Classical biological control of banana weevil borer, *Cosmopolites sordidus* (coleoptera; curculionidae) with natural enemies from Indonesia (With emphasis on west Sumatera)

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Introduction

General basis and protocol for classical biological control

Biological control is defined as "the action of parasites (parasitoids), predators or pathogens in Maintaining another organism's population density at a lower average than would occur in their absence" (Debach 1964). Thus, biological control represents the combined effects of a natural enemy complex in suppressing pest populations. The concept of biological control arose from the observed differences in abundance of many animals and plants in their native range compared to areas in which they had been introduced in the absence of (co-evolved) natural enemies. As such, populations of introduced pests, unregulated by their natural enemies may freely multiply and rise to much higher levels than previously observed. Biological control is a component of natural control which describes environmental checks on pest buildup (Debach 1964). In agriculture, both the environment (i.e. farming systems) and natural enemies may be manipulated in an attempt to reduce pest pressure.

Classical biological control concerns the search for natural enemies in a pest's area of origin, followed by quarantine and importation into locations where the pest has been introduced. One underlying assumption is that herbivores are under natural biological control by co-evolved natural enemies and may be inconspicuous (i.e. non-pests) in their endemic range. These herbivores may reach pest status when they move into areas when freed from control by their natural enemies. Chances of natural enemy establishment and success are greatest when ecological conditions are similar between the areas of collection and release. The objective of a classical biological control program is the establishment of an equilibrium between pest and natural enemy populations such that damage levels are below economic threshold. Pest eradication is neither a sustainable nor a desirable outcome. The most effective natural enemies are monophagous or narrowly oligophagous (i.e. have narrow host or prey ranges) and they would quickly disappear if they were to exterminate their hosts. This would create new problems should the pest be reintroduced from a nearby area. An example of a successful biological control program involved the introduction of natural enemies (most notably the encyrtid wasp *Epidinocarsis lopezi* De Santis) into Africa for the control of the cassava mealybug *Phenacoccus* *manihoti* Matile-Ferrero 1977 (Herren and Neuenschwander 1991). The cassava mealybug was accidentally brought into sub-Saharan Africa during the 1970s. It quickly spread across the cassava growing belt, causing devastating losses. Searches were undertaken in Latin America (the area of origin for cassava) for the mealybug (where it was virtually unknown) and its natural enemies. These were eventually found on cassava in Paraguay and Brazil. Release of *E. lopezi* and several predacious coccinellids quickly brought the mealybug under control throughout most of Africa. Biological control is only one of many approaches available to reduce the abundance of pests and the damage they cause. In some cases, biological control may be sufficiently effective that no other control measures are required. Quite often, however, only partial control may be achieved and it is necessary to integrate biological control with other measures. Biological control may require an initial research expenditure, but has the advantages that it is permanent, ecologically sound, compatible with most farming practices (except the use of pesticides) and requires little or no investment on the part of the farmer. Occasionally, modification of farm management practices might be encouraged to enhance the efficacy of natural enemies. In general, parasitoids are more effective than predators. Parasitoids tend to have narrower host ranges while many predators (including all known enemies of banana weevil) are opportunistic predators. Specialist natural enemies are likely to have more efficient searching behaviour in locating their hosts, and to be more adapted to the range of conditions under which the host lives. Ants might be an exception: although opportunistic predators, they are very effective foragers. It is also important to ensure that candidate natural enemies do not attack other beneficial insects such as herbivores which control undesirable weeds (e.g. water hyacinth). In South Africa, for example, two coccinellids (the native *Exochomus flavipes* and the imported *Cryptolaemus montrouzieri*) effectively control *Leucaena* pysillid (*Heteropsylla cubana*), while at the same time interfering with the biological control of prickly pear cactus by the introduced cochineal insect *Dactylopius tomentosus*. Natural enemy host or prey range is normally ascertained through a careful review of the literature (on what is known about the candidate natural enemy and other species in the same genus or family), and by testing in the laboratory. A careful study of the biology and behavior of selected natural enemies, including detailed observations in their original home, often permit sound conclusions to be drawn as to their probable host range in a new site. The primary advantage of a classical biological control program is that exotic natural enemies (from the area of origin) most often tend to be far more effective at controlling introduced pests than endemic natural enemies already present in the pest's new range. Natural enemies from the area of origin have had a long period of association with the pest during which both have co-evolved together. Such natural enemies are often specialists well adapted to locate the host plant and/or the pest insect. Though this line of reasoning is sometimes contested (Pimentel 1961), the fact remains that most successful biological control programmes have used natural enemies from a pest's area of origin. Sampling both the pest and its natural enemies is necessary to determine pest density and whether adequate numbers of natural enemies are present to control the insect. For example, natural enemy numbers may initially lag behind those of pests. Thus, in some cases, pest numbers may be nearing action levels (e.g. a threshold for pesticide application), while natural enemy populations may also be increasing such that they will overtake and suppress the pest before it effects serious damage. However, it is often necessary to demonstrate to producers, accustomed to using pesticides on a timetable or at first sight of a pest that natural enemies may bring the pest under control if they refrain from applying chemicals.

