also tolerant to podfly and *Helicoverpa* | Saxena *et al.* (1996) |
| ICPL 85010 and ICPL 90011 | Less suitable for growth and development of larvae | Sharma (1998) |
| Cowpea | | |
| TVu 946, TVu 4557 (VITA 5), VITA 4, and Ife Brown | Showed resistance to peduncle damage. TVu 946 and TVu 4557 also showed resistance to flower damage | Singh (1978) |
| New Era 169, SES no.5, IR 58-162, Wake Jaba, and Idad Market | Moderate to high levels of resistance to post-flowering pests as measured by seed yield ratio | Wooley and Evans (1979) |
| TVu 946 and VITA 5 | Less number of larvae in different plant parts | Jackai (1981) |
| TVu 946, Kamboinse local, TVu 1, VITA 5, TVx 3890-010F, and VICA M-1/5P | TVu 946 was most resistant | Jackai (1982) |
| TVu 946, Ife Brown, and VITA 1 | Showed resistance in field and screenhouse experiments | Macfoy *et al.* (1983) |
| IT 82E-32, IT 82E-77, IT 82E-18, TVx 1843-1C, ER 7, and Tvu 72-59-25 | Less susceptible | Marfo (1985) |
| CES 15-27, TVu 461, TVu 1061-1, TVu 1248, TVu 1499-1, TVu 3 (Local Brown), and TVu 946 | Less susceptible under field conditions | Valdez (1989) |
| MRx 6-84F, TVu 946, Mokwa, MRx 2-84F, MRx 5-84F, MRx 54-84M, MRx 8-84F, MRx 49-84M, and MRx 50-84F | Based on cluster analysis, MRx 6-84F showed wide adaptability. TVu 946 was placed in a single cluster | Oghiakhe and Odulaja (1993b) |

nonpreference for oviposition compared to Ife Brown and Vita 1 (Macfoy *et al.*, 1983). However, Valdez (1989) indicated that there is no oviposition antixenosis in cowpea to the pod borer. Nonpreference to larval feeding has been reported by Echendu and Akingbohungbe (1990). Attraction and arrest-stay of first-instar larvae contribute to the resistance of TVu 946 and VITA 5 to the pod borer (Okech and Saxena, 1990).

### Antibiosis

Survival of the larvae is low on TVu 946, and this is due to nutritional and antibiotic factor(s) (Macfoy *et al.*, 1983). Valdez (1989) observed only a slight effect of the host on larval survival. Oghiakhe *et al.* (1993c) reared larvae successfully on floral buds, flowers, and sliced pods, but not on stems, terminal shoots, and intact pods. Sliced pods were most suitable for growth and development, followed by flowers, and flower buds. Okech and Saxena (1990) indicated that antibiosis was a component of resistance in TVu 946 and VITA 5 stems and pods. Highest larval weight gain was recorded on TVu 3 and least in CES 15-27. Consumption index (CI) was higher on TVu 1248 and TVu 1 compared to CES 15-27, TVu 161-1-2, TVu 461, TVu 946, TVu 1016-1, and TVu 1499-1. On pigeonpea, the third-instar larvae consumed 27.0 to 47.2 mg food on the flowers, and had growth rates of 114.7% on ICPL 88020 to 207.3% on ICPL 85010. Approximate digestibility (AD) was lower on ICPL 85010 than on ICPL 90011. Efficiency of conversion (ECI) of ingested food into body matter was lower on ICPL 90011 compared to ICPL 85010 and ICPL 88007. The fifth-instar larvae consumed 52.3 to 80.6 mg of food on pods, and showed growth rates of 30.1 to 41.8%. ECI was lowest on ICPL 90011, followed by that on ICPL 88020, ICPL 88007, and ICPL 85010 (Sharma, 1998). Thus, some of the pigeonpea genotypes are less suitable for the growth and development of pod borer, which may be due to nutritional or antibiotic factors.

### Tolerance

ICPL 88034 and MPG 679, showing low *Maruca* damage (10–25%), have excellent recovery from damage. These lines need to be evaluated to confirm their tolerance to *Maruca* (Saxena *et al.*, 1996).

