MONITORING RICE STEM BORER, *Chilo polychrysus* (LEPIDOPTERA: CRAMBIDAE) AND INSECTICIDAL ACTIVITY OF SELECTED INSECTICIDES

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by

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF PLATES

LIST OF SYMBOLS AND ABBREVIATION

MADA	Muda Agricultural Development Authority
PPK	Pertubuhan Peladang Kawasan
MARDI	Malaysian Agricultural Research and Development Institute
UKM	Universiti Kebangsaan Malaysia
RRSV	Rice ragged stunt virus
RGSV	Rice grassy stunt virus
RTSV	Rice tungro spherical virus
DH	Deadheart
WH	Whitehead
IPM	Integrated pest management
IRAC	Insecticide Resistance Action Committee
GABA	The ionotropic γ-aminobutyric acid
RDL	The genomic and cDNA sequences of insect
RyR	The ryanodine receptor
R1	Region 1
R2	Region 2
R3	Region 3
R4	Region 4
DAS	Days after sowing
DAT	Days after transplant
RH	Relative humidity
ANOVA	Analysis of variance
CRD	Complete Randomized Design
DMRT	Duncan's multiple range test
SE	Standard error
S1	Season 1
S2	Season 2
RH_{max}	Maximum RH
RH_{min}	Minimum RH
RH_{diff}	RH difference
T_{max}	Maximum temperature
T_{min}	Minimum temperature

T_{diff}	Temperature differences
TN1	Taichung Native 1
L	Length
W	Width
H	Height
l_x	Age-Specific Survivorship
N_x	The number of rice stem borer that were alive on day x
N_o	The starting number of rice stem borer in the population
S_x	Survival rate within stage
N_{x+1}	The number of individuals living at the next age from the N_x
e_x	Age specific life expectancy
T_x	Development life stage at time, x
L_x	Number alive between stage X and X+1
m_x	Fecundity
F_x	Total number of eggs
a_x	Total number of females
R_0	Net reproductive rate
$l_x m_x$	The number of eggs produced per original individual at each age
r_m	Intrinsic rate of natural increase
T	Generation time
λ	Finite rate of increase
t	Doubling time of population
S_x	The survival rate within the stage
X	developmental stage
d_x	number that died in stage X
$100q_x$	percent apparent mortality
T_x	total number of age X units beyond the age
X	developmental stage
ETL	The economic threshold level
IADA	Integrated Agricultural Development Area
C_1	Initial concentration
V_1	Initial volume
C_2	Final concentration

V_2	Final volume
SC	Suspension concentrate
WG	Wettable granule
a.i	Active ingredient
E_t	The insecticide efficacy
E_0	The initial efficacy at 24 hours
E_1	The insecticide efficacy at 48 hours
E_2	The insecticide efficacy at 72 hours
E_3	The insecticide efficacy at 96 hours
E_4	The insecticide efficacy at 120 hours
LI	Lethality index
LC_{50}	Lethal concentration
CI	Confidence interval
SAS	Statistical Analysis System
χ^2	Chi-squared value for the lethal concentration

LIST OF APPENDICES

PEMANTAUAN KE ATAS ULAT PENGOREK BATANG PADI, *Chilo polychrysus* (LEPIDOPTERA: CRAMBIDAE) DAN AKTIVITI INSEKTISID TERPILIH.