Area of origin of banana and banana weevil

The genus *Musa* originated in Southeast Asia and has a centre of diversity in Assam-Burma-Thailand-Indonesia-Papua New Guinea, with a minor centre on the Southeast African Highlands (Simmonds 1966). Edible bananas originated in South and Southeast Asia from two wild progenitors, *Musa acuminata* (donor of A genome) and *Musa balbisiana* (donor of B genome), and have spread throughout the humid tropics (Stover and Simmonds 1987). Secondary centres of crop diversity exist in East Africa (highland cooking bananas, unique to the region) and West Africa (plantains) (Stover and Simmonds 1987).

The banana weevil (*Cosmopolites sordidus* Germar) is believed to be a native of the Indo-Malaysian region (Zimmerman 1968, Clausen 1978). However, bananas (and the weevil) have long been disseminated throughout the world; therefore, the centre of origin of the weevil remains obscure. Furthermore, the existence of but a single congeneric species (*C. pruinosus*, reported from Borneo and the Philippines (Zimmerman 1968) makes it difficult to use taxonomic evidence to speculate on the origin of banana weevil.

Pest status of banana weevil in Asia

The banana weevil egg, larval and pupal stages all occur within the host plant or crop residues. The eggs are placed superficially within the host, but are at low density and often below the soil surface (Abera *et al.* 1999). The damaging larvae live in galleries within the banana corm, making them largely inaccessible to parasitoids and opportunistic predators. This suggests that the most likely natural enemies would either be specialized parasitoids or predators which can attack eggs or enter crop residues. The weevil appears to be unimportant in much of Asia, although it may be among the most destructive banana pests in certain parts of the region. Other important banana herbivores include the banana pseudostem borer, *Odoiporus longicolis* (Olivier) and banana leaf roller, *Erionota thrax* L. In Indonesia, for example, the banana weevil is considered a major problem in some lowland and highland zones, yet many clones and areas have low levels of damage. In general, banana weevil pest status in Asia is unclear, with most reports being subjective rather than based on conclusive data (Table 1).

Country	**Pest importance (*)**	**Data on incidence**	**Data on yield losses**
Burma	?	-	-
Thailand	+	-	-
Laos	?	-	-
Cambodia	+	-	-
Malaysia	+++	-	-
Vietnam	++	-	-
Brunei	++	-	-
Indonesia Philippines	++	-	-
India	++	-	-
Sri Lanka	+	-	-
	+	-	-

(*) +++ Important / ++ Moderate important / + Present.

Sources: Viswanath (1977), Geddes and Iles (1991), Waterhouse (1993); adapted from Gold (1998).

The pest status of banana weevil outside of Asia is also controversial (Purseglove 1972, Ostmark 1974, Waterhouse and Norris 1987) and may be related to the genome group and management practices (Gold *et al.* 1994, 1999). In New South Wales, Lobel (1975) controlled banana weevils over a 2-year period in experimental plots using insecticides, yet failed to find improved growth or yield. He concluded that heavy infestations by this weevil in New South Wales are a symptom, rather than a cause, of declining plantations. However, Rukazambuga *et al.* (1998) found that yield losses to banana weevil in highland banana increased with crop cycle and reached 44% in the third ratoon of an on-station yield loss trial.

