BIOLOGICAL AND ECOLOGICAL STUDIES OF FALL ARMYWORM, *SPODOPTERA FRUGIPERDA* (J.E. SMITH) AND ITS CONTROL: A CASE STUDY FROM MAIZE FIELD IN PHITSANULOK, THAILAND

SOTHEARITH HONG

A Thesis Submitted to the Graduate School of Naresuan University
in Partial Fulfillment of the Requirements
for the Master of Science in (Agricultural Science)
2020

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By SOTHEARITH HONG

has been approved by the Graduate School as partial fulfillment of the requirements for the Master of Science in Agricultural Science of Naresuan University

Oral Defense Committee

..... Chair
(Associate Professor UDOMPORN PANGNAKORN, Ph.D.)

..... Advisor
(Suphannika Intanon, Ph.D.)

..... Co Advisor
(Panisara Thepkusol, Ph.D.)

..... Internal Examiner
(Assistant Professor Thanatchasanha Poonpaiboonpipattana, Ph.D.)

Approved

.....
(Professor Paisarn Muneesawang, Ph.D.)

Dean of the Graduate School

Title BIOLOGICAL AND ECOLOGICAL STUDIES OF FALL ARMYWORM, *SPODOPTERA FRUGIPERDA* (J.E. SMITH) AND ITS CONTROL: A CASE STUDY FROM MAIZE FIELD IN PHITSANULOK, THAILAND

Author SOTHEARITH HONG

Advisor Suphannika Intanon, Ph.D.

Co-Advisor Panisara Thepkusol, Ph.D.

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ABSTRACT

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith), is a polyphagous insect, and a native pest to tropical and subtropical America. This insect has recently reported its first appearance in the Africa continent and caused a huge infestation since 2016. This transboundary pest has continued to spread across Asia and become a new invasive species in Thailand which mainly affected maize. Since the *S. frugiperda* occurrence, the baseline information of this insect biological aspect and its distribution in various conditions is essential. Therefore, to expand the knowledge and support for planning the efficiency management, this study was organized into three experiments which were conducted in the laboratory of the National Biological Control Research Center (NBCRC) (16°44'10.5"N 100°11'37.0"E) and the experimental field (16°44'08.9"N 100°11'38.7"E) of the Faculty of Agriculture, Natural Resources and Environment, Naresuan University, Phitsanulok Province, Thailand.

The first experiment was performed in the laboratory to assess the biological characteristic and the parameters of the fertility life table of *S. frugiperda* on three maize (*Zea mays* L.) cultivars (field, sweet, and waxy maize) under controlled conditions (30±2°C, 55±5% RH, and a 12 h of photoperiod). Results suggested that larvae were

developed through six instars on all the maize cultivars. The duration of larval stage when fed with sweet maize (10.83±0.14 d) was shorter than those when fed with field maize (11.28±0.05 d) (P<0.05). More than 70.5% of them were transformed into the pupal stage. The life cycle duration lasted 28.11±0.40, 27.16±0.37, and 28.41±0.34 d on field maize, sweet maize, and waxy maize, respectively. Significant differences among host plants were not observed for the different development durations. Sex ratio (female:male) was varied between 0.83:1 when reared on field maize, 1.07:1 on sweet maize, and 1.18:1 on waxy maize. The survivorship curve of *S. frugiperda* exhibiting a type I. The highest values of net reproductive, R_0 (220.41±5.88), innate capacity of increase, r_c (0.23±0.001) and finite rate of increase, λ (1.25±0.002) obtained on sweet maize, were not statistically different from other cultivars. The mean generation time (T_c) differed between waxy maize and sweet maize (P<0.05) which was 26.36±0.43 d on waxy maize and 23.80±0.24 d on sweet maize. Those results have indicated the potential and suitability of host-plant on *S. frugiperda* immature development and adult fitness.

The second experiment was conducted at the field level to describe the population dynamic of *S. frugiperda* and its affecting factors. The field maize (Nakhon Sawan 3) trial was conducted during the dry season (October 2019-February 2020) and repeated in the rainy season (July-October 2020). The highest number of *S. frugiperda* was observed during the whorl-stage of maize, 0.85 and 1.25 larvae per grid in the dry and rainy season, respectively. Meanwhile, the lowest number of *S. frugiperda* was observed during the post whorl-stage of maize, 0.71 larvae per grid for the dry season and 0.70 larvae per grid for the rainy season. The highest percentage of *S. frugiperda* infestation was recorded during the whorl-stage of maize, 21.95±3.91% for the dry season and 23.06±3.75% for the rainy season, while the lowest percentage was recorded during the post whorl-stage of maize, 7.47±2.60 and 0.90±0.00% for the dry and rainy seasons, respectively. The actual yield loss due to *S. frugiperda* was recorded at 1.94% in the dry season and 2.48% in the rainy season. Two species of parasitoids were identified and associated with the pest, of which *Chelonus* sp. (Hymenoptera: Scelionidae) was larval parasitoid, while *Telenomus* sp. (Hymenoptera: Braconidae) was egg parasitoid. According to correlation analysis between the *S. frugiperda*

population and its affecting factors, parasitism was the major influenced factor on the population dynamic of *S. frugiperda*, contributing to 21.77% of the variation in pest abundance. The climatic conditions (temperature, humidity, rainfall) recorded during the field experiment did not influence pest abundance. However, this is a primary report of population dynamic of *S. frugiperda* and its parasitoids from the small-scale maize field in northern Thailand, which a long-term observation from the various community are necessary.

Finally, the third experiment was conducted in the laboratory to evaluate the efficacy of 12 insecticides from the different mode of action (MoA) and 3 biopesticides against third instar larvae of *S. frugiperda* under the laboratory conditions (25±2°C, 75±5% RH, and a 12 h of photoperiod). Results indicated that spinosad caused the highest mortality of 100% at 1 d after treatment application, followed by emamectin benzoate, and chlorantraniliprole which caused mortality of 100% at 2 and 3 d after treatment application, respectively. At 7 d, the minimum reduction was still noticed in biopesticides consisting of *Bacillus thuringiensis* var. *aizawai* (15.83%), *Metarhizium anisoplia* (15.00%) and *Beauveria bassiana* (11.67%), however, they had effective on adult emergence which was below 76% on all biopesticides treatments compare to control. The median lethal time (LT_{50}) value of 2.02, 10.73, and 33.75 h was recorded on spinosad, emamectin benzoate and chlorantraniliprole, respectively. These data can be used as a guideline for planning the integrated pest management (IPM) for *S. frugiperda* under smallholder farmer conditions.

In conclusion, *S. frugiperda* has its particular feature which varying depend on the host-plant and the environmental conditions, therefore, the information presented here would greatly provide a comprehensive knowledge of *S. frugiperda* and could be useful information for the preparation of the efficiency management techniques for this critical crop pest. Further study by combination and implement on the field will be helpful.

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CHAPTER I
INTRODUCTION

Background

Maize (*Zea mays* L.) is the third most important cereal grain after wheat and rice which is providing nutrition for humans and animals, and also serving raw materials for industry use (FAO, 1992). In 2017, the world's total maize harvested area was estimated at 197 million hectares with 1.1 billion tonnes of production. Meanwhile, in Thailand, the total harvested area was 1.1 million hectares and producing nearly 5 million tonnes (FAO, 2019b). However, maize production is generally hampered by abiotic and biotic stresses such as insect pests, diseases, soil nutrients, and unstable temperature (Tefera et al., 2011). Regarding the insect pests, over 40 species were recorded as insects attacked maize crop in any stages until storage (Alejandro & CIMMYT, 1987), and four species of moth group including cutworms, stem borers, earworms, and armyworms were considered as the major pests which caused serious damage to maize worldwide (Capinera, 2008).

Among those four major pests, the fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), is a polyphagous insect and natives to tropical and subtropical regions of the United States (Luginbill, 1928), causing a huge infestation throughout the Southeast and along the Atlantic coast during the 1970s (Sparks, 1979). In recent years, *S. frugiperda* has reported its first detection in Southern India (CABI, 2018) and continued to spread across Asia including Sri Lanka, Bangladesh, Myanmar, and Thailand (CABI, 2019). In Thailand, the presence of *S. frugiperda* was reported more than 50 of 76 Thailand's provinces and concentrated in 6 western provinces with large maize areas (Isranews, 2020). It has been calculated that *S. frugiperda* caused damage to maize up to 75,800 hectares (30.60% of total production in 41 provinces) in Thailand since 2018 (Wareerat, 2019). The larvae of *S. frugiperda* fed on a wide host range which has been reported of 353 plant species from 76 families were consumed, especially maize, sorghum, bermudagrass, and cotton (Capinera, 2001; Hardke et al., 2015; Montezano et al., 2018). In addition to its characteristics, great mobility, widespread on several crop species and higher reproductive potential, which made them caused a serious impact not only on the economic and food security but also particularly hard to control (Prasanna et al., 2018).

The development of an adequate management strategy, with minimum pesticide use, requires basic knowledge of the population dynamics of insect pests. In ecological studies, the life table is a component of population ecology structure which provides the essential information of insect population changes during different stages throughout their life cycle and determines key factors of mortality under various environmental conditions (Khaliq et al., 2014; Price et al., 2011). It was constructed by a combination of four classical parameters containing fertility, longevity, the birth rate, and the death rate (Carey, 2001; Caswell, 1982). The analysis of life tables has also emphasized life fecundity and the stable age distribution which was the most useful information to predict the potential of the population growth of further life (Deevey, 1947; Southwood & Henderson, 2000). Understanding the abiotic and biotic factors which affect the insect distribution and their abundance is also fundamental to ecology

(Berggren et al., 2009). Changing of limited resources, competitors or related environment may also affect insect immune response, rate of development as well as its physiological functions (Schowalter, 2011; Yamamura & Kiritani, 1998). Since the occurrence of *S. frugiperda* in several countries, synthetic insecticides have been widely used as an emergency to slow the spread and limited the damage from the insect pests (Rwomushana et al., 2018). The Department of Agriculture (DOA) of Thailand is also launching several projects and experiments to manage *S. frugiperda* through prevention, early detection, eradication/containment and control. Currently, there are no data or any report have been published yet so far. From a pest management viewpoint, the combination of life table and population dynamic is very important to know the most susceptible stage of the pest and would be the most opportune periods to apply the control option which following the integrated pest management (IPM) concepts.

Statement of the problems

S. frugiperda has a high reproductive capability, a relatively short generation time and great dispread ability (Luginbill, 1928; Montezano et al., 2018; Vickery, 1929) which FAO (2019a) has raised an extreme awareness against this insect. The invasion of *S. frugiperda* has significantly impacted not only the economy but also threaten food security (Prasanna et al., 2018). To prevent this enormous invasion, fundamental knowledge of *S. frugiperda* population dynamics and its biological aspect is crucial. However, obtaining that information seems to be complicated and still limited. Therefore, life table parameters and the population dynamic were used to indicate the survival of insects, identify the mortality rate, predict the potential of population growth and explain the factors that influence their abundance. Acquisition of all the information will be useful to decide the appropriate application to control the insect pest.

Research objectives

The specifics of this study were:

1. To assess the biological characteristic and the fertility life table parameters of *S. frugiperda* on three different maize cultivars under laboratory conditions
2. To study the population dynamics of *S. frugiperda* and its affecting factors under field conditions in Phitsanulok province, Northern Thailand
3. To evaluate the efficacy of selected insecticides and biopesticides against *S. frugiperda* under laboratory conditions

Research significance

The previous studies of *S. frugiperda* have been deployed from various locations such as in Argentina (Murúa et al., 2006; Murúa & Virla, 2004), Honduras (Wyckhuys & O'Neil, 2006), Africa (Sisay et al., 2018), and India (Sharanabasappa et al., 2019; Shylesha et al., 2018) as well as a successful insecticides options against this pest (Cook et al., 2004; Hardke et al., 2011; Sisay et al., 2019). Nonetheless, no data or any report have been announced in Thailand yet so far. Consequently, this study directly assess the potential development of *S. frugiperda* on various maize cultivars as well as defines the mortality on each developmental stage by using a life table. More

importantly, several parameters of the fertility life table such as the net reproductive rate (R_0), cohort generation time (T_c), the innate capacity of increase (r_c) and the finite rate of increase (λ) is provided as crucial information of the population growth under the given growing conditions. The study also demonstrates the variation of *S. frugiperda* population as well as their relationship with the influence factors such as temperature, humidity, rainfall, and the natural enemies in the maize field trial. The results from these experiments could contribute an extra detail to the pest management. Additionally, the study will also express the efficacy of various selected insecticides and biopesticides against *S. frugiperda*. The information is given a valuable guideline of when is the most susceptible period and provides a better option to control this insect. Overall, the information and data presented would greatly expand the knowledge of *S. frugiperda* and could be used for planning the efficiency management for this critical crop pest.

Scope of the study

This study was conducted in the laboratory of the National Biological Control Research Center (NBCRC) and the experimental field of the Faculty of Agriculture, Natural Resources and Environment, Naresuan University, Phitsanulok province, Thailand, which is divided into three experiments. Two of the experiments were performed in the laboratory which focused on the biological life cycle and fertility life table parameters of *S. frugiperda* on three maize cultivars, and the bioassay of selected insecticides and biopesticides against *S. frugiperda*. The data of mean duration, mortality, and fertility throughout the development stages of *S. frugiperda* were observed daily and were used for calculating the fertility life table parameters and constructed survivorship curve. The percent of mortality due to the efficacy of selected insecticides and biopesticides on the third instar larvae of *S. frugiperda* were evaluated from 12 hours until 7 days and the bioassay study was repeated twice. The other experiment was practiced in the field to study the population dynamics of *S. frugiperda* and its affecting factors. The field maize (Nakhon Sawan 3) trial was conducted during the dry season from October 2019 to February 2020 and repeated in the rainy season from July to October 2020. The Person's *r* correlation analyses were used to estimate the relationship between the *S. frugiperda* population and its affecting factors, while mean yield per infested and uninfested plant were combined to calculate the actual yield loss.

Key words

Fall armyworm, Population ecology, Maize cultivars. Insecticides, Biopesticides

Hypotheses of the study

1. Three maize cultivars may affect differently on *S. frugiperda* developmental stages and their fertility
2. The *S. frugiperda* population may relate with its affecting factors
3. The selected insecticides and biopesticides tested against the third instar larvae of *S. frugiperda* may significantly different

CHAPTER II
LITERATURE REVIEW

Fall armyworm (*Spodoptera frugiperda*)

1. Origin and distribution

"Corn-bud-worm-moth" is the first common name on the record (Smith & Abbot, 1797), however commonly named "Fall armyworm, *Spodoptera frugiperda*" in the present. *S. frugiperda* is a native species to the tropical regions of the United States due to it did not pass the winter (Luginbill, 1928), but it can be successfully overwintered only in southern Florida and southern Texas and during warm winter it may survive along the Gulf Coast and in southern Arizona (Capinera, 2001). *S. frugiperda* has been noticed as a strong flyer and spread over nearly all part of United States annually from northward such as southern Florida, Louisiana, southern Texas, followed by Mississippi river, Mississippi, Alabama, Georgia, and Carolina until the upper north of American Maryland, Ohio, Indiana, and Western of American Arizona, California, and Tempe (Capinera, 2001; Luginbill, 1928). *S. frugiperda* was added to the European and Mediterranean Plant Protection Organization (EPPO) A1 list (a quarantine pest) as it was found and infected on sweet maize in Baden-Württemberg, Germany since 1999 till now are eradication (EPPO, 2000). In recently, *S. frugiperda* has been reported as their first time present in the Africa continent such as Benin, Nigeria, São Tomé et Príncipe, and Togo since early 2016 (Goergen et al., 2016). In 2018, more than 30 counties in African have been confirmed the presence of *S. frugiperda* and caused a high impact on the economy (FAO, 2018a). In the same year, this pest was first reported in India subcontinent and Asia (CABI, 2018; IITA, 2018). Until now, *S. frugiperda* has been reported in most of the counties in Asia such as Sri Lanka, Bangladesh, Myanmar, Thailand, China, Republic of Korea, Japan, Indonesia, and Nepal (CABI, 2019).