## Factors associated with resistance

### Plant architecture

Singh (1978) reported that resistance of TVu 946 and TVu 4557 is due to long peduncles, pods held over the plant canopy and at a wider angle than the normal. Oghiakhe *et al.* (1991a) observed that defoliated cultivars suffered lower damage than the undefoliated ones. Percentage pod damage and larval infestation in flowers were positively correlated with R.H. and negatively with temperature. Cowpea genotypes with bunched pods suffer greater damage (Usua and Singh, 1979). Oghiakhe *et al.* (1992b) observed negative relationships between pod angle and pod damage, and seed damage index in two cowpea cultivars. Pods with wide angles ( > 89°) were damaged on one side, and rarely on both sides. Erect and profuse flowering contributed to the resistance of TVu 946 to *M. vitrata* (Oghiakhe *et al.*, 1993b). Tayo (1988) reported that the period of flower opening spanned over 13 days in TVu 946, 17 days in ICV 2, and 18 days in Vita 1. About 85–100% of the pods retained to maturity were from flowers opening within 8 days of anthesis. The efficiency of pod production from open flowers was highest in TVu 946 (54%), lowest in Vita 1 (11%), and median in ICV 2 (31%). Pod elongation and enlargement were initially rapid in all varieties, but pods in TVu 946 reached physiological maturity 2 days earlier than the other varieties. Open canopy, long peduncles, erect pods with wide angles, profuse flowering, pod size, and rate of pod growth can be used to select for resistance to *M. vitrata*.

In pigeonpea, determinate lines with clustered inflorescence were more susceptible than the indeterminate types (Saxena *et al.*, 1996). Only four determinate lines (MPG 359, 531, 532, and 566) suffered a damage rating of $<3$, while 12 indeterminate lines had a damage rating of $<3$. Fifty-six percent of indeterminate lines had $<50\%$ damage in contrast to 15% of the determinate lines, confirming the suggestion made by Lateef and Reed (1981).

### Anatomical characteristics

Stem epidermis influences both larval movement and feeding within the stem tissue (Oghiakhe *et al.*, 1991b). Collenchyma cells in 21-day old TVu 946 and IT 82D-716 stems form a network of closely knit interlocking cells with a few intercellular spaces. Significant differences have been observed in the distance between the epidermis and collenchyma cells of the slightly raised (convex) and concave portions of TVu 946 and IT 82D-716 stems. TVu 946 has a smaller stem diameter than IT 82D-716 stem. Distance between epicarp and mesocarp tissues of 7-day old TVu 946 and IT 82D-716 pod wall did not show any significant differences. Stem tissue structure (epidermis and collenchymma cells) is an important factor in stem resistance to *M. vitrata*, but this does not appear to be the case in pod wall resistance (Oghiakhe *et al.*, 1992c). Feeding and development is adversely affected on two wild cowpea (*Vigna vaxillata*) accessions (TVNu 72 and TVNu 73) compared to the susceptible variety IT 84E-124 (Jackai and Oghiakhe, 1989). *Maruca* larvae fed and developed better when the trichomes were removed. Growth index was 13× less when the trichomes were left intact both on TVNu 72 and TVNu 73. The resistance of these lines was based on trichomes and phyto-chemicals. Oghiakhe *et al.* (1993a) observed an uncharacteristic network of fibrous structures on the petals of TVNu 72, but not on the susceptible control IT 82D-716. The stems had thick and closely packed collenchyma cells and both have resistance to stem feeding. Trichomes are the principle factor in TVNu

72 resistance to *M. vitrata*. Trichomes varied in length and density, but not in type on different plant parts (Oghiakhe *et al.*, 1992d). Significant correlations were observed between trichome density and pod borer damage.

### Biochemical factors

Sugar content in the pod walls of TVNu 72 is greater than in IT 82D-716, and phenol content is lower in the pod wall of TVNu 72, but the reverse is true for fresh and dry seeds (Oghiakhe *et al.*, 1993a). Neither sugars nor phenols seem to be involved in the resistance of TVNu 72 to *M. vitrata* (Oghiakhe *et al.*, 1993c, 1993d). Phenol concentration varies significantly between different plant parts, and generally decreases with an increase in plant age. Otieno *et al.* (1985) indicated that ethyl-acetate soluble fraction of methanol extracts of stems of TVu 946 showed significantly greater feeding inhibition than the extract from ICG 1.