Prospects for biological control for banana weevil

The banana weevil evolved in Asia, from where it has spread to all of the world's major banana-growing regions. Introduced pests, unimportant in native habitats, often reach damaging levels when released from the control of co-evolved natural enemies. The banana weevil appears to fit this pattern, although there is some belief that the weevil might reach pest status in parts of Asia (Waterhouse 1993). Nevertheless, exploration for banana weevil natural enemies in Asia followed by selection, quarantine and release of suitable species could establish an herbivore equilibrium below economic thresholds. Possibilities and considerations for classical biological control of banana weevil have been reviewed by Greathead (1986), Waterhouse and Norris (1987), Neuenschwander (1988), Greathead *et al.* (1989), Kermarrec (1993) and Koppenhofer (1993) while Schmitt (1993) provides a partial list of arthropod natural enemies. Koppenhofer *et al.* (1992) and Koppenhofer (1993) found that endemic natural enemies of the weevil in Kenya did not show much promise. In contrast, ants (i.e. *Tetramorium guinense, T. bicarinatum* (Nylander) and *Pheidole megacephala* Fabricius) contribute to control of banana weevil in Cuba (Roche 1975, Roche and Abreu 1983, Castineiras *et al.* 1991). Based on the weevil's biology, Greathead *et al.* (1989) give a 30% chance for a complete success in biological control. In Asia, a large number of beneficial organisms (parasites, predators and pathogens) occur naturally in banana plantations and may provide some degree of pest control.

Predatory spiders, coccinellids, lacewings, reduviids, ants, and parasitic flies and wasps are the most important beneficial insect groups active in banana plantations. Cane toads feed on beetle weevil and other insects near the ground. Tree frogs, which frequent the banana plants also, feed on insects. Many natural enemies appear small and insignificant, or are nocturnally active, and may go largely unnoticed. Their real value is only appreciated when they are destroyed by inappropriate use of insecticide. Previous searches for natural enemies of banana weevil in Asia have produced a number of generalist predators. These have been largely unsuccessful in biological control attempts (Waterhouse and Norris 1987). In contrast, egg parasitoids may be effective against banana weevil (Neuenschwander 1988).

Research activities on banana weevil borer in West Sumatera -- Searches for parasitoids

Searches for natural enemies were conducted at study site of Bukit tingi, Sitiung, Pariaman, and Batu Sangkar. To increase the number of eggs available for collection at field sites, we manipulated field plants to create highly attractive oviposition sites that would be used by naturally occurring weevils in the study area, concentrating their oviposition and making eggs easier to collect. To create these oviposition sites, we: (1) cut the stumps of recently harvested plants at 0–10 cm above ground level and (2) made fresh cuts on the exposed corm surfaces of these stumps. These cuts produced ridges that trapped water droplets and kept the corm surface moist. To prevent water accumulation and fungal growth, ridges were cut at a slant so that water would gradually run off. Each prepared corm was loosely covered by a piece of pseudostem to further retain moisture and to protect eggs from desiccation. This method had the effect of attracting large number of banana weevils and aggregating eggs at a specific site. Three days after preparing the corms, newly deposited banana weevil eggs were located by gently paring the corm surface. To collect eggs, we gently pared the corm and pseudostem surfaces using a small knife until eggs were visible. The eggs were then extracted (using the blunt edge of the knife) and placed in clean Petri dishes using a fine artist paintbrush. These were transferred to the laboratory where they were cleaned with the paintbrush. Batches of 10 eggs were placed on moist tissue paper inside sterilized Petri dishes sealed with parafilm. These were held at 25 °C for 2 weeks. At this temperature, most eggs are expected to hatch in 5–8 days (Waterhouse and Norris 1987). The Petri dishes were opened (and then resealed) every 2–3 days to maintain an even moisture level. Data were taken every 3 days on number of eggs hatched, died/desiccated or parasitized. Eggs that did not hatch in 2 weeks were considered to be non-viable.

About 24,360 naturally occurring eggs were collected from the fields (Table 2). Over 84% of eggs were hatched, fungi killed 16% of the eggs, and none were parasitized. The eggs of banana weevil have been observed to have no parasitoids in Uganda (Gold et al. 1994).

Table 2. Fates of field collected and trap host banana weevil eggs from different sites in West Sumatera (2002-2003) (% of total in brackets)

Location	Dead*	Hatched	Signs of parasitism	Total
Bukit Tinggi	1360 (15)	7773 (85)	0 (0)	9133
Sitiung	745 (14)	4699 (86)	0 (0)	5444
Pariaman	545 (18)	2507 (82)	0 (0)	3052
Batu Sangkar	1212 (18)	5519 (82)	0 (0)	6731
Average	***3862 (16)***	***20,468 (84)***	**0 (0)**	**24,360**

*Eggs that died either due to fungal attack, mechanical injury or failed to hatch during 2-3 weeks of rearing

Although the banana weevil is believed to be a native to the Indo-Malay region of Southeast Asia (Zimmerman, 1968), it is possible that its true area of origin may be elsewhere in Asia. Further searches for egg parasitoids should be undertaken in other possible areas of origin, especially southern India, which is the center of origin of plantains (AAB) and where the banana weevil is also considered unimportant (Gold *et al*. 2001).

