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Bioecology and Management of the Banana Skipper (*Erionota thrax*)

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ABSTRACT

Bananas and plantains are important food crops to several people in the world. One of the most important folivorous insect pest on these crops is the banana skipper; *Erionota thrax*. The larvae of these large butterflies can cause mean leaf defoliation of about 60%, leading to yield losses of about 20%. Indigenous to Southeast Asia, life stages of the pest are attacked by several parasitoids of which *Ooencyrtus erionotae*, *Cotesia erionotae* and *Brachymeria* spp. are the major ones. Infestation and parasitism of the pest varies with plant growth stages, leaf ages, between interior and field edges, and seasons. Significantly higher infestation and parasitism found on pre-flowered plants, younger leaves and during the rainy season. In addition, eggs and larvae are randomly distributed while pupae are clumped and parasitized eggs and pupae are clumped while that of larvae is random. Although *E. thrax* has never been reported on non-*Musa* species or weeds, other smaller Erionota species have been recorded on *Asystacia intrusa*, *Ipomoea cairica*, *Mimosa pudica* and *Cloeme rutidesperma*.

Keywords: distribution, management, natural enemies

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INTRODUCTION

In developed countries and some areas of developing countries, bananas (including plantains) are still considered only as dessert, fruit eaten after a meal, or an addition to breakfast cereal. However, in reality and with the increasing food crises in the world, bananas are considered as an important agricultural product to most developing tropical countries (Purseglove 1972; Samson 1980; Abdullah *et al*. 1990; Anon 1991; InfoMusa 1994; Youdeowei 2002; Nkedah and Akyeampong 2003; Jacobsen *et al*. 2004; Desdoigts *et al.* 2005; Loeillet *et al*. 2009; Okolle *et al*. 2009a; Mararuai 2010). This food crop has therefore been rated as the fourth most valuable food after rice, wheat, and milk (Ploetz 2001). Three main problems are usually associated with the consistent increase in world population and globalization *viz*., increasing food demand, environmental pollution and species invasiveness. Tackling these problems has resulted in a global emphasis on sustainable food production, minimizing environmental pollution and proper quarantine.

Emphasis on the significance of agriculture and agro-based industries is one of the major strategies in tackling the above-mentioned problems. This usually calls for modernization and transformation of traditional farming systems (Musa 2005). This obviously means increasing intensification of production systems; including increasing use of agrochemicals especially pesticides to improve food quality and protect plants from pests and diseases. Although pesticides are and will continue to be a vital tool as far as crop protection is concerned, frequent and injudicious use of agrochemicals is usually accompanied by ecological backlashes in the long term (Anon. 1971; Berryman 1986; Van

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Emden and Peakall 1996; Pedigo 1999; Norris *et al*. 2003; Speight *et al*. 2008). In field crops, such backlashes include resistance to pesticides, pest resurgence, secondary pest outbreaks, mortality to non-target and beneficial species as well as contamination of water sources.

In spite of the increasing awareness on food safety, most farmers are still much concerned only on profit making without thinking of long-term consequences following their injudicious use of agrochemicals and other ineffective production practices. Based on this, it is necessary for farmers and associated stakeholders to divert their focus towards sustainable management of agro-ecosystems and such sustainability can be realized only through an understanding of the major components of such systems. In a field crop system such as a banana plantation, detailed knowledge of the biology and ecology of a pest are essential components in life system studies. These components form the basis of an effective pest management strategy particularly for a defoliating insect like *E. thrax* that is gradually invading more and more non-native areas.

BIOLOGICAL ASPECTS

Erionota species

Members of the genus *Erionota* (Mabile) are large butterflies, with the upper side dark brown, and with the pale yellow hyaline spots on the forewing separated, except in *E. harmachis* (Flemming 1983; Corbert and Pendlebury 1992). There are six major species under this genus*:* *E. thrax* (Linneus), *E. torus* (Evans) (Chiang 1988), *E. acroleuca* (Evans), *E. sybirita* (Hewitson), *E. hislopi* (Evans), and *E. hermachis* (Hewitson). Keys for the separation of these species are found in Corbert and Pendlebury (1992) and the genus is distributed from India and China via the Archipelago to the Moluccas. According to Lai and Funasaki (1990), *E. thrax* was first discovered in Hawaii at Hickam Air Force on Oahu, infesting backyard banana plants in the military housing areas.

E. thrax and *E. torus* are common and well known, as their larvae live in the rolled-up strips of banana leaves. However, although both species differ only as stated in the identification keys (Corbet and Pendlebury 1992) and in the male genitalia, Anon (2007) and Anon (2008) stated that in the literature, *E. thrax* remains confused with *E. torus* and *E. hiraca* (formerly *E. acroleuca*) (de Jong and Treadaway 1993). *Erionota thrax* is one of the largest of the Malayan hesperiids, having a forewing length of about 32 to 37 mm. Its wings are dark brown above, and the forewing has three prominent separated yellow hyaline spots (**Fig. 1**) in the cell near the distal end and overlapping the larger spot in the middle of space 3. *Erionota acroleuca*, *E. sybirita*, *E. hislopi*, and *E. harmachis* are very rare. *Erionota acroleuca* is smaller than *E. thrax* and has a forewing length of about 28 mm. The male *E. acroleuca* has a distinct whitened apical patch on the fore-wing above and the female appears to be separable from *E. thrax* only by its smaller size.

Life stages and life history

Dammerman (1929), Mau *et al*. (1980), Christie *et al*. (1989) and Igarashi and Fukado (2000) have described considerable aspects of the biology of this pest. The adults are referred to as skippers because of their erratic darting flight (Khoo *et al*. 1991). This species can be distinguished from other native skipper butterflies by their size, shape, and spots on the forewing. Both sexes of the butterfly are brown with three prominent yellow, elongate and translucent spots on each forewing. Adults have large heads and clubbed antennae with recurved tips. Wingspan averages about 70 mm while the 5^{th} instar averages 50 mm. Although copulation of adults has been observed at different times of the day, oviposition has only been observed at dusk or early dark periods (Waterhouse *et al*. 1998; Okolle, pers. obs.). *E. thrax* females are known to deposit 60 eggs and probably more

Fig. 1 Adult of *Erionota thrax* with three yellow prominent spots on its forewings. Photo by Justin Okolle.

depending on the quality of food plant of each individual larva (Don Sands, pers. comm) and newly laid eggs are bright yellow, turning to orange, bright red and then to pale yellow when mature (Okolle *et al*. 2008). These eggs are laid singly or in clusters mostly on the lower surface of the host leaves and the eggs hatch in 5–8 days (Mau *et al*. 1980; Khoo *et al*. 1991; Okolle *et al*. 2009b).