## Natural enemies

Several parasites and predators have been recorded on *M. vitrata* by Usua and Singh (1977), Barrion *et al.* (1987) and Vishakantaiah and Jagadeesh Babu (1980) (*Tables 5* and *6*). Okeyo-Owuor and Oloo (1991) observed that mortality from the egg to adult stage was 98.2–99.4% in Kenya. Highest mortality occurred between egg stage and the third-instar larvae. The

Table 5. Parasitoids of the legume pod borer, *Maruca vitrata*

| Parasitoid | Life stage parasitized | Reference |
|---|---|---|
| Diptera | | |
| Tachinidae | | |
| *Aplomya metallica* (Weid.) | Larva | Agyen-Sampong (1978) |
| *Exorista xanthaspis* (Wiedemann) | Larva | Barrion *et al.* (1987) |
| *Palexorista solemnis* (Walker) | Larva | Barrion *et al.* (1987) |
| *Peirbaea orbata* (Wiedemann) | Larva | Barrion *et al.* (1987) |
| *Zygobothria atropivora* (Rob.-Desv.) | Larva | Barrion *et al.* (1987) |
| *Zygobothria ciliata* (Wulp) | Larva | Barrion *et al.* (1987) |
| *Thelairosoma* sp. | Larva | Usua and Singh (1977) |
| *Pseudoperichaeta laevis* (Vill.) | Larva | Agyen-Sampong (1978) |
| *Pseudaporichaeta* sp. | Larva | Usua and Singh (1977) |
| *Thecocarcelia incedens* (Rond.) | Larva | Agyen-Sampong (1978) |
| Hymenoptera | | |
| Baraconidae | | |
| *Apanteles* sp. | Larva | Okeyo-Owuor *et al.* (1991) |
| *Bracon greeni* Ashm. | Larva | ICRISAT (1981) |
| *Bracon* sp. | Larva | Okeyo-Owuor *et al.* (1991) |
| *Braunsia* sp. | Pupa | Okeyo-Owuor *et al.* (1991); Agyen-Sampong (1978) |
| *Cardiochiles philippinensis* Ashm. | Larva | Barrion *et al.* (1987) |
| *Chelonus* sp. | Larva | Barrion *et al.* (1987) |
| *Cremnops* sp. | Larva-Pupa | Barrion *et al.* (1987) |
| *Snellenius manilae* Ashm. | Larva | Barrion *et al.* (1987) |
| *Phanertoma handecasisella* Cam. | Larva | ICRISAT (1978); Subasinghe and Fellows (1978) |
| *Phanertoma* sp. | Larva | Usua and Singh (1977) |
| Chalcididae | | |
| *Antrocephalus* sp. nr *subelongatus* Kohl | – | Subasinghe and Fellows (1978) |
| *Antrocephalus* sp. | Pupa | Okeyo-Owuor *et al.* (1991) |
| *Brachymeria* sp. A. | Larva-pupa | Barrion *et al.* (1987) |
| *Brachymeria* sp. B. | Larva-pupa | Barrion *et al.* (1987) |
| Eulophidae | | |
| *Nesolynx thymus* (Gir.) | – | Subasinghe and Fellows (1978) |
| *Tetrastichus sesamiae* Risbec | Pupa | Okeyo-Owuor *et al.* (1991) |
| *Tetrastichus* sp. | Pupa | Barrion *et al.* (1987); Usua and Singh (1977) |
| Ichneumonidae | | |
| *Caenopimpla arealis* (Cushman) | Larva | Barrion *et al.* (1987); Usua and Singh (1977) |
| *Charops nigrita* Gupta and Maheswary | Larva | Barrion *et al.* (1987); Usua and Singh (1977) |
| *Meloboris sinicus* (Holmgren) | Larva | Barrion *et al.* (1987); Usua and Singh (1977) |
| *Metopius rufus browni* Ashm. | Larva | Barrion *et al.* (1987); Usua and Singh (1977) |
| Pteromalidae | | |
| *Trichomalopsis* sp. | Larva-pupa | Barrion *et al.* (1987) |
| Scelionidae | | |
| *Telenomus* sp. | – | Subasinghe and Fellows (1978) |
| Acarina | | |
| *Dinothrombius* sp. | Larva | Agyen-Sampong (1978) |
| Nematodes | Larva-Pupa | Okeyo-Owuor *et al.* (1991) |
| Protozoa | | |
| *Mettesia* sp. | Larva-Pupa | Okeyo-Owuor *et al.* (1991) |
| *Nosema marucae* sp. n. | Larva-Pupa | Odindo and Jura (1992) |
| *Nosema* sp. | Larva-Pupa | Okeyo-Owuor *et al.* (1991) |
| Bacteria | | |
| *Bacillus* sp. | Larva-Pupa | Okeyo-Owuor *et al.* (1991) |
| *Colostridium* sp. | Larva-Pupa | Okeyo-Owuor *et al.* (1991) |