Table 3. Fates of banana weevil larvae collected from farmers fields in West Sumatera (2002-2003) (% of total in brackets)

Location	Dead[a]	Hatched	Signs of parasitism[b]	Total
Bukit Tinggi	162 (19)	691 (81)	3 (0.3)	856
Sitiung	155 (24)	492 (75)	7 (1.0)	654
Pariaman	120 (25)	355 (75)	2 (0.2)	477
Batu Sangkar	217 (19)	926 (81)	5(0.5)	1148
Average	***654 (21)***	***2464 (79)***	**17(0.5)**	**3135**

[a] Number of larvae that died or had not pupated within 2 weeks of collection.
[b] Number of dishes with Phorids

We reared 3135 fourth to seventh instar larvae collected from banana residues (Table 3). Of these, 79% pupated and 21% died. Adult *Drosophila* sp. were observed in rearing dishes from larvae collected from Moko (*Pseudomonas solanacearum* Smith) infected plants. It is quite possible that *Megaselia* sp. and *Drosophila* sp. were scavengers that had been in the banana material used for rearing. Therefore, we have no conclusive evidence of parasitism of banana weevil larvae at our study sites. Known *Megaselia* species are mostly saprophagous, but the biology of the species collected from banana weevil larvae is unknown. Regardless, these data do not provide evidence of any significant level of larval parasitism.

Banana weevil predators

To estimate the abundance of non-social predators (i.e., those other than ants), we searched in and around standing and prostrate banana residue pseudostems where these insects are most often encountered. On each farm, 10 residues each were examined from plants that had been harvested 1–4 weeks, 5–8 weeks or 9 or more weeks before our visit to the site. To detect predators, plant residues were split and shredded. In addition, the ground and trash around the base of stumps and underneath prostrate residues were searched. For each residue, we recorded the number, by order, family and morphospecies, of all species we presumed might be banana weevil predators. Based on previous work, presumed predators were species of Dermaptera (several families), as well as staphylinids, histerids, and hydrophilids (all Coleoptera). However, no hydrophilids, while previously reported, were encountered in our surveys. Samples of the different morphospecies were saved in alcohol for later identification. Vouchers of the predators other than ants are housed at Entomological Laboratory of Tropical Fruit Research Institute (TFRI) in Sumani Solok, West Sumatra. Ant abundance was estimated by examining every other mat along each of two 40-m transects run diagonally through each study plot. For every sampled mat, we checked visually both the mat and the immediately surrounding area (within 1m of the base of plant stems) for both the ant colonies and the foragers. The number of mats sampled per farm ranged from 25 to 38, depending on field size. The number of ant colonies/transect was classified as 1–4, 5–15 or >15, corresponding to low, moderate and high ant densities on a farm.

Three histerids [*P. javanus*, *Plaesius laevigatus* (Marseul), and *Hololepta* sp.], three staphylinids [*B. ferrugatus* (Erichson), *Leptochirus unicolor* (Lepelitia) and one unidentifed species], three Dermaptera (one labiid, one forficulid, one chelioschid, not identified beyond family) (Table 4) and 13 formicids (Table 5 for names) were found associated with banana mats or residues.

Table 4. Abundance of Coleopteran and Dermapteran predators of banana weevil found in crop residues in farmer´s fields in survey of five locations in west Sumatera (mean number/residu ± SE n = 30 per farm)

Sites	No. Histeridae/residue		Staphylinidae/ Residue	No. Dermaptera/residue		Total predator/ residue
				Chelisochidae	Others[a]	
	P.javanus	Other species	(three species)	(One species)	(two species	(nine species)
Bukit Tinggi	1,6 ± 0.1 b	0.9 ± 0.03 a	0,8 ± 0.1 b	7.8 ± 0.3 a	0,4 ± 0.1 a	10.7 ± 0.4 a
Sitiung	1.3 ± 0.1 b	0.1 ± 0.03 b	0.5 ± 0.1 bc	3.1 ± 0.3 b	0,0 ± 0.0 b	4.9 ± 0.4 b
Pariaman	1,1 ± 0.1 b	0.0 ± 0.03 b	1,3 ± 0.1 a	3,4 ± 0.3 b	0,0 ± 0.0 b	5,9 ± 0.4 b
Batu Sangkar	2.0 ± 0.1 a	0.1 ± 0.03 b	0.9 ± 0.1 b	8.2 ± 0.3 a	0,0 ± 0.0 b	11.1 ± 0.4 a
Pasaman	2,1 ± 0.1 a	0.1 ± 0.03 b	0,3 ± 0.1 c	2,6 ± 0.3 c	0,4 ± 0.1 a	5,5 ± 0.4 b

Mean in a column followed by the same letter are not significantly different at P<0.005% level according to least significant different test.
[a] One species each from Forficulidae and Labiidae.