Immediately after hatching, the young caterpillars (first instars) begin to feed on the edge of the leaf and to construct shelters by rolling and attaching the edge of the leaf using a sticky substance. Due to intra-specific competition, poor leaf quality and hardness, first and second instars tend to move towards younger leaves. As the larvae grow, the leaf rolls also increase in size and a protective white and waxy powdery substance is secreted and covers the entire body. This substance which is believed to be a by-product of metabolism (Waterhouse *et al*. 1998), is found on all the larval stages except the first instars. Larval development takes 23–32 days depending on temperature (Waterhouse *et al*. 1998), 25–30 days (Mau *et al*. 1980), and 20–29 days (Khoo *et al*. 1991). Larvae are nocturnal, hiding within leaf rolls during the day. Older larvae close their rolls or shelters more securely and produce enough waxy powder to be water-repellent.

The larvae transform into pupae within leaf rolls and the pupae are light brown, long, and slender. The pupal duration is about 10 days (Mau *et al*. 1980; Waterhouse and Norris 1989) and 8–12 days (Khoo *et al*. 1991). The pupae are sensitive to movement and will wriggle violently if disturbed (Corbert and Pendlebury 1978). Adult emergence begins with the splitting of the anterior portion of the pupae and the adult emerges head first and then forces its way out of the leaf roll and emergence is usually in the afternoon. The adult then stays for a few minutes on or nearer the leaf roll before flying to nearby banana plants. Waterhouse *et al*. (1998) reported that in Southeast Asia, five generations occur per year and this is probably similar in other favorable environments. Adults that usually emerge in the afternoon are powerful fliers and apparently fly erratically about banana plants in the early evenings and mornings (crepuscular in nature) and occasionally attracted to light (Mau *et al*. 1980; Christie *et al*. 1989; Waterhouse *et al*. 1998). Sex ratios are equal (Don Sands, pers. comm).

Host plants, damage and damage effects

Musa species have been mentioned as the major or main host of *E. thrax* (Mau *et al*. 1980; Kalshoven 1981; Khoo *et al*. 1991; Waterhouse *et al*. 1998; Mararuai 2010). Other recorded or minor hosts include Manila hemp (*Musa textiles* Nee), bamboo (*Bambusa* sp.), coconut (*Cocos nucifera* L.), other palms as well as *Canna* sp., S*trelitzia*, and *Heliconia papuana* (an ornamental species) (Waterhouse and Norris 1989). In Malaysia, the pest has been recorded from *Caryota* sp., *Musa* sp., and nipa (*Nypa fruticans* Wurmb) (Khoo *et al*. 1991) while in Papua New Guinea, eight varieties (Dwarf Cavendish, Tall Cavendish, Babi Yadefana, Kuriva, Small Kalapua, Wudupataten, and Brown River) have been

Fig. 2 Damage caused by *Erionota thrax* larvae (leaf rolls). Photo by Justin Okolle.

reported to be infested, of which Dwarf and Tall Cavendish were the least infested (Mararuai 2010). However, it seems that other skipper species may be responsible for infestation on coconuts and other palms. The coconut skipper (*Hidari irava* Moore) has been reported to commonly feed on oil palms, coconuts, sugar palm, bamboos, and Livistona palms (Khoo *et al*. 1991).

The feeding by the larvae and the rolling of leaves cause damage. Larvae cut leaf blades at their edges and roll strips of leaves towards the mid-vein into barrel-shaped structures hanging from the mid ribs held by silky threads (Prasad and Singh 1987). The larvae feed within the shelters (leaf rolls) (**Fig. 2**) and will occasionally make new rolls when fresh food is needed (Corbert and Pendlebury 1978). After about one or two weeks, these leaf rolls become necrotic and turn brown in color. In a survey carried out in Papua New Guinea (Waterhouse *et al*. 1998), as few as two larvae per leaf resulted in several localities in plants being completely defoliated, leaving only leaf stalks. Also, the maximum number of leaves carrying leaf rolls was 94% while the maximum number of leaf rolls recorded was 6/leaf. Okolle (2006) recorded mean maximum of 2.5 infested leaves/banana mat and a significant linear regression between the mean number of larvae and mean number of infested leaves/banana mat ($r^2 = 0.74$, $P < 0.05$).

Although *E. thrax* is generally considered a minor pest in its native region, occasionally very heavy infestations occur and these result in crop defoliation (Ahmad and Balasubramaniam 1975; Kalshoven 1981; Waterhouse and Norris 1989; Christie *et al*. 1989; Khoo *et al*. 1991). It is worth noting that this pest has caused economic damage to bananas in newly colonized areas (Hasyim *et al*. 1994; Waterhouse *et al*. 1998). Mean defoliation of 60% by this pest has been reported (Sands *et al*. 1993) and in addition, Khoo *et al*. (1991) reported cases of some banana farms being completely defoliated by this pest. In spite of these, Okolle *et al*. (2006b) did not find any plant death as a result of *E. thrax* infestation. Waterhouse *et al*. (1998) mentioned that any factor that reduces weight of bananas, extends the time required for a bunch to mature, or impair banana leaves for traditional uses will obviously result in losses. Based on a pest risk assessment recorded in the Anon (2008), the implication of these therefore is that *E. thrax* poses a serious threat to banana growers. Furthermore, Waterhouse *et al*. (1998) showed a positive linear relationship between percentage defoliation and reduction in weight of bunch at harvest. They also mentioned that defoliation at the time of appearance of the fruiting bud caused the greatest reduction in fruit weight and fifty percent defoliation at this time caused 28% weight loss (Hartman and Bailey 1929). In Southern China, Hoffman (1935) reported that banana plants are not only damaged but also unsightly – an important consideration to many Chinese families growing bananas for aesthetic pleasure.

