FIELD STATUS, DAMAGE SYMPTOMS AND POTENTIAL NATURAL ENEMIES OF THE INVASIVE FALL ARMYWORM, *Spodoptera frugiperda* (J.E. SMITH) IN MALAYSIA

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ABSTRACT

The fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), is a new invasive alien species attacking corn in Malaysia. This aggressive pest has been recorded attacking more than 350 plant species including our most important staple namely rice. Being relatively new to this region, detailed information of this pest and their potential local natural enemies are limited. The objective of this preliminary study was to assess the status, document the damage symptoms graphically, and explore potential local natural enemies of this new pests on corn in Malaysia. In order to assess the status of the *S. frugiperda* attacks, a cooperative field survey on both sweet and grain corn was carried out throughout the country. During this field survey, damage symptoms on corn and evidences of arthropods attacking or feeding the *S. frugiperda* were documented. By the end of 2019, the *S. frugiperda* has invaded corn farms in all states of Malaysia. In total, 25.5% (151.3 ha) from 594.1 ha of corn planted area were affected by the pest. Damages on plants were apparent in affected farms. We observed the presence of two species of predatory assassin soldier bugs (*Eocanthecona furccellata* and *Andralus spinidens*) and two species of coleopteran larvae, (*Micraspis discolor* and unidentified Staphylinidae) directly attacking the *S. frugiperda.* In this paper, we took the initiative to propose few provisional management recommendations to limit the damage of this serious pest in Malaysia based on our observations during the field survey. This preliminary study is of paramount importance to elucidate the status of the pest as well as identifying the presence of local natural enemies which may provide additional impetus towards the sustainable management of the *S. frugiperda* in Malaysia.

Keywords: *Spodoptera frugiperda*, status, damage, natural enemies, management

ABSTRAK

Rama-rama *fall armyworm*, *Spodoptera frugiperda* (Lepidoptera: Noctuidae), adalah spesies invasif asing baru yang kini menyerang tanaman jagung di Malaysia. Berdasarkan laporan, perosak agresif ini mampu menyerang lebih dari 350 spesies tumbuhan termasuklah tanaman ruji rakyat tempatan iaitu padi. Memandangkan perosak ini masih baru di Malaysia, maklumat terperinci mengenai perosak ini serta keberadaan musuh semula jadi tempatan adalah terhad. Objektif kajian awalan ini adalah untuk menilai status perosak rama-rama *S. frugiperda*, mendokumentasikan simptom kerosakan melalui gambarfoto, serta merekodkan maklumat musuh semula jadi tempatan berpotensi yang ditemui pada jagung semasa kajian lapangan dijalankan. Bagi menilai status serangan rama-rama *S. frugiperda* pada jagung manis dan bijirin, tinjauan lapangan telah dijalankan melalui kolaborasi di seluruh negara. Dalam kajian lapangan ini, gejala kerosakan pada tanaman jagung serta kehadiran artropoda yang menyerang rama-rama *S. frugiperda* telah direkodkan. Menjelang akhir tahun 2019, *S. frugiperda* didapati telah menyerang ladang jagung di semua negeri di Malaysia. Secara keseluruhan, 25.5% (151.3 hektar) daripada 594.1 hektar jagung telah diserang oleh perosak ini. Kerosakan pada tanaman jagung dapat dilihat dengan jelas di ladang-ladang jagung yang terjejas. Dua spesies pemangsa kumbang askar pembunuh (*Eocanthecona furccellata* dan *Andralus spinidens*) serta dua spesies kumbang pemangsa larva (*Micraspis discolor* dan Staphylinidae yang tidak dikenali) didapati menyerang larva *S. frugiperda* secara langsung. Dalam kertas kerja ini, kami juga telah mencadangkan beberapa kaedah pengurusan perosak bagi mengawal kerosakan perosak ini di Malaysia. Sebagai kesimpulan, kajian awalan ini sangat penting bagi mengenalpasti status makhluk perosak dan kehadiran musuh semula jadi tempatan. Ini merupakan faktor yang kritikal bagi mencapai matlamat pengurusan rama-rama *S. frugiperda* secara lestari di Malaysia.

Kata kunci: *Spodoptera frugiperda*, status, kerosakan, musuh semula jadi, pengurusan