ABSTRAK

Pemantauan kesan insektisid ke atas ulat pengorek batang padi dijalankan dengan melihat kelimpahan dan serangan ulat batang di kawasan MADA, membina jadual perkembangan hidup *Chilo polychrysus* di rumah kaca dan untuk menentukan keberkesanan insektisid terpilih terhadap *Chilo polychrysus* di rumah kaca. Dapatan kajian menunjukkan Wilayah 3 (Hutan Kampung, Tajar dan Pendang) adalah yang paling banyak diserang ulat pengorek batang padi diikuti oleh Wilayah 4, Wilayah 2 dan Wilayah 1. Di antara tiga daerah yang dinilai di Wilayah 3, daerah Pendang diserang ulat pengorek batang padi tertinggi iaitu di lokasi Pendang B dengan 20.53% serangan. Musim 1 (November hingga Februari) mencatatkan serangan tertinggi di peringkat vegetatif padi dengan 30.83% simptom 'mati anak'. Ulat pengorek batang padi diperhatikan menyerang secara optimum apabila nilai RH_{max} lebih rendah (80.0%), T_{max} lebih tinggi (32.8°C) dan jumlah curahan hujan yang lebih rendah (0.6mm). Tiga spesies dijumpai di keempat-empat wilayah di MADA iaitu *Chilo polychrysus* (ulat pengorek batang berkepala hitam), *Sesamia inferens* (ulat pengorek batang merah jambu) dan *Scripophaga incertulas* (ulat pengorek batang kuning). Sebelum ini, *Chilo polychrysus* (ulat pengorek batang berkepala hitam) hanya dilaporkan sebagai spesies ulat pengorek batang padi yang minor di Malaysia namun kini telah menjadi salah satu spesies ulat batang yang major dalam kajian ini iaitu di Wilayah 1. Untuk lebih memahami biologi ulat pengorek batang

padi, satu 'Jadual perkembangan hidup' telah dibina dan didapati purata satu kitaran hidup *C. polychrysus* adalah 49 hari. Lekuk kemandirian *C. polychrysus* adalah menghampiri Jenis - III iaitu kadar kematian yang sederhana diawal kehidupan dan penurunan secara beransur-ansur ketika mendekati tahap dewasa. Keputusan mendapati bahawa 13.01% telur *C. polychrysus* rosak, dengan purata kadar pembiakan bersih (R_0) adalah 34.59. *C. polychrysus* mempunyai kadar kenaikan intrinsik semulajadi (r_m) dan kadar kenaikan terhingga harian (λ) masing-masing adalah 0.0775 dan 1.0805 ekor ulat betina setiap hari, dengan min masa penjanaan (T_c) adalah 45.75 hari. Masa penggandaan untuk *C. polychrysus* (R_0) ialah 8.95 iaitu populasi meningkat dengan faktor 9. Demografi data jadual hidup *C. polychrysus* memberikan gambaran tindak balas ulat pengorek batang terhadap racun serangga terpilih. Dari kajian ini, *C. polychrysus* berkesan dikawal menggunakan racun serangga dengan bahan aktif fipronil, flubendiamide dan chlorantraniliprole dengan 100% kematian. Dalam kajian ini fipronil menunjukkan prestasi yang paling baik dalam kebanyakan analisis dengan keberkesanan racun serangga (Et) sebanyak 87.5%, keberkesanan akhir terpantas (72 jam), indeks kematian tertinggi (LI), iaitu sebanyak 96.7% dan paling toksik dengan kesan ketoksikan terendah, (LC_{50} = 16.12 mg/L. Walau bagaimanapun, chlorantraniliprole juga terbukti berkesan untuk mengawal *C. polychrysus* tetapi dengan keberkesanan awal sederhana (E_0 = 21.67 %), keberkesanan akhir (E_t = 120h) dan sederhana dalam indeks kematian (LI = 70.33%) dan nilai ketoksikan (LC_{50} = 43.78 mg/L). Flubendiamide diperhatikan memerlukan masa yang lebih lama dalam mengendalikan *C. polychrysus* berdasarkan keberkesanan awalnya yang rendah (E_0 =15.83%), kurang toksik dan sederhana pada hasil keberkesanan akhir (E_t = 96h) dan indeks kematian (LI = 72.17%). Sebagai kesimpulan, serangan ulat pengorek batang padi yang semakin meningkat di lapangan adalah mungkin disebabkan oleh peningkatan kerintangan terhadap racun serangga tersebut; kerana populasi yang rentan di rumah kaca memberi respons positif terhadap racun serangga tersebut.