ECOLOGICAL ASPECTS

Origins and world distribution

E. thrax is one of the most successful members of the most primitive family of butterflies, the Hersperiidae. This pest is native to Southeast Asia from where it spread to Mauritius in 1970, Hawaii in 1973, Guam in 1956, Saipan in 1960 and 1983 (Arura 1987; Waterhouse and Norris 1989; Sands *et al*. 1991, 1993) and mainland Papua New Guinea in 1983 (Dori 1988). In its native areas, it is a widespread but usually uncommon insect, and therefore not considered to be of much economic significance. Muraruai (2010) also mentioned that in Papua New Guinea, *E. thrax* is considered as a seasonal pest. This is believed to be because the insect is widely attacked in the egg, larval, and pupal stages by a number of parasitic wasps and flies and to a lesser extent, by predators (Waterhouse *et al*. 1998).

The spread of *E. thrax* to new areas can be very rapid (up to 500 Km/year) (Waterhouse *et al*. 1998). The possible dispersal mechanisms of this pest have been mentioned and include: (i) flight by adults, (ii) transportation of eggs or young larvae across borders on banana leaves used for wrapping, (iii) attraction to lights in boats and loading aircrafts. Recently a few egg masses have been found on bunches and this could also be a potential dispersal mechanism (Okolle 2006).

Banana – *Erionota thrax* interactions

1. Within-farm distribution

Generally, studies that show how *E. thrax* life stages are distributed within banana farms or plants are scarce. As a defoliator, there is high probability that such a pest would target farm areas that contain high quality plants (fresh leaves or succulent leaves). Knowledge of within-field distribution of *E. thrax* and its parasitoids may help in the identification of blocks or management units that are most attractive to ovipositing adults of the pest and its parasitoids. In addition, such knowledge helps to improve sampling techniques as well as efficacy of insecticides.

Irrespective of the region where the pest is found, there is a higher probability that it is going to be present in any farm where *Musa* spp. are found. However, abundance and distribution will vary based on farm management, plant quality, natural enemy abundance or weather. So far, the only available primary data concerning within-farm/within-plant distribution of the pest and its parasitoids is that by Okolle *et al*. (2006a). These authors studied the distribution in relation to the following banana growth stages: (i) Bunched Plants (BP), (ii) Flowering Plants (FP), (iii) Pre-Flowered Plants (PFP) – 4-5 months old and greater than 1.6 m in height, (iv) Broad Leaf Followers (BLF) – 2-4 months old, broader leaves, greater than 1 m but less than 1.6 m in height, (v) Narrow Leaf Followers (NLF) – 1-2 months old, narrow leaves, and less than 1 m in height.

In addition, the same authors studied the distribution of this pest in well-managed and poorly-managed sections of a plantation of Cavendish bananas in Penang State, Malaysia. Their results showed that infestation (number of eggs and larvae) was significantly higher on well-managed/vigorous plants. Furthermore, using different dispersion indices, Okolle *et al*. (2006a) found that eggs and larvae were randomly distributed while pupae were clumped or aggregated. As part of his PhD research project, Okolle (2006) carried out a study to find out whether infestation and parasitism of *E. thrax* were different at the perimeters (edges) and interiors (50 m and 100 m from field edges) of the plantation. Except for mean number of pupae, his results showed that infestation of eggs and larvae were not significantly different between the interiors and perimeters of the field. In all these studies, a potential limitation is that they were carried out only within a single plantation. Based on this, it would be necessary to extend such studies to other farms/ plantations in different regions and with different cultivars.

2. Within-plant distribution

Musa spp. consists of roots, corm, pseudostem, leaves, fruits and flowers (Speijer and De Waele 1997). Growth stage of a plant or different parts of a plant can influence the number of phytophagous insect species on it as well as the severity of their damage (Pencoe and Lynch 1982; Snodderly and Lambdin 1982; Pitre *et al*. 1983; Eckel *et al*. 1992; Preszler and Price 1995; Inbar *et al*. 2001; Zarrabi *et al*. 2005). Most authors have reported that a majority of leaf-chewing insect pests prefer younger plants or younger plant parts (Wilson *et al*. 1982; Fowler and Lawton 1984; Overholt *et al*. 1994; Smyth *et al*. 2003; Okolle *et al*. 2006b, 2009a). Most researches on the bioecology of *E. thrax* have concentrated mainly on seasonal fluctuations, identification and quantification of impact of their natural enemies.

Although there are many reports showing that *E. thrax* is a folivorous pest on bananas and plantains (Waterhouse and Norris 1989; Khoo *et al*. 1991; Gold *et al*. 2002; Okolle *et al*. 2006a, 2006b, 2006c), the only available research that attempts to quantify distribution of *E. thrax* immature within banana plants is that of Okolle *et al*. 2009a). In a commercial plantation of Cavendish bananas and a local variety (Pisang Mas), the researchers counted numbers of eggs, younger instar larvae and older instar larvae from different leaf ages. The categories of the leaf ages sampled were (i) newly emerged leaves – central leaf of plant not completely expanded or unrolled and usually very fresh and soft, (ii) young leaves – the first 4 leaves surrounding the newly emerged leaves; usually fresh and softer than older leaves, (iii) older leaves – those surrounding the younger leaves; not very fresh and usually hard/tough. Irrespective of the observation period (low or high density period), significantly higher mean number of eggs and younger instar larvae were found on older leaves while highest mean number of older instar larvae was recorded on younger leaves. For both Pisang Mas and Cavendish varieties, mean number of egg batches and individual eggs were significantly more on lower than on upper leaf surfaces.

Interactions with natural enemies

1. Identified natural enemies

E. thrax is widely attacked in the egg, larval, and pupal stages by a number of parasitic wasps and flies, and to a lesser extent by predators. It has been suggested that these natural enemies, especially parasitoid wasps are important in keeping the skipper density at low levels in endemic areas (Ashari and Eveleen 1974; Kalshoven 1981; Khoo *et al*. 1991; Lubulwa and McMeniman 1998; Okolle *et al*. 2006c). Hasyim *et al*. (1994) reared 12 hymenopteran primary parasitic wasps of banana skipper belonging to 6 families (Braconidae, Chalcididae, Encyrtidae, Eulophidae, Pteromalidae, and Ichneumonidae). Of these, were 4 species of egg parasitoids (*Ooencyrtus erionotae* Ferriere, *Anastatus* sp., *Pediobus erionotae*, and *Agiommatus sumatraensis*), one parasitoid from second instar larvae (*Elasmus* sp.), two from third instars (*Casinaria* sp. and *Charops* sp.), three from fourth instars (*Cotesia erionotae* Wilkinson, *Casinaria* sp., and *Charops* sp.), one from firth instars (*Cotesia erionotae*) and four from pupae (*Brachymeria lasus*, *B. thracis*, *Theronia zebra zebra*, and *Xanthopimpla gampsura*). In Indonesia, Hasyim *et al*. (1994) reared four dipteran parasitoids from *E. thrax* larvae: two tachinids (*Palexorista solensis* and *Blepharipa* sp.) from third, fourth, and fifth instars, one sarcophagid from a fifth instar, and one phorid from pupae.