INTRODUCTION

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), has been recognized as a destructive pest of various agricultural crops all over the world, spreading throughout Europe, Africa, Asia and Australia (Early et al. 2018; Ginting et al. 2020; Goergen et al. 2016; Hang et al. 2020; Kebede & Shimalis 2019). Indigenous from the American continent, this long-distance and sporadic migratory pest are able to fly over 100 km in a single night (Johnson 1987). The pest was first detected in the African continent in 2016 (Goergen et al. 2016). A couple years later, the pest has spread across South Asia (Kalleshwaraswamy et al. 2018). It did not take long for the pest to invade South-east Asia. By 2019, the pest has been reported to attack corn in Vietnam, Thailand, Myanmar, and Indonesia (Ginting et al. 2020; Hang et al. 2020; Yee et al. 2019). The *S. frugiperda* was first detected in Malaysia in the northern states of Peninsular Malaysia (Kedah and Perlis) in February 2019 (Jamil et al. 2021). By the end of the calendar year, the insect has spread to all states in Malaysia, including the Borneo states i.e. Sabah and Sarawak (Jamil et al. 2021). The International Food and Agriculture Organization of the United Nation (FAO) has declared the pest as one of the major pests in the world, while denoting that *S. frugiperda* is given serious attention as the insect may threaten the safety of human food due to its polyphagous nature (FAO 2017). The larvae of *S. frugiperda* feed on more than 350 plant species, including several economically-important crops such as corn, sugarcane, or rice (Montezano et al. 2018). As the name implies, the presence of large numbers of *S. frugiperda* larvae, in an army, will cause severe damage to grains and other important horticultural crops. To ensure their survival, an adult female

butterfly may also lay up to 1,500 eggs throughout its life – thus complicating the management of this aggressive pest. All these features contribute directly to the success of *S. frugiperda* spreading and conquering the globe. Numerous studies on different management practices have been recommended so far in America and Africa to reduce the damage and losses caused by the *S. frugiperda* (Harrison et al. 2019; Midega et al. 2018; Prasanna et al. 2018). However, due to recent introduction of this pest to Malaysia, there is an evident knowledge gap in the information and management of *S. frugiperda* locally. The objectives of this preliminary study were to (i) assess the status of the *S. frugiperda* in Malaysia, (ii) graphically document the damage symptoms of this pest on corn and, (iii) to explore potential local natural enemies of this new pests on corn in Malaysia. In addition, due to the lack of formal information on the management of *S. frugiperda* locally, we therefore propose few provisional management recommendations as a fast guide for local farmers and relevant stakeholders in order to limit the damage of this serious pest in Malaysia.

MATERIALS AND METHODS

Field Survey of *Spodoptera frugiperda* Infestation

Field surveys were conducted between February 2019 and January 2020. Survey of *S. frugiperda* were conducted in major corn growing areas in every state in Malaysia. Both sweet corn and grain corn farms were included in the field survey. Survey were done extensively with the assist by personnel from the Biosecurity Agriculture Extension Officers (Malaysia Department of Agriculture) in each state, respectively. *Spodoptera frugiperda* incidence were done according to the standard method as described by FAO (FAO 2018). In each zone, scouting was done by inspecting 10 plants, moving along a W-shape design. The middle of the field was also sampled, making 50 plants surveyed per zone. Distance between two consecutive plants was a function of field size and shape but was representative of the plot area. The presence of the *S. frugiperda* larvae was determined using the following indicators: (i) presence of fresh frass in the leaf funnel; (ii) presence of larvae on leaves or in the leaf funnel identifiable with the inverted Y-Shape in the head and the set of four dot forming a square on the upper surface of the last segment of its body; (iii) irregular damage (cuts) on leaves while the adults are detected through the presence of egg masses on the leaves (Day et al. 2017) (Figure 1).

Figure 1. Main characteristic of the *S. frugiperda*. From left to right: (a) Inverted Y on the larva head; (b) squarish four dots on each segments (c) clear 4 dark spots on their last segment

Damage Symptoms of the *Spodoptera frugiperda*

Due to the complexity of pests in the corn ecosystem, the exact location of the feeding damage and the type of damage on the corn plant caused by the *S. frugiperda* feedings are the most important characteristics in defining the damage on the plant. During the field survey, plants were thoroughly inspected from the base to the top for any damage symptoms. For early stage plants (less than 4 weeks), priority of the observation was given to the young leaves and inside the whorl. On the other hand, observations were done on all plant parts including the tassel, stalk, whorl, fruit, silk, ear, leaf sheath and the leaves for matured plants (4 weeks and above). Photoshoots of damages on corn plant were taken using the Olympus Tough TG-5 point-and-shoot camera.

Observation of Potential Biological Control Candidates

In each farm, five personnel randomly walk into the corn field from 0730h to 0900h and try to observe and sample arthropods which exhibit obvious predation behaviour (directly feeding/ attacking/ sucking) the pest *S. frugiperda*. Arthropods which met the criteria were collected manually using forceps, put into individual four ounce-sized pillbox, and transported back to the lab for identification. Photoshoots were taken with the TG-5 camera before the insects were collected (if possible). The time, date, latitude, and longitude of the picture taken were recorded digitally by the camera. In the lab, individuals are then exposed to different life stages of the *S. frugiperda* to confirm their predacious behaviour.

Statistical Analyses

Minitab 19 Statistical Software (version 19.1.1) was used to perform all statistical tests. The Levene's test for equality of variances was calculated prior to the comparisons of means of sweet corn and grain corn. A two-sample t-test for unequal sample sizes and equal variances be chosen if the two distributions of the corn type have similar variances. However, assuming that the variances between the two corn type distributions do not have equal variances, then the Welch's t-test (two-sample t-test for unequal (or equal) sample sizes and unequal variances) be chosen instead.

