EVALUATION OF NATURAL ENEMIES IN CONTROLLING
OF THE BANANA WEEVIL BORER *Cosmopolites sordidus* Germar
IN WEST SUMATRA

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ABSTRACT

The banana weevil, *Cosmopolites sordidus* Germar, is an important pest of highland banana and plantain in Africa, but it exists in low densities in presumed area of origin in Southeast Asia such as in Indonesia. This suggests a possible existence of effective co-evolved natural enemies in the origin area of Indonesia, especially West Sumatra. The objectives of this study were: (1) to evaluate banana weevil pest status at selected sites in West Sumatra, (2) to survey parasitoids and predators, and (3) to determine the control potential of the most important natural enemies. Surveys were undertaken in March 2002-August 2003 in five locations in West Sumatra, i.e., Bukittinggi, Sitiung, Pariaman, Pasaman, and Batusangkar. Five farms per site were selected randomly among all farms that contained banana stands of > 0.5 ha. Sampling for banana weevil adults and damage, and for predators was done throughout small banana stands and within a 20 m x 40 m (0.08 ha) subplot on larger farms. Field-collected larvae were taken to the laboratory and reared on corm pieces (3 cm x 3 cm x 3 cm) until pupation. Larvae were collected from pseudostem as well as corm residues. To estimate the abundance of non-social predators, i.e., those other than ants, 10 residues each on each farm 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. Samples of the different morphospecies were saved in alcohol for later identification. The result showed that the banana weevil incidence was found to be low, 0.6-1.7 adults per trap. Plant damage indices were below 2.2%. We collected and reared 24,360 eggs and 3118 larvae, but no parasitism was detected. Phorids (*Megaselia* sp.) and drosophilids were recovered from larval rearings, but most likely were scavengers. A complex of predators was detected, the most important of which was the histerid beetles, *Plaesius javanus* Erichson. In laboratory tests, adults and larvae of *P. javanus* attacked 75-88% and 38-53% of banana weevil larvae and pupae, respectively. Predatory ants, including species of Myrmicinae, Ponerinae, Formicinae, and Dolichoderinae, were found to be associated with banana plants and residues. Adults of *Myopopone castanea* Smith (Ponerinae) were directly observed attacking banana weevil larvae in crop residues. The adult banana weevil mortalities caused by the entomopathogen fungi of *Beauveria bassiana* from Baso, Sungaitarab, 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. The high diversity of habitat conditions in which crop-pest-natural enemies systems exist, support the idea that banana weevil population and damage intensity in the study area is low due to active role of natural enemies.

[*Keywords*: *Cosmopolites sordidus,* bananas, natural enemies, *Plaesius javanus*, ants, predators, entomopathogen]

INTRODUCTION

Indonesia is one of the most important banana-growing countries in Asia, with production spread across Sumatra, Java, Bali, and Sulawesi. Most banana cultivation can be categorized into four systems, i.e. backyard, mixed cropping, commercial smallholder, and corporate farm (agribusiness) plantations. The majority of banana growers are small-holders, with most field management done with minimum cultivation input.

The banana weevil borer, *Cosmopolites sordidus* Germar, is the most damaging insect pest of banana and plantain in worldwide (Gold *et al*. 1998; Ostmark 1974). The weevil has been implicated in the decline and disappearance of highland banana in central Uganda (Gold *et al*. 1998) and western Tanzania (Bosch *et al*. 1995). Larval damage affects plant growth and development, reduces bunch weight and quality, and in heavy infestations, may cause the corm to snap at ground level before the bunch is ripe (Ndiege *et al*. 1991).

The banana weevil is believed to be originated along with banana in the Indo-Malay region of

Southeast Asia (Zimmerman 1968; Waterhouse 1993; Hasyim and Gold 1999) and has spread to all banana and plantain production regions in the tropics and subtropics (Waterhouse and Norris 1987). In Africa, the banana weevil has become a serious constraint to production of highland banana (*Musa* sp., AAA-EA) and plantain (AAB; Gold *et al*. 2001). The larvae attack the corm, damaging the vascular system and weakening the plant's vigor. Banana weevil reduced yields and shortened plantation life, killed existing roots, limited nutrient uptake, delayed flowering, and increased susceptibility to other pests and diseases. (Rukazambuga *et al*. 1998; Gold *et al*. 2004). Under outbreak conditions, yield losses can reach 100% (Sengooba 1986, unpubl.).