2. Life cycle and description

Normally, *S. frugiperda* completes their life cycle about 30 days during summer (at a daily temperature of 28ºC) (Prasanna et al., 2018), but could reach 60 days in spring and autumn and maybe extend to 80-90 days in winter (Capinera, 2001). *S. frugiperda* could continuously infest the crop throughout the year due to the ability to diapause (a biological resting period) does not present in this species (Prasanna et al., 2018). The number of generations per year occurring in an area varies with temperature. In Minnesota and New York, this inset does not appear until August and has only one generation. In Kansa and Missouri, there are one or two-generation, three in South Carolina and four in Louisiana (Capinera, 2001; Luginbill, 1928).

The life cycle of *S. frugiperda* includes four stages as following: egg, larva, pupa and adult (Figure 1). The egg is "oblate-spheroidal shape" in which the base is flattened and curves upward to a broadly round point at the apex. It is well-marked with 47-50 ridges that radiate outward from the apex (Capinera, 2001). The egg measure is 0.47 mm in diameter and 0.39 mm in height. Freshly oviposited eggs are greenish-gray in color and 12 hours later, they are become blackish-brown (Luginbill, 1928). The eggs of *S. frugiperda* are laid in groups or clusters of 20-350 (EPPO, 2015)

and total egg production per female average about 1500, with a maximum of over 2000 (Capinera, 2001). Eggs are generally laid spreading over in one layer or sometimes in two (partial) layers attached under the foliage and they are covered with hairs from the female's abdomen (EPPO, 2015). Oviposition usually occurs in the early evening and hatching will normally occur in 2-4 days under appropriate conditions (Luginbill, 1928; Sparks, 1979).

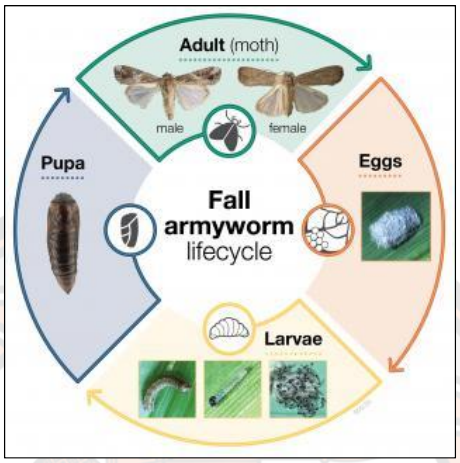

Figure 1 Life cycle of *Spodoptera frugiperda*

Source: FAO, 2017.

There usually are six larval instars of *S. frugiperda*. In the head capsule widths are about 0.35, 0.45, 0.75, 1.3, 2.0 and 2.6 mm, respectively. Larvae attain lengths are about 1.7, 3.5, 6.4, 10.0, 17.2 and 34.2 mm, respectively, during these instars (Capinera, 2001). However, Murúa and Virla (2004) reported that the number of larval instars was reached to seven, eight and nine when fed on *Z. mays*, *Panicum maximum*, and *Cynodon dactylon*, respectively. As the first instar (L1) hatching, they are whitish or yellow colour, with a black head capsule. They have a small black spot along with theirs white longitudinal stripes. After feeding, they appeared from greenish to brownish in second instar (L2) and the head turning to orangish as the third instar (L3). The proceeding between L2-L3 are nearly similar by the dorsal surface of the body becomes brownish and lateral white lines begin to form. In the fourth (L4) to sixth (L6) instar, body colour varying from olivaceous, brown, and dull grey to almost dark in which depending on their diet and other factors. The insect's sub-dorsal and lateral lines are white and have elevated spots that occur dorsally on the body which are usually dark and bear spines. The head is variable in colour, from very dark brown to reddish-brown. The face of the mature larva is marked with a white inverted "Y" and the epidermis of the larva is rough or granular in texture when examined closely. The best identifying feature of *S. frugiperda* is showing four black dots in a square pattern on the eighth abdominal segment (Figure 2). Larvae are most active in the early morning and tend to hide themselves during the brightest time of the day. Duration the larval stage tends to be about 14 days in warm weather and 30 days in cool weather (Capinera, 2001; EPPO, 2015; Hardke et al., 2015; Luginbill, 1928; Sparks, 1979). Moreover, Murúa and Virla (2004) found that the total duration of *S. frugiperda* larvae stages was

26.97, 29.89 and 30.90 days when feeding on *Z. mays*, *P. maximum*, and *C. dactylon*, respectively under artificial conditions.

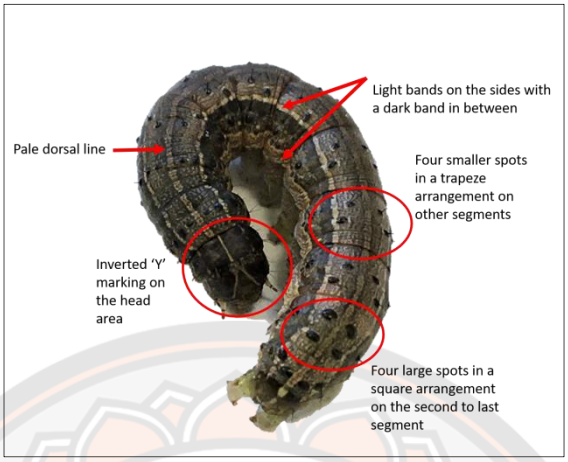

Figure 2 Characteristic marks and spots for *Spodoptera frugiperda* identification

Source: FAO, 2017.

The pupa is reddish-brown and darker on the prothorax which will become black before the adult emergence. The pupa measure is about 14-18 mm long and 4.5 mm wide. The pupation generally occurs in the soil at 2-8 cm depth depending on soil texture, moisture and temperature. The larva constructs a loose cocoon by trying together particles of soil with silk. When the soil is hard to dig, the larva will web together with leaf debris and other material to form a cocoon on the soil surface. The cocoon is oval (Capinera, 2001; Sparks, 1979). However, a large amount of pupa was found on the maize husk during an outbreak at Columbia, South Carolina in 1920. The humidity did not affect the duration of the pupal stage, only the temperature which has greatly influenced. In summer, the average period of the pupal stage is about 6-9 days and it could reach 15-30 days during winter in Texas (Luginbill, 1928).

The moth is quite variable in appearance (Figure 3), with a wingspan of 32-40 mm (Capinera, 2001). The male body length is 1.6 cm and the forewing is mottled with shaded gray and brown colour. On the wings, it has a discal cell containing straw colour on three-quarters of the area and dark brown on one-quarter of the area with triangular white spots at the tip which is near the center of the wing. The female body length is 1.7 cm and the forewing is less distinctly marked, ranging from a uniform greyish brown to fine mottling of grey and brown (CABI, 2019). Both male and female, the hind wing is iridescent silver-white with a narrow dark border (Capinera, 2001). On the first night of emergence, moths feed on the nectar of many plants. The adults are nocturnal and most of the activity including mating and oviposition occurring during warm and humid in the early evening. Females are usually mating on the second day after emergence and repeatedly mate, but only once per night. The oviposition period lasts for 3-4 days. The females normally deposit most of their eggs during the first 4-5 days after oviposition begins, although some oviposition takes up to 3 weeks. The average adult longevity is about 10 days and varied from 7-21 days depending on food and temperature (Luginbill, 1928).

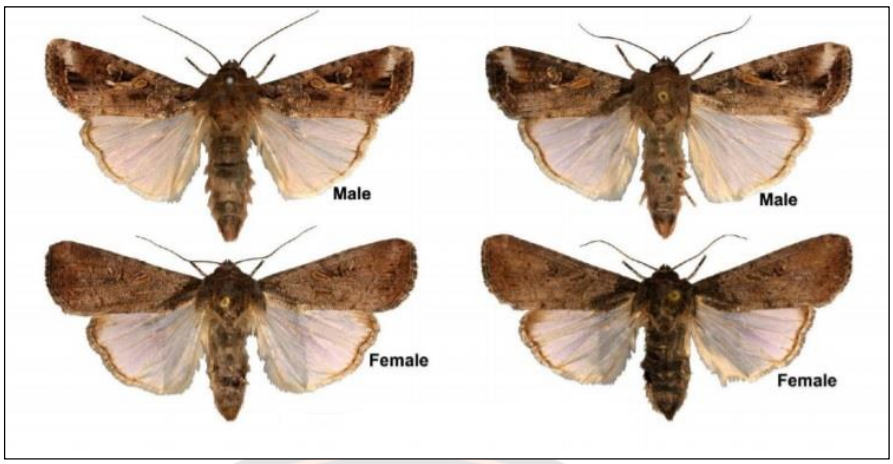

Figure 3 Variation in patterns on wings of *Spodoptera frugiperda* adult

Source: FAO, 2017.

3. Host plant

S. frugiperda is a polyphagous insect that feeds on a very wide host range with over 80 plants recorded (Capinera, 2001; Luginbill, 1928), but recently 353 plant species from 76 plant families were reported as a host thorough literature review and additional surveys in Brazil (Montezano et al., 2018). *S. frugiperda* preferred the plants of the family Poaceae (grass) such as corn, sorghum, sugarcane, rice, bermudagrass, forage grass, and weeds e.g. crabgrass, turf grass, finger grass, etc. Vegetables are frequently injured, but only occasionally damage including asparagus, cabbage, cowpea, kale, cucumber, onion, pepper, potato, spinach, tomato, turnip and watermelon. Field crops are also invaded as well as barley, buckwheat, cotton, oat, millet, peanut, sugar beet, soybean, tobacco, and other fruit crops like apple, grape, orange, papaya, peach, strawberry, and many flowers. The habit of larvae when they are feeding like an army with a large numbers and consume nearly all vegetation in their path (Capinera, 2001; Hardke et al., 2015; Sparks, 1979).

S. frugiperda consists of two strains adapted by their host plant preference. One is the corn-strain (C-strain) which particularly feeds on corn, cotton, and sorghum and the other one is the rice-strain (R-strain) which prefers feeding on rice and many pasture grass. Those two strains are morphologically identical but differ in pheromone compositions, mating behavior and host range. Mating between the two strains results in viable offspring (Capinera, 2001; Dumas et al., 2015; Hardke et al., 2015; Pashley, 1988).

4. Damages

Larvae cause most of the damage by consuming foliage and appear on a ragged edge of the leaf toward the midrib. Young larvae especially the first instar feed gregariously on the underside or the top of young leaves causing a characteristic skeletonizing or windowing effect (CABI, 2019). By the second or third instar, larvae begin to make holes in leaves like a row of perforations and eat from the edge of leaves inward. Larva densities regularly reduce 1-2 larvae per plant due to cannibalistic

behaviour. The older larvae feed solitarily, extending their mines and causing some of the small plants to destroy. The larvae also burrow into the growing point (bud, whorl, or cob), which collapses the growth potential of plants (Figure 4). In corn, they sometimes burrow into the ear, feeding on kernels in the same manner as corn earworm (*Helicoverpa zea*). However, *H. zea* tends to feed down through the silk before attacking the kernels at the tip of the ear, while *S. frugiperda* feed by burrowing through the husk on the side of the ear (Capinera, 2001). Young larvae usually feed during the early morning and in the late evening, but the older ones like to feed at night time. During the day, they conceal themselves from predators under the foliage of the host plants. Some of the larvae hatching from eggs, drop themselves to the ground by spinning silk thread not only to escape from enemies but also migrate to neighbourhood plants (CABI, 2019; Luginbill, 1928). Luginbill (1928) reported *S. frugiperda* required an average of ca. 14,000 sq. mm of crabgrass to develop through six instars per caterpillar. The percentage of consumption per instar average is 0.1, 0.6, 1.1, 4.7, 16.3 and 77.2, respectively. The first third-instars are quite small, easily overlooked and require less than 2% of the total foliage consumed (Capinera, 2001; Sparks, 1979).

Figure 4 Signs of *Spodoptera frugiperda* infestation on maize (*Zea mays* L.), early instars (A), later instars (B and C)

Source: FAO, 2017.

5. Managements

Monitoring, scouting, and sampling are the most principal activities for the successful implementation of an integrated pest management (IPM) program. Blacklight trap and pheromone lure baited are the easiest way to monitor the seasonal *S. frugiperda* population (Mitchell, 1979). The combination of commercial pheromone lure with universal bucket trap (green lid, yellow funnel, and white bucket) has shown a high efficiency over four times rather than using a virgin female-baited to catch a male moth per night in Florida (Meagher & Nagoshi, 2013). The trap should apply just after seedling and should be inside or on the edge of the maize field, or in the open area nearby. The trap should be hanged at a canopy height (Capinera, 2001) about 1.5 m above ground. One trap should be used for 0.5-2 ha and check twice a week. The pheromone lure usually replaces every 3-6 weeks to achieve the optimum results

depending on temperature, pheromone components and release characteristics (strain) (Prasanna et al., 2018). Field scouting should be done in the early morning or late evening due to their morphology. Knowing the growth stage of the crop when scouting will be more helpful and effective. Moreover, it could help farmers consider whether to use control management. A generally checking 20 plants for 5 locations or 10 plants for 10 locations is consider to practice in field sampling for insect infestation. Otherwise, 10-plant count and 10-minute collection was determined as the best techniques for forecaster and refine the prediction equation compare with sampling intervals (Tollefson, 1975). Scouting pattern "W" could be carried out in the maize field at early and late whorl stage, while "Ladder" pattern shall be done in tassel stage (VT) reproductive stage for evaluation (Prasanna et al., 2018).

S. frugiperda has known as an absence of diapause mechanism and does not survive during winter, so selecting an optimal time for planting could avoid the infestation. Early planting after the high effect of rain or choosing the early maturity varieties not only provide better-growing conditions for the crop but also reduces damage from pests (Capinera, 2001; Prasanna et al., 2018). In Brazil, more than 95% of early larvae die due to predation, drown and dislodgment by rainfall (Varella et al., 2015). Only reduced tillage single technique appears to have less effect on *S. frugiperda* infestation (All, 1988). However, combining with polycultures or crop residue retention e.g. mulch, may help not only in the improvement of plant growth but also increase the abundance of natural enemies (Andrews, 1988; Harrison et al., 2019; Kumar & Mihm, 2002). Companion crop strategy was also suggested to give a highly effective against *S. frugiperda*. In Africa, the climate-adapted push-pull system has successfully reduced the percentage of damaged maize 86% and increased maize yield 2.7 times by intercropping with pest-repellent (push) plant species (e.g. *Desmodium* spp.) and surrounding by a border pest-attractive trap (pull) plant species (e.g. *Pennisetum purpureum* and *Brachiaria* spp.). Besides, planting such as pigeon pea, cassava, sweet potatoes, cowpea and other beans inside maize row were protected the main crop and enhanced the diversity of beneficial organisms including natural enemies as well (Midega et al., 2018; Prasanna et al., 2018).

Genetically modified maize is engineered to express lepidopteran resistance by using insecticidal crystal protein genes (*cry*) isolated from *Bacillus thuringiensis* (or Bt). Several *cry* genes are toxic to many lepidopteran species e.g. *cry1A*, *cry1Ab*, and *cry1F* which have been distributed in commercial Bt maize varieties for over 20 years. Moreover, Bt produced another class of lepidopteran-specific protein encoded by vegetative insecticidal protein genes (*vip*). *Vip3A* genes were the most notable which used to consult *S. frugiperda* resistance (Prasanna et al., 2018). Bt maize hybrid varieties included a various combination of *cry* and *vip* genes are globally commercialized on the market in South America and European counties (Huesing & English, 2004; James, 2004). Brazil, South Africa and the United States are the most cultivated and contributor counties of Bt maize (Prasanna et al., 2018). There is also significant potential for Bt maize field trials in Asia include Thailand (James, 2007). However, GM crops have been issued to ban in Thailand due to the concerns of environmental impacts. GM crops have been allowed for a field trial for research purpose which is approved by DOA and collaboration with the government sector (Napasintuwong, 2015). Until 2013, only a few GM maize varieties e.g. Roundup Ready *NK603*, *GA21*, *Bt11*x*GA21*, and *30B80* were tested with a private company in

Thailand (Napompeth, 2015). Although, the evolution of Bt resistance strain on *S. frugiperda* has been developing where a high degree of monoculture with Bt maize varieties expressing a single resistance gene (Huang et al., 2014). Insect resistance management (IRM) strategies were suggested that using a combination of multiple transgenic "stacking" or "pyramiding" Bt genes (e.g. *cry* and *vip3A*) in plants will also prolong resistance along with corporation of conventional resistance (Gerpacio & Pingali, 2007).