RESULTS

Status of *Spodoptera frugiperda* Infestation

By early January 2020, *S. frugiperda* was detected in all states in Malaysia including Sarawak dan Sabah (Table 1). Attack of the pest was consistent throughout the country but varied greatly upon states and corn type. Apart from Sabah and Sarawak (in which the information on the type of corn was not specified for these two states), five states cultivated the less popular grain corn i.e. Kedah, Perlis, Selangor, Johor and Pahang while all states in Peninsular Malaysia cultivated the sweet corn.

Kedah had the highest total corn planted area affected by the *S. frugiperda* (30.4 ha) followed by Sabah and Selangor with 29.4 ha and 27.3 ha, respectively (Table 1). On the other hand, Penang recorded the lowest total corn planted area being attacked by the fall armyworm (0.3 ha). In terms of percentage value, Sarawak had the highest percentage of *S. frugiperda* attacking their corn (97.4%) followed by Sabah (67.7%) and Kelantan (34.3%) respectively. Conversely, Negeri Sembilan recorded the lowest proportion of attack at only 1.4% (Table 1).

Focusing on the grain corn, Perlis had the largest grain corn planted area (54.1 ha) (Table 1). However, the northern state managed to record the lowest area being affected by the *S. frugiperda* – at only 15.7% (8.5 ha). In comparison, Selangor only had 24.0 hectares of grain

corn planted area, but they recorded the highest rate of area being attacked by the *S. frugiperda* (58.8%). Another northern state, Kedah, recorded the highest grain corn affected area at approximately 16.0 hectares. In contrast, for sweet corns, Pahang had the largest cultivated area (63.4 ha), followed by Selangor (61.8 ha) and Negeri Sembilan (61.1 ha). However, the percentage of area being affected by the *S. frugiperda* was less than 15% for these three states. While Kelantan and Terengganu had lower sweet corn planted area (less than 17 hectares), both states recorded higher percentage of sweet corn area affected by the *S. frugiperda* at 34.3% and 30.6% respectively (Table 1).

In order to statistically test whether the *S. frugiperda* had any preference towards corn type, the *Levene's test* for equality of variances was initially conducted. In the test, we found that the corn type variances were found to be homogenous ($F_{1,14}$ = 0.3414, p = 0.5683). Therefore, we used the Minitab software to compute the *two-sample t-test* with unequal sample sizes and equal variances. This test was found to be statistically significant, t_{14} = -3.015, p = 0.007, p < 0.05; g = 1.6988. The effect size for this analysis (g = 1.6988) was found to exceed Hedges' (1981) convention for a large effect (d = 0.80). These results indicate that the *S. frugiperda* (M = 37.6, SD = 16.0) generally preferred the grain corn in comparison to the sweet corn (M = 15.5, SD = 11.6).

Table 1. *Spodoptera frugiperda* infestation in Malaysia according to states and corn type

Description	Kedah	Perlis	Penang	Perak	Selangor	N. Sembilan	Melaka	Johor	Pahang	Terengganu	Kelantan	Sarawak	Sabah	Total
Grain Corn (GC)														
Planted (ha)	37.2	54.1	-	-	24.0	-	-	22.0	8.0	-	-	-	-	145.3
Affected (ha)	16.0	8.5	-	-	14.1	-	-	8.9	2.4	-	-	-	-	49.9
% affected	43.0	15.7	-	-	58.8	-	-	40.5	30.0	-	-	-	-	34.4
Sweet Corn (SC)														
Planted (ha)	61.8	12.0	16.6	49.7	57.3	61.1	25.4	18.2	63.4	12.4	16.3	-	-	394.1
Affected (ha)	14.4	1.0	0.3	7.0	13.2	0.8	0.4	2.3	12.2	3.8	5.6	-	-	60.9
%	23.2	8.0	1.8	14.0	23.0	1.4	1.8	12.7	19.2	30.6	34.3	-	-	15.5
Total (GC + SC)														
Planted (ha)	99.0	66.0	16.6	49.7	81.3	61.1	25.4	40.2	71.4	12.4	16.3	11.4	43.4	594.1
Affected (ha)	30.4	9.5	0.3	7.0	27.3	0.8	0.4	11.2	14.6	3.8	5.6	11.1	29.4	151.3
%	30.7	14.3	1.8	14.0	33.6	1.4	1.8	27.9	20.4	30.6	34.3	97.4	67.7	25.5

Note: - data was not readily accessible and/or not recorded due to small farm size

Spodoptera frugiperda Damage Symptoms

Spodoptera frugiperda damage symptoms was considerably high in the farm based on the field surveys. In largely affected farms, corn plants did not look healthy (Figure 2). Damage symptoms were visible on almost every plant part and are presented in Figure 3, 4 and 5.