causes of mortality were disappearance, followed by disease and parasitism. Seven parasitoids, two predators, one nematode, and several pathogens were recorded (Okeyo-Owuor *et al.*, 1991; Otieno *et al.*, 1983; Otieno, 1989). A pupal endoparasitoid, *Antrocephalus* sp. was the predominant natural enemy, while *Nosema* sp. and *Bacillus* sp. caused the highest natural mortality. Parasitoids and pathogens contributed 41% and 36% to the total generation mortality (*K*) at two sites, respectively, but observed that parasitism contributed <4%. Mortality due to disappearance, which also included predation, accounted for about 60% of *K*. Life table data and survival curves revealed high mortality (ca. 98%), most of which occurred in the early life stages. So, there is a high potential for utilizing biocontrol agents for the management of this pest.

## Cultural practices

### Planting time

Pod borer populations tend to build up over the season (Ekesi *et al.*, 1996). Thus, pod borer infestation increases on the late sown crop (Alghali, 1993a). Grain yield also decreases in late planted crops. Simultaneous plantings of maize and cowpea increase pod borer infestation in cowpea (Ezueh and Taylor, 1984), whereas sowing cowpea 12 weeks after maize reduces the pod borer damage.

### Intercropping

Pod borer damage in a monocrop is greater than the maize–cowpea–sorghum inter-mixed crops (Amoako-Atta and Omolo, 1982; Amoako-Atta *et al.*, 1983; Fisher *et al.*, 1987; Omolo *et al.*, 1993). Pod borer incidence was significantly lower in intercropped and higher plant populations than in pure stands, and in a lower plant population of common bean, *Phaseolus vulgaris* (Karel, 1984, 1993). Flower and pod damage was significantly lower in an intercrop combination of one third bean–two thirds maize, so intercropping maize with bean was considered useful as a cultural method for controlling pod borers in common bean. However, Alghali (1993b), Ofuya (1991), Natarajan *et al.* (1991), Patnaik *et al.* (1989) and Saxena *et al.* (1992) reported no effect of intercropping on the incidence of *M. vitrata*.

### Weeding

Cowpea weeded two, three or four times had less flower infestation by *M. vitrata* than the non-weeded plots (Ofuya, 1989). However, effects of weeding