MONITORING RICE STEM BORER, *Chilo polychrysus* (LEPIDOPTERA: CRAMBIDAE) AND INSECTICIDAL ACTIVITY OF SELECTED INSECTICIDES

ABSTRACT

Monitoring of rice stem borer insecticidal activity has been initiated by studying the abundance and infestation level of rice stem borer in MADA area, constructing the life table of *Chilo polychrysus* and determining the insecticdal efficacy of selected commercial insecticides towards *C. polychrysus* in the glasshouse. The study revealed that Region 3 (Hutan Kampung, Tajar and Pendang) was the most highly infested by rice stem borer followed by Region 4, Region 2 and Region 1. Among the three districts evaluated in Region 3, Pendang suffered the highest rice stem borer infestation at specific location, Pendang B with 20.53% of infestation. Season one (November to February) recorded the greatest infestation during the vegetative stage of the rice plant with 30.83% of dead heart. The rice stem borer was observed to infest at optimum level with lower value of RH_{max} (80.0%), higher T_{diff} (32.8^{o}C) and lower amount of rainfall (0.6mm). Three species were found at all four regions in MADA and that were *Chilo polychrysus* (black-headed stem borer), *Sesamia inferens* (pink stem borer) and *Scripophaga incertulas* (yellow stem borer). *Chilo polychrysus* (black-headed stem borer) was once a predominant species of rice stem borer in Malaysia and have became dominant in this study at Region 1. To further understand the biology of the rice stem borer, a life table has been constructed and the total development time of this insect was 49 days in

average. The survival curve showed a near-type III survival curve, a modest rate of early life mortality and a gradual decline as it approached adult stage. It was discovered that 13.01% of *C. polychrysus* eggs died, with a mean net reproductive rate (R_o) of 34.59. *C. polychrysus* had an intrinsic rate of natural increase (r_m) of 0.0775 female offspring per day and a daily finite rate of increase (λ) of 1.0805 female offspring per female per day, with a mean generation time (T_c) of 45.75 days. The doubling time for *C. polychrysus* (R_o) was 8.95; the population increased by a factor of 9. The demographics of *C. polychrysus* life table data provided the insight for the insecticidal activity respond by the stem borer. The susceptible populations of the *C. polychrysus* were effectively controlled by fipronil, flubendiamide and chlorantraniliprole with 100% of mortality. In this study fipronil showed the most excellent performance in most of the analysis with insecticide efficacy (E_t) 87.5%, fastest final efficacy (72 hours), highest lethality index (LI), 96.7% and most toxic with the lowest toxicity effect, 16.12 mg/L. However, chlorantraniliprole also was proven effectively to control the *C. polychrysus* but with moderate initial efficacy (E_0), final efficacy (E_t) and moderate in lethality index (LI) and toxicity value (LC_{50}). Flubendiamide was observed to take longer time in controlling the *C. polychrysus*, *C. polychrysus* based on its low initial efficacy (E_0), less toxic and moderate in the final efficacy (E_t) and lethality index (LI) results. To conclude, the increasing of rice stem borer infestation in the field might be due to the development of insecticide resistance in the stem borer because the susceptible populations respond positively to the insecticides.

CHAPTER 1

GENERAL INTRODUCTION

Rice stem borer is an important insect pest of rice in Malaysia and some other countries in Asia and Europe (Sardesai, 2001). It infests rice plants from the seedling stage to maturity and may cause deadhearts and whitehead during the vegetative and reproductive stages, respectively (Baloch *et al*., 2011). Losses caused by rice stem borer can lead up to 20% at early stage and 80% at late stage (Dhaliwal *et al*., 2010). This infestation can reduce the yield significantly and in addition can increase the cost production. Previous study reported that there were five species of rice stem borers identified in Sarawak and only four major species of rice stem borers were found in Peninsular Malaysia. One of the rice stem borer found in Malaysia is *Chilo polychrysus,* the black headed stem borer and one of the important pest of rice in Malaysia (Othman *et al*., 2008). The population of *C. polychrysus* is increasing year by year and is spreading all over the country recently.