Figure 2. The devastation caused by the *S. frugipreda* in one of the affected grain corn farms in the Kedah

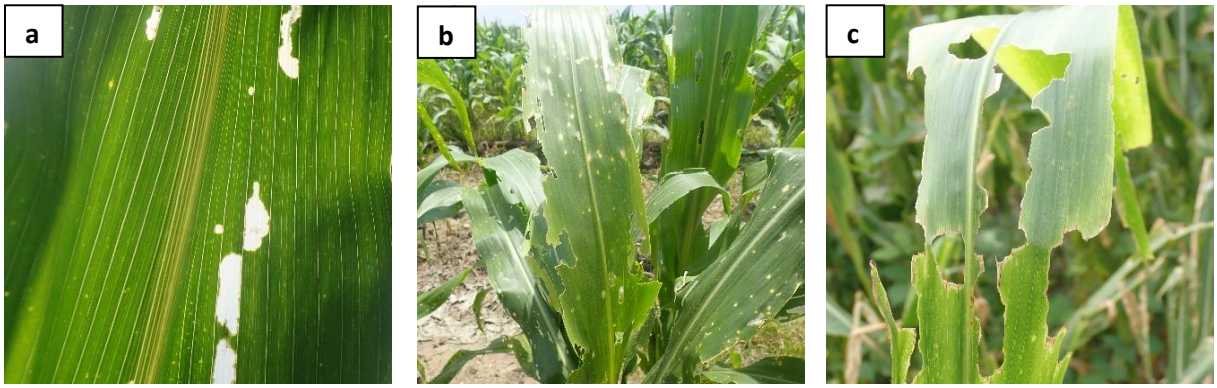

Figure 3. Damage symptoms of *S. frugiperda* larvae on corn leaves (a) damaged caused by early stages of the pest (b) and (c) visible windowpanes on the corn leaves

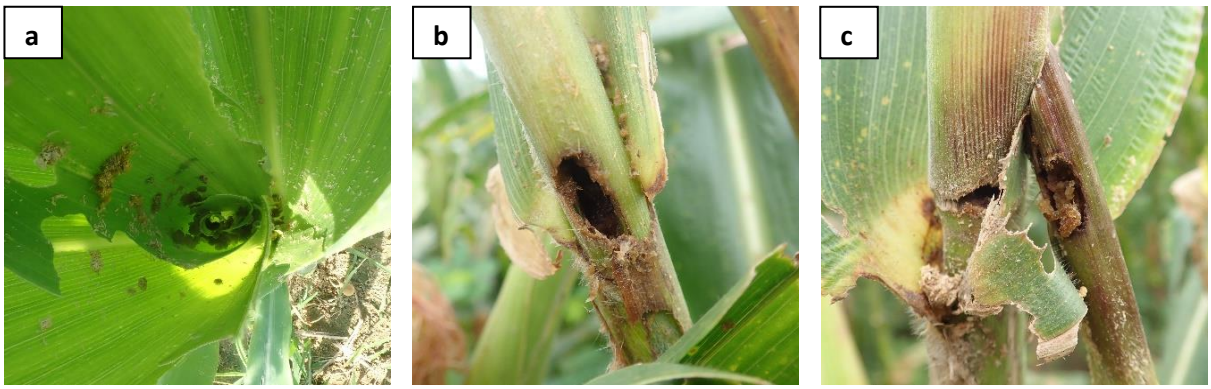

Figure 4. Damage symptoms of *S. frugiperda* larvae on different corn parts (a) damage on the whorl during early plant developmental stage (b) larvae burrowing the plant stem (c) serious attack (more than 5 larvae per plant) may break the plant stem

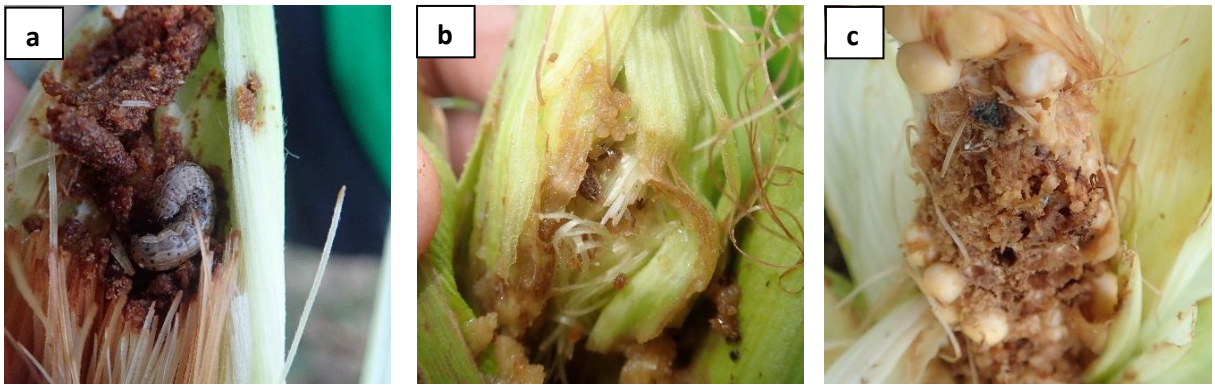

Figure 5. Damage symptoms of *S. frugiperda* larvae on different corn parts (a) the late stage larva burrow through the corn silk (b) wet-brownish frass which differentiates it from other common lepidopteran pests on corn (c) serious attack on the corn cob – total lost