Among the nonsocial predators, Dermaptera were more abundant than Coleoptera at all sites. The mean number of predators per residue was 7.6±0.22 (SE), range 4.9–11.1. Chelisochids, staphylinids and *P. javanus* accounted for >90% of observed non-social predators. Labiids (F=14.88, P < 0.001), staphylinids (F=3.34, P<0.01) and *P. javanus* adults (F=8.98, P < 0.001) and early instar *P. javanus* larvae were more abundant in fresh (1–4 weeks) rather than old residues (5–12 weeks); in contrast, larger *P. javanus* larvae were twice as common in old than in fresh residues (F=41.71, P<0.001).

In West Sumatera at least 13 species of ants were found to be closely associated with banana mats or banana trash. In Cuba, the myrmicine ants *Pheidole megacephala* (Fabricius) and *Tetramorium guinense* (Nylander) have been used as biological control agents against banana weevils (Casteñieras and Ponce, 1991; Perfecto and Casteñieras, 1988). The density of colonies of ants on farms in Indonesia (seven species with 5–15 colonies per 40m transects, Table 4) suggests that native ants might be important natural enemies of banana weevil.. Of the ants associated with banana mats, *Anoplolepis gracilipes* Smith (Formicinae), *Pseudolasius* sp. (Ponerinae), and *Pheidole plagiaria* Smith (Myrmicinae) were found at the greatest number of the sample sites and were the most abundant ants where they occurred. We commonly encountered 15 or more colonies per 40m transect for each of these species. Three species, *Camponotus* (*Tanaemyrmex*) sp. (Formicinae), *Odontomachus rixosus* Smith (Ponerinae), and *Odontomachus simillimus* Smith (Ponerinae), were not widely distributed but were abundant where they occurred.

Myopopone castanea Smith (Amblyoponinae) was found in three locations with 65 colonies per transect. Five species, *Diacamma rugosum* Le Guillou (Ponerinae), *Leptogenys peuqueti* Andre (Ponerinae), *Polyrhachis dives* Smith (Formicinae), *Monomorium* sp. (Myrmicinae), and

Technomyremex sp. (Dolichoderinae), were found at only one site. Species of *Myopopone*, *Pheidole*, *Pochycondyla*, and *Monomorium* established their colonies inside corms or pseudostems of banana plants, while *A. gracilipes*, *Camponotus* (*Tanaemyrmex*) sp., *D. rugosum*, *O. rixosus*, and *Pseudolasius* sp. colonies were found in pseudostem leaf sheaths or in leaf trash at the base of mats. The close proximity of the colonies of these ants to banana plants and residues suggests that these ants are very likely to forage in or on banana plants. *M. castanea* was directly observed attacking and removing banana weevil larvae from pseudostem and corm galleries.

Table 5. Ants associated with bananas farmer´s fields in five locations in West Sumatera.

Subfamily	Species	Site[a]	Abundance (average # colonies per 40 transect)	Weevil stage attacked
Amblyoponinae	*Myopopone castanea* Smith	1,2,4	< 5	L
Dolichodeninae	*Technoremex* sp.	2	< 5	-
Formicidae	*Anoplolepis gracilipes* Smith	all sites	>15	-
	Camponotus (*Tanaemymex*) sp.	2,3, 5	5-15	-
	Polyrhachis dives Smith	2	5-15	E, L
	Polyrhachis proxima Roger	2,3	< 5	-
Ponerinae	*Diacamma rugosum* Le Guillou	2	5-15	E, L
	Leptogenys peuqueti Andre	3	5-15	-
	Odontomachus rixosus Smith	3, 5	5-15	-
	Odontomachus similiamus Smith	3,1	5-15	E,L
	Pseudolsius sp.	1,2,3,4,5	>15	-
Myrmicinae	*Monomorium* sp	1	5-15	-
	Pheidole plagarua Smith	all site	>15	E,L

[a]Site(1) Pariaman, (2) Pasaman, (3) Sitiung, (4) Bukit Tinggi (5) Batu Sangkar
E= banana weevil eggs, L= banana weevil larvae (_) stage was not established; attack by combining ants and banana weevil stages in petri dish and noting disappearance of prey after an interval of time.