In Papua New Guinea, Sands *et al*. (1991, 1993) recorded the following indigenous parasitoids: *O. erionotae*, *Anastatus* sp., *Ectopiognatha* sp. Perkins (Ecyrtidae), *Telenomus* sp. (Scelionidae) attacking eggs, *Brachymeria* sp. and an unidentified tachnid attacking pupae, as well as *Palexorista* sp. (Tachinidae). In Malaysia, a good number of parasitoids have been reared from banana skipper life stages (Nakao and Funaski 1976; Khoo *et al*. 1991; Yeo and Zakaria 2001) including *O. erionotae*, *Agiommatus* sp., *Anastatus* sp., *Cotesia* sp., *Palexorista inconspiuoides* (Baranov), *Brachymeria euploeae* (Westwood), *Xanthopimpla gampsura* (Krieger) and *Scenocharops* sp. In Peninsular Malaysia, Sabah, and Thailand, *O. erionotae*, *C. erionotae* and *Brachymeria* sp. are recognized as among the important parasites (Hasyim *et al*. 1994). In a subsistence farm and a commercial plantation in Penang, Malaysia, Okolle *et al*. (2006c) recorded five primary endoparasitoids; *O. erionotae*, *C. erionotae*, *B. albotibialis*, *Elasmus* sp. and *Melaloncha* spp. *Ooencyrtus erionotae*, *C. erionotae* and *B. albotibialis* were, respectively, the major egg, larval and pupal parasitoids. Additional parasitoids from Hawaii include the egg parasitoid – *Trichogramma* sp. (Trichogrammatidae), the larval parasitoid – *Ecthromorpha fuscator* Fabricius (Ichneumonidae) and the pupal parasitoid – *Brachymeria obscurata* (Walker) (Chalcididae) (Mau *et al*. 1980).

Of all the above-mentioned parasitoids, only *O. erionotae* and *B. albotibialis* have been widely mentioned to inflict significant parasitism on *E. thrax* in its native and non-native areas (Kalshoven 1981; Waterhouse and Norris 1989 Khoo *et al*. 1991; Yeo and Zakaria 2001; Okolle *et al*. 2006c). Peculiar characteristics of these two parasitoids are (i) they do not oviposit on hosts that are already parasitized, (ii) in cases where banana leaf rolls were tightly secured, females of *B. albotibialis* easily chewed holes in order to reach the hosts. In Papua New Guinea, *O. erionotae* caused significant mortality, averaging 30%, although it reached 82% in some occasion (Sands *et al*. 1991). In Indonesia, *O. erionotae*, *Agiommatus* sp., and *Anastatus* sp. were reported parasitizing 50–70% of eggs (Kalshoven 1981). In Papua New Guinea, only about 5% of pupae were parasitized by *Brachymeria* sp. and a fly (*Palexorista* sp.) (Sands *et al*. 1991, 1993). Hasyim *et al*. (1994) recorded a 10–40% parasitism of eggs by *O. erionotae* and *P. erionotae*, 1–80% of larvae killed by *Casinaria* sp., 5–20% pupae killed by *B. thracis* and *B. lasus*, 41–66% by *B. euploeae*, and about 50% larvae attacked by *C. erionotae*. In Peninsular Malaysia, Okolle *et al*. (2006d) recorded highest mean percentage parasitism from *O. erionotae* (51.3 ± 5.8) and *B. albotibialis* (38.59 ± 12.4).

Cotesia erionotae has been reported as the only braconid parasitizing larvae of Hesperiidae in the Australasian region (Sands *et al*. 1993). *Cotesia erionotae* and *O. erionotae* seem to be very specific to the larvae and eggs of *E. thrax* respectively (Waterhouse *et al*. 1998). These two parasitoids have not been recorded from hosts other than *E. thrax*. According to Sands *et al*. (1993), *C. erionotae* prefers second or third instar larvae of *E. thrax* for oviposition. Hasyim *et al*. (1994) summarized the developmental stages of *E. thrax* susceptible to parasitoid oviposition: second instars – fifth instars for *C. erionotae*, fifth instar larvae and pupae for *Brachymeria* sp., first – fourth instar larvae for *Casinaria* sp., second instars for *Elasmus* sp., first – fourth instar larvae for *Charops* sp., third instar larvae, fifth instar larvae, and pupae for *X. gampsura*, third instar larvae, fourth instar larvae and fifth instar larvae for *Palexorista* sp., and pupae for Phoridae. (Okolle *et al.* 2008) carried out a research on the oviposition preferences of three major identified parasitoids of *E. thrax*. For *O. erionotae*, egg stage 1 (newly laid), stage 2 (intermediate), and stage 3 (advanced) were susceptible to *O. erionotae* oviposition although stage 3 was the most preferred egg host. For *C. erionotae*, second, third, and fourth larval instars were susceptible and the third instar larva was the most preferred larval stage for oviposition. For *B. albotibialis*, only prepupae and pupae were susceptible and the pupa was the most preferred host stage.

Fig. 3 Dead larva of *E. thrax* with cocoons of parasitoids (*C. erionotae*) beside dead body. Photo by Justin Okolle.

Fig. 4 *E. thrax* pupa with typical sign of parasitism (three dark rings on the abdomen) caused by *B. albotibialis*. Photo by Justin Okolle.