Potential Biological Control Candidates

Two species of generalist predatory soldier bugs were found attacking the *S. frugiperda* namely *Andralus spinidens* (Figure 6) and *Eocanthecona furcellata* (Figure 7). A single male of the *A. spinidens* and nine adults of the *E. furcellata* were collected physically and were brought back to the Entomology lab, Block G, MARDI Serdang. Both species were found on a grain corn farm located in Kedah. The *E. furcellata* were mass-reared for three generations before the colony collapsed. In a simple feeding test experiment, both predatory soldier bugs species were observed to pierce and feed the *S. frugiperda* larvae (instar 2 and above) (Table 2). On the other hand, only the *E. furcellata* was observed eating *S. frugiperda* pupae during the feeding test. While the *E. furcellata* showed promising results in our preliminary feeding test as a natural enemy of the *S. frugiperda*, further studies need to be conducted to study its life cycle, behaviour, feeding preferences and efficacy (predation rate) before introducing the soldier bug in a biological control programme locally. Two species of predatorial coleopteran larvae were sampled during the field survey. The first species was the common ladybird, *Micaspis discolor* beetle (3 individuals) (Figure 8). The other species was a pair of Staphylinidae larvae (rove beetle which we were unable to identify to the species level)

(Figure 8). The Staphylinidae larvae were observed as being more aggressive than the *M. discolor* larvae and readily attacked the larger *S. frugiperda* larvae.

Two species of parasitoid emerged from the many samples of egg masses on corn leaves that were brought back to the laboratory. The species were: Phoridae sp. (single individual) and *Megaselia* sp. (2 individuals). Unfortunately, the number of individuals were insufficient to establish a colony (Table 2). Further studies on the efficacy (parasitism rate) and viability of these two potential parasitoids needs to be done.

Table 2. Preliminary feeding study on locally collected natural enemies of the *S. frugiperda*

Species of field collected natural enemy of *S. frugiperda*	**Number of collected specimens**	**Type of food (*S. frugiperda* life stage)**		
		Early larvae	**Late larvae**	**pupae**
Predator				
Eocanthecona furcellata	9	Yes	Yes	Yes
Andralus spinidens	1	Yes	Yes	No
Micraspis discolor (larvae)	3	Yes	No	No
Staphylinidae larvae	2	Yes	Yes	No