Table 6. Predators of the bean pod borer *Maruca vitrata*

| Predator | Life stage attacked | Reference |
|---|---|---|
| Dermaptera | | |
| *Diaperastichus erythrocephala* Ol. | Larva/pupa | Okeyo-Owuor *et al.* (1991) |
| Dictyoptera | | |
| Mantidae | | |
| *Polyspilota* sp. | Moths | Usua and Singh (1977) |
| *Spodromantis* sp. | Moths | Usua and Singh (1977) |
| Coleoptera | | |
| Carabidae | | |
| *Chlaenius* sp. A | Larva | Barrion *et al.* (1987) |
| *Chlaenius* sp. B | Larva | Barrion *et al.* (1987) |
| *Cicindela lacrymosa* (F.) | Larva | Barrion *et al.* (1987) |
| Coccinellidae | | |
| *Coccinella repanda* (Thunberg) | Larva | Barrion *et al.* (1987) |
| *Menochilus sexmaculatus* (F.) | Larva | Barrion *et al.* (1987) |
| *Synharmonia octomaculata* (F.) | Larva | Barrion *et al.* (1987) |
| Hemiptera | | |
| Anthocoridae | | |
| *Orius tantillus* Motsch. | Egg and larva | Barrion *et al.* (1987) |
| Hymenoptera | | |
| Formicidae | | |
| *Camponotus sericeus* Fab. | Larva | Usua and Singh (1977) |
| *Camponotus rufoglaucus* (Jerd.) | Larva | Okeyo-Owuor *et al.* (1991) |
| Vespidae | | |
| ? *Eumenes* sp. | Larva | Barrion *et al.* (1987) |
| *Ropalidae flavopicta flavobrunnea* van der Vecht | Larva | Barrion *et al.* (1987) |
| Araneida | | |
| Selenopidae | | |
| *Selenops* sp. | Larva and adult | Usua and Singh (1977) |
| Araneidae | | |
| *Nephila maculata* (F.) | Adult | Barrion *et al.* (1987) |
| Oxyopidae | | |
| *Oxyopes javanus* Thorell | Larva and adult | Barrion *et al.* (1987) |
| Salticidae | | |
| *Evarcha* sp. | Adult | Barrion *et al.* (1987) |
| *Marpissa bengalensis* Tikader | Adult | Barrion *et al.* (1987) |
| *Marpissa calcutaensis* Tikader | Adult | Barrion *et al.* (1987) |
| Sparassidae | | |
| *Heteropoda venatoria* (L.) | Adult | Barrion *et al.* (1987) |

frequency on pod damage by *M. vitrata* are not consistent and Akinyemiju and Olaifa (1987) and Ezueh and Amusan (1988) concluded that weed control did not affect borer damage.

## Chemical control

Endosulfan (applied at 35 DAP twice at weekly intervals) (Dina and Medaiyedu, 1976; Jackai, 1983); one spray of cypermethrin, biphenthrin, cyhalothrin, and in combination with dimethoate (Amatobi, 1994); a mixture of cypermethrin+dimethoate (using Electrodyn sprayer (Jackai *et al.*, 1987; Ezueh, 1990); or two applications of cypermethrin+dimethoate at 10 day intervals (beginning at bud formation) (Amatobi, 1995) give effective control of the pod borer on cowpea.

On pigeonpea, deltamethrin, cypermethrin, and fluvalinate (Bhalani and Prasana, 1987); monocrotophos and endosulfan (three applications of endosulfan starting at flower initiation at 20 days interval) (Samolo and Patnaik, 1986); cypermethrin or dimethoate at flowering or when egg numbers reached two per meter row, and repeated at 10–15 days interval (Rahman, 1991); cypermethrin, deltamethrin, fenvalerate, and endosulfan (three sprays) (Sontakke and Mishra, 1991); triazophos, endosulfan, and monocrotophos (Sundara Babu and Rajasekaran, 1984); endosulfan+miraculan (a plant growth stimulant), fenvalerate, and monocrotophos (Venkaria and Vyas, 1985); and benomyl+monocrotophos and permethrin (Oladiran, 1990) are also effective against this pest. Some of these insecticides are too expensive for small scale farmers and efforts are needed to avoid application of highly toxic broad spectrum insecticides.

### Spray schedules

Atachi and Sourokou (1989) reported that a sequence of deltamethrin–dimethoate–deltamethrin sprays resulted in the highest grain yield (1367 kg/ha). Spray regimes which terminated early offered better protection against the pod borer, but were inadequate for controlling sucking insects (Dina, 1988). Calendar based sprays result in less borer infestation than when sprays are based on economic thresholds (Afun *et al.*, 1991). However, there were no differences in grain yield between the calendar based sprays and those based on economic thresholds. Crop monitoring reduced the number of sprays by half compared to those based on calendar schedules. Four high volume sprays of cypermethrin 0.008% (1st spray at initiation of flowering, 2nd spray at 50% flowering, 3rd spray at 100% flowering, and 4th spray at 100% pod setting) were effective for protecting the pigeonpea crop against *Maruca*. This schedule also offered the highest benefit–cost ratio (6.23) (Rahman and Rahman, 1988).

### Persistence

Endosulfan (0.14%) applied thrice at 20 day intervals resulted in maximum residues (1.85 ppm) (Senapati *et al.*, 1992). Insecticide residues were greater in the husk than the grain. Grain or husk should not be consumed following application of quinalphos or monocrotophos.