In Indonesia, Hasyim *et al*. (1994) recorded six hyper-parasitoids from the primary parasitoids of *E. thrax*. These included *B. lasus* (Chalcididae), *Eurytoma* sp. (Eurytomidae) and *Theonia* sp. bred from cocoons of *Casinaria* sp.; *Eurytoma* sp. and *Pediobius elasmi* bred from cocoons of *C. erionotae* while *Aspilota* sp. (Braconidae) was bred from a dipteran primary parasitoid. These authors also recorded the average number of primary parasitoids emerging per host: 2.8 for *O. erionotae*, 1 for *Anastatus* sp and *P. erionotae*, 57.4 for *C. erionotae*, 8.8 for *Brachymeria* sp., 12 for *Elasmus* sp., and 1 each for *Agiommatus sumatraensis*, *Casinaria* sp, *Charops* sp., *T. zebra zebra* and *X. gampsura*. In Malaysia, Okolle *et al*. (2006c) also recorded mean number of adults emerging per host as follows: 3.4 ± 0.011 for *O. erionotae* (range from 1 to 9, n ± 156), 87 ± 4.9 for *C. erionotae* (range from 14 to 192, n = 103) (see **Fig. 3** for *C. erionotae* cocoons on *E. thrax* mature larva), and 7.1 ± 0.46 for *B. albotibialis* (range from 1 to 21, n = 106). A typical sign of a parasitized *E. thrax* pupa by *B. albotibialis* are three dark rings on the abdominal region (**Fig. 4**).

As for predators of *E. thrax*, few have been recorded. Sands *et al*. (1993) recorded two predators from Papua New Guinea: A bug, *Platynopus melacanthus* Boisduval (Pentatomidae), feeding on larvae and birds (particularly crows) opening leaf rolls to feed on larvae and pupae, causing 72% mortality of these stages. In a banana plantation in Malaysia (Okolle *et al*. 2006c), mean percentage of predated larvae was 0.81 ± 0.5 (range from 0 to 4.6) while that for pupae was 2.26 ± 1.8 (range from 0 to 16.7) and the main predators seen were ants and spiders. Mean percentage mortality of eggs, larvae, pupae and emerging adults due to unidentified causes was 20.29 ± 9.1, 2.44 ± 0.5, 5.5 ± 2.1 and 4.17 ± 2.4, respectively. These mortalities may possibly have resulted mainly from diseases, harsh weather conditions and insecticide applications. **Fig. 5** shows the contribution of mortalities (combination of different mortality agents) on different *E. thrax* stages on the overall mortality of *E. thrax*.

2. Within-farm and within-plant distribution of parasitoids of E. thrax

Like distribution of *E. thrax*, parasitism of the life stages of the pest within farm and within the plants is very scarce, and the only available published research is that by Okolle *et al*. (2006a). As the pest finds itself in different areas, so too its natural enemies especially parasitoids are likely to disperse with it. However, parasitism depends on weather, level of management of the farm, relation to growth stages of the plant and the abundance of *E. thrax* life stages.

In their research carried out in a commercial plantation of Cavendish bananas in Penang State, Malaysia, Okolle *et al*. (2006a) reported that parasitism of *E. thrax* eggs during a low-density period was significantly different between the banana stages with highest parasitism recorded on BLF. However, for larvae and pupae, only mean percent parasitism on BLF was significantly different from other banana growth stages. During the high-density *E. thrax* period, egg and pupal parasitism were significantly different while larval parasitism on PF and BLF were significantly different from parasitism on other banana growth stages. In relation to farm management, only parasitism of larvae was statistically different on well-managed and poorly-managed sections of the plantation.

In addition, based on four different commonly used dispersion indices (Variance-to-Mean Ratio, Taylor's Power Law, Green's Coefficient, and Iwao's Patchiness Regression) (Taylor 1961; Iwao 1968; Cherry 1984; Taylor 1984; Legg and Chiang 1985; Overholt *et al*. 1994; Liang *et al*. 1996; Blank *et al*. 2000; Schexnayder *et al*. 2001), Okolle *et al*. (2006a) found out that all the indices showed that numbers of *E. thrax* eggs and pupae parasitized by *O. erionotae*, *C. erionotae* and *B. albotibialis* within the plantation were clumped while for the larvae, three indices revealed a random pattern. Furthermore, analysis of variance (ANOVA) showed that numbers of parasitized eggs were significantly different among the nine blocks in the plantation although

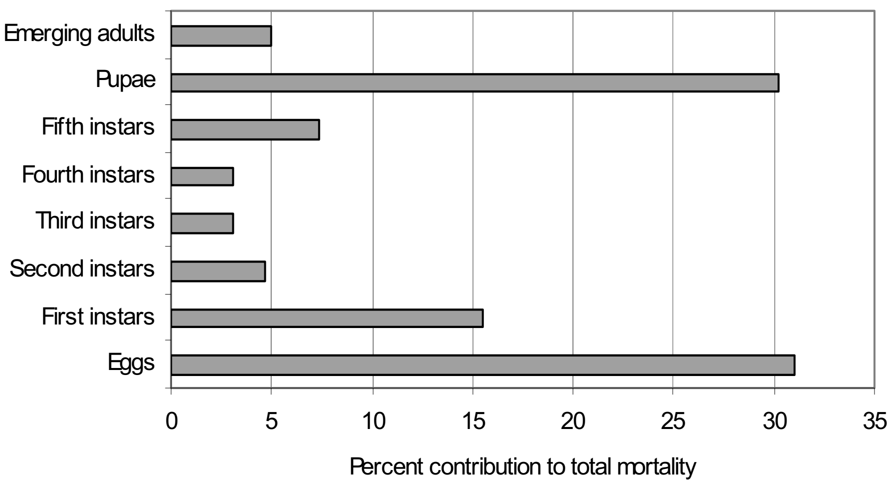

Fig. 5 Contribution of mortalities on different *E. thrax* stages on the overall mortality of *E. thrax* (combination of high and low infestation period). (Culled from PhD thesis of Justin Okolle, Universiti Sains Malaysia, 2007).

Table 1 Leaf-eating insect species on two banana cultivars (Pisang Mas and Cavendish) in Synergy Farm, Penang, Malaysia.