FAW = *S. frugiperda*

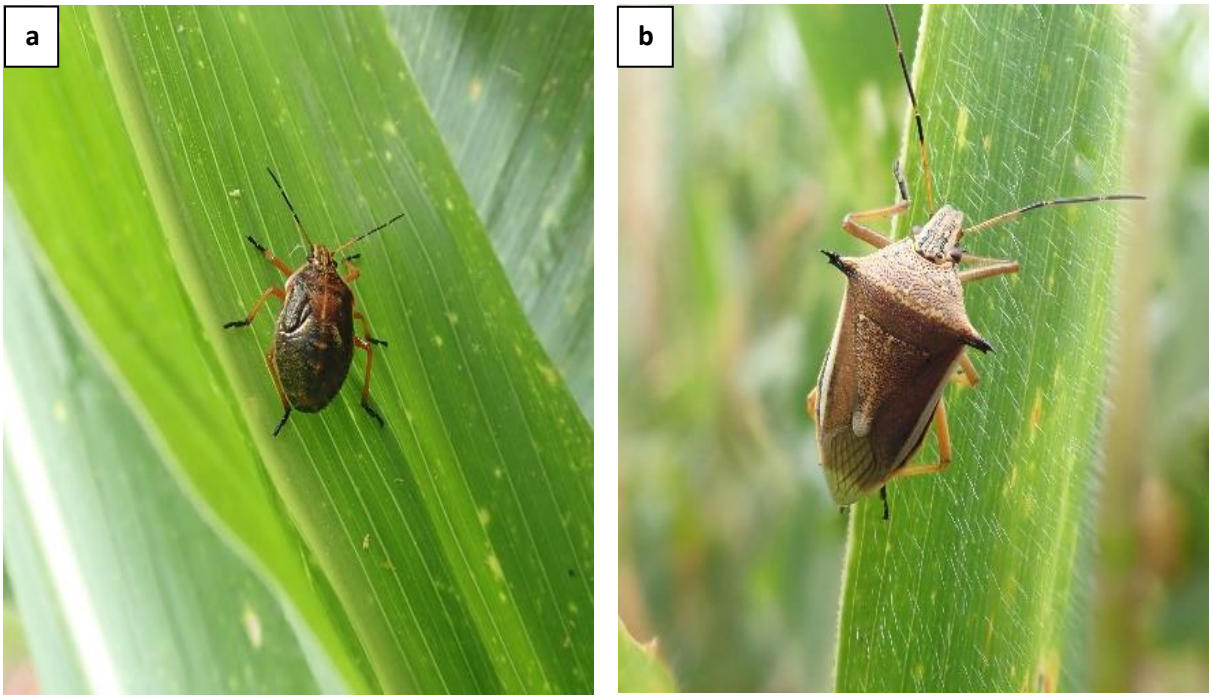

Figure 6. *Andralus spinidens* (a) immature (b) adult

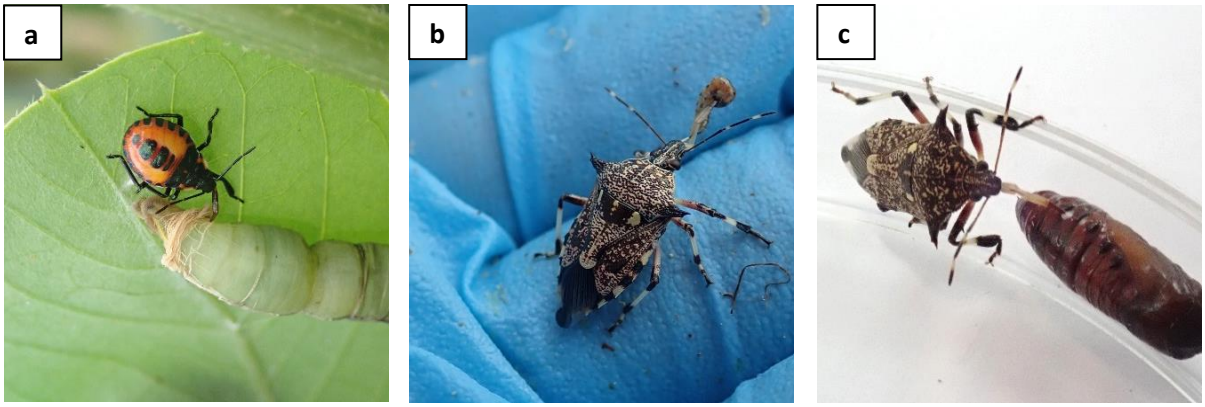

Figure 7. *Eocanthecona furcellata* (a) immature (b) adult (c) an adult feeding on a *S. frugiperda* pupa

Figure 8. (a) *Micraspis discolor* immature and adult (b) Staphylinidae attacking a *S. frugiperda* larva (c) an adult Staphylinidae (rove beetle)

DISCUSSIONS

The *S. frugiperda* was first detected in the northern states of Peninsular Malaysia (Kedah and Perlis) in February 2019 (Jamil et al. 2021). By the end of the same calendar year, our findings indicated that the pest has spread to all states in Malaysia, including the Borneo states i.e. Sabah and Sarawak. While not being explicitly explained in earlier sections, the *S. frugiperda* have invaded Sabah and Sarawak in December 2019, merely 8 months after the first population of *S. frugiperda* was first detected in Perlis. The rapid expansion of this new invader was in line with the modelling predictions by Early et al. (2018) in which the authors projected that nations in the sub-regions such as South Asia (India, Bangladesh & Pakistan) and South-East Asia (Thailand, Myanmar, Malaysia, & Indonesia) were more vulnerable and bound to *S. frugiperda* attacks due to favourable climate conditions and availability of alternative hosts all year round. Eventually, in February 2020, this successful pest managed to disperse across Indonesia into the Oceania continent, specifically northern part of Queensland, Australia (EPPO Global Database 2020). Having traits which enables them to be as successful as invaders (discussed in the introduction section), the *S. frugiperda* is indeed one of the most successful modern invaders recorded in this millennia. While we confirmed the incidence of *S. frugiperda* in all states, the mechanism or pathway on how the pest initially entered Malaysia remains unelucidated. Currently, local researchers are debating on two possible pathways i.e. (i) the *S. frugiperda* may have entered Malaysia directly via Thailand through natural dispersion, or (ii)

the *S. frugiperda* may have arrived indirectly through imported commodities or passenger air travel. While natural dispersion may seem the most reasonable pathway, the second opinion also remains likely because entry ports (including baggage, cabins, and air cargo) are often found in environmentally suitable locations for an invader pest such as the *S. frugiperda* (Tatem 2009). Having the capability to migrate internationally, the *S. frugiperda* larvae are also capable of migrating from plant to plant efficiently as well. The early stage larvae travel to neighbouring plants through ballooning – a process where the larva produce silk threads and subsequently utilise the wind to fly in the direction of an adjacent plant where food is available (Njuguna et al. 2021; Sokame et al. 2020).