There are 53 species of parasitoids belonging to 43 genera and 10 families which attacked *S. frugiperda* globally (Ashley, 1979). Four types of parasitoids were classified (Prasanna et al., 2018) as follows: 1) egg parasitoids, e.g. *Trichogramma* sp. and *Telenomus* sp., is the most abundant species. *Trichogramma pretiosum* was the most obtainable species from lepidopteran eggs which collected on various crops in Brazil (Souza et al., 2016), and also changing its behaviors on *S. frugiperda* egg masses due to effective of lay-scales (Beserra et al., 2005). *Telenomus remus* was preferred to parasitize on *S. frugiperda* rather than rice meal moth, *Corcyra cephalonica*, egg masses due to where the host of the parasitoids was reared on (Souza et al., 2016). Additionally, the density of *T. remus* from 0.231 to 0.264 females per *S. frugiperda* egg could reach parasitism more than 90% (Pomari et al., 2013). Egg parasitoids are considered the most important ones, regarding these species, prevent the pest from causing any damage to the host plant. Besides that, these parasitoids are easily reared on a large scale, thus it available from bio-factories in several countries (Prasanna et al., 2018). 2) egg-larval parasitoids, e.g. *Chelonus* sp., is the widest spread species throughout America (Molina-Ochoa et al., 2003a) and a few species were spotted appearance in Eastern Africa (Sisay et al., 2018). 3) larval-parasitoids, e.g. *Winthemia trinitatis* is the most efficient species which destroyed a large number of *S. frugiperda* during an outbreak since 1913 (Luginbill, 1928), and *Cotesia icipe* is the most dominant larval parasitoids as well by nearly 40% were found on *S. frugiperda* in Ethiopia (Sisay et al., 2018). 4) larval-pupal parasitoids, e.g. *Archytas* sp., and *Lespesia archippivora* are deposited their eggs on or near the caterpillar and kill its host in a pupal stage. In addition, both of parasitoids are the most widespread species in southern America (Molina-Ochoa et al., 2003a), and often rear on *S. frugiperda* (Luginbill, 1928). Among the predators of *S. frugiperda* including ground beetles, lady beetles, earwigs, assassin bugs, big-eyed bugs, flower bugs, pirate bugs, and spined soldier bugs are also attacked many other caterpillars. Moreover, birds, skunks, lizards, frogs, some of the rodents and even chicken are fed on *S. frugiperda* larvae (Capinera, 2001; Luginbill, 1928; Prasanna et al., 2018).

A naturally-occurring entomopathogen on *S. frugiperda* is reported including viruses, fungi, bacteria, and nematodes. Two types of Baculovirus frequently study against *S. frugiperda* namely, granulovirus (SfGV) and multiple nucleopolyhedroviruses (SfMNPV). Pidre et al. (2019) reported the symptom of infected larvae by SfGV are yellowing, swelling, and in some cases showed serious lesions in the last abdominal segments of larval. SfMNPV caused larvae to reduce their feeding and died from 8-10 days (Prasanna et al., 2018). The spores produced by several entomopathogens fungi were outspread by wind, water and soil. These fungi usually attach to the external body surface and penetrate through the cuticle into the insect body to obtain nutrients for their growth and reproduction. The infected insect then stops feeding becomes discolored (cream, green, reddish, or brown depending on the fungi

species) and eventually dies. *Beauveria bassiana*, *Metarhizium anisopliae* and *Nomuraea rileyi* are common fungi with potential used against insect pests and commercial biopesticides products (Prasanna et al., 2018). *Metarhizium rileyi* (previously known as *Nomuraea rileyi*), codified Nm06 which was isolated from a natural infected on *S. frugiperda* in Meta, Colombia, has shown their highly effective and 57% of the damage was reduce under greenhouse experiment due to optimizing storage condition (Grijalba et al., 2018). The combination of *B. bassiana* and *M. anisopliae* with a low dose of chlorpyrifos and spinosad showed an increase in mortality and fungal performance. However, the results of the combination have been conflicted by application subsequent to produce a poor quality (Rivero-Borja et al., 2018). *Bacillus thuringiensis* or (Bt) is a gram-positive, soil-dwelling and produce the toxin crystal proteins which was used as biopesticides against many lepidopteran pest (Prasanna et al., 2018). Several *Bacillus thuringiensis* strains (var. *aizawai* and var. *thuringiensis*) caused mortality of *S. frugiperda* at 100 and 80%, respectively (Polanczyk et al., 2000), while *B. thuringiensis* var. *kurstaki* was affected to other lepidopteran species (Silva et al., 2004). Different *cry* genes produce from *B. thuringiensis* showed their effect according to selective target pests. For instance, *cry1Aa* and *cry1Ab* encoding toxin active against *S. frugiperda* and *Spodoptera cosmioides,* while *cry2Aa* encoding toxin active against *Spodoptera eridania*. However, producing new insecticides made from *B. thuringiensis* strains or developing plants expressing the *cry* genes should be considering the multiple toxin genes to reduce *Spodoptera* spp. resistance (Santos et al., 2009).

Several active ingredients of insecticide have been registered for controlling *S. frugiperda*. FAO (2018c) reported that 16 highly hazardous pesticides have been recommended for controlling *S. frugiperda* in Africa countries such as benfuracarb, carbaryl, carbosulfan, methomyl [carbamates], acephate, chlorpyrifos, diazinon, methyl-parathion, profenofos [organophosphates], endosulfan [organochlorines], cyfluthrin, cypermethrin, lambda-cyhalothrin, zeta-cypermethrin [pyrethroids], imidacloprid [neonicotinoids] and abamectin [avermectins]. During the survey in Ghana, the percentage of farmer 25, 12.5 and 12.3 were used *B. thuringiensis*, emamectin benzoate and ethyl palmitate, respectively to manage *S. frugiperda* infestation. Meanwhile, the farmers in Zambia 31.43% were continued using lambda-cyhalothrin and 23.43% used cypermethrin. In addition, seed treatment with product based on cyantraniliprole and thiamethoxam were promoted by Syngenta, is being used in Zambia. As a result, crop seedling is protected up to 4 weeks and reduce foliar insecticides spray 1-3 times in commercial farm (Rwomushana et al., 2018). The Peruvian Ministry of Environment suggested that using a dry formulation of trichlorfon mix with the sand, then applied into the whorl maize was consider effective and widely used by smallholder farmers in Peru. In Nicaragua found that a mixture of sawdust and chlorpyrifos helped reduce the number of pesticides used by 20% (Day et al., 2017). Even though using pyrethroids and neonicotinoids can control *S. frugiperda*, the insects could develop resistance to insecticides (FAO, 2018b). The Arthropod Pesticide Resistance Database (APRD) reported the list of insecticides (41 active ingredients) resistance in *S. frugiperda* including fluvalinate [pyrethroids], methyl-parathion [organophosphates] and carbaryl [carbamates] (Yu, 1991). *S. frugiperda* strains from the North, Central, and South Florida were highly resistant to carbaryl and methyl-parathion but remain susceptible to permethrin (Yu et al., 2003). Gutiérrez-Moreno et

al. (2018) also indicated that *S. frugiperda* population form Mexico has expressed higher resistance ration (RR_{50}) 20-fold to chlorpyriphos, 19-fold to permethrin and 10-fold to flubendiamide, while the Puerto Rico population exhibited resistance to more than 10 insecticides. The following information related to the pesticide used was considered important, consisting of inappropriate rates of chemical application, wrong application, fake pesticides labeling, farmer lack of basic skills in spraying servicing and necessary field information (Prasanna et al., 2018). These showed a negative effect on not only human health and environment but also effect on non-target species (natural enemies and pollinator) (FAO, 2018c). Using pesticides in the early growth stage of the crop (e.g. corn from emerging to tasselling), larvae still young and spraying in the early morning or late afternoon when the larvae are more active, are the most effective way. Besides that, the essential data of crop growth stages and *S. frugiperda* scouting life stages would also provide a low-risk and cost-effective optimal for farmers (Day et al., 2017).

Theory of population ecology

1. Concepts

Population ecology is the processes study of how growth and decline, birth and death, immigration and emigration, life histories adapted to the environment, and dynamical behavior of animal and plant population. Population dynamics, life histories and population structure which include life tables are the essential parts of insect ecology that impart the way of understanding species in nature, predict population trends and plant pest-management strategies (Price et al., 2011). Basic demographic contained four categories of population: 1) size, the number of individuals of the population, 2) distribution, the division of the population in location by the given time, 3) structure, the distribution based on age and sex which sex ratio the principal measure and 4) change, the fluctuation of population or one of its structural units. Size, distribution and structure were considered as the population statistics, while change was referred to as the population dynamic (Shryock et al., 1976). Biologists and entomologists often applied the term "population" as an estimation of demographics. For example, sampling leaves of insect infestation as the population by using statistics.

2. Density independence and dependence

Insect populations can change dramatically in size due to high fecundity rate, short life cycle and powerful adaptive organisms to natural (Khaliq et al., 2014). Two main factors affect population size as following: density independence (DI) is a sensitive change in abiotic conditions such as temperature, humidity, light, pollution and water availability or caused by the natural disaster that changes in population size (Price et al., 2011). The difference of constant temperature was tested on *S. frugiperda* development, Barfield et al. (1978) showed that the total period of egg-adult was ranged from 66.6 days (15.6°C) to 18.4 days (35°C). Simmons and Marti (1992) indicated that the frequency duration of *S. frugiperda* mating was influenced by temperature. The number of mating peaked between 2200 and 0300 h at 25 and 30°C, while lower mating was recorded at 10 or 15°C. In addition, rainfall was highly influenced the mortality dynamics of *S. frugiperda* by egg dislodgement more than 95% (Varella et al., 2015). Density dependence (DD) is limiting factors that tend to be biotic which response from one species to others causing a population's per capita growth rate change typically (Price

et al., 2011). The biotic factor was divided into 3 categories including 1) host-plant effect, food has been a major and complex component in the dynamics of organisms e.g. food quality variation, the quantity of food available and the competition within the population (inter- and intraspecific). Food nutrition may impact herbivore's fecundity, the viability of larvae and resistance to natural enemies. *S. frugiperda* has been known as a polyphagous insect that consumed on many plant species (Capinera, 2001; Montezano et al., 2018). Several researchers have reported the variation of *S. frugiperda* biological development including several instars, duration and its fineness according to host-plant ability such as different maize cultivars (Santos et al., 2003), soybean, cotton, maize, wheat, and oat leaves (Da Silva et al., 2017) and fed on maize, potato and tobacco (Guo et al., 2020). 2) lateral effect, cooperative interaction between species at the same tropic level e.g. competition for resources, food chain concept, favorable of each species, landscape pattern, biodiversity caused the individual species to survive, reproduce and disperse. *S. frugiperda* was reported a cannibalistic behaviour which consumes each other (Luginbill, 1928; Prasanna et al., 2018). However Silva and Parra (2013) indicated that *S. frugiperda* larval cannibalism was not obligatory; and 3) natural enemies (predators, parasitoids, and pathogens) are regulators of insect herbivore population and also correlate with nature. Top-down (or trophic cascade) regulation is the response of predators and parasites to increasing prey or host availability. As prey abundance increases, predators and parasites encounter more prey. However, with low prey density, the mortality of its predators rises since it is difficult to locate the food source. Complex response of natural enemy abundance and diversity with *S. frugiperda* infestation showed the differences between altitude and development stages (Wyckhuys & O'Neil, 2006). The abundance of parasitoids in Tafí Viejo and Vipos, Argentina are similar, but the diversity seems to be different due to the native vegetation habitat around that area (Murúa et al., 2006). Moreover, the cropping system or plant phenological stage may also affect parasitoid activity (Pomari et al., 2013). Even though insect outbreaks are natural phenomena, but both abiotic and biotic involve with a changing climatic ecosystem may also affect their population dynamics, distribution, abundance, intensity, feeding behavior and various biological like fecundity and viability (Kakde et al., 2014; OpenStax, 2013; Price et al., 2011; Schowalter, 2011).

3. Life table construction and age-specific analysis

Life table study is a fundamental knowledge which ecologists built and used to understanding the population dynamics of species (Carey, 1993). Life tables describe how successful age and stage intervals, the number of deaths, the survivors, the rate and the factors of mortality throughout their life cycle with the expectation of further life (Kakde et al., 2014; Price et al., 2011). Originally, life tables were used to study on human population for actuarial and the probability of death (Harcourt, 1969). Since then the first life tables were developed for insect population in the field which was prepared on spruce budworm, *Choristoneura fumiferana* (Morris & Miller, 1954), and was adopted by many other researchers. An age-specific life table is based on the fate of a real cohort, which is the number of the population belonging to a single generation and maybe stationary or fluctuating (Southwood & Henderson, 2000). It was constricted by a combination of four classical parameters containing fertility, longevity, the birth rate and the death rate (Caswell, 1982). In the study of life table parameters of beet armyworm, *Spodoptera exigua* on four commercial sugar beet cultivars, Karimi-

Malati et al. (2012) indicated the lowest percentages of larval mortality were recorded on Dorothea, while the highest percentage was observed on Renger. The life expectancy at the beginning of the life of *S. exigua* was ranged between 26.94 and 30.16 days, and the life expectancy at the adult emergence ranged between 13.82 and 14.24 days on Renger and Shirin, respectively. Naseri et al. (2009) also indicated the daily mortality of the cotton bollworm, *Helicoverpa armigera* fed on different soybean cultivars ranged from 0.068 to 0.077 on the first day of adult emergence, which the highest and lowest values were recorded on BP and M4, respectively. Subsequently, the fertility life table describes the natality and interaction with the mortality in the population. The net reproduction rate (R_0) shows the multiplication rate per generation obtained by the summing of the multiplication between the age-specific survival (l_x) and the age-specific fertility (m_x) (Deevey, 1947; Southwood & Henderson, 2000). Several studies were carried out to estimate R_0 value of *S. frugiperda* on various diets such as maize, potato, and tobacco (Guo et al., 2020), maize, Guineagrass, and bermudagrass (Murúa & Virla, 2004), and corn-base diet (Pinto et al., 2019; Silva & Parra, 2013). Furthermore, the combination of the fertility life table parameters could express the population growth. The innate capacity of increase (r_c) was defined as the intrinsic rate of natural increase which use to predict the potential of the population growth rate under a given environmental conditions (Birch, 1948; Laughlin, 1965). However, temperature may impact on the population growth. Qin et al. (2018) reported that when the temperature increase the cohort generation time (T_c) of the armyworm, *Mythimna roseilinea*, was declined but the finite rate of increase (λ) and r_c were increased. Karimi-Malati et al. (2012) showed the highest value of the intrinsic rate of increase (r_m) of *S. exigua* on FD0005, of which r_m and r_c were used similarly.