Malaysia, located in the equator experienced hot and humid climate along the year. The climate of peninsular Malaysia is directly affected by wind from the mainland therefore, peninsular Malaysia faces two monsoon seasons. This changes contribute to the fluctuation of rainfall, temperature, relative humidity and large drought. All these factors plays important role to the insect pest as well. Infestation of insect pest in the field can be various including field conditions such as the meteorological condition. The field condition is not the only effect on the percentage of infestation, but also contribute to the species distribution of the insect especially the rice stem borer. Rice stem borer as the cold-blooded organism depends too much on temperature (Narayanasamy, 2013). The changes in the degree of temperature influenced the increasing of the severity of rice stem borer infestation and species preference. *Chilo suppressalis* for example is one of the major stem borer in most temperate and subtropical Asia, but in other countries the importance of the pest were declining. *Sesamia inferens,* the pink stem borer can be found in upland and near to the area with cereals and sugarcane plantation not only in paddy fields. The presence of the alternate host encourage the pink stem borer to multiply and survived in winter and dry season (Pathak, 1994). On the other hand, *Scirpophaga incertulas*, the yellow stem borer is a monophagous pest of paddy and considered as most important pest of rain fed low land and flood prone paddy eco-systems (Deka, 2020).

To understand the insect population distribution and dispersal, construction of life table of *C. polychrysus* as the basic reference was indispensable (San San, 2011). The life table study could provide the basic biology of the *C. polychrysus.* It revealed the life cycle, the number of eggs laid, larvae survivality, fecundity of the adult moth and the sex ratio of *C. polychrysus*. This information enhanced the understanding of the biology of the insect pest and can be useful in manipulating the control method of the pest (Kakde *et al*., 2004).

The increasing symptom of the stem borer infestation require an effective management. Managing rice stem borer include biological, cultural, mechanical and chemical control. Management practice to control the rice stem borer is mostly by using chemical substances as the control agents. Most countries in the world such as Taiwan (Cheng, 2010), Korea (Hong, 2009), and China (Li, 2007) used several insecticides to control the stem borer. Malaysia not to left behind, used chlorantraniliprole widely besides fipronil, chlorpyrifos, cartap and fethion in controlling this pest. However, some reports complaint that the insecticides applied were less effective to control rice stem borer at a high infestation level. However, the occurrence of ineffective control of insecticide such as carbofuran in Chiayi and Changhua, China to the rice stem borer was detected due to high resistance level (Cheng, 2010). In Taiwan, two species of rice stem borers were less sensitive to chlorpyrifos and carbofuran therefore they were not effective to control the borers (Li, 2011). In addition, Mansoor *et al*. (2019) found that pink stem borer, *Sesamia inferens* (Walker) had become resistance to fipronil in Pakistan. Hence, as initiative for insecticide resistance monitoring study for rice stem borer, this study was conducted to verify the efficacy of selected insecticides in controlling the rice stem borer in a glasshouse by using seedling-dip technique.

Keeping the above facts in view, the present investigation on *C. polychrysus* response to selected insecticides were carried out, following these objectives:

1. To study the abundance and infestation level of rice stem borer in MADA areas.
2. To construct a life table of *C. polychrysus* in glasshouse condition.
3. To determine the insecticidal efficacy of selected commercial insecticides towards *C. polychrysus* in glasshouse.

CHAPTER 2

LITERATURE REVIEW

2.1 Paddy cultivation in granary area of Malaysia

Most of the world's population eat rice as the staple food in daily routines. Rice cultivation is predominately origin in Asia and contributes to 90% of rice production in the world. However, only 7% of total rice production is exported from the country of origin (Rice Almanac, 2013). Because of that, rice and paddy become an ultimate role in food security, sosio-culture and influence in government policies, decision and strategy in most of the developing countries (Omar *et al*., 2019).

In Malaysia, paddy plants are widely planted in both granary and non-granary area. The granary areas or called 'Jelapang padi' refer to major irrigation schemes (areas greater than 4,000 hectares) and recognized by the Government in the National Agricultural Policy as the main paddy producing areas (Shah, 2019). The granary areas covered approximete 75% from total planted areas with a coverage of 214 015 hactares and are managed by government agencies including Muda Agricultural Development Authority (MADA). The MADA granary area is the largest paddy plantation area in Peninsula Malaysia. It comprises 47% of the total area of the granary and is managed by a sub-unit organisation called Pertubuhan Peladang Kawasan (PPK) where farmers' activities and technologies are transferred (MADA, 2021). Malaysia's paddy granaries are regarded as the country's rice bowl and source of food security. The establishment of the granary area as the wetland for paddy plantation specifically (Government of Malaysia, 1984) was a strategic intervention to support the development of the paddy and rice sectors while also ensuring the food security of the country.