On affected farm where incidence and severity of was as high as 100% (Jamil et al. 2021), the farm owners reportedly apply pesticides according to recommendations given by local agricultural extension officers, but effective control was not achieved as incidence of *S. frugiperda* damages remain noticeable on every plant. Damage symptoms of *S. frugiperda* is apparent and can easily be differentiated from damages from other lepidopteran stem borers on corn. Early stage larvae were found feeding on leaf gregariously till the leaf becomes dry and subsequently moves to other leaf for feeding. Early symptoms of *S. frugiperda* resemble other stem borers damage with the likes of holes or windowpane on the leaves emerging from the whorl (Deole & Paul 2018). However, the nature of early stage damage from the *S. frugiperda* includes moist sawdust-like frass which was usually observed on the funnel, whorl, and upper leaves. Larger larvae were found digesting large amounts of leaf tissue resulting in a ragged appearance to the leaves similar to grasshopper damage. These larger larvae were then found to feed into the corn ear and seek shelter from natural enemies and environmental factors such as rain (De Groote et al. 2020). Apart from the *S. frugiperda*, during our nation-wide field survey, we did come across other species of corn borer such as the *Ostrinia* sp., *Chilo* spp., *Helicoverpa* sp. and as well as other *Spodoptera* species like the *S. litura* and *S. exigua* but their number was few and far between. If this scenario continues, then the invasiveness of the *S. frugiperda* may possibly contribute to the displacement of these species to other cropping systems like rice. A prime example would be the displacement of cereal stemborers in Africa by the *S. frugiperda* which leads to the stemborers moving their preferences to sorghum cropping system (Hailu et al. 2021). Further studies will need to be done to evaluate such scenario (i.e. ecological displacements) especially in the local context.

The utilisation of natural enemies in the form of biological control insects is one of the most sustainable and natural way to manage pest outbreaks (Cruz et al. 2018; Harrison et al. 2019; Tepa-Yotto et al. 2021). A wide range of natural enemies have been recorded to attack the *S. frugiperda* compassing predators, parasitoids, and microbes. In this study, we encountered four species of predators (*E. furcellata, A. spinidens, M. discolor* and an unidentified rove beetle, Staphylinidae). The predatory soldier bug, *E. furcellata* is a generalist predator of various insects' pests, especially lepidopteran and homopteran pests. This predator is widely distributed in the South-East Asian region (Shylesha & Sravika 2018). In Malaysia, the *E. furcellata* have been recorded to prey upon the diamondback moth, *Plutella xylostella* (Azzulaikha 2013), and the curry plant pest, *Silana farinosa* (Nur Asmah 2013; Nur Famieza Farhana 2013). *Andrallus spinidens* is another predatory soldier bug from the Asopinae subfamily, which is widely distributed in the South-East Asian region. Unlike the *E. furcellata* which are mostly black and white in colour (Figure 7), the *A. spinidens* is dark brown with sub marginal yellowish stripes running along entire length of their body (Figure 6). In Malaysia, the *A. spinidens* are commonly found in rice field attacking rice stem borers and leaf folders. The ladybug, *M. discolor* is one of the most abundant species of coccinellid in rice ecosystems in Malaysia (Razali et al. 2015). While the ladybug is touted as a useful biocontrol agent for

the management of brown planthopper, *Nilaparvata lugens* a key pest of rice, the predator has been reported to be both entomophagous and phytophagous (Shanker et al. 2013). Another predatory beetle that we collected was a Staphylinidae immature. Staphylinids or commonly known as rove beetle are also a generalist that is widely found in rice ecosystems in Malaysia. A comprehensive study natural (field density levels, host preferences, feeding patterns, behaviour, and biology) on a common species of Staphylinidae in Malaysia has been carried out by Manley (1997).

While the use of predators seems like a feasible and sustainable solution, implementation is not straightforward. There are also cases where natural enemies that are released in field (augmentation) failed to survive in the newly introduced environment. A classic example would be the study of Gross and Pair (1986) where they found that fragmented introduction of biocontrol strategies against the *S. frugiperda* may not necessarily be better than natural environment conditions. A more recent study also discovered that the performances of *E. furcellata* to manage the *S. frugiperda* in the field was affected by the presence of secondary parasitoids parasitising the predators' egg (Keerthi et al. 2020). The introduction of an entomophagous and phytophagous agent like the *M. discolor*, will require a thorough study to be done before being widely used as biological agents in the corn field (Shanker et al. 2013). And finally, the use of rove beetles as natural enemies would need to be carefully considered as the beetles are known to cause humans serious allergic reaction upon being bitten (Heo et al. 2013).

Provisional Management Recommendations

A plethora number of studies have been conducted to evaluate strategies to manage the *S. frugiperda* (Harrison et al. 2019; Juárez et al. 2014; Molina-Ochoa et al. 2003; Prasanna et al. 2018). It is vital that any measures taken should be sustainable and does not induce further complications such as the *S. frugiperda* building up resistance towards chemical pesticides (Yu 1991). We hereby suggest 4 provisional management practices which may be applied by corn farmers to reduce the incidence and severity of *S. frugiperda* attacks in Malaysia.