Order	Family	Species	Common name	Damage
Lepidoptera	Noctuidae	*Spodoptera litura*	Cluster caterpillar	Very serious
Lepidoptera	Hesperiidae	*Erionota thrax*	Banana skipper	Not very serious
Orthoptera	Acrididae	*Valanga nigricornis*	Malaysian locust	Not significant
Coleoptera	Curculionidae	*Hypomeces squamosus*	Gold dust weevil	Not significant
Homoptera	Aleyrodidae	*Aleurodicus dispersus**	White fly	Not significant

* The only species found on Cavendish but not found on Pisang Mas: Source: **Okolle JN, Mashhor M, Abu Hassan A** (2006b) Folivorous insect fauna of two banana cultivars and their association with non-banana plants. *Journal of Bioscience (Malaysia)*, **17(1)**, 89-101, with kind permission, Journal of the School of Biological Sciences, Universiti Sains Malaysia)

parasitized larvae and pupae were not. Based on these results, the authors concluded that *O. erionotae* and *B. albotibialis* have abilities to concentrate their search on high-density patches of *E. thrax*. Also, with the exception of percent parasitism of pupae, parasitism of eggs and larvae were not significantly different between interiors (50 m and 100 m) and the perimeters (10 m) from the field edges (Okolle *et al.* 2009b). As for distribution in relation to leaf age, interesting results were also recorded. For both low and high-density *E. thrax* periods, on both PF and BLF, significant parasitism of eggs were recorded from older leaves while parasitism of larvae and pupae were significantly higher on young leaves (Okolle *et al.* 2009b).

Seasonal abundance and causes of population fluctuations

In its native areas, *E. thrax* primarily exists in low densities throughout the year. However, abundance of *E. thrax* can sometimes be affected by environmental factors such as rainfall, wind, drought, natural enemies, and even elevation. These factors have been the main causes for the seasonal fluctuations of *E. thrax*. Studies on the seasonal abundance of *E. thrax* especially in the native areas are very scarce. Following a survey of insect pests of bananas and their incidence in Manipur–India, Prasad and Singh (1987) recorded maximum incidence of *E. thrax* during April to July with lowest incidence during October to January each year. In Papua New Guinea, Sands *et al.* (1993) monitored the population of *E. thrax* from January 1989 to March 1990 before the release of *C. erionotae*. In this 15 months survey before the release of *C. erionotae*, peak egg abundance was recorded in April, July, December 1989 as well as February 1990. However, after the release of *C. erionotae* in March 1990 and following a survey of *E. thrax* egg abundance from March 1990 to February 1991, Sands *et al.* (1993) recorded maximum peak from May to June 1991.

Fluctuations in numbers of *E. thrax* seem to be related mainly to weather, topography (elevations), and natural enemies, with weather playing both direct and indirect roles. Peak abundance and peak parasitism were recorded during periods of high rainfall (Sands *et al.* 1993; Maramis 2005). Gold *et al.* (2002), however, reported that heavy rainfall and strong winds are unsuitable for *E. thrax* as water in leaf rolls drowns young instars and wind-torn leaves are unsuitable for production of leaf shelters.

Outbreaks of *E. thrax* in Malaysia and Indonesia are common after a drought and in wind-protected areas (Kalshoven 1981). Khoo *et al.* (1991) also suggested that a possible reason for such outbreaks is the adverse effect of severe droughts on natural control agents. Site elevation seems to affect fluctuations of *E. thrax* depending on geographical region, country or region within a country. In Sumatra Barat (Indonesia), following equal samplings, egg abundance recorded in Sitiung (100 m above sea level (masl)) was twice as much as that of Bandar Buat (20 masl) (Hasyim *et al.* 1994). In Indonesia, Maramis (2005) recorded highest populations of the egg and pupal parasitoids in Lembang (1200 masl) compared to Subang (50 masl) irrespective of the season. Implications being that Subang (low elevation) had lower *E. thrax* population compared to Lembang (high elevation).

As far as natural enemies are concerned, several researchers have emphasized their importance in maintaining the population of *E. thrax* below economic damaging levels (Mau *et al.* 1980; Kalshoven 1981; Christie *et al.* 1989; Khoo *et al.* 1991; Sands *et al.* 1993; Hasyim *et al.* 1994; Okolle *et al.* 2006c). Of all these enemies, highest or substantial and persistent mortalities have been recorded mainly from parasitoids (both hymenopterans and dipterans). Details on the interaction of *E. thrax* with its natural enemies are found in section dealing with identified natural enemies.

ASSOCIATION OF *ERIONOTA* SPECIES WITH NON-BANANA CROPS AND WEEDS

Generally, growth stage of a plant can influence the number of insect species on it as well as the severity of damage (Wilson *et al.* 1982; Pencoe and Lynch 1982; Fowler and Lawton 1984; Overholt *et al.* 1994; Steinbauer *et al.* 1998; Smyth *et al.* 2003). Although there are several reports listing various insect pests on bananas or *Musa* spp. (Pinto 1928; Waterhouse and Norris 1989; Nakasone and Paull 1998; Padmanaban and Sathiamoorthy 2001; Gold *et al.* 2002), only reports by Okolle *et al.* (2006b) were found to deal with interactions or associations of these insects with non-banana crops or weeds within banana agro-ecosystems. In their study carried out in two plantations of Pisang Mas and Cavendish bananas separately grown, Okolle *et al.* (2006b) recorded five different insect species feeding on the leaves (**Table 1**). In the first six months after planting, the total number of insect species increased as the banana plants mature. Of all these insect species, the most damaging on young plants was *Spodoptera litura* (61.2% dead plants as a result of *S. litura* infestation).

On Pisang Mas, *Valanga nigricornis* and *S. litura* were the first colonizers appearing one month after planting, while *E. thrax* and *Hypomeces squamosus* only appeared four months after planting. Like the case of Pisang Mas, *V. nigrocornis* and *S. litura* were also the first colonizers on Cavendish plants; appearing on the second month after planting while *E. thrax*, *H. squamosus* and *Aleurodicus dispersus* only appeared by the third month after planting. Of the five species of banana folivorous insects recorded, only *V. nigricornis* and *H. squamosus* were found on non-banana crops and weeds (**Table 2**). Although these two insects where found on *Elaeis guineensis* (oil palm) and *Psidium guajava* (guava) respectively, they were never found on weeds. Both insects fed on the leaves and also spend some time mating on the plants.

Although *E. thrax* was never found on any of the non-banana crops/weeds, other *Erionota* species and butterflies were commonly found on *Asystasia intrusa*, *Ipomoea cairica*, *Mimosa pudica* and *Cloeme rutidesperma*. Adults of these insects fed on the nectar of the flowers of these weeds while their larvae fed on the leaves and construct leaf rolls/shelters, and of these four weeds, *A. intrusa* was the most frequently visited by the insects.