Prey consumption of predators

A chelisochid species (Dermaptera), adults of the staphylinid *Belonochus ferrugatus* (Erichson), and adults and larvae of the histerid *P. javanus* were evaluated for predation against banana weevil stages in the laboratory. Ten banana weevil eggs were placed in a thin slice of corm tissue and offered to single predators in a 250-mL cup serving as a test arena. Similarly, groups of five medium to large larvae (instars 5–7; Gold et al., 1999), pupae or teneral adults were placed in corm pieces and offered to individual predators in the test arena. After 48 h, the number of remaining banana weevil life stages in each cup was recorded. Treatments were replicated 15 times (3 individual predators per species, 5 times per individual). Predation rates were scored by assessing the number of stages remaining uneaten after the exposure period. Since life stages presented were easily observed and were not mobile, no controls (dishes without predators) were used.

Among the three predators tested in the laboratory, the chelisochid earwigs consumed the highest percentage of banana weevil eggs and were least efficient in attacking larvae and pupae (Table 6).

Table 6. Consumption rates of life stages of the banana weevil by three predators in laboratory experiment over 48-h period at TFRI, Solok West Sumatera.

Predator group	%±SE of banana weevil stage eaten in 48 h (n=15)			
	Egg	Larvae	Pupae	Teneral adult
Chelisochidae	42.0 ± 3.5 a	25.0 ± 3.4 d	2.7 ± 3.4 d	0.0 ± 0.0 c
Staphylinidae	21.3 ± 3.1 b	50.4 ± 3.1 c	10.7 ± 3.3 c	0.0 ± 0.0 c
P. javanus larvae	0.0 ± 0.0 c	87.6 ± 2.9 a	53.5 ± 3.5 a	0.0 ± 0.0 c
P. javanus adult	0.0 ± 0.0 c	74.7 ± 3.2 b	37.6 ± 2.9 b	0.0 ± 0.0 c

Means in a column followed by the same letter are not significantly different at P<0.005 according to least significant differences test.

P. javanus larvae and adults consumed high number of banana weevil larvae and pupae, but did not attack the eggs. The staphylinid *B. ferrugatus* consumed intermediate number of banana weevil eggs, larvae and pupae. None of the tested predators attacked the teneral adult stage. In the experiment testing *P. javanus* larval searching efficiency in banana weevil-infested suckers, the two predatory larvae consumed an average of 6.3±0.2 (SE) of the nine banana weevil larvae inserted per sucker. The presence of *P. javanus* larvae in corms resulted in significantly fewer live banana weevil larvae [1.7±0.3 (SE)] at the end of the test than in controls [7.8±0.2 (SE); F=746.0, P<0.001]. Predator feeding tests confirmed earlier reports of earwigs (Sun, 1994) and staphylinids (Edwards, 1934; Jepson, 1914; Koppenhöfer, 1993, 1994) as being banana weevil predators. In cages, Koppenhöfer (1994) found that staphylinids reduced banana weevil larvae by 42% and eggs by 20%. This was comparable to our findings, in which individuals of the staphylinid *B. ferrugatus* consumed 50% of the larvae and 21% of the eggs presented to them.

P. javanus larvae either moves among interconnected tunnels inside corms in search of larvae or exited one tunnel moved over the corm surface and entered other tunnels to attack larvae. In our study, *P. javanus* larvae were more efficient predators than *P. javanus* adults. The shape and soft body of the larvae allowed them to readily enter and more easily maneuver within banana weevil tunnels than could the adults. Moreover, the larvae consumed a significant number of banana weevil immatures within the tunnels. This is in contrast to previous reports, that *P. javanus* attack on weevil stages was limited by inability of the predator (adults and larvae) to find larvae in corms (Hasyim and Gold, 1999). The ability of *P. javanus* larvae to go deep into corms, together with the long development period of larvae and slow population growth rate of the banana weevil, suggest that *P. javanus* larvae may significantly reduce weevil larval survival rates inside corms to low levels. Previous attempts to introduce *P. javanus* as a classical biological control agent of the banana weevil have met with limited success (Waterhouse, 1998) and surveys in Uganda did not detect this species (Abera-Kanyamuhungu, 2005). These efforts, however, were mostly characterized by low release numbers and poor establishment (Greathead, 1971). Given its apparent importance in West Sumatra, we believe that the value of this species as a candidate predator for banana weevil in Uganda should be revisited. Even partial control of the banana weevil from natural enemies, if combined with plant resistance, would likely reduce the importance of the banana weevil.