Bioassay

1. Definition and evaluation of toxicity

A bioassay is an experiment which is used living organisms as a test subject. Quantal response bioassays are often done with pest species and use to estimate the relationship between the responses and the quantity of a stimulus. The bioassay can differ in the term of response variables (a random outcome of the experiments) and explanatory variables (a measurable stimulus cause a response to varying) (Robertson et al., 2017). Chemical synthetic insecticides have been used as pest control for over a decade. As a result of increasing the use of highly toxic insecticides not only to control the devastating of the pest but also to develop the immune enzyme caused resistance. The main purpose of bioassay is to test newer insecticides and the appropriate dose that affect insect as well as to evaluate the resistance response and the pesticide selectivity to natural enemies (Paramasivam & Selvi, 2017). To evaluate the bioassay, the data correlated with expected field efficacy, selection of insecticides formulation and mode of action, the growth stage of insects, method of application, bioassay environment, a quantity of lethal dose (LD) or lethal concentration (LC) and assessment time are the major factors (Ball, 1981). To obtain the efficacy of insecticides accurately, various methods were established. Although topical application is the most common use and gives high accuracy of treatment to the insect, it required specific equipment, time for preparing as well as due to the insect small and movement thus the treatment are difficult to be done (Yu, 2014). The dipping and contact method or residual exposure

is the simplest method which shows more efficiency, inexpensive and easy to perform as well as indicates accuracy similar to the actual field. Terefe et al. (2004) expressed the high efficacy of insecticides against *H. armigera* through square dipping which similarity to the field sprays. The susceptibility of *S. frugiperda* to various insecticides was carried out by using the spraying method, Belay et al. (2012) indicated that thiodicarb, acephate and spinetoram or spinosad were sufficient to control this insect. In general, the evaluation of toxicity is express in terms of LD_{50} (value of lethal dose which could kill 50% of the population of the organism) and commonly use mg/kg. In some cases, LC_{50} (lethal concentration) is used instead due to the exact dose given to the insect cannot be determined. Furthermore, when the time is necessary to kill a target organism especially relevant for biological control, median lethal time (LT_{50}) should consider (Robertson et al., 2017). Three different doses from 12 insecticides were tested in laboratory bioassay on third instar larvae of *H. armigera*, Carneiro et al. (2014) showed the result that chlorpyrifos and spinosad were highly effective in both tropical and ingestion. Among the insecticides tested on third instar larvae of *S. frugiperda* by diet-incorporated showed that low LC_{50} values of spinetoram and chlorantraniliprole were significantly toxic compare to the traditional insecticides e.g. indoxacarb and lambda-cyhalothrin (Hardke et al., 2011).

2. The mode of action of insecticides

Insecticides can be classified into many groups according to their chemical structures or their toxicological action. Among a total of 364 active ingredients of pesticides (Coble et al., 2004), chlorinated hydrocarbons, organophosphates and carbamates are the main synthetic group and widely uses (Britannica, 2019). Although, the different groups of insecticides could have the same mode of action (MoA) (Yu, 2014). The Insecticides Resistance Action Committee (IRAC) was classified the MoA into Acetylcholinesterase (AChE) inhibitors, GABA-gated chloride channel blockers, Sodium channel modulators, etc. to guide the development of the IRM strategy (IRAC, 2019). Since the occurrence of *S. frugiperda*, many insecticides in the current marketplace were used against this pest (Day et al., 2017). Several insecticides from different MoA were tested against *S. frugiperda*. For instance, Sisay et al. (2019) exhibited the efficacy of Radiant (spinetoram), Tracer (spinosad), Karate (lambda-cyhalothrin) and Ampligo (chlorantraniliprole + lambda cyhalothrin) were caused over 90% of mortality, while Malathion and Carbaryl were caused moderate and less effective, respectively. Deshmukh et al. (2020) expressed that emamectin benzoate 5%SG was the highest acute toxicity, followed by chlorantraniliprole 18.5%SC, and spinetoram 11.7%SC, while the toxicity of flubendiamide 39.35%SC, indoxacarb 14.5%SC, lambda-cyhalothrin 5%EC, and novaluron 10%EC were at par by the leaf dipping bioassay.

3. Resistance management strategies

To prevent the rapid development of insecticide resistance, several strategies included using biopesticides or bio-agent were implemented. Likewise, the IRM was aim to optimize the appropriate of selective insecticides as well as ensure the low effective to natural biological control (Kranthi, 2005). Among those strategies, the rotation of various insecticides with the different MoA groups has recently expressed more efficiency (Yu, 2014). Zhao et al. (2010) experimented with insecticide rotations as a resistance management strategy with *Plutella xylostella* for nine generations. The

results were indicated that the resistance development was slower and better when the insecticides were rotated every generation rather than rotation every third generation or applied as a mosaic. According to IRAC suggestion, introduce a new class of insecticides, apply novel eco-friendly insecticides which less effective to biological control agents, promote the resistance predators and parasites, as well as inter-cropping with the transgenic crop, could delay or prevent the evolution of resistance to insecticides (Sparks & Nauen, 2015).

CHAPTER III

RESEARCH METHODOLOGY

Research location

The study was organized into three experiments which were conducted in the experimental field (16°44'08.9"N 100°11'38.7"E) of the Faculty of Agriculture, Natural Resources and Environment, and in the laboratory of the National Biological Control Research Center (NBCRC) (16°44'10.5"N 100°11'37.0"E) located at Naresuan University, Phitsanulok Province, Thailand (Figure 5). Phitsanulok is in northern Thailand covered approximately 10,815 square kilometers and about 45.25% of the total area was used for agricultural production (OAE, 2019).

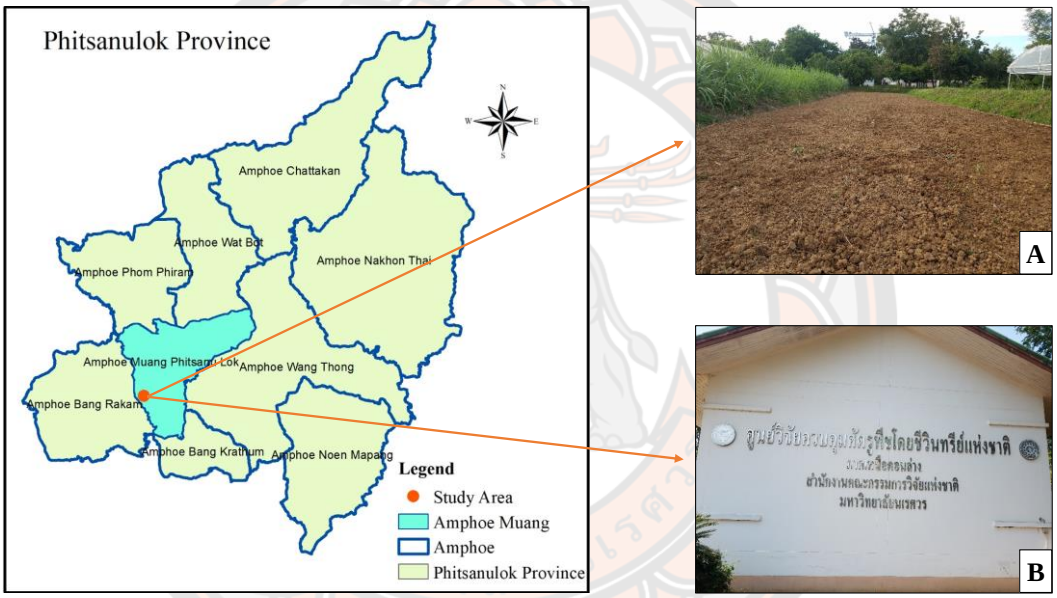

Figure 5 Naresuan University, Phitsanulok province, the experimental field (A) and the laboratory of the National Biological Control Research Center (B)

Biology and ecology of *Spodoptera frugiperda* on three maize cultivars

1. Stock culture of *Spodoptera frugiperda*

Late larval instar of *S. frugiperda* were originally collected from unsprayed maize field in the Phitsanulok area during March 2020. Larvae were placed in a 20.5 cm (L) x 15 cm (W) x 6.5 cm (H) plastic rearing containers with 10-20 larvae per container (Figure 6). The containers were kept in a controlled temperature room maintained at 30±2°C, 55±5% relative humidity (RH) with a light-dark 12L:12D of artificial photoperiod at NBCRC. Larvae were reared to the pupal stage on fresh green maize leaves. The pupae were transferred onto a paper napkin which was placed in a container, water was then added daily to moisten the paper until eclosion. At eclosion, adult moths were sorted by sex and released into insect breeding cages (30 x 20 x 30 cm) provided with nylon wire screen. These cages contained pieces of paper that

allowed the female to rest and to lay the eggs. Food was provided via a cotton plug saturated with honey and water mixture (1:9 v/v).

2. Biology and life table of *Spodoptera frugiperda* on three maize cultivars

The experiment was installed in a completely randomized design (CRD) to investigate the effects of 3 plant resources, field maize (Nakhon Sawan 3), sweet maize (Insee-2) and waxy maize (Pacifc-1) on insect biology (Figure 7). A single 1-day old *S. frugiperda* egg was placed individually in a clear plastic cup (7.9 cm (W) x 7.1 cm (D) x 5.8 cm (H)). For aeration, each cap of the experimental plastic cup was cut and a circular hole of 3 cm in diameter was made at the center and closed with a nylon mesh cloth. Upon hatching, the larva was fed on fresh maize leaves. The food was changed daily. Developmental stages were checked daily and developing insect was observed at each larval ecdysis. Four replicates were run sequentially for a total of 100 eggs tested at each maize cultivar. The experiment was continued until the death of all individual members of each cohort. To obtain sex ratio, a cohort life table was constructed with the heading proposed by Southwood and Henderson (2000). The initial l_x was based on the total number of 100 eggs. Statistical analysis of the data from this experiment was by one-way analysis of variance (ANOVA) and the F-test. It was followed by the Duncan Multiple Range Test (DMRT) to evaluate all possible pairs of treatment mean. All data were analyzed by R-statistics (version 3.6.1).

3. Reproductive rate and life table parameters of *Spodoptera frugiperda*

Three pairs of newly emerged male and female adults of *S. frugiperda* were used to collect innate capacity and finite rate of increase data on field maize, sweet maize and waxy maize cultivars with 3 replications on each maize cultivar respectively. Adult moths were less than 24 hours old. An oviposition cage (50 x 30 x 60 cm) covered with fine nylon mesh for ventilation was used to confine the insects. A clean cotton wick containing a 10% honey solution was placed in the cage to provide food for adults. A 3-week old maize plant was added to the cage on which the females lay their eggs. Moths were introduced into the cage and left for 24 hours. The plant provided for oviposition was replaced daily and the number of eggs laid by each female on subsequent days recorded. The observation on fecundity was made daily from the day after emergence up to the last female died. As the sex ratio was 1:1, the number of eggs obtained per female was divided by two to get the number of female birth (m_x). To obtain the fertility rate, deposited eggs produced on each maize cultivar were maintained until the larvae emerged and the fertility rate of emerged larvae was determined. In this experiment it was assumed that the time interval (t) equals the cohort generation (T_c), the net reproductive rate (R_0) = $\Sigma l_x m_x$ equals the finite (geometric) rate of increase (λ) = e^{rc}. The mean cohort generation or the mean period elapsing between the birth of parents and the offspring's birth was estimated by dividing the log to the base e of R_0 by the innate capacity of population increase (r_c) = $\log_e R_0/T_c$, and T_c = $\Sigma l_x m_x.x/\Sigma l_x m_x$, where x is the age of *S. frugiperda* in days, l_x is the number of *S. frugiperda* surviving at the beginning age of 100, and m_x is the number of *S. frugiperda* female born per female in each age interval which assume a 50:50 sex ratio (Carey, 1993; Southwood & Henderson, 2000).

Figure 6 Stock culture of *Spodoptera frugiperda*

Figure 7 Experiment on biology and ecology of *Spodoptera frugiperda*, experimental layout (A) and data collection (B)

Population dynamics of *Spodoptera frugiperda* and its affecting factors on maize field trial

The experiment was conducted in the experimental field plot of the Faculty of Agriculture, Natural Resource and Environment, Naresuan University. The population dynamics of *S. frugiperda* was evaluated during the dry season (from October 2019 to February 2020) and the rainy season (from July to October 2020). The size of the field trial plot was 7 x 35 m (W x L) total area 245 m^2. The row spacing and between plant spacing were 0.7 and 0.5 m, respectively. The whole field trial was divided into 56 grids with a size of 1.4 x 2.5 m. Each grid consisted of 10 plants. The first and last maize row were not allowed on insect sampling to avoid any possible border effects (Figure 8).

The field was plowed by tractor three weeks before planting, then was harrowed one week before to obtain loose and crumbly by using steel hand harrow. All litters were removed when harrowing. The hybrid field maize seed, Nakhon Sawan 3, obtained from Nakon Sawan Field Crops Research Center was used for this experiment. Maize seeds were soaked in warm water (55-60°C) for 3 min to remove microbial pathogens. They were then washed with cold water and kept in a piece of cloth to germinate for 3 days. Direct seeding was done by dibbling 2-4 seeds per hill (about 3

kg seeds/rai). By the following day, maize seeds were planted in a plastic seedling tray for substitution. Seed germination was nearly 90% over the plot. The replacement was practiced after the maize seedling was 10 days old. Thinning out was also carried out to maintain 1 plant per hill (Figure 9). Fertilizer application was used following by the recommended rate of urea (46-0-0) at 28 kg/rai, diammonium phosphate (18-46-0) at 17 kg/rai and NPK (15-15-15) at 7 kg/rai. The fertilizer application was divided into 3 times. Firstly, 50% of urea and 100% of diammonium phosphate and NPK were used during the top-dressing. Secondly, 25% of urea was applied at 20-25 days after planting (DAP) and finally, 25% of urea were used at 40-45 DAP. Watering was carried out twice a day in the morning from 8 a.m. to 9 a.m. and in the evening from 3 p.m. to 4 p.m. by sprinkler irrigation. Weeds were removed from the field trial by handling every 2-4 weeks. All types of insecticides were not applied in the experiment (Murúa et al., 2006).

The population of *S. frugiperda* was sampled beginning approximately 12-14 DAP and continuously a 7-day interval until maize maturity following the methodologies describes by Harcourt (1961), Tollefson (1975), and Southwood and Henderson (2000). Fourteen grids were randomly selected for monitoring the presence of *S. frugiperda* between the hours 6 a.m. to 9 a.m. The collected eggs, larvae and pupae from the field were reared in a clear plastic cups as described above without food in a controlled temperature room (25±2°C, 75±5% RH, and 12L:12D), except for larva was fed with fresh maize leaves. They were maintained until the emergence of adult or parasitoids for identification followed the method of Riggin et al. (1993). On the field observation day, the total number of infested and un-infested plants per gird were observed (Figure 10). Abiotic factors, temperature, humidity and rainfall, during the experiment were obtained from the provincial weather station of the Thai Meteorological Department. The relationship of *S. frugiperda* population and abiotic factors was performed using Person's *r* correlation analyses. All analyses were conducted using R-statistics (Version 3.6.1). Mean yield per infested and un-infested plants, and the actual yield loss (ACT) were calculated by following Judenko's formula (1973); ACT = (a-b) x NAT while a = mean yield per un-infested plant, b = mean yield per infested plant and NAT = number of infested plant.