The genus *Musa* originated in Southeast Asia and has a center of diversity in Assam, Burma, Thailand, Indonesia, and Papua New Guinea, with a minor center on the Southeast African highlands (Simmonds 1966). Insects unimportant in their native habitat may reach damaging levels if released from the control of important natural enemies through invasion of new geographic areas (Van Driesche and Bellows Jr. 1996). 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. This suggests that exploration for banana weevil natural enemies in Asia might detect species suitable for use in a classical biological control program.

The banana weevil is a cryptic pest. The immature stages are inside the plant, making control of the pest difficult. The eggs are deposited at the base of the plant within 2 mm of the corm or pseudostem surface. Egg density is greatest on flowered plants, toppled plants, and crop residues. The larvae tunnel deeply in the corm. Pupation is inside the plant. The egg, therefore, appears to be the stage most readily accessible to natural enemy attack (Koppenhöfer 1994). Egg parasitoids, if present, could have potential for use in biological control of the banana weevil (Neuenschwander 1988).

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, lady beetles or 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.

Earlier efforts to find natural enemies of banana weevil in South Asia were confined to investigations of predatory groups, including histerid, hydrophilid, and staphylinid beetles and rhagionid flies (Waterhouse and Norris 1987; Waterhouse 1998), of which the most important previously noted species was the histerid *Plaesius javanus* Erichson. Attempts to introduce these natural enemies into banana growing regions in Africa and elsewhere met with little success, although this may have been due to importation of too few individuals to allow for establishment (Waterhouse and Norris 1987; Gold *et al*. 2001). 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).

Although several strategies have been employed with various degrees of success for management of *C. sordidus*, characteristically weevil control depends on insecticide use to reduce the adult population (Roman *et al*. 1982; Ingles and Rodriguez 1989). The development of Integrated Pest Management (IPM) programs depends on the understanding of the biology, behavior, population dynamics, and natural enemies of the pest. Mortality factors are important in the interpretation of the effects of control methods on pest populations and damage; therefore, knowledge of the presence of natural enemies is important in developing IPM programs.

The study aimed to (1) evaluate banana weevil pest status at selected sites in West Sumatra through on-farm estimates of damage, (2) survey parasitoids and predators through on-farm observation and laboratory rearing studies, and (3) determine the control potential of the most important natural enemies through laboratory studies.

MATERIALS AND METHODS

Study Areas and Activities

Exploration for natural enemies of banana weevil was carried out in West Sumatra. Surveys were conducted in March 2002-August 2003. The activities were: (1) site and farm selection, (2) determination of banana weevil incidence and damage levels at survey locations, (3) collection and rearing of banana weevil eggs and larvae to detect parasitoids, and (4) collection of potential banana weevil

predators in crop residues and testing their predatory potential in the laboratory.

Site and Farm Selection

We selected five survey locations in banana production center in West Sumatra, i.e., Bukittinggi (950 m elevation, 3000 mm rainfall), Sitiung (100 m, 2900 mm), Pariaman (20 m, > 4000 mm), Pasaman (100 m, 2800 mm), and Batusangkar (500 m, 1800 mm). Five banana farms (per site) were selected randomly among all farms in the site that contained banana stands of > 0.5 ha. Sampling for banana weevil adults and damage, and for predators was done throughout small banana stands and within a 20 m x 40 m (0.08 ha) subplot on larger farms.

Banana Weevil Incidence and Damage

Abundance of banana weevil adults was estimated by counting the number of weevils captured in split pseudostem traps (Mitchell 1978) over a 4-day trapping period. Such traps are made by cutting pieces of freshly harvested pseudostems longitudinally and then placing the flat surface face down on the soil. Traps were made from 30 cm pieces of *pisang kepok* (AAB), a cultivar susceptible to banana weevil, and placed on alternate banana mats, i.e., plants sharing a common corm in study plots. All traps were placed within a 2-week period. Approximately 80-100 traps were placed on each farm (± 1 ha). They were then left in place for 96 hours after which the number of banana weevil adults at each trap was recorded.