We were unable to quantify consumption of banana weevil stages by ants in the laboratory because of the difficulties in establishing colonies and the high variation in the number of workers among colonies of a given species. We were able, however, to directly observe that individual workers of *P. plagiaria*, *D. rugosum*, *O. simillimus*, and *P. dives*, when confined with banana weevil life stages were able to find and did consume eggs and larvae inserted into the surface layer of banana corms. However, we were not able to quantify predation potential on a per colony basis.

Predator:prey ratios

At survey sites, banana weevil damage on farms (as determined by our damage assessments) was negatively correlated with the ratio of number of non-social predators to the number of banana weevils per trap. This ratio was constructed using our count of predators per sampled residue (cut plants) to the number of adult weevils found in pseudostem traps.

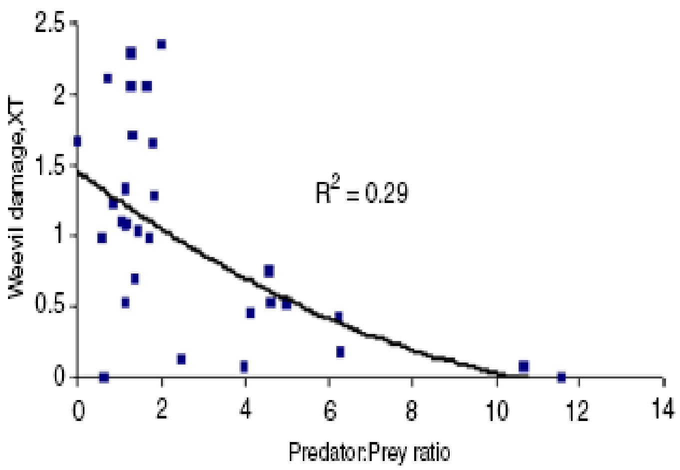

Figure 1. Correlation of banana weevil damage and predator-prey ratio on plant surveyed at location in West Sumatera.

Although the *r*2 value of this relationship was low (0.29) (Fig. 1), the slope of the regression line was significantly different from 0 ($P<0.05$). This suggests that banana weevil populations were under a certain level of natural enemy control. Successful biological control attempts require establishment of the insect in a new environment and repression (control) of a pest population. To date, biological control attempts against banana weevil have met little success. Most attempts were made before 1940, using limited numbers of predators. *Plaesius javanus* has been successfully introduced into both the Pacific region and Trinidad, but failed to establish following introduction attempts into Australia, Cameroon, Jamaica, Japan, Samoa, Tanzania and Uganda (Waterhouse and Norris 1987). Among other predators, only *Hyposolenus laevigatus*, *Hololepta quadridentata* and *Dactylosternum hydrophiloides* have been established outside of Asia. In Fiji, *P. javanus* successfully established following introduction from Java and reportedly provided control in an area severely infested by banana weevil (Kalshoven 1981, Waterhouse and Norris 1987). However, it took eight years for the predator species to become fully established. Otherwise, there are no reports of any introduced natural enemy controlling banana weevil. Previous attempts to introduce *P. javanus* as a classical biological control agent of the banana weevil have met with limited success (Waterhouse, 1998). These efforts, however, were mostly characterized by low release numbers and poor establishment (Greathead, 1971). Given its apparent importance in Indonesia, we believe that the value of this species as a candidate predator for banana weevil in Uganda should be revisited. Even partial control of the banana weevil from natural enemies, if combined with plant resistance, would likely reduce the importance of the banana weevil in Africa.

Pathogenicity of entomopathogenic fungi, *Beauveria bassiana* (Balsamo) Vuellemin isolates in controlling of banana weevil borer

Entomopathogenic fungi of *B. bassiana* occur naturally in many parts of West Sumatera, and some were found infected insect in the field. The result showed that the effectiveness of the *B. bassiana* from four isolates increase with increasing spore dose (Table 7).

The adult banana weevil mortalities caused by entomopathogen fungi of *B. bassiana* from Baso, Sungai Tarab, Sei Sariek and Sikabau at highest density (3,2 x 10^8 spores/ml^{-1}) after two weeks were 96,67%, 90.00%, 60.00% and 83.33% respectively. This means that the isolate from *B. bassiana* from Baso has higher pathogenicity than other isolates. The spore dose used to infect *C. sordidus* was an important factor in determining the level of mortality of the weevils, the high spore doses being most effective. Mortalities cause by three isolates after four weeks.