Practice 1. General plant management

Farmers should avoid growing corn in a staggered manner in an area especially for medium and small-sized farms. Staggered plantation may provide continuous food and breeding site for the *S. frugiperda* (Chhetri & Acharya 2019). Farmers also need to ensure the plants are in optimal condition through proper fertilization. Healthy (nutrient-rich) plants are less at risk for *S. frugiperda* attacks. Unbalanced fertilization (especially excessive nitrogen use) can increase oviposition by *S. frugiperda* females in corn (Altieri & Nicholls 2003). The use of organic fertilizers versus chemical fertilizers has been found to reduce *S. frugiperda* damage in corn (Rowen & Tooker 2020). However, the long term impact of using organic fertilizers towards the soil and plant will need to be investigated.

Practice 2. Improving diversity in the farm through poly-cropping

Farmers should implement and practise poly-cropping in their farm. Poly-cropping can be defined as the presence of two or more crops in the same area at the same time, cultivated in an order that the plants do not compete with each other for resources (Kugbe et al. 2018). Diversity of plants in the same locality may potentially confuse female the olfactory of *S. frugiperda* and disrupt their physiological processes such as selecting host (corn), underage or lay eggs in small quantities when compared to corn mono-cropping method (Gebreziher 2018). Among the most popular methods in Africa to control *S. frugiperda* is the push-pull method using the Napier grass (pull) and *Desmodium sp.* (push- repellent) on corn (Khan et al. 2018;

Midega et al. 2018). While this method may be promising in Africa, further studies need to be conducted in local conditions to evaluate such technology. In addition, the various plants in poly-cropping systems may provide natural enemies of the *S. frugiperda* (the beneficial predators and parasitoids) with resources such as protection, nectar, alternative foods and pollen (SNAP - Shelter, Nectar, Alternative Food, Pollen). Planting flowering plants which are not alternative host for the *S. frugiperda* may encourage the population of beneficial biological control agents (Sousa et al. 2011). Finally, farmers should ensure that large woody trees be maintained and not being cut down totally in a farm environment. The presence of these trees may provide protection and shelter to birds that feed on the *S. frugiperda* larvae and pupae.

Practice 3. Enhance farm monitoring and mechanical control in the field

Monitoring of insect and plants should be carried out regularly by the farmers in order to detect new *S. frugiperda* infestations while simultaneously assessing the extent of damage at the farm. The FAO has recommended that the monitoring, or scouting, to be conducted at least twice a week in the early and mid-stage planting and once a week during the late stage of corn (FAO 2017). During the monitoring practice in the field, *S. frugiperda* eggs and larvae should be destroyed promptly if found.

Practice 4. Use biopesticide first and only use chemical pesticides as a last option

Prior to using 'hard' chemical pesticides, the use of biopesticides such as the *Basillus thurigiensis*, should be utilized to control the *S. frugiperda* (Walker et al. 2003). Apart from the well-known *Bt* sprays, preliminary studies have discovered that the nuclear polyhedrosis virus (NPV) may also control the *S. frugiperda* population (Cuartas-Otálora et al. 2019).When severity an damage is too high, and may affect productions, the use of chemical pesticides should be considered. Chemical insecticides such as emamectin benzoate and chlorantraniliprole were found to be able to control *S. frugip*erda populations (Song et al. 2019). Further studies are in line to determine the suitability of integrating other classes of pesticides to control the *S. frugiperda* in Malaysia. Furthermore, in order to obtain the optimum spraying effect, farmers are advised to spray the *S. frugiperda* during late afternoon (dusk from 6-8pm) as the *S. frugiperda* is a butterfly from the family Noctuidae which is more active during the night. It is important to note that prolong use of a single type of biopesticide/ chemical may result in *S. frugiperda* resistance. Hence, spraying chemicals should be done judiciously while considering alternating different classes of chemical (based on IRAC).

CONCLUSION

The new invasive fall armyworm, *S. frugiperda* is one of the most destructive pest species of corn in Malaysia and other neighbouring countries. In January 2020, all states in Malaysia have reported cases of *S. frugiperda* infestation on corn. While the pest is here to stay, researchers, farmers and stakeholders should be wary of the pest attacking our staple crop (rice) and indirectly displacing key species in corn ecosystems and disrupt native ecological balances. We have mentioned earlier in the discussion section where farmers have reported that chemical pesticides sprays were ineffective. Hypothetically, efficacy of chemical pesticides may have been compromised by larval behaviour of the *S. frugiperda* that generally remains inside the whorl during the day, making it difficult to reach the target with chemical sprays especially contact-based pesticides. Nevertheless, we believe that rotating the use of selective pesticides, ensuring the correct (proper) timing of spray, and practising good pesticides application techniques (PAT) may negate this issue. Correct identification of the symptoms and early damage monitoring in corn farms are also vital processes. Incorporating these actions, in

addition to biological agents, as part of the *S. frugiperda* integrated management programme will be key to minimise the impact of this pest in Malaysia.

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