Paddy is one of Malaysia's most important crops. End product of paddy, the white rice, is consumed by Malaysian adults for 2.5 plates per day on average (Kasim *et al*., 2018). It is not only serves as a staple food for the community, but the high consumption provides a source of income for small-scale farmers who are the landowners, tenants or agricultural workers (Bishwajit, 2015). Because of that, the paddy cultivation required a high rice yield production to fulfill the demand. There are many efforts to increase the paddy productions, which included the breeding of good rice varieties, the best agronomic practices, effective pest and disease management and reduced post harvest losses (Omar *et al*., 2019).

Until February 2021, Bernama reported that two more rice varieties are launched by MARDI giving a total of 52 rice varieties had been launched in Malaysia since 1970 (Bernama, 2021). The newly launched rice varieties are MR315 (Seri Waja) with characteristic of high yield production, which can reach nine tonnes per hactares and MRQ104 (Kembang Sari), an aromatic rice that has moderate tolerance to rice disease (Nur Izzati, 2021). Other than MARDI, UKM also contribute two rice varieties to the rice industry in Malaysia which are UKMRC-2 and UKMRC-8. Both rice varieties are bred from wild type of rice (*Oryza rufipogon*) and local premium variety (*Oryza sativa*) that are potentially to reach 12 tonnes per hectares (Asmahanim, 2018).

Malaysia is located near to the equator and the climate is known as equatorial, tropical rainforest, or wet-humid tropical, with a fairly consistent average daily temperature (Jamaluddin *et al*., 2015). The mean annual temperature variability varies from 26°C to 28°C. Due to minor temperature fluctuations, the trends in rainfall significantly determine seasonal shifts in weather conditions. Such rainfall fluctuations are closely linked to monsoon winds blowing at various times of the year in Peninsular Malaysia (Firdaus, 2020). The warm climates are ideal for the rice cultivation and appropriate for the year round cultivation of rice. However, most farmers plant and harvest rice more or less during the same period (Negin, 2016). Generally, paddy are planted twice (in two rice planting seasons) a year in Malaysia. In most granary area especially MADA, rice planting season one (Season 1) take place on Mac until August and rice planting season two (Season 2) occurs between September to February (MADA, 2021). In both seasons, there are four key activities involved which are the land preparation, crop establishment, crop management and harvesting (Siti Rahyla, 2019). Most paddy plantation are using direct seeding technique which is a method of introducing rice seed into the soil by manually broadcasting pre-germinated rice seed or using a row seeder (Singh, 2008). Another method of paddy plantation is by transplant, which is done by manually planting 25-35 day old seedlings into the main field or using a mechanical transplanter with seedlings sown on trays (Pasuquin, 2008). The paddy cultivation activities in MADA area for season one and season two are according to the MADA Paddy Cultivation schedule that has been set by the MADA Level Water Supply and Paddy Planting Committee Meeting (MJBAPP). Irrigation and water supply to the rice field were organised in three phases so that farmers could begin sowing or planting rice as soon as the water supply was ready.

There are two main phases of paddy plant development, the vegetative and reproductive phases. Germination, tiller initiation, early tillering, and mid tillering are all part of the vegetative phase, while panicle initiation and heading are part of the reproductive phase (Linscombe, 2012). Rice varieties can be classified into two groups which are short-period varieties which mature in 105–120 days, and long-period varieties which mature in 150 days (Won, 2020). In the tropical climate, the

120-day variety spends approximately 60 days in the vegetative process, 30 days in the reproductive phase and 30 days in the pre-harvesting phase. The information on the paddy development phases is important to manage the agronomic part and pest menagement to produce a high quantity of rice grain with good quality.