The damage caused by banana weevil borer was assessed on harvested plants of two ages. Group 1 consisted of the remains of plants that had been harvested 1-4 weeks before we assessed their damage, and plants in group 2 were ones that had been harvested 8-12 weeks before the date of damage assessment (damage continues to increase after the plants are cut due to weevil breeding in postharvest residues). Damage was measured following the methods of Gold *et al*. (1994). For each stump, cross-sectional cuts were made at the collar, i.e., pseudostem/corm junction, and at 5 cm below the collar. In each cross-section, damage was assessed by visually estimating the percentage of corm tissue consumed by weevil larvae, i.e., in galleries. Distinct scores were given for the central cylinder and cortex for each cut. The average of these four scores was then calculated as a total damage score.

Searches for Parasitoids

Searches for natural enemies were conducted at study site of Bukittinggi, Sitiung, Pariaman, and Batusangkar. 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. To create these oviposition sites, we cut the stumps of recently harvested plants at 0-10 cm above ground level and 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 and 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.

Field-collected larvae were taken to the laboratory and reared on corm pieces (3 cm x 3 cm x 3 cm) until pupation. Larvae were collected from pseudostem as well as corm residues to increase sample size. A high proportion of the larvae from pseudostems, however, were likely to be of the banana stem borer, *Odoiporous longicollis* Oliv., which cannot be distinguished in the field from the larvae of banana weevil. Larvae of these two species select distinct oviposition sites in live plants (pseudostems for the stem borer and corms for the banana weevil). But both will oviposit in cut pseudostem residues. This material had previously been heat-treated in water to

60°C for 20 minutes to eliminate immatures of saprophagous flies. The corm pieces were transferred to the laboratory in tightly covered buckets and then placed in 250-ml plastic cups with tight fitting lids for rearing. The cups were held in plastic rearing cages (30 cm on a side), fitted with organdy sleeves through which cups could be introduced or removed without allowing insects to fly in or out. Cups were observed daily through the clear plastic cage walls for emergence of banana weevils or other adult insects. Any adult insects other than the banana weevil found in rearing cups were placed in 70% alcohol and saved for identification.

Searches for 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. Specimens were identified Dr. Katsuyuki Eguchi at the Kagoshima University Museum, Kagoshima University, Korimoto, Japan. Vouchers of the predators other than ants are housed at Entomological Laboratory of the Indonesian Tropical Fruits Research Institute 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 sur-rounding area (within 1 m 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 per transect was classified as 1-4, 5-15 or >15, corresponding to low, moderate, and high ant

densities on a farm. Samples of each species were saved in ethanol and sent to Prof. Seiki Yamane (Kagoshima University, Korimoto, Japan) for identification.

Prey Consumption of Different 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 hours, 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.

Field observations revealed that *P. javanus* larvae often entered banana weevil larvae tunnels inside plant corms. Therefore, we ran tests to measure the ability of *P. javanus* larvae to find prey inside corms. First, we drilled nine holes (using a 0.5-cm drill bit) into the corm (ca. 7 cm x 7 cm x 10 cm) of intact suckers. Then, we introduced one active mid-sized banana weevil larva into each hole and plugged the holes with corm pieces. Banana weevil larvae burrow into the corm soon after introduction and cover their path with frass. To allow escape from direct predation, we allowed 6 hours before we introduced a *P. javanus* larva into two of the nine holes per sucker. Control suckers consisted of corms with banana weevil larvae as described above but with no *P. javanus* present. All (the) suckers were held inside buckets for 3 days, after which their corms were dissected and the number of live banana weevil larvae was recorded. The experiment was repeated 20 times.

Colonies of the ants commonly found nesting near the soil surface in banana stands were scooped with plant debris into 1-L containers. The ants were taken to the laboratory and transferred into 2.5-L buckets. Wet cotton wool was placed in Petri dishes kept at the bottom of the buckets. The laboratory colonies

were kept moist by the addition of wet cotton wool. Five banana weevil eggs or larvae were inserted in a corm piece as described above. One corm piece was offered to each colony. After 2 days, the corm pieces were examined for eggs or larvae and replaced with new corm pieces. For each test colony, we recorded 'attack on eggs' if eggs were found missing or 'attack on larvae' if larvae were found missing or damaged.