Table 7. The effect of the three concentrations of each *B. bassiana* isolate against the mortality of banana weevil adult, *C. sordidus*

Treatment	Day after inoculated by *B. bassiana*				
	7	14	21	28	35
BS1 3,2 x 10^4	6.67 de	56.67 d	80.00 c	86.67 b	6.67 b
BS2 3,2 x 10^6	36.67 b	86.67 b	100.00 a	100.00 a	46.67 a
BS3 3,2 x 10^8	46.67 a	96.67 a	100.00 a	100.00 a	46.67 a
ST1 3,2 x 10^4	6.67 de	46.67 ef	60.00 d	76.67 c	6.67 b
ST2 3,2 x 10^6	16.67 c	76.67 e	93.33 b	96.67 ab	46.67 a
ST3 3,2 x 10^8	13.33 cd	90.00 ab	100.00 a	100.00 a	46.67 a
SS1 3,2 x 10^4	0.00 e	30.00 g	43.33 e	56.67 d	6.67 b
SS2 3,2 x 10^6	0.00 e	53.33 de	66.67 d	96.67 ab	46.67 a
SS3 3,2 x 10^8	3.33 e	60.00 d	80.00 e	100.00 a	46.67 a
SK1 3,2 x 10^4	0.00 e	23.33 g	43.33 e	63.33 c	6.67 b
SK2 3,2 x 10^6	3.33 e	40.00 f	46.67 e	86.67 b	46.67 a
SK3 3,2 x 10^8	3.33 e	83.33 bc	96.67 ab	100.00 a	46.67 a

Mean followed by the same letters in the same column are not significantly different at 5% level of Duncan Multiple Range test (DMRT), BS1 1 = Isolate from Baso, treatment 1, ST1 = Isolate from Sungai Tarab, treatment 1, SS1= Isolate from Sei Sariek, treatment 1, SK1= Isolate from Sikabau, treatment 1, BS2 = Isolate from Baso, treatment 2, ST2 = Isolate from Sungai Tarab, treatment 2, SS2= Isolate from Sei Sariek, treatment 2, SK2= Isolate from Sikabau, treatment 2, BS3 = Isolate from Baso, treatment 3, ST3 = Isolate from Sungai Tarab, treatment 3, SS3= Isolate from Sei Sariek, treatment 3, SK3= Isolate from Sikabau, treatment 3 varied between 92.9-96.4%, 60.7-69.3%, 22.9-37.1% and 7.9-18% at concentrations of 3.35 x 10^7 , 3.35 x 10^6 and 3.35 x 10^4 spores/ml^{-1} (Nankinga et al. 1996). Busofi et al (1989) working in Brazil, obtained mortalities of 86-100% within 30 days when banana weevils *C. sordidus* were inoculated with *B. bassiana* at a concentration of 1 x10^8 conidia/ml.

CONCLUSION

The weevil appears to be unimportant in West Sumatera, although it may be among the most destructive banana pests in certain parts of Sumatera Island. The pest status of banana weevil in Indonesia is controversial and may be related to the genome group and management practices. Captures of banana weevil adults in 4-day-old pseudostem traps averaged 1.1±0.2 (SE) per trap. The damage of recently harvested plants averaged 1.5%±0.9 (SE) (farm mean range 0.6–2.2%) while on older crop residues, reaching an average of 6%±0.8 (SE) on 8–12 week old residues. Over 84% of eggs were hatched; fungi killed 16% of the eggs, and none were parasitized. We have no conclusive evidence of parasitism of banana weevil larvae at our study sites. The mean number of predators per residue was range 4.9–11.1. Chelisochids, staphylinids and *P. javanus* accounted for >90%. At least 13 species of ants were found to be closely associated with banana mats. *P. javanus* larvae and adults consumed high number of banana weevil larvae and pupae, but did not attack the eggs, while staphylinid *B. ferrugatus* consumed intermediate number of banana weevil eggs, larvae and pupae. The adult banana weevil mortalities caused by entomopathogen fungi of *B. bassiana* from Baso was 96.67% and it has higher pathogenicity than other isolates.

In Indonesia, environmental conditions are extremely diverse. Therefore, the results obtained from one geographical location can rarely be applied elsewhere. The high diversity of habitat conditions in which crop-pest-natural enemies systems exist, is not only essential to develop effective control measures, but also provides a fascinating arena for ecological study in general. It is hoped that this workshop will provide the foundation for establishing a network for exploration of candidate natural enemies in Asia so that they may be introduced in other countries.

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