2.2 Insect abundance and diversity in paddy cultivation

In rice cultivation, the abundance and diversity of insects play a significant role. The species richness of insects for example the order lepidoptera (Karsholt and Razowski, 1996) provides an extraordinarily thorough insight of the site's environmental conditions. Hundreds of insect species occupy these rice ecosystems, serving a range of ecological functions (such as pest, predation and pollination) (Heong, 2011). The presence of each parties in equilibrium is crucial since an absence of certain from each side would result in an imbalanced ecosystem, which can harm rice production. However, the dynamics of pests and natural enemies in the area can be influenced by the crop management such as the extensive use of chemical fertilizers and pesticides which in return frequently disrupted the equilibrium (Bottrell, 2012). Other than that, the abundance of insect pests and natural enemies is also influenced by different growth stages of rice plant and neighboring crops (Mukherjee, 2017).

In Malaysia, rice fields are mostly monoculture, and a lack of ecological variety may be a major cause of pest issues since the food, hosts, prey and habitats of most pests' natural enemies are decreased, reducing natural biological control. Modern agricultural systems based on internal monoculture also discriminate and limit the activity of predatory insects because of the lack of ecological diversity (Hagen & Hale 1974). Continuous rice cultivation has produced a favourable environment for insect pests. Furthermore, the warm and humid climate of peninsular

Malaysia has favoured the rapid multiplication of insect pests and diseases (Khan, 2013). The shift of the abundance of the pest to other localities also could affects the ecosystem and contribute to outbreaks. The future habitat suitability can be predicted using the modelling approach (Biber-Freudenberger, 2016). Insects that are either rare or extremely abundant, and hence live in high enough numbers to be classified as pests, are said to as endemic, which is opposed to outbreak or epidemic species (Walner, 1987). Epidemic pest populations multiply rapidly and frequently exhaust their hosts, drastically altering their habitats, whereas endemic species seldom change their hosts' ecosystems or significantly damage their hosts (Walner, 1987).

The increment of the insects abundance cause competitions which are intraspecific (within-species competition for food), interspecific (between-species compete for the same resource) and natural enemy competition (Svanbäck, 2019). The most of insect pests in rice agriculture, such as the rice stem borer, engage in interspecific competition for the same resource. Several species of rice stem borer attacking the same resource which is the paddy stem and cause the reduction in grain yield. The abundance of the rice stem borer species influences the management method such as the species-specific pheromone trap. Monitoring the abundance of pests is therefore important to protect the ecosystem and to prevent the epidemic species emerged.

2.3 Insect Pest in Paddy

Paddy plants are subjected to a variety of insect pest infestations, as well as a variety of other biotic and abiotic stresses, in order to survive and produce high yield. Insect infestation in rice begins after seed germination at vegetative phase and continues through the heading stages at reproductive phase (Dale, 1994). The most common insect pest found in Malaysia paddy granary are thrips, brown plant hopper, leaf roller and rice stem borer (Nik Mohd Noor, 2012). The thrips, *Stenchaetothrips biformis*, which is an insect pest that sucks the plant sap, is attracted to the young leaves after one month. Rice thrips larvae and adults use their mouthparts to puncture plant cells and eat the contents. Insects tend to feed on the developing tips of the young leaves, which consequently curl inward at the margins. Patches of clear and thus transparent epidermal cells appear as silvery streaks. Later, they turn yellow-brown, and as the infestation progresses, the leaves begin to wilt down from the tip and become 'scorched'. Plants remain stunted and can be completely destroyed in serious situations (Bindra, 2014). Other than Malaysia, the oriental rice thrips also can be found in other Asia countries, Europe, Caribbean island of Trinidad and the northern part of South America attacking on sugarcane (Sallam *et al*., 2013)

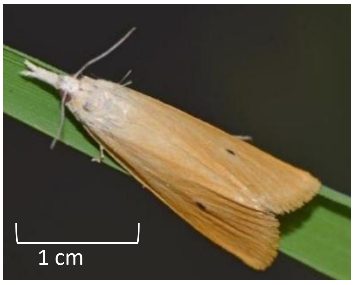
The hoppers are another important pest for the paddy plant. The brown plant hopper (*Nilaparvata lugens*), the green leaf hopper (*Nephotettix* spp.), and the white back hopper are three of the most common hoppers that attack paddy plants (*Sogatella furcifera*) in Malaysia (Nik Mohd Noor, 2012). Other than the three hoppers, sixty five hoppers are reported by Barrion (2009) found in tropical Asia rice ecosystems. By sucking the plant fluid, the hoppers cause hopperburn, which causes the paddy plants to turn yellowish, dry, and eventually die. The hopper's nymph and adult stages are usually the most destructive. In addition to its role as a direct pest, the brown plant hopper also acts as a vector for viruses such as Rice ragged stunt virus (RRSV), Rice grassy stunt virus (RGSV) and Rice tungro spherical virus (RTSV) (Chen and Chiu, 1981). The damage can be very severe that can destroy the whole field.