Isolation and Pathogenicity of *Beauveria bassiana* in Controlling Banana Weevil

Natural enemies including entomopathogens have great potential to reduce the population of the weevils in severely infested gardens. Entomo-phatogenic fungi *Beauveria bassiana* is known to occur naturally in soil and plant residues. The objectives of this study was to investigate the influences of spore dose on the infectivity of the isolates against banana weevils which were treated with *B. bassiana* isolates.

The soil samples were collected from banana production centers at Baso (Bukittinggi), Sungaitarab (Batusangkar), Sei Sariek (Pariaman), and Sikabau (Sitiung). The soil collected were screened for presence of fungal pathogens using the *Tenebrio molitor* L. bait method (Zimmermann 1986). Five hundred grams of each soil samples collected from the four sites were transferred to plastic bowls (10 cm diameter and 20 cm depth), and moistened by spraying with 150 ml of water. Ten to fifteen third instar larvae of *T. molitor* were placed in depressions made in the soil samples and covered with the soil. Perforated lids were put in place and the bowls incubated under laboratory conditions. The *T. molitor* larvae were inspected at intervals of 4 days. The dead, diseased or mummified larvae were used for pathogen isolation. The insect cadavers were surface sterilized with 1.0% sodium hypochlorite, rinsed 3-4 times in sterile water and placed on moist filter paper in Petri dishes to facilitate fungal outgrowth. Dry spores were picked from the cadaver using a sterilized inoculating loop and inoculated on tap water agar plates in zigzag pattern. The plates were incubated at 25ºC for 7 days, after which isolates were transferred to Sabroud Dextrose Agar (SDA).

Preliminary identification of the pathogens was based on the color of the sporulating cultures as described by Madelin (1963). From the fourth day, however, while Beauveria cultures remained white, the Metarhizium cultures turned green in areas of sporulation, with white mycelial growth at the margin. To establish the dose mortality relationship for *B.*

bassiana isolates from Baso, Sungaitarab, Sei Sariek and Sikabau, spore suspension containing 3.2×10^4, 3.2×10^6, and 3.2×10^8 derived from 3-week old SDA cultures of isolates were used. Ten male or female were inoculated with each isolate by immersing in 5 ml of spore suspension above. Three replicate dishes being used for each spore and weevil. The immersed weevils were incubated at 27ºC and checked everyday over 35 days starting 5 days after inoculation. Dead weevils were removed, surface sterilized and monitored for fungal growth. A completely randomized design with twelve treatments and three replications were used in this study.

Statistical Analyses

Banana weevil abundance at locations was compared with one-way analysis of variance using the GLM procedure of SAS (SAS Institute Inc. 1997). Survey data on damage were analyzed using a mixed model procedure (SAS Institute Inc. 1997), in which plant stages nested in location were treated as fixed effects and farms at a location as a random effect. Data on the fates of eggs and larvae collected and reared for parasitoid emergence were presented as percentages of total eggs and larvae collected from the field. The abundance of predators in residues was also analyzed using the mixed model procedure with plant stages nested in location as fixed effects and farms as a random effect. Relationships between predator numbers and damage in plants were investigated using regression analysis.

In laboratory experiments, the mixed model procedure was applied to compare predation potential of different natural enemies. Experiment date was set as a random effect, while predator types and banana weevil immature stages being tested were set as fixed effects. Means associated with ANOVA procedures were compared by least significant different (LSD) test criterion ($P < 0.05$). To fulfill conditions of normal distribution, data collected as percentages were arcsine square root transformed, while count data were log transformed before analysis.

RESULTS AND DISCUSSION

Banana Weevil Incidence and Damage

Captures of banana weevil adults in 4-day-old pseudostem traps averaged 1.1 ± 0.2 per trap (farm mean range of 0.6-1.7). Weevils were recovered in

only 45% and 16% of the traps. Damage to recently harvested plants averaged $1.5 \pm 0.9\%$ (farm mean range of 0.6-2.2%). Trap captures and damage indices at our study sites were far lower than those commonly observed in East Africa. In Uganda, for example, average trap catches of 3.6 ± 0.2 have been observed in their studies with damage in recently harvested plants being $8 \pm 0.5\%$ (Abera *et al.* 1999). In West Sumatra, most banana weevil attack was observed on older crop residues, reaching an average of $6 \pm 0.8\%$ on 8-12-week-old residues. Corm damage in this study on the highly susceptible AAB clone at harvest was very low (0-2%) compared to 8% for this clone in Uganda (Abera *et al.* 1999). Banana weevils were mostly found in residues of harvested plants, not living banana plants. Pieces of rhizome and the lower part of pseudostem (corm) remain moist long enough to attract significant number of weevil borer.