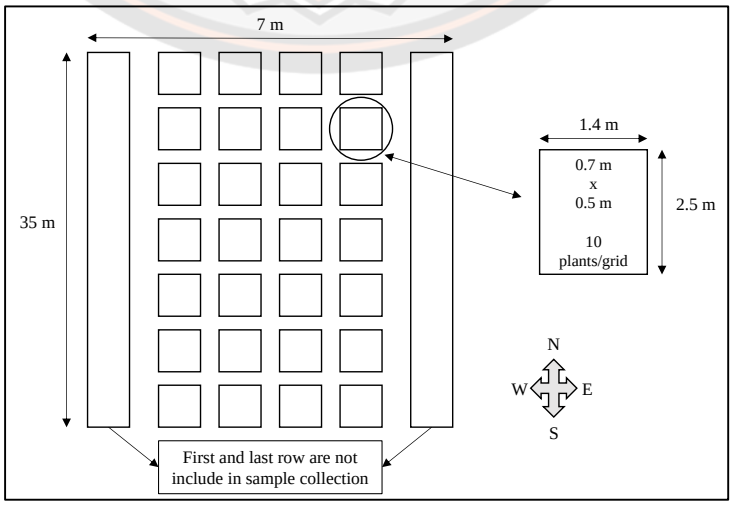

Figure 8 Experimental layout and the data sampling grid

Figure 9 Experiment on population dynamic of *Spodoptera frugiperda* in maize field trial

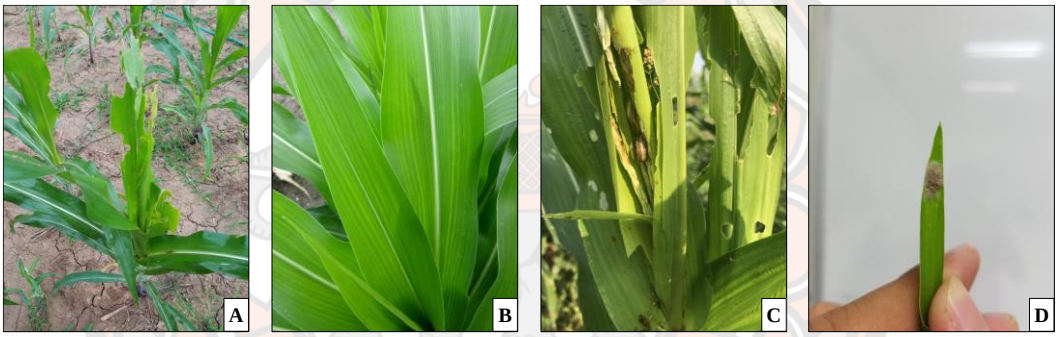

Figure 10 Field observation of *Spodoptera frugiperda* in maize field trial, infested plant (A), un-infested plant (B), *Spodoptera frugiperda* larva (C) and eggs (D)

Efficacy of selected insecticides and biopesticides against *Spodoptera frugiperda*

1. **Insect colony**

Late larval instar of *S. frugiperda* were originally collected from unsprayed maize field in Phitsanulok province during June 2020. Each larva was placed individually in a plastic rearing container (7.9 x 7.1 x 5.8 cm) with fresh maize leaves until the pupal stage. The containers were placed in the laboratory of NBCRC under the controlled conditions at 25±2°C, 75±5% RH, and 12L:12D. After adult emergence, adult moths were released into oviposition cage (30 x 20 x 30 cm) covered with nylon wire screen. The cage contained a piece of paper that allowed the females to rest and lay the eggs. Adults were provided a cotton soaked with honey and water (1:9 v/v) solution, which was replaced daily. After an oviposition period of 2-3 days, egg clusters were collected and placed in plastic containers (20.5 x 15 x 6.5 cm) covered with moist tissue paper. The emerged larvae were provided with tender and fresh maize leaves until the third larval instar for the experiments.

2. **Experimental procedure**

Commercial formulation of 12 insecticides and 3 biopesticides against third instar larvae of *S. frugiperda* in laboratory bioassay were benfuracarb (On-call

20%EC), carbosulfan (Marshal 20%EC), profenofos (Monja 50%EC), prothiofos (Tokuthion 50%EC), triazophos (Besti 40%EC), fipronil (Ascend 5%SC), etofenprox (Trebon 20%EC), lambda-cyhalothrin (Karate Zeon 2.5%SC), spinosad (Success 12%SC), emamectin benzoate (Proclaim 1.92%EC), chlorfenapyr (Rampage 10%SC), chlorantraniliprole (Prevathon 5.17%SC), and biopesticides including *Bacillus thringiensis* var. *aizawai* (Floorback F.C 8500 IU/mg SC), *Metarhizium anisopliae* (Metazan 1 x 10^9 cfu/gm WP), and *Beauveria bassiana* (Buverin 1 x 10^9 cfu/g WP). Each of the treatments was applied based on the manufacture's recommendation (Table 1).

Table 1 List of group insecticides and biopesticides, mode of action (MoA), active ingredient, trade name and recommendation rate

Group	MoA	Active ingredient	Trade name	Rate
carbamate	1A	benfuracarb	On-call 20%EC	30 ml
		carbosulfan	Marshal 20%EC	30 ml
organophosphate	1B	profenofos	Monja 50%EC	40 ml
		prothiofos	Tokuthion 50%EC	20 ml
		triazophos	Besti 40%EC	35 ml
phenylpyrazoles	2B	fipronil	Ascend 5%SC	10 ml
pyrethroid	3A	etofenprox	Trebon 20%EC	10 ml
		lambda-cyhalothrin	Karate Zeon 2.5%SC	30 ml
spinosyns	5	spinosad	Success 12%SC	30 ml
avermectins	6	emamectin benzoate	Proclaim 1.92%EC	12.5 ml
pyrroles	13	chlorfenapyr	Rampage 10%SC	20 ml
diamines	28	chlorantraniliprole	Prevathon 5.17%SC	35 ml
bacteria	11A	*Bacillus thuringiensis* var. *aizawai*	Floorback F.C	70 ml
fungi	UNF	*Metarhizium anisopliae*	Metazan	200 g
		Beauveria bassiana	Buverin	70 g

UNF = fungal agents of unknown MoA (IRAC, 2019)

Insecticides and biopesticides against *S. frugiperda* were tested by spraying methods. Approximately 60 g of maize leaves (3-5 pieces of 5-6 cm in length) were prepared and placed in a plastic container (17 x 11.5 x 5.5 cm) with a perforated lid using wire mesh to allow ventilation. Ten of the third instar larvae were released into each plastic container and rested for 30 min before applied insecticides to avoid overstress. Each plastic container containing larvae was sprayed separately with 1 ml of each insecticidal solution using a mini airbrush sprayer, while control larvae were sprayed distilled water (Figure 11). Newly fresh maize leaves were added daily.

The larvicidal bioassay was arranged in the CRD with four replications (Figure 12). Larva mortality was assessed after treatment application from 12 h until 7 d (B et al., 2020; Gunning, 1993; Paramasivam & Selvi, 2017; Terefe et al., 2004). A larva was considered dead when it was unable to claw by prodding with a fine paintbrush. The bioassay was repeated twice. Concerning the lagging of efficacy, the larvae treated with the biopesticides were continued rearing until the emergence of adults to estimate the survival. Larval mortality was corrected by Abbott's formula (1925) and subjected to ANOVA. DMRT was used to differentiate the mean among treatments at the 5% significance level. The median lethal time value (LT_{50}) was determined by logistic regression based on the method of probit analysis (Finney,

1952). All statistical analyzes were performed using R-statistics (Version 3.6.1) (R Core Team, 2019).

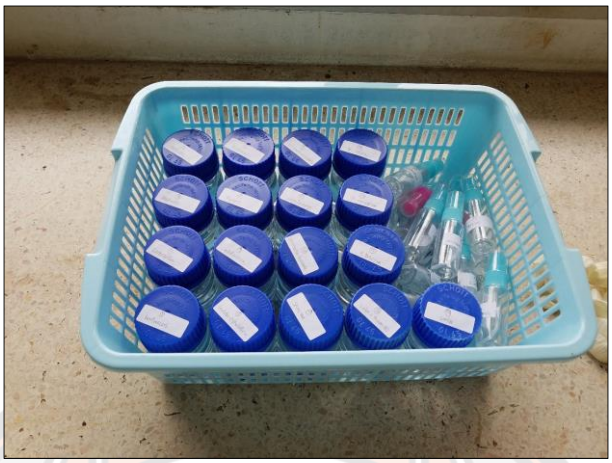

Figure 11 Selected insecticides and biopesticides solution for laboratory testing

Figure 12 Experimental layout of *Spodoptera frugiperda* bioassay

CHAPTER IV

RESULTS

Biology and ecology of *Spodoptera frugiperda* on three maize cultivars

In laboratory and under the established ambient conditions, the life cycle (egg to adult) of *S. frugiperda* lasts a mean of 28.11±0.40 days on field maize, 27.16±0.37 days on sweet maize, and 28.41±0.34 days on waxy maize (Table 2). However, there were not statistically differences among these means. Egg incubation period lasted 2.00±0.00, 2.03±0.02, and 2.02±0.01 days on field maize, sweet maize, and waxy maize respectively. The egg duration showed non-significant difference. Significant effects (P<0.05) of the host plant were found in the duration of larval stage 11.28±0.05, 10.83±0.14 and 11.15±0.15 days when fed with field maize, sweet maize, and waxy maize respectively. Significant differences (P<0.05) were found in the means duration of pupal stage 7.93±0.09 when fed on field maize, 7.57±0.09 on sweet maize and 8.24±0.09 days on waxy maize. The smallest duration both in the larval and pupal stages was observed with sweet maize. There was slightly different between sexes in development time of *S. frugiperda* fed on 3 different maize cultivars. Significant differences (P<0.05) were found only adult male life cycle. The smallest duration of male life cycle was observed with sweet maize.

Table 2 The duration of developmental stages (days) and sex obtained of *Spodoptera frugiperda* fed on three maize cultivars at 30±2ºC, 55±5% RH and a 12-hours photoperiod

Developmental Stage	Field maize[1/]		Sweet maize[1/]		Waxy maize[1/]	
	Mean±SE	Range	Mean±SE	Range	Mean±SE	Range
Egg	2.00±0.00^{ns}	2	2.03±0.02	2-3	2.02±0.01	2-3
Larval Instar:						
Instar I	2.08±0.05^{ns}	2-3	2.23±0.18	2-3	2.03±0.03	2-3
Instar II	1.64±0.22^{ns}	1-3	1.31±0.09	1-3	1.61±0.20	1-4
Instar III	1.52±0.13^{ns}	1-2	1.40±0.23	1-5	1.41±0.19	1-3
Instar IV	1.57±0.12^{ns}	1-3	1.51±0.17	1-3	1.64±0.28	1-4
Instar V	2.34±0.05^{ns}	1-4	2.31±0.15	1-3	2.11±0.13	1-3
Instar VI	2.14±0.06^{a}	2-3	2.07.0.01^{a}	2-4	2.35±0.07^{b}	1-4
Total larvae duration	11.28±0.05^{b}	10-16	10.83±0.14^{a}	9-14	11.15±0.15^{ab}	10-14
Pre-pupae	1.03±0.02^{ns}	1-2	1.04±0.02	1-2	1.09±0.04	1-2
Pupae	7.93±0.09^{b}	7-9	7.57±0.09^{a}	7-9	8.24±0.09^{c}	7-9
Adult:						
Male life cycle	28.26±0.39^{b}	24-32	26.90±0.37^{a}	25-31	28.61±0.30^{b}	25-32
Female life cycle	27.96±0.41^{ns}	24-32	27.42±0.36	24-31	28.21±0.38	22-32
Sexes:						
Male	7.25±2.02^{ns}		7.25±2.66		8.00±1.08	
Female	6.50±2.33^{ns}		7.75±1.25		9.75±2.21	

[1/]Treatment mean within a row not following by the same letter are significantly different (P<0.05, DMRT), ns: nonsignificant

Sequential examination of the development of the individuals revealed that the mortality of *S. frugiperda* occurred sequentially in the successive development stages on each host plant cultivars. The relatively high mortality rate experienced during the egg and the early stages of *S. frugiperda* but no mortality occurred on the fourth larval

instar. After completing through six molts, more than 70.5% of the larvae were transformed into pupal stage and the adult emergence percentages 89.06%, 85.71% and 92.31% were obtained from field maize, sweet maize and waxy maize respectively. Sex ratio (female:male) as the larvae reached the adult stage, varied between 0.83:1 when reared on field maize to 1.18:1 (F:M) for those reared on waxy maize. Larvae reared on sweet maize yielded a sex ratio of 1.07:1 (F:M). The results of this experiment are shown in Table 3.

Survivorship curve (l_x) analysis of *S. frugiperda* showed maximum mortality at older ages which having an age-specific survivorship curve type I (Deevey, 1947). The emergence of the first females was on the 20th day when larvae were reared on sweet maize and on the 21st day for those reared on the field and waxy maize. First egg-lay occurred on the third days after the emergence of females under all treatments tested. The females began to lay eggs in the age of 23.67±0.67, 24.67±0.33 and 25.00±0.58 days on sweet maize, field maize, and waxy maize cultivars, respectively. The life cycle (egg to adult) of *S. frugiperda* lasted 26 days on sweet maize, and 27 days in both the field and waxy maize. It was noted that females of all the treatments died approximately 5.5 days after their last oviposition (Figure 13).

Table 3 Partial ecological life table of *Spodoptera frugiperda* fed on three maize cultivars under controlled laboratory conditions

Developmental	**Field maize**				**Sweet maize**				**Waxy maize**			
Stage (X)	l_x	d_x	$100q_x$	S_x	l_x	d_x	$100q_x$	S_x	l_x	d_x	$100q_x$	S_x
Egg	100	15	15.00	85.00	100	19	19.00	81.00	100	7	7.00	93.00
Larval Instar:												
Instar I	85	7	8.24	91.76	81	6	7.41	92.59	93	6	6.45	93.55
Instar II	78	3	3.85	96.15	75	2	2.67	97.33	87	2	2.30	97.70
Instar III	75	10	13.33	86.67	73	0	0.00	100.00	85	4	4.71	95.29
Instar IV	65	0	0.00	100.00	73	0	0.00	100.00	81	0	0.00	100.00
Instar V	65	1	1.54	98.46	73	1	1.37	98.63	81	0	0.00	100.00
Instar VI	64	0	0.00	100.00	72	1	1.39	98.61	81	1	1.23	98.77
Pre-pupae	64	0	0.00	100.00	71	1	1.41	98.59	80	2	2.50	97.50
Pupae	64	7	10.94	89.06	70	10	14.29	85.71	78	6	7.69	92.31
Adult:	57				60				72			
Male	31				29				33			
Female	26				31				39			
Sex ratio												
Male	1				1				1			
Female	0.83				1.07				1.18			

l_x: Number of surviving at the beginning of X, d_x: Number of dying in stage, $100q_x$: Mortality rate, S_x: Survival rate in stage