### Natural pesticides

*Bacillus thuringiensis* (Bt) is effective in controlling pod borers (Karel and Schoonhoven, 1986; Otieno and Karikuri, 1991; Supriyatin, 1990). Neem seed powder and neem kernel extract were also effective against legume pod borer (Singh *et al.*, 1985; Hongo and Karel, 1986; Kareem *et al.*, 1989; Tanzubil, 1991; Jackai *et al.*, 1992), but neem seed kernel extract (NSKE) was less effective than fenvalerate and monocrotophos. Defatted neem seed kernel powder applied as a dust to soil around the cowpea plants reduced the pod borer damage and increased the seed yield (Cobbinah and Osei-Owusu, 1988). Ivbijaro and Bolaji (1990) observed that pod borer damage was reduced by four sprays of *Azadirachta indica* or *Piper guineense* extracts. Different concentrations of neem oil emulsifiable concentrate (NOEC) (5, 10, and 20%) exhibited a high degree of activity against *M. vitrata* (Jackai and Oyediran, 1991). Neem oil slurry emulsifiable concentrate (NOSEC) and 5% NOEC exhibited similar insecticidal activity, but neem oil and NOEC were superior to NOSEC. Flower infestation was not reduced by 5 and 10% neem leaf extracts, except in 1994 (Bottenberg and Singh, 1996). Neem leaf extract applied four times on Cv 715 resulted in less pod borer damage than on Cv 941. Neem application reduced pod damage by 12% in Cv 715, and by 16% in Cv 941. Neem can be effective in combination with host plant resistance. Isopongaflavone and rotenone are also highly active against the pod borer (Bentley *et al.*, 1987; Lwande *et al.*, 1986), whereas harrisonin and obacunone have antifeedant activity against the larvae (Hassanali *et al.*, 1986).

## Conclusions

Information on the biology of *M. vitrata* has been generated on cowpea, and to a limited extent on pigeonpea. Information on population dynamics (which is essential for developing resistance screening techniques and pest management strategies) and insect density–yield–loss relationships (necessary for estimating economic thresholds, the level of insect infestation needed to screen for host plant resistance, and the desirable levels of resistance needed in the commercial cultivars) still needs to be generated. Screening for resistance has been carried out using natural infestations with multi- and no-choice tests under greenhouse and laboratory conditions. Laboratory/greenhouse tests are useful to confirm the resistance observed under field conditions. Procedures for infestation and evaluation of resistance under field and greenhouse conditions using artificial infestation need to be standardized to breed for plant resistance to this insect. Considerable information has been generated on genotypic resistance/susceptibility to *M. vitrata* in cowpea, while such information on

pigeonpea and other pulse crops is scanty. Levels of resistance seem to be repeatable across seasons. Several plant characteristics, such as stem and leaf tissue thickness, pod wall thickness, and podding habit (clusters versus spread out pods, pod angle, etc.), have been shown to contribute to less susceptibility to *Maruca*, and should be integrated with chemical and other control tactics. Some of these characteristics, such as growth habit, pods exposed above the foliage, days to complete flowering, and time required for pod maturity, can be used to select genotypes as possible candidates for resistance to *Maruca*. The relative contribution of these traits needs to be assessed in a diverse array of genotypes with resistance to *Maruca*. This will also help to identify lines with different mechanisms of resistance, which can be used in the resistance breeding program to increase the levels and diversify the bases of resistance to *M. vitrata*. Several natural enemies have been reported on *M. vitrata*. Usefulness and effectiveness of *Bacillus thuringiensis* may be explored for integrated management. Cultural practices, such as intercropping, weeding, time of planting, planting density, and pruning, has been shown to reduce the damage by legume pod borer. However, the results are not consistent over seasons, and locations. Such studies should be repeated involving large plots, and possibly including genotypes that are less susceptible to this insect. Several insecticides have been evaluated for the control of this insect. Future studies should focus on timing of insecticide application based on economic thresholds. Various control options for minimizing the losses due to *M. vitrata* should be tested on farmers fields in collaboration with the NARS and other organizations. A network of IARCs working on *Maruca* may be established to share information for integrated management of *M. vitrata*.

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