Apart from these leaf-eating insects, some predators and parasitoids were often found on the non-banana plants/weeds. An unidentified species of red ants was found on all the weeds while ladybird beetles and the pupal parasitoid *Brachymeria albotibialis* of *E. thrax* were present only on *P. guajava* and *Digitaria ciliaris*. The red ants visited these

Table 2 Association of banana leaf-eating insects with non-banana crops/weeds in Synergy Farm Sdn Bhd, Penang, Malaysia.

Non-banana plants and Weeds	Insects									
	Red ants*	**Other *Erionota* species**	**Ladybirds***	**Aphids**	***Brachymeria albotibialis*****	***Valanga nigricornis***	***Hypomyces squamosus***	***Spodoptera litura***	***Erionota thrax***	***Aleurodicus disperses***
Psidium guajava[#]	+	-	+	+	+	-	+	-	-	-
Digitaria ciliaris	+	-	+	+	-	-	-	-	-	-
Asystacia intrusa	+	+	-	-	-	-	-	-	-	-
Ipomoea cairica	+	+	-	-	-	-	-	-	-	-
Mimosa pudica	+	+	-	-	-	-	-	-	-	-
Cloeme rutidesperma	+	+	-	-	-	-	-	-	-	-
Borreria laevicaulis	+	-	-	-	-	-	-	-	-	-
Elaeis guineensis[#]	+	-	-	-	-	+	-	-	-	-
Emilia sonchifolia	-	-	-	-	-	-	-	-	-	-

* Insect predators. ** Parasitoid of *E. thrax* pupae. [#] *Non-weedy species*. + Presence of insect on non-banana plant. – Absence of insects on non-banana plants. Source: **Okolle JN, Mashhor M, Abu Hassan A** (2006b) Folivorous insect fauna of two banana cultivars and their association with non-banana plants. *Journal of Bioscience (Malaysia)*, **17(1)**, 89-101, with kind permission, Journal of the School of Biological Sciences, Universiti Sains Malaysia)

non-banana plants/weeds to get nectar from the flowers, collect honeydew from aphids if present and/or feed on larvae of the butterflies. On the other hand, ladybird beetles were always found feeding on aphids as well as mating and laying their eggs while *B. albotibialis* frequently visited and rests on leaves of *P. guajava*. For all the non-banana plants/ weeds, highest numbers of insect species were recorded on *P. guajava* (total of five species) and *D. ciliaris* (total of three species) (**Table 2**).

MANAGEMENT OF *ERIONOTA THRAX*

The management or control of *E. thrax* usually involves three methods *viz*., biological, chemical, or cultural/physical control. In some farms or plantations, these methods are applied separately while in others they are used simultaneously. In its native areas, due to the very low infestations resulting from natural mortality agents, control measures are seldom applied against this pest.

Use of chemicals

Use of chemicals as the oldest form of control against pests has being used for *E. thrax* since its discovery. A variety of chemicals has been used and are still been used in large and medium-sized plantations where hand removal of leaf rolls may be impracticable. Ashari and Eveleen (1974) stated that organophosphorus sprays might be timed so as to synchronize with the appearance of newly hatched larvae. Lead arsenate has also been used for the control of *E. thrax* during the earlier days in Malaysia (Richards 1914). In Mauritius, before effective biological control, methomyl or monocrotophos were recommended for use on commercial plantations (Monty 1977). However, although insecticidal control is a potential option and has been used extensively in the past, Waterhouse *et al*. (1998) stated that there is no evidence on its effectiveness. These authors further mentioned that the reasons for this could be (i) the sheltering of larvae and pupae within leaf rolls and (ii) the banana leaf expands so rapidly that a surface film of insecticide on a leaf rapidly becomes incomplete.

In banana plantations in Penang, Malaysia, several insecticides (**Table 3**) have been used. Most often, these are applied on a calendar schedule e.g. once or twice a month.

Use of biological control agents

Classical biological control has so far been recorded as the most successful non-chemical control for *E. thrax* (Waterhouse and Norris 1989; Sands *et al*. 1993; Waterhouse *et al*. 1998). When *E. thrax* appeared in Mauritius in 1970, four parasitoids were introduced, of which two became established (*O. erionotae* and *C. erionotae*). These two species together with a third (*Scenocharops* sp.) from Malaysia established in Hawaii after the skipper appeared in 1973. In both Mauritius and Hawaii, *E. thrax* was rapidly brought under good to excellent biological control (Waterhouse and Norris 1989). In 1974, *C. erionotae* was introduced into both Guam and Saipan, where satisfactory biological control of *E. thrax* was also achieved (Waterhouse *et al*. 1998). Following the invasion and establishment of *E. thrax* in 1983 in Papua New Guinea, *C. erionotae* was introduced in 1990 (Sands *et al*. 1993) and it was successfully established, attacking up to 67% of the larvae. At all sites where *C. erionotae* became established, populations of *E. thrax* declined.

Cultural/physical techniques

In most small farms in Malaysia, collection and destruction of leaf rolls is carried out frequently especially during periods of outbreaks (Khoo *et al*. 1991). In Southern China, Hoffmann (1935) advised collecting eggs and larvae and placing them in screened receptacles close to banana plants, so that any parasites could emerge and escape while the pest dies.

CONCLUSIONS AND PERSPECTIVES

Generally, lepidopterans are the most important folivorous insects on bananas and *Spodoptera litura* and *E. thrax* (both lepidopterans) are the most damaging folivorous insects on young banana plants (1–5 months after planting) for Pisang Mas and Cavendish varieties, respectively.

Parasitism caused by *O. erionotae* and *B. albotibialis* have substantial effects on population of *E. thrax* and parasitism of these parasitoids is also persistent in spite of frequent use of insecticides. Therefore these parasitoids are potential candidates for classical biological control or integrated management of *E. thrax*. In addition, *Ooencyrtus erionotae* prefers stage three eggs (two to three days old) for oviposition while *C. erionotae* prefers second and third instar larvae, and *B. albotibialis* prefers pupae. Furthermore, it is likely that outbreaks of *E. thrax* will occur during the rainy season (October to December) and will occur simultaneously in several banana farms within a region or area. However, prolonged droughts have serious effects on the parasitoids than *E. thrax* and higher effects on *C. erionotae* compared to the other major parasitoids (*O. erionotae* and *B. albotibialis*).