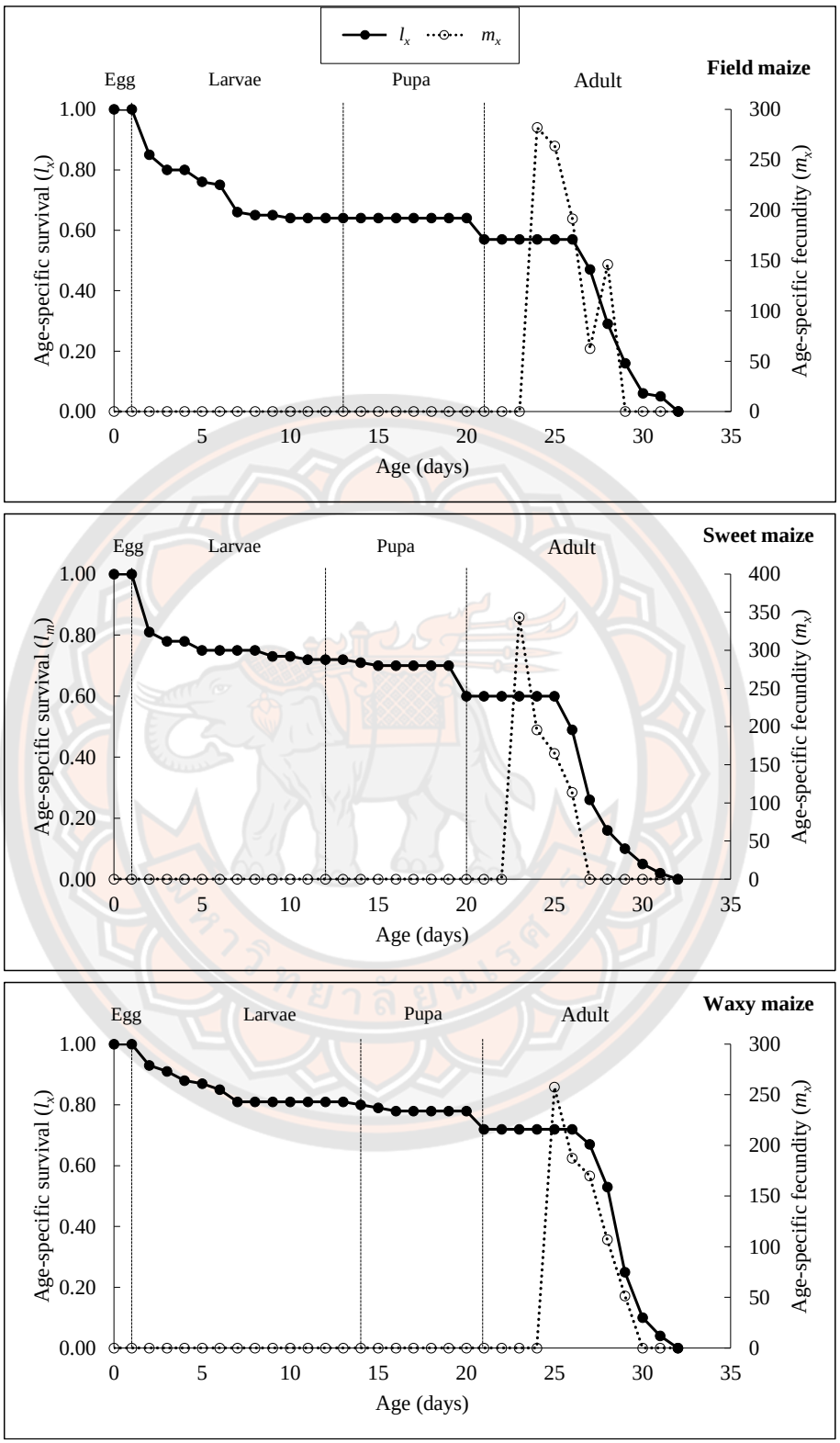

Figure 13 Age-specific survival (l_x) and age-specific fecundity (m_x) of *Spodoptera frugiperda* as larvae reared on three maize cultivars at 30±2ºC, 55±5% RH and a 12 h photoperiod

In all treatments, adult females lived slightly longer than males in spite of this the differences were not significant. The longest pre-oviposition period was found on field maize (3.33±0.33 days) while the longest oviposition period (4.00±0.00 days) was found on waxy maize. There was a significant effects (P<0.05) of host plant in the fecundity rate 1523.00±56.28 when fed on sweet maize, 1400.50±41.28 on field maize and 1238.00±69.28 on waxy maize, respectively. Significant differences (P<0.05) were also found in the oviposition rate. The highest number of eggs laid per female per day was observed with sweet maize. Besides, nearly 90% of egg hatching was collected from all maize cultivars (Table 4).

Table 4 Reproduction parameters of *Spodoptera frugiperda* reared on three maize cultivars under controlled laboratory conditions

Parameters	Maize cultivars[1/]		
	Field maize	Sweet maize	Waxy maize
Male longevity (days)	4.82±0.46^{ns}	4.71±0.42	4.53±0.52
Female longevity (days)	5.64±0.44^{ns}	6.13±0.35	5.35±0.43
Pre-oviposition period (days)	3.33±0.33^{ns}	2.67±0.67	2.67±0.33
Oviposition period (days)	3.33±0.33^{ns}	3.00±0.58	4.00±0.00
Fecundity (eggs/female)	1400.50±41.28^{ab}	1523.00±56.58^{a}	1238.00±69.28^{b}
Oviposition rate (egg/female/day)	405.50±21.65^{a}	440.13±20.14^{a}	309.50±17.32^{b}
Hatching rate (%)	91.06±3.47^{ns}	95.13±1.92	89.71±1.50

[1/]Treatment mean within a row not following by the same letter are significantly different (P<0.05, DMRT), ns: nonsignificant

The combined results of life table parameters of *S. frugiperda* mature females whose larvae were fed with field maize, sweet maize, and waxy maize were tabulated in Table 5. The highest net reproductive rate, R_0 (220.41±5.88), innate capacity of increase, r_c (0.23±0.001), and finite rate of increase, λ (1.25±0.002) were obtained on sweet maize. However, there was no significant difference between the values of these parameters on other maize cultivars. The mean age of females in a female offspring at birth or the mean cohort generation time, T_c (26.36±0.43 days) was significantly higher on waxy maize compared to field maize (25.25±0.49 days) and sweet maize (23.80±0.24 days). R_0 value was varied from 156.61 to 220.41 which was higher on sweet maize (220.41±5.88), but there was no significant difference compared to field maize (156.61±6.08) and waxy maize (189.18±35.81) respectively. The values of λ were 1.22±0.007, 1.25±0.002, and 1.22±0.013 obtained on field maize, sweet maize, and waxy maize were not found to be significantly different on these maize cultivars.

Table 5 Population growth parameters of *Spodoptera frugiperda* reared on three maize cultivars under controlled laboratory conditions

Parameters	Maize cultivars[1/]		
	Field maize	Sweet maize	Waxy maize
Net reproductive rate (R_0)	156.61±6.08^{ns}	220.41±5.88	189.18±35.81
Cohort generation time (T_c)	25.25±0.49^{ab}	23.80±0.24^{a}	26.36±0.43^{b}
Innate capacity of increase (r_c)	0.20±0.005^{ns}	0.23±0.001	0.20±0.011
Finite rate of increase (λ)	1.22±0.007^{ns}	1.25±0.002	1.22±0.013

[1/]Treatment mean within a row not following by the same letter are significantly different (P<0.05, DMRT), ns: nonsignificant

Population dynamics of *Spodoptera frugiperda* and its affecting factors on maize field trial

The population and the infestation of *S. frugiperda* observed on maize field trial were varied according to the seasons and maize growth stages (Figure 14).

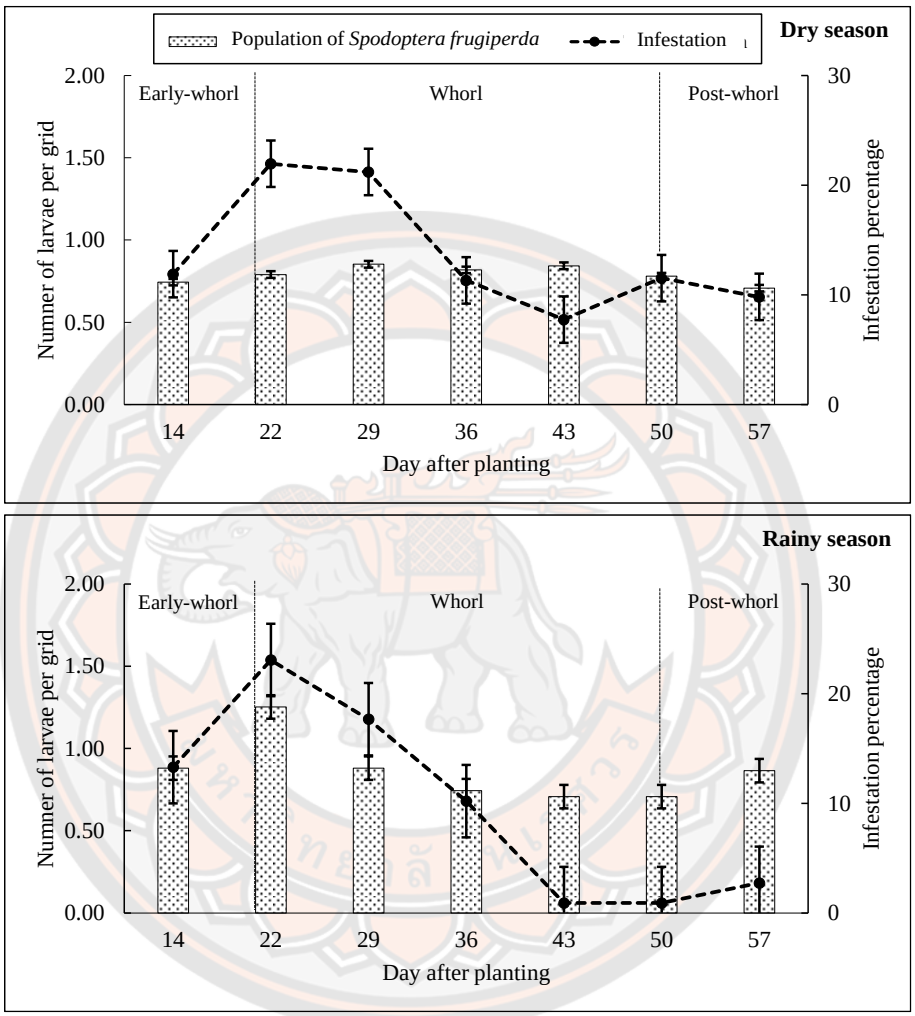

Figure 14 Population dynamics and infestation percentages of *Spodoptera frugiperda* in maize field trial during dry and rainy season

Approximately 980 maize plants were examined during dry and rainy seasons. In the dry season, the highest peak of *S. frugiperda* was observed during the whorl stage maize (0.85 larvae per grid), while the lowest number of *S. frugiperda* was observed during the post whorl stage maize (0.71 larvae per grid). The first detection of *S. frugiperda* was obtained since the early vegetative stage maize. The dominance of *S. frugiperda* (3-5 larvae) was found during vegetative stage (V6-V9) when the plants had 6 to 9 leaves. The highest percentage of *S. frugiperda* infestation (21.95±3.91%) was recorded during the whorl stage maize and the lowest percentage (7.47±2.60%) was recorded at the post whorl stage. The mean yield was approximately 5,695 kg per ha and the actual yield loss (ACT) caused by *S. frugiperda* was about 110 kg per ha (1.94%

of total yield) during the dry season. In the rainy season, the highest number (1.25 larvae per grid) and the lowest number (0.70 larvae per grid) of *S. frugiperda* were observed during the whorl and post whorl stage maize, respectively. However, less than three *S. frugiperda* larvae were found after maize beginning the reproductive stage. The highest percentage of *S. frugiperda* infestation was 23.06±3.75% during the whorl stage maize, while the lowest was 0.90% during the post whorl stage maize. During the rainy season, the mean yield and the ACT were 4,584 and 114 kg per ha (2.48% of total yield), respectively. Overall, a comparison of the population and the infestation of *S. frugiperda* between the dry and rainy seasons were no significant differences.

The biotic factors (natural enemies) have slightly influenced the variation of *S. frugiperda* population in the maize field trial. In the dry season, eighteen *S. frugiperda* larvae were collected and two parasitoid species were recovered, while in the rainy season, thirty-seven *S. frugiperda* larvae were collected and only one parasitoid species was obtained. Two species of parasitoid (*Chelonus* sp. and *Telenomus* sp.) were shown in Figure 15. *Chelonus* sp. is a larval parasitoid belonging to the family Scelionidae (Hymenoptera), while *Telenomus* sp. is an egg parasitoid belonging to the family Braconidae (Hymenoptera) (Figure 16-17). *Chelonus* sp. was caused 5.5 and 16.21% of total *S. frugiperda* parasitism in dry and rainy seasons, respectively. Moreover, significant correlation was recorded between *S. frugiperda* larvae and *Chelonus* sp. (*r* = 0.68) (Figure 18). On the other hand, *Telenomus* sp. (16.83%) was obtained from collected egg of *S. frugiperda* during the vegetative period in only the dry season.

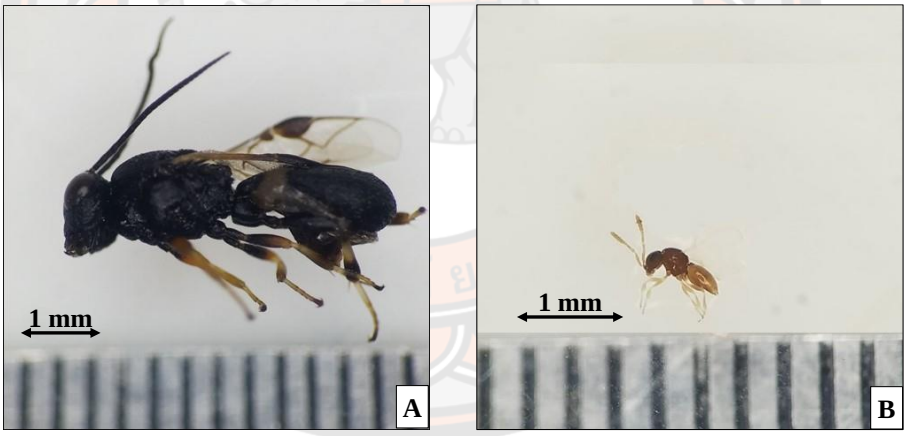

Figure 15 Parasitoids species recovered from maize field trial, *Chelonus* sp. (A) and *Telenomus* sp. (B)

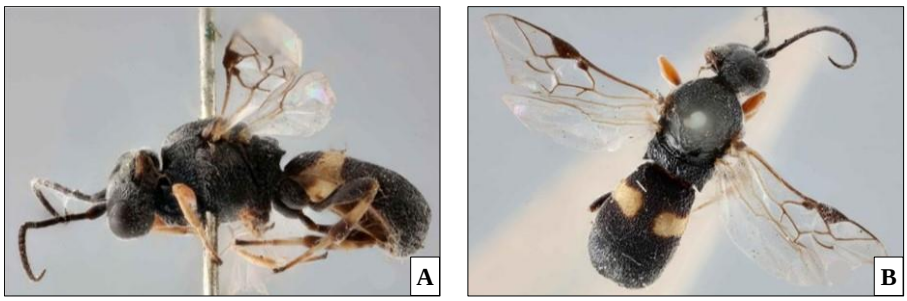

Figure 16 Diagnosis of *Chelonus formosanus* Sonan, female, India, front picture (A) and upper picture (B)

Source: Gupta et al., 2020

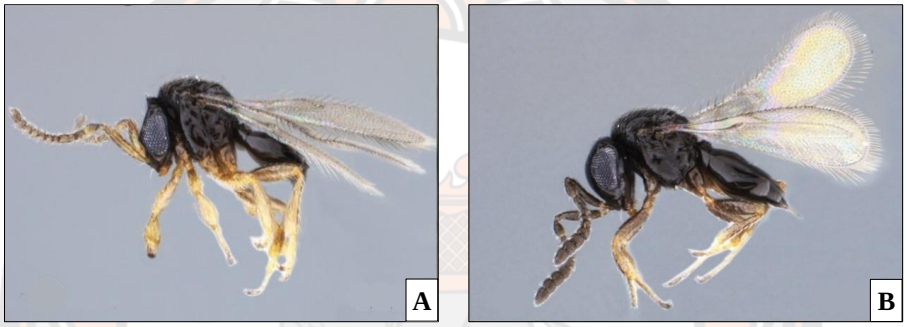

Figure 17 Diagnosis of *Telenomus remus* Nixon, China, male (A) and female (B)

Source: Liao et al., 2019

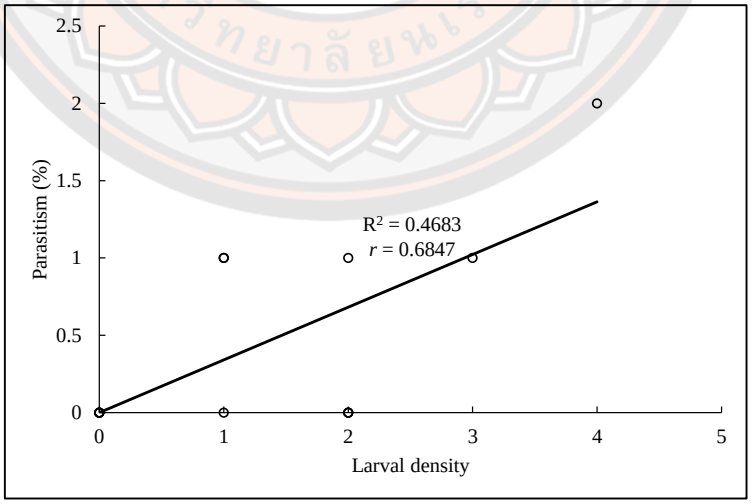

Figure 18 Correlation between *Spodoptera frugiperda* population and *Chelonus* sp. in maize field trial

The environmental parameters of the maize field trial as following: the average temperature, relative humidity and rainfall recorded during the dry season were ranged from 27.04°C, 54.21% RH and 0.43 mm, while during the rainy season were 26.81°C, 83.35% RH and 6.17 mm, respectively (Figure 19-21). The correlation analysis were shown in Table 6. In the dry season, there was a negative correlation recorded between the incidence of *S. frugiperda* and temperature (r = -0.48), relative humidity (r = -0.70) and rainfall (r = -0.39). In the rainy season, a negative correlation was recorded with temperature (r = -0.25) and rainfall (r = -0.02), except relative humidity (r = 0.35).