The rice leaf folder (*Cnaphalocrosis medinalis*) is another insect pest on paddy that are widely studied in the world including Malaysia. The larvae stitch the leaf margins together to fold the leaves longitudinally and feed by scraping the green mesophyll tissue from within the folded leaves. This feeding results in membranous patches of linear, pale white stripes and causes major losses to the rice ecosystem (Bhatti, 1995). Besides Malaysia, rice leaf folder, become a major threat to rice production in many Asian countries, including China, Sri Lanka, Vietnam, Pakistan, Japan, Korea, Malaysia and India (Padmavathi *et al*., 2017). An outbreak of the *C. medinalis* infestation was reported by Ooi and Yazid (1982) in Sekinchan, Selangor due to the incerasing of abundance. It was considered as minor pest before evolving as major pest in late 1980's (Hafeez *et al*., 2010). Recently, the presence of rice leaf infestation in the local paddy field has been observed, but no recorded outbreak of insect pest is observed after 20 years, however the possibility of an outbreak is possible (KADA, 2011 and Ooi, 2015).

Rice stem borer is one of the most common insect pests in paddy fields and a severe infestation can contribute to significant yield loss. Rice stem borer has now become a serious insect pest in paddy fields, with more outbreaks recorded by farmers and government agencies in Peninsular Malaysia (Noor Ainon, 2019). There are four main species of rice stem borer (Plate 2.1) exist in paddy plantation in Peninsular Malaysia which are yellow stem borer (*Scirphophaga incertulas*), black-headed stem borer (*Chilo polychrysus*), striped stem borer (*Chilo suppressalis*) and pink stem borer (*Sesamia inferens*) (Nik Mohd Noor, 2012). They come from family Pyralidae and Noctuidae (Lepidoptera). Among the stem borers, the pyralid borers are the most well-known and ruinous (Pathak and Khan, 1994, Soundararajan and Katti, 2018). All rice stem borers cause similar symptoms to paddy plants by forming the deadheart (DH) symptom (drying of the central tiller during the vegetative phase) and whitehead (WH) (whitish unfilled grain during reproductive phase)

(Muralidharan, 2006). The larvae of the stem borers enter the turner and feed inside, which prompts the harm of dead heart. The stem borers invasion at the grain filling stage prompts the stoppage of the further grain filling and that cause the arrangement of halfway filled grains called whitehead (Casida and Quistad, 1998).

Chilo polychrysus has increased in number and the population become more notable in most paddy granary in Peninsular Malaysia (Noor Ainon, 2019). The adult is yellow brown with small dark spots, 2-3 spots centrally on forewing and span is 16-25 mm (Kranz 1977 & Kalshoven 1981). The adult female lays her eggs in shiny white clusters on either side of the plant's leaves, which gradually darken in colour. After hatching from the dark eggs, a dirty white neonates larvae with 5 longitudinal grey violet lines, a dark head and shield crawled out of the egg case onto the leaves' surface and start eating (Anderson, 2012). They make a hole to enter the stem, feed inside the stem and complete the larvae instar. Prior to pupating the complete instar larvae makes a leave opening in the internodes and it is covered with fine web. The pupation of the stem borers ordinarily happens in the straw. The adult moth comes out through this opening (Pathak and Khan, 1994; Soundararajan and Katti, 2018).