Parasitism of Banana Weevil Immatures

About 24,360 naturally occurring eggs were collected from the fields (Table 1). 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)

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).

We reared 3118 fourth to seventh instar larvae collected from banana residues (Table 2). Of these,

Table 1. Fates of field collected and trap host banana weevil eggs from different sites in West Sumatra, 2002-2003.

Location	Dead[1]	Hatched	Signs of parasitism	Total
Bukittinggi	1360 (15)	7773 (85)	0 (0)	9133
Sitiung	745 (14)	4699 (86)	0 (0)	5444
Pariaman	545 (18)	2507 (82)	0 (0)	3052
Batusangkar	1212 (18)	5519 (82)	0 (0)	6731
Total	3862 (16)	20,498 (84)	0 (0)	24,360

[1]Egg that died either due to fungal attack, mechanical injury or failed to hatch during 2-3 weeks of rearing.
Number in parentheses are percentages to total.

Table 2. Fates of banana weevil larvae collected from farmers fields in West Sumatra, 2002-2003.

Location	Dead[1]	Hatched	Signs of parasitism[2]	Total
Bukittinggi	162 (19)	691 (81)	3 (0.6)	475
Sitiung	155 (24)	492 (76)	7 (1.0)	647
Pariaman	120 (25)	355 (75)	2 (0.2)	1143
Batusangkar	217 (19)	926 (81)	5 (0.5)	853
Total	654 (21)	2464 (79)	17 (0.5)	3118

[1]Number of larvae that died or had not pupated within 2 weeks of collection.
[2]Number of dishes with Phorids.
Number in parentheses are percentages to total.

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* sp. 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

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 3), and 13 formicids (Table 4 for names) were found associated with banana mats or residues. Among the non-social predators, Dermaptera were more abundant than Coleoptera at all sites. The mean number of predators per residue was 7.6 ± 0.22, range of 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 Sumatra, at least, 13 species of ants were found to be closely associated with banana mats or

Table 3. Abundance of Coleopteran and Dermapteran predators of banana weevil found in crop residues in farmer´s fields in five locations in West Sumatra (mean number/residu ± SE, n = 30 per farm).

Site	No. Hesteridae/residue		No. Staphylinidae/residue (three species)	No. Dermaptera/residue		Total predators/residue (nine species)
	P. javanus	Other species		Chelisochidae (one species)	Others[1] (two species)	
Bukittinggi	1.6 ± 0.1b	0.9 ± 0.03a	0.8 ± 0.1b	7.8 ± 0.3a	0.4 ± 0.1a	10.7 ± 0.4a
Sitiung	1.3 ± 0.1b	0.1 ± 0.03b	0.5 ± 0.1bc	3.1 ± 0.3b	0.0 ± 0.0b	4.9 ± 0.4b
Pariaman	1.1 ± 0.1b	0.0 ± 0.03b	1.3 ± 0.1a	3.4 ± 0.3b	0.0 ± 0.0b	5.9 ± 0.4b
Batusangkar	2.0 ± 0.1a	0.1 ± 0.03b	0.9 ± 0.1b	8.2 ± 0.3a	0.0 ± 0.0b	11.1 ± 0.4a
Pasaman	2.1 ± 0.1a	0.1 ± 0.03b	0,3 ± 0.1c	2.6 ± 0.3c	0.4 ± 0.1a	5.5 ± 0.4b

Means in a column followed by the same letter are not significantly different at $P < 0.05$ level according to LSD test.
[1]One species each from Forficulidae and Labiidae.

Table 4. Ants associated with bananas farmer´s fields in five locations in West Sumatra.