Table 6 Correlation coefficient (r) between incidences of *Spodoptera frugiperda* and abiotic factors during dry and rainy seasons in maize field trial

Season	Temperature (°C)	Relative humidity (%)	Rainfall (mm)
Dry	-0.48	-0.70	-0.39
Rainy	-0.25	0.35	-0.02

N = 7

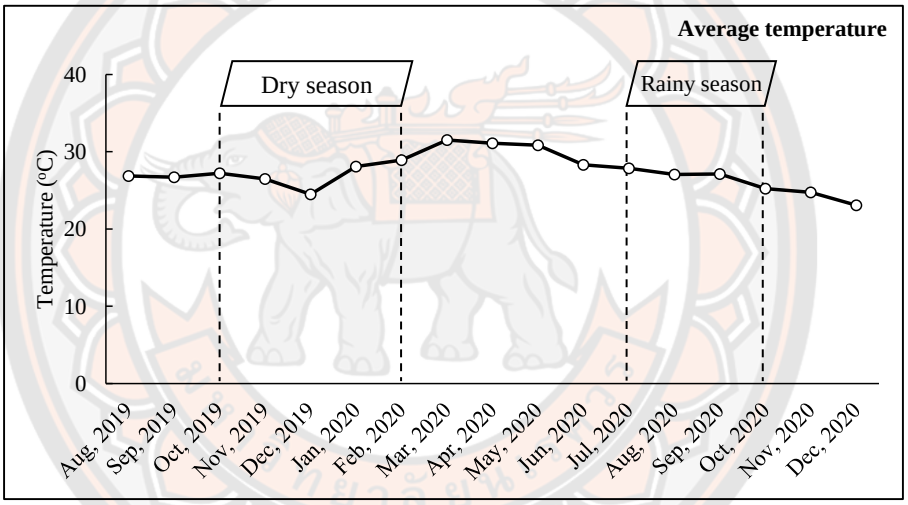

Figure 19 Average temperature in maize field trial during dry and rainy seasons

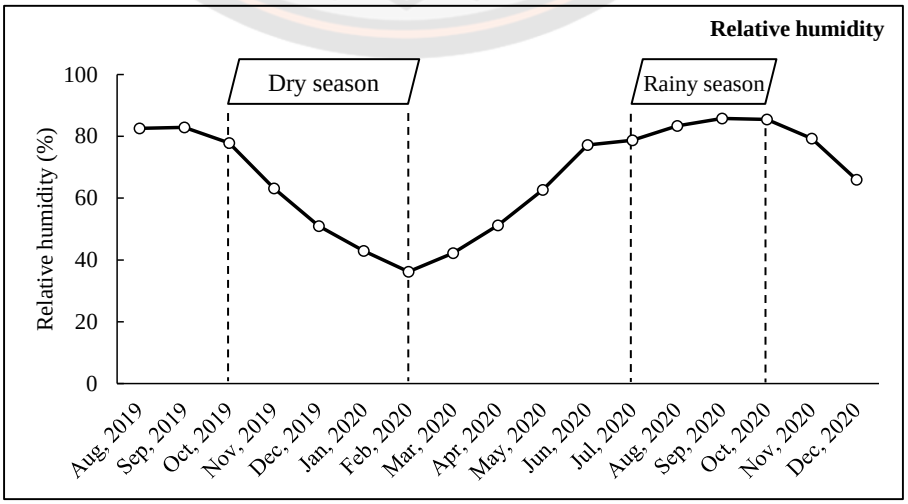

Figure 20 Relative humidity in maize field trial during dry and rainy seasons

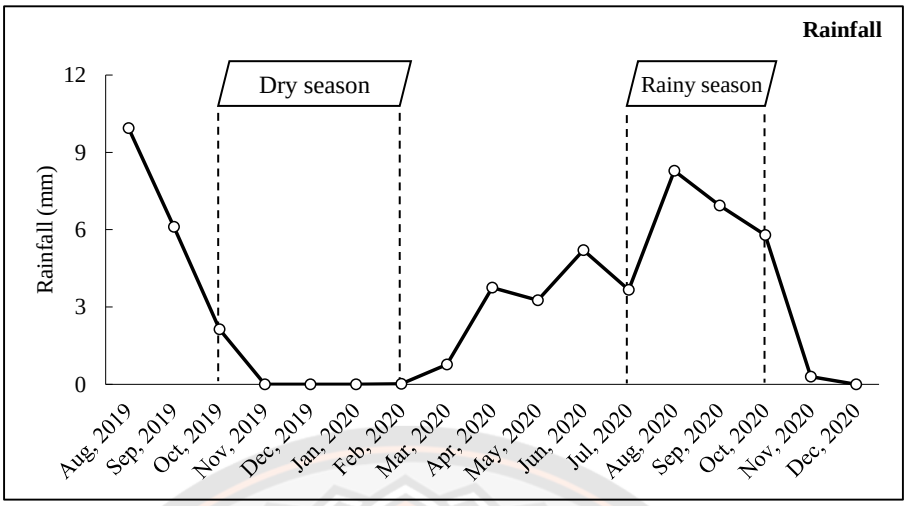

Figure 21 Rainfall in maize field trial during dry and rainy seasons

Efficacy of selected insecticides and biopesticides against *Spodoptera frugiperda*

The efficacy among selected insecticides and biopesticides tested on *S. frugiperda* larvae was significantly difference based on time assessment (Table 7). Spinosad caused the highest mortality of 94.64±2.70% at 12 h after treatment application and 100% mortality at 1 d after treatment application, followed by emamectin benzoate causing 58.70±6.04% mortality at 12 h after treatment application. Emamectin benzoate exhibited mortality of 91.25±2.62 and 100% after the treatment application of 1 and 2 d, respectively, while chlorantraniliprole caused mortality of 76.11±10.66% at 2 d and 100% at 3 d after treatment application. Meanwhile, moderate mortality was noted in chlorfenapyr and profenofos, causing 66.20±5.96 and 65.16±5.68% at 1 d after treatment application, respectively. On the other hand, fairly high mortality was also recorded in chlorfenapyr and profenofos, causing 83.33±5.12 and 75.61±4.65% at 7 d after treatment application, respectively. Larval morality assessed at 7 d after treatment application were 28.61±5.94% on lambda-cyhalothrin, 28.57±5.23% on etofenprox, 27.36±7.51% on fipronil, 26.44±4.32% on benfuracarb, 25.10±4.47% on prothiofos, 18.08±3.34% on triazophos, 15.83±4.41% on *B. thuringiensis* var. *aizawai*, 15.37±4.88% on carbosulfan, and 15.00±5.44% on *M. anisopliae* which not significantly different. *B. bassiana* was the lowest effective, causing 11.67±3.45% larval mortality after 7 d after treatment application. Concerning the lagging of efficacy of biopesticides (after treatment application approximately 25 d), the percentage of normal adult that emerged was significantly less than control. Percentages of adult emergence were 73.89±2.25, 75.40±4.12, and 75.83±4.94% when observed on *M. anisopliae*, *B. thuringiensis* var. *aizawai*, and *B. bassiana*, respectively (Figure 22).

Exposure of *S. frugiperda* to spinosad, emamectin benzoate, chlorfenapyr, profenofos, and chlorantraniliprole for 168 h result in LT_{50} value of 2.02, 10.73, 13.41, 16.40, and 33.75 h, respectively.

Table 7 Mortality of *Spodoptera frugiperda* larvae from 12 hours to 7 days after application of selected insecticides and biopesticides in laboratory testing

Treatment	Percentage larval mortality (±SE)[1/]							
	12h	1d	2d	3d	4d	5d	6d	7d
benfuracarb	9.51±4.55^{de}	11.63±5.03^{cd}	24.59±4.85^{c}	26.44±4.32^{c}	26.44±4.32^{cd}	26.44±4.32^{cd}	26.44±4.32^{c}	26.44±4.32^{c}
carbosulfan	6.20±3.71^{de}	7.04±3.67^{d}	12.87±4.99^{cdef}	15.37±4.88^{cd}	15.37±4.88^{cde}	15.37±4.88^{cde}	15.37±4.88^{cd}	15.37±4.88^{cd}
profenofos	34.87±5.89^{c}	65.16±5.68^{b}	71.09±5.06^{b}	71.92±5.40^{b}	74.78±4.81^{b}	75.61±4.65^{b}	75.61±4.65^{b}	75.61±4.65^{b}
prothiofos	1.77±1.11^{e}	9.27±2.85^{cd}	16.77±4.29^{cde}	21.77±4.36^{cd}	23.44±4.27^{cde}	23.44±4.27^{cde}	24.27±4.47^{cd}	25.10±4.47^{cd}
triazophos	2.60±1.29^{e}	3.44±1.40^{d}	11.32±2.03^{cdef}	15.48±3.14^{cd}	16.32±3.12^{cde}	17.24±3.40^{cde}	18.08±3.34^{cd}	18.08±3.34^{cd}
fipronil	1.88±1.27^{e}	6.23±2.44^{d}	17.69±4.85^{cde}	22.06±5.43^{cd}	22.06±5.43^{cde}	24.86±6.23^{cde}	27.36±7.51^{c}	27.36±7.51^{c}
etofenprox	8.10±1.90^{de}	8.93±2.47^{cd}	18.57±4.66^{cde}	26.07±4.56^{c}	28.57±5.23^{c}	28.57±5.23^{c}	28.57±5.23^{c}	28.57±5.23^{c}
lambda-cyhalothrin	16.57±5.77^{d}	18.33±5.56^{c}	21.76±5.78^{cd}	24.26±5.85^{cd}	25.09±5.99^{cde}	26.76±6.09^{cd}	27.69±5.94^{c}	28.61±5.94^{c}
spinosad	94.64±2.70^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}
emamectin benzoate	58.70±6.04^{b}	91.25±2.62^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}
chlorfenapyr	38.06±8.79^{c}	66.20±5.96^{b}	81.67±5.20^{b}	81.67±5.20^{b}	83.33±5.12^{b}	83.33±5.12^{b}	83.33±5.12^{b}	83.33±5.12^{b}
chlorantraniliprole	5.83±3.58^{de}	10.00±4.08^{cd}	76.11±10.66^{b}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}	100±0.00^{a}
Bacillus thuringiensis var. *aizawai*	3.61±2.06^{e}	6.30±2.52^{d}	10.56±2.74^{cdef}	14.91±4.38^{cd}	14.91±4.38^{de}	14.91±4.38^{cdef}	15.83±4.41^{cd}	15.83±4.41^{cd}
Metarhizium anisopliae	0.00±0.00^{e}	0.00±0.00^{d}	6.04±3.39^{ef}	14.17±5.57^{cde}	14.17±5.57^{def}	14.17±5.57^{def}	15.00±5.44^{cd}	15.00±5.44^{cd}
Beauveria bassiana	0.83±0.83^{e}	4.17±2.29^{d}	9.17±2.88^{def}	11.67±3.45^{de}	11.67±3.45^{ef}	11.67±3.45^{ef}	11.67±3.45^{de}	11.67±3.45^{de}
Control	0.00±0.00^{e}	0.00±0.00^{d}	1.01±1.01^{f}	2.02±2.02^{e}	2.02±2.02^{f}	2.02±2.02^{f}	2.02±2.02^{e}	2.02±2.02^{e}

[1/]Mean within a column with a similar letter are not significantly different (P<0.05, DMRT)

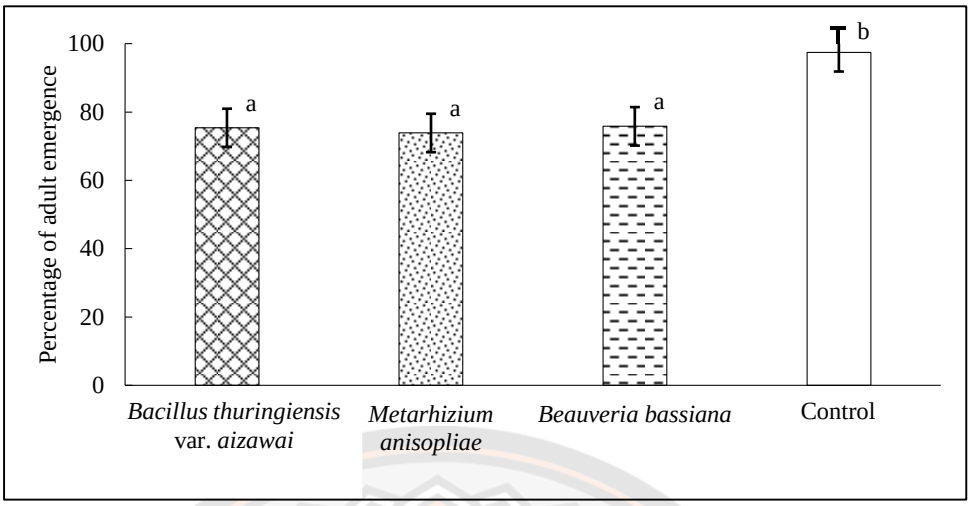

Figure 22 Adult of *Spodoptera frugiperda* emergence after treated larvae with biopesticides in laboratory testing

CHAPTER V
DISCUSSION AND CONCLUSION

Discussion

Host plant availability and quality may play an important role in the population dynamics of herbivorous insects by affecting immature development as well as adult performance. Shorter duration of immature and higher fecundity of adult females of herbivore insects on a host indicate greater suitability/susceptibility of a host crop. Based on the findings of this study, the maize cultivars had direct consequences on the development of immature stages (or instars) and some physiological fitness of *S. frugiperda* adult females. Our results represented the number of *S. frugiperda* larvae instar existed 6 larval instars when fed on all 3 maize cultivars (field maize, sweet maize and waxy maize). The shortest developmental duration was recorded on those larvae reared on sweet maize (10.83 days). Previous laboratory studies illustrated that the additional (seventh) larval instar was more common on female *Spodoptera* spp. e.g. *S. cosmioides*, *S. albula*, *S. eridania* and *S. dolichos* while reared on artificial diet (Montezano et al., 2016; Montezano et al., 2013; Montezano et al., 2014; Specht & Roque-Specht, 2016). However, there are some reports showed *S. frugiperda* has highly variable larval development due to different host plant, existing 5 larval instars when reared on sweet and field maize (Santos et al., 2003), 6 larval instars on maize leaves and artificial diet (Luginbill, 1928; Montezano et al., 2019) and from 7 up to 10 larval instars when reared on various wild grasses (Murúa & Virla, 2004; Pencoe & Martin, 1981, 1982). The variation of larval development could be due to unsuitable host-plant, diet nutrition as well as insect biological flexibility from different geographic which caused longer development (Esperk et al., 2007). The larval duration of *S. frugiperda* in our tests was ranged between 10.83 and 11.28 days, similar to those reported by Da Silva et al. (2017) reared on maize and oat and Du Plessis et al. (2020) reared on sweet maize stems and leaves. In a study conducted by Montezano et al. (2019) and Pinto et al. (2019), the larval duration fed on artificial diet were slightly longer than fed on natural diet.