As far as management is concerned, aerial spraying of

Table 3 Various insecticides used for managing *E. thrax* on bananas in Malaysia.

Insecticides	Application mode	Application rate	Application time
Capture 605 (Cypermethrin)	Mist blower (tractor and motorized knapsack)	220 ml/300 L water	08.00 – 16.00
Wesco Malathion 57 (Malathion)	Mist blower (tractor and motorized knapsack)	135 ml/300 L water	08.00 – 16.00
Decis (Deltamethrin)	Mist blower (tractor and motorized knapsack)	Not available	08.00 – 16.00
Endotox 555 (Endosulfan)	Mist blower (tractor and motorized knapsack)	530 ml/300 L water	08.00 – 16.00
Dipel (*Bacillus thuriengensis* Berl.)	Mist blower (tractor and motorized knapsack)	Not available	08.00 – 16.00

Source: Okolle JN (PhD thesis, 2007, Universiti Sains Malaysia)

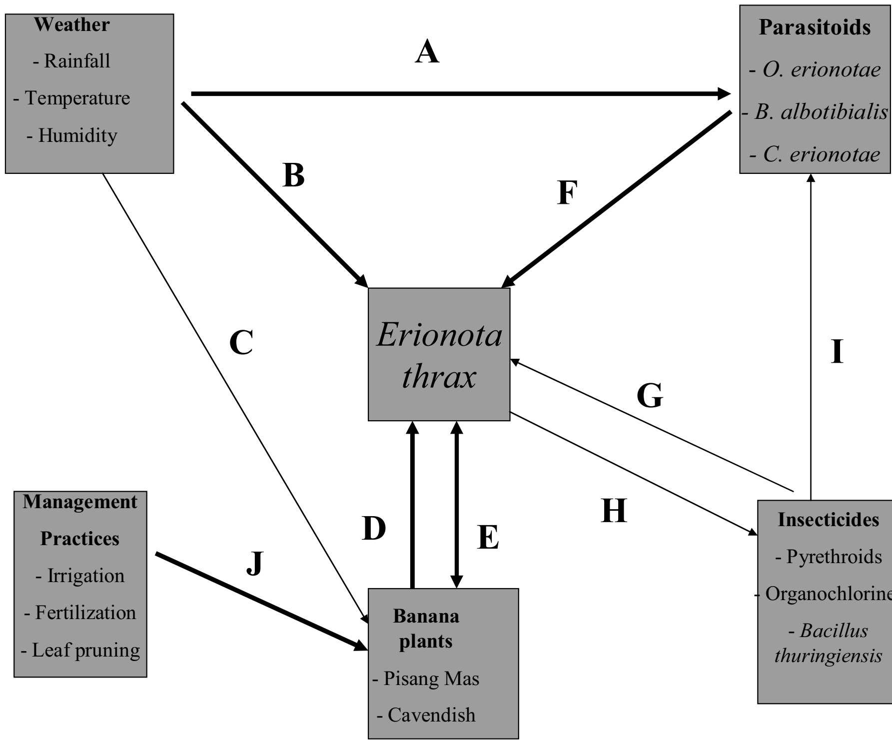

Fig. 6 Conceptual model of the major interacting factors in the population dynamics of *Erionota thrax* in banana plantations (Synergy Farm SDN.BHD), Penang, Malaysia. (Culled from PhD thesis of Justin Okolle, Universiti Sains Malaysia, 2007). A = Enhancement of parasitoid activities or mortality on parasitoids. **B** = Enhancement of oviposition and larval development of *E. thrax* or mortality on *E. thrax*. **C** = Stress on plants (changes in chemical composition and moisture). **D** = Bottom-up effects (poor quality/stressed plants or high quality/vigorous plants). **E** = Defoliation and induce defense effects. **F** = Top-down effects (parasitism). **G** = Insecticide mortality on *E. thrax*. **H** = Development of resistance to insecticides. I = Insecticide mortality on parasitoids. **J** = Stressed and low quality plants (lower infestation) or vigorous and high quality plants (higher infestation). Larger/thick arrows = Serious effects. Smaller/thin arrows = Less to moderate effects.

insecticides in large plantations for the control of *E. thrax* will not be effective because infestation is significantly higher on the Broad Leaf Follower stages (BLF), which is covered and protected by the broader leaves of the taller Flowering plants (FP) and the Bunched plants (BP). Also, use of fertilization and irrigation in monocultures will greatly affect banana quality and *E. thrax* population. Infestation of *E. thrax* is higher on well-managed/vigorous plants compared to the poorly-managed/stressed plants. Weather plays both a direct and an indirect role in the population dynamics of *E. thrax*. It acts indirectly through top-down effects (action of parasitoids) and bottom-up effects (poor quality and/or stressed banana plants) (**Fig. 6**).

Although the several researches cited in this book chapter have contributed significantly as far as interaction of *E. thrax*, its host plant and natural enemies is concerned, more studies are still needed to further enhance effective management of this pest. We therefore propose some recommendations for future research or investigations as follows:

- More survey for alternative host or food plants of *E. thrax* in its native area.
- Laboratory tests to find out variations in the composition of chemicals (nitrogen, carbon), moisture and secondary compounds (e.g. phenols, terpenes, tannins) in relation to banana growth stages and leaf age.
- Rigorous field or greenhouse experiments to test the effects of different concentrations of fertilizers on *E. thrax* oviposition and larval development.
- Controlled experiments to evaluate the efficacy of different classes of insecticides (including microbials) on infestation and parasitism of *E. thrax* in the field and laboratory. Such experiments should also include the effects of mixing one or more insecticides or mixing insecticides with fungicides on *E. thrax*.
- Field and laboratory studies to find out the reasons for the relatively low rates of parasitism of *C. erionotae* on *E. thrax* compared to the other parasitoids (*O. erionotae* and *B. albotibialis*).
- Extension of population dynamic studies to more farms with different production systems and sizes in the native areas of *E. thrax*.
- Extensive survey to find out the potential hosts and alternate hosts of the major parasitoids of *E. thrax*.
- Laboratory studies on the duration of the various larval stages (instars) in relation to different temperatures.

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