Subfamily	Species	Site[1]	Abundance (average number of colonies per 40 m transect)	Weevil stage attacked[2]
Amblyoponinae	*Myopopone castanea* Smith	1, 2, 4	< 5	L
Dolichoderinae	*Technomyremex* sp.	2	< 5	-
Formicidae	*Anoplolepis gracilipes* Smith	1, 2, 3, 4, 5	>15	-
	Camponotus (*Tanaemyrmex*) 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 simillimus Smith	3, 1	5-15	E, L
	Pseudolasius sp.	1, 2, 3, 4, 5	> 15	-
Myrmicinae	*Monomorium* sp.	1	5-15	-
	Pheidole plagiaria Smith	1, 2, 3, 4, 5	> 15	E, L

[1]Site 1 = Pariaman, 2 = Pasaman, 3 = Sitiung, 4 = Bukittinggi, 5 = Batusangkar
[2]E = eggs, L = 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.

banana trash. In Cuba, the myrmicine ants *Pheidole megacephala* Fabricius and *Tetramorium guineense* Nylander have been used as biological control agents against banana weevils (Perfecto and Casteñieras 1988; Casteñieras and Ponce 1991). The density of colonies of ants on farms in Indonesia (seven species with 5-15 colonies per 40 m transect, 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 40 m transect for each of these species. Three species, *Camponotus* (*Tanaemyrmex*) sp. (Formicinae), *Odon-tomachus rixosus* Smith (Ponerinae), and *Odon-tomachus 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*, *Campanotus* (*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.

Prey Consumption of Predators

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 5). *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 of testing *P. javanus* larval searching efficiency in banana weevil-infested suckers, the two predatory larvae consumed an average of 6.3 ± 0.2 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) at the end of the test than in controls (7.8 ± 0.2); ($F = 746.0$, $P < 0.001$). Predator feeding tests confirmed earlier reports of earwigs (Sun 1994) and staphylinids (Jepson 1914; Edwards 1934; 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 moved 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, pers. comm.). 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.

Table 5. Consumption rates of life stages of banana weevil by three predators in laboratory experiment over 48-hour period.

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

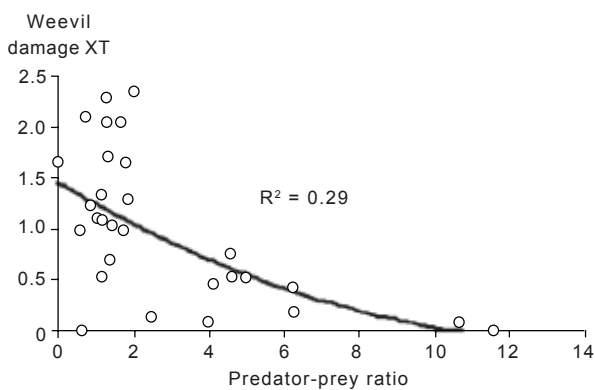Means in a column followed by the same letter are not significantly different at $P < 0.005$ according to LSD test.

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. 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. *P. 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 8 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.

Isolation and Pathogenicity of *B. bassiana* in Controlling Banana Weevil Borer

Entomopathogenic fungi of *B. bassiana* occur naturally in many parts of West Sumatra, and some were found infected insect in the field. The result showed that the effectiveness of the *B. bassiana* from four isolates improved with increasing spore dose (Table 6).

The adult banana weevil mortalities caused by *B. bassiana* from Baso, Sungaitarab, Sei Sariek, and

Table 6. The effect of the three concentrations of each *Beauveria bassiana* isolate against the mortality of banana weevil adult *Cosmopolites sordidus*.

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

Means followed by the same letters in the same column are not significantly different at 5% level of DMRT.
BS1 = 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.

Fig. 1. Correlation of banana weevil damage and predator-prey ratio on plant at survey location in West Sumatra.

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. It means that *B. bassiana* isolate from Baso has higher pathogenicity than other isolate. 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 (Table 4). Mortalities caused by three isolates after 4 weeks varied between 92.9-96.4%, 60.7-69.3%, 22.9-37.1% and 7.9-18.0% 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^{-1}.

CONCLUSION

The banana weevil appears to be less important in West Sumatra due to active role of various natural enemies co-evolved in the area. Captures of banana weevil adults in 4-day old pseudostem traps averaged 1.1 ± 0.2 per trap. The damage of recently harvested plants averaged 1.5 ± 0.9% (farm mean range of 0.6-2.2%), while on older crop residues, reaching an average of 6 ± 0.8% on 8-12-week old residues.

Over 84% of eggs were huched, 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 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 mortality caused by *B. bassiana* from Baso was 96.67% and it has higher pathogenicity than other isolates.

ACKNOWLEDGMENTS

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