The survivorship curve of *S. frugiperda* on all 3 maize cultivars in our study was considered as type I which most adults died at the older ages. A similar result had been reported for beet armyworm, *S. exigua* reared on 4 commercial sugar beet cultivars (Karimi-Malati et al., 2012). Although, most lepidopteran species had a high mortality rate in the early larval stage and tended to be survivorship curve type III (Zalucki et al., 2002), a well-fed insect in the laboratory probably caused a high survival rate until the end of its maximum life span, which indicated to type I curve (Hutchinson, 1978). The adult longevity from our study ranged between 5.42 and 4.94 days, which was fairly shorter than the study conducted by Bailey and Chada (1968) who found 7.5 days when fed on sorghum and artificial (wheat germ) diet. Pencoe and Martin (1982) reported *S. frugiperda* adult longevity was slightly long, which was 8.70, 9.10, 9.85, 10.45, and 10.70 days on bahiagrass, yellow nutsedge, large crabgrass, coastal bermudagrass, and goose grass, respectively. The pre-oviposition in our study was ranged from 2.67 and 3.33 days, which normally the adults of *S. frugiperda* started to oviposit after emerged 3 to 4 days (Capinera, 2001; Johnson, 1987; Sparks, 1979). *S. frugiperda* female has

shown an attractive to oviposit on maize plant rather than potato and tobacco (Guo et al., 2020). The oviposition period was ranged from 3.00 to 4.00 days, whereas the study conducted by Murúa and Virla (2004), the oviposition period was 8.5 to 11 days. The short period of oviposition probably due to high reproductive output in the early life stage which showed the cost of reproduction. The highest value of fecundity and oviposition rate in current study were recorded on sweet maize. Murúa and Virla (2004) was also showed similar value of fecundity while fed on maize. However, the fecundity of *S. frugiperda* was simply higher when fed on artificial diets (Pinto et al., 2019; Silva & Parra, 2013). Regarding the egg hatching of our study seemed to be higher than the study by Murúa et al. (2008), which found 76.81, 46.53, 49.04, 93.84 and 77.12 percentage of egg hatch on maize, alfalfa, soybean, wheat and weeds, respectively. The innate capacity of increase (r_c), the finite rate of increase (λ) and cohort generation time (T_c) were used to describe the population growth rate under the given growing conditions (Carey, 1993; Southwood & Henderson, 2000). The innate capacity of increase (r_c) was provided the potential of reproduction and used similarly as r_m, the intrinsic rate of natural increase (Laughlin, 1965). A high value of r_m indicated the susceptibility of a host plant to insect feeding (Naseri et al., 2009). According to our results, the highest values of r_c (0.23), λ (1.25) and the lowest T_c (23.80 days) were observed on sweet maize, suggested to be the most suitable for *S. frugiperda* population growth. On the contrary, waxy maize has provided lower values of r_c, λ and the highest T_c (26.36 days) shown the *S. frugiperda* population declined. Pinto et al. (2019) found the values of r_c (0.23) and λ (1.26), similar to results that we obtained in this study but fed on artificial diet. However, Guo et al. (2020) reported the r_c values were varied from 0.16, 0.07 and 0.03 on maize, potato and tobacco, respectively. The current net reproductive rate (R_0) value observed on 3 maize cultivars was similar to those reported by Guo et al. (2020) with a value of 248.35 on maize. The R_0 value present the number of time of a population multiple per generation (Southwood & Henderson, 2000). The variation of R_0 value was influenced by insect life history (established colonies or field collection) and the absence of natural enemies or other mortality factors (Birley, 1978; Murúa et al., 2008), which caused the value great in number. There are many other factors affecting *S. frugiperda* development including the nutrients provided to the host plant (Nascimento et al., 2018), the secondary substance of the host and the capability of digestion as well as absorption by the insect (Holtof et al., 2019). Moreover, the survival rate and fecundity of *S. frugiperda* can be affected by many environmental conditions, including temperature and humidity (Du Plessis et al., 2020; Simmons & Marti, 1992). Those information would provide the better understanding of the insect and could prepare the plan for controlling the insect pests.

The fluctuation of insect density possibly influences by crop phenology, natural enemies such as parasitoids, entomopathogen, and arthropod predators as well as the climatic conditions in the region. Based on our study, during the dry and rainy seasons the highest and lowest of *S. frugiperda* population were observed in the whorl stage and post whorl stage of maize, respectively. Beserra et al. (2002) illustrated that the variation of *S. frugiperda* distribution was related to the maize phenology, in which a higher number of *S. frugiperda* was collected at the early developmental stage maize. Barfield and Ashley (1987) also indicated that *S. frugiperda* larvae developmental period, food consumption, and adult longevity were changing frequently according to the difference of maize phenological development and temperature. Likewise, *S.*

frugiperda population was consistent throughout the developmental stage maize in the dry season. In contrast, the larval population during the rainy season was relatively high in the early whorl stage and remain lower in the later stage. Insect feeding behaviors may also effect to their density. For example, most of insect (larvae) was preferred to consume a younger leaves or a tender parts which caused the insect mobility. On the other hand, *S. frugiperda* has a cannibalism behavior (Capinera, 2001) which also caused population reduce. The study of Silvain and Hing (1985) revealed that the population of *S. frugiperda* moths and larvae found during the rainy season was higher than in the dry season, which consistent with our study. Murúa et al. (2006) reported that the fluctuation of the *S. frugiperda* population in the field was particularly affected by the difference in climatology among the localities. The reduction of *S. frugiperda* during the vegetative stage was probably the cause of rainfall. Varella et al. (2015) emphasized that higher mortality of the early *S. frugiperda* larvae (>95%) were recorded on the field study due to drowning and dislodgment by rainfall which the total mortality by those factors was irreplaceable. In this study, the infestation of *S. frugiperda* was risen during the early whorl stage and was gradually declined until the later stage in the dry season but seems to be higher in the rainy season. Similarity reports of the *S. frugiperda* infestation peak during the maize vegetative stage were indicated by Wyckhuys and O'Neil (2006) in Honduras and Murúa et al. (2006) from northwestern Argentina. Even though the correlation analysis between the *S. frugiperda* population and its abiotic factors obtained was negative correlation in both seasons, those factors possible indirectly influenced to the insect population. These results may contain various information of the fluctuation of *S. frugiperda* population on the field and the relationship with the abiotic factor which could improve time for monitoring and decide a better period for planting in order to avoid the infestation by this insect.

The diversity of parasitoids on *S. frugiperda* was reported from several studies and different regions such as America (Ashley, 1979; Luginbill, 1928), South America (Molina-Ochoa et al., 2003a), Africa (Prasanna et al., 2018) and India (Sisay et al., 2018). In the study, the Hymenopterans wasps, *Chelonus* sp. and *Telenomus* sp. were discovered. The *Chelonus* sp. was the major larval-pupal parasitoids of *S. frugiperda* and frequently found in the maize field in Argentina (Murúa et al., 2006; Murúa et al., 2009). *Chelonus insularis* occurrence has emphasized the importance and wide distribution throughout North and South America (Molina-Ochoa et al., 2003a; Molina-Ochoa et al., 2004; Molina-Ochoa et al., 2001). In addition, *C. insularis* was also reported to attack other Noctuidae species included *S. eridania*, *S. exigua*, *S. ornithogalli*, *S. praefica*, *H. zea*, etc. (Ruíz-Nájera et al., 2007). Besides that, *Telenomus remus* has been reported as the main egg parasitoid of *S. frugiperda* in the Americas and Caribbean basin (Molina-Ochoa et al., 2003a). Since the invasion of *S. frugiperda*, the presence of *T. remus* was reported in several counties such as East, South, and West Africa (Kenis et al., 2019), Ghana (Agboyi et al., 2020), South India (Shylesha et al., 2018) and in southern China (Liao et al., 2019). The positive relationship between the incidences of *S. frugiperda* population and the parasitoid may indicate by the seasonal climate, the effective of host population as well as the surrounding planting area which could attract the natural enemies. Several studies also reported the complex density of *S. frugiperda*'s parasitoid could be related to the farming environment and geographic altitude (Murúa et al., 2006; Wyckhuys & O'Neil, 2006). Considering the important of the natural enemies, conservation of those target

parasitoids and develop as biological control probably a great idea. However, this is a primary report of the parasitoids population obtain from *S. frugiperda* in the small-scale maize field in northern Thailand, which is a long-term monitoring and other location observations are necessary.

Among the synthetic insecticides that are currently sold on the market, the insect nerve-muscle system has been the most widely used, following by the insecticides which affected growth development and through the respiratory. Concerning the difference of MoA on insect targets, the duration of efficacy could be varied. Based on the results obtained, the selected insecticides and biopesticides tested on third instar larvae of *S. frugiperda* were toxic as well as some of the insecticides were indicated high mortality in a short period. Spinosad 12%SC was demonstrated the quickest and highest mortality followed by emamectin benzoate 1.92%EC and chlorantraniliprole 5.17%SC. According to Ujváry (2010), spinosad is a broad-spectrum insecticides that was isolated from soil bacterial organism and it was a mixture by two active components (spinosyn A and spinosyn D). Spinosad was highly effective by both contact poison and through ingestion (Hagstrum & Subramanyam, 2006) and it also has low toxicity to mammals, but slightly active to pollinator (Prasanna et al., 2018). Hardke et al. (2011) expressed that spinosad was significantly effective on *S. frugiperda* larvae through the diet bioassay with LC_{50} of 0.55 µg/ml, as well as Belay et al. (2012) indicated that spinosad caused more than 80% of mortality to third larval instar of *S. frugiperda* by spraying bioassay. On the other hand, emamectin benzoate is generally a white salt and is produced by the isolation of soil bacterium belonging to the family of the avermectins which used to control lepidopteran species in vegetable, cotton and tobacco (Stevens et al., 2010). According to Lewis et al. (2016), emamectin benzoate caused insect paralysis within hours of ingestion and it has slightly effective on aquatic life and pollinator (Prasanna et al., 2018). Adamczyk et al. (1999) stated the high effect of emamectin benzoate against the first larval instar of *S. frugiperda*, but appear to be less effective on the fifth larval instar in the field trial. In addition, Argentine et al. (2002) reported that emamectin benzoate was potentially effective on *S. frugiperda* in both diet incorporation and residual efficacy assay. Spinosad and emamectin benzoate were also effective on various lepidopteran species including *S. littoralis*, *S. exigusa* and *P. xylostella* (Argentine et al., 2002; Cook et al., 2004; El-Sheikh & El-Sayed, 2015; Kandil et al., 2019). On top of that, the insects exposed to chlorantraniliprole were shown muscle paralysis then followed by ultimately death (≥72 h) (Bentley et al., 2010). Several insecticides including chlorantraniliprole were required longer to reach higher mortality of *S. frugiperda* larvae as reported by Belay et al. (2012). The previous study demonstrated that higher mortality of *S. frugiperda* (>40%) was obtained after exposure to chlorantraniliprole (>28 days) in the field trial (Hardke et al., 2011). Deshmukh et al. (2020) indicated that chlorantraniliprole was highly effective on the field, but it expressed moderate in the laboratory against *S. frugiperda* in India. Moreover, chlorfenapyr 10%SC and profenofos 50%EC also showed a moderately high effective against *S. frugiperda*. Chlorfenapyr exhibited the potentially effective for controlling several lepidopteran species including *S. exigua* (Argentine et al., 2002). Even though profenofos was approved to control *S. frugiperda* in Africa, but it was only used for the emergence stage (Prasanna et al., 2018). Otherwise, benfuracarb 20%EC, carbosulfan 20%EC, prothiofos 50%EC, triazophos 40%EC, fipronil 5%SC, etofenprox 20%EC and lambda-cyhalothrin 2.5%SC from our study were showed less

efficacy on *S. frugiperda* larval mortality. For some reasons, *S. frugiperda* could develop their resistance to the insecticides from that group or required a higher concentration. In Florida, *S. frugiperda* was reported their high resistance to carbaryl and methyl-parathion which belong to insecticides class 1A and 1B (Yu et al., 2003). As well as in Southern America, *S. frugiperda* was less susceptible to various insecticides including chlorpyrifos, permethrin, methomyl and flubendiamide while most of them were in 1A group (Gutiérrez-Moreno et al., 2018). Although synthetic insecticides are very effective to control *S. frugiperda*, they also increase the risk to human as well as the insect develops their resistance to the major classes of insecticides (Rwomushana et al., 2018). Suggestion from those experiences, the resistance management such as routine monitoring of pests, choose proper insecticides to control at thresholds levels, rotation insecticides scheme with a different MoA, the combination of biological and cultural control as well as host plant resistance are essential to prevent and delay the infestation of *S. frugiperda*.

For biopesticides, *B. thuringiensis* var. *aizawai*, *M. anisopliae*, and *B. bassiana* showed slightly effective (less than 15%) against *S. frugiperda* larvae. Even biopesticides expressed less effective, yet *S. frugiperda* was susceptible to several entomopathogenic microorganisms (Molina-Ochoa et al., 2003b). According to B et al. (2020), natural isolations of *B. bassiana* were caused mortality on *S. frugiperda* at a second instar larvae ranged between 28.6 and 64.3%, while the effective of *M. anisopliae* was varied from 10.7 to 67.8%. Additionally, multiple applications of those two bio-pesticides on the field experiment were presented more than 65% reduction of *S. frugiperda* infestation. Romero Arenas et al. (2014) reported the commercial strain of *M. anisopliae* which was caused 32.5% of mortality on *S. frugiperda* larvae at 72 h and reduced 55% of the adult emergence. Although biopesticides provided a long-term effective, the screening of insecticides and biopesticides on the fields and greenhouses are also required to obtain more reliable results.

Conclusion

Based on the data obtained, each result has fully supported our objectives of the study. Firstly, *S. frugiperda* larvae are developed through six larval instars on all maize cultivars. The shortest immature developmental period is recorded on sweet maize. The life table showed that most of *S. frugiperda* is successfully developed from the egg to the adult. The *S. frugiperda* has a high rate of its survival until the end of life span, which is considered a survivorship type I. The value of reproduction and population growth parameters are varied depending on the host-plant. The highest values of reproduction and population growth are observed on sweet maize which is expressed the susceptibility of the cultivar to *S. frugiperda*. Secondly, the phenological development of maize and climatic conditions in the location was responsible for the fluctuation of the *S. frugiperda* population and the infestation. In both dry and rainy seasons, the highest peak of *S. frugiperda* population is observed during the whorl stage of maize, while the lowest is observed during the post whorl stage of maize. Similar result also found in the *S. frugiperda* infestation. Two species of parasitoids (*Chelonus* sp. and *Telenomus* sp.) are recovered from the maize field trial. The parasitism is the major influenced factor on *S. frugiperda* population, while the climatic conditions (temperature, humidity, and rainfall) are not associated with this pest abundance. Finally, among the selected insecticides and biopesticides screening on *S. frugiperda*

larvae, spinosad was indicated a significantly effective on larvae mortality followed by emamectin benzoate and chlorantraniliprole. On the other hand, the biopesticides tested are shown their potential on suppression of the adult emergence. In conclusion, this is the preliminary information of the newly invasive species, *S. frugiperda*, in Thailand. All information from this study do not only provide the fundamental knowledge of the insect but also contain the comprehensive guideline which could be used to improve the efficiency of management techniques for this critical crop pest. However, *S. frugiperda* has a particular feature relative to its host plant and the efficacy of the environmental condition, which causes our study still be limited. To better understanding and obtain more accurate results, hence, the insect-plant interaction, basic biochemical of the isolation and phytochemicals, and long-term surveillance studies with the combination management by implement on the field conditions, which adversely affect the built-up of *S. frugiperda*, are needful.

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