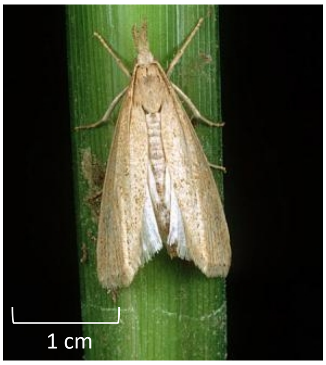


A) *Scirpophaga incertulas* - Yellow stem borer adult (Alchetron, 2018)

a) *Scirpophaga incertulas* - Yellow stem borer larvae (Minden, 2020)

B) *Chilo polychrysus* - Black-headed stem borer adult (Mashhoor, 2018)

b) *Chilo polychrysus* - Black-headed stem borer larvae (AG-GRO, 2021)



C) *Chilo supressalis* - Striped stem borer adult (Nature, 2019)

c) *Chilo supressalis* - Striped stem borer larvae (Nature, 2019)

D) *Sesamia inferens* - Pink stem borer adult (Duttamajumder, 2007)

d) *Sesamia inferens* - Pink stem borer larvae (Alchetron, 2018)

Plate 2.1. Rice stem borers in Peninsular Malaysia's field.

2.4 Insect life table

The life table analysis is very useful for evaluating insect population mortality and identifying main factors that cause the highest mortality within the population (Kakde, 2014). It is grouped into age specific (horizontal) and stage specific (vertical) life table (Ahsan, 2014). Age specific life table more precise on the fate of a real cohort, particularly a group of individual who belong to the same generation and are the same age but the population can be constant or shift over time.

Life table of insect is important in pest management and can be manipulated to plan a good management strategy. For example, early sown rice cultivation can reduce the risk of a high infestation of rice stem borer because the larvae present at the time was provided with a resistance stage of the rice (Hong-xing, 2017). The early instar larvae were unable to survive because they failed to penetrate the rice stem, resulting in increased mortality (Zalucki, 2002).

Other than that, time for insect application can be arrange due to the life stage provided by the life table. If the rice cultivation has to be sown later than the planting schedule, the high risk of insect pest infestation is awaiting because the resting moth from early rice cultivation field will completed its life cycle by laying eggs to the susceptible early seedlings (Litsinger, 2009). With the information, management of the rice field can be carried out more precisely to get an efficient control of the insect pest.

The life expectancy of beneficial insects also can be measured using life tables, and they can be used for biological control by predicting naturally which instar has the highest mortality (Jagtap, 2007). On this foundation, a plan for insect pest management at a specific time can be developed. The use of key factor analysis to classify the environmental variables that are most closely linked to cross - generational population trends has proven to be a useful tool (Sugawe, 2007). For example, many insect pests in India, such as *H. armigera* (Acharya, 2007), *S. litura* (Gedia, 2008) and others life tables have been prepared, and main mortality factors have been described.

2.5 Management of rice stem borer

Prior to the infestation, rice stem borers must be controlled before the damage appear. To avoid serious accidents and uncontrollable circumstances, management starts before the planting season and is focused on the stage of paddy development. There are many methods for managing rice stem borers. The integrated pest management (IPM) is the most suitable approach to have a sustainable monitoring and management (Horgan, 2017). IPM is a cost-effective and environmentally friendly pest-control strategy that employs a variety of pest control methods that make use of current, comprehensive information on pest life cycles and interactions with the environment (Zalom, 2010).

The preservation and conservation of natural enemies is one of the components in biological control. There are a number of natural beneficial organisms that naturally regulate rice stem borers in the paddy field ecosystem (Ardestani, 2020). For example, many species of parasitoid such as *Tetrastichus schoenobii*, *Trichogramma japonicum* and *Telenomous rowani* are well known to attack the eggs of the rice stem borer (Kyaw, 2020). The cultivation of attractive ornamental flowering plants such as *Lantana camara* and *Turnera* sp. can indirectly serve as a breeding ground for insect predators (Jamian, 2017). This biodiversity balance can be maintained by limiting the use of chemical pesticides or, where possible, by increasing the population of these biological agents and by helping to minimise the reproduction of rice stem borer.

The control of rice stem borer may also be performed by physical or mechanical means. For example, the use of pheromone traps to reduce the population of stem borers where these traps capture adult male moths (Chen & Klein, 2012). The pheromone traps disrupt the mating process of the male and females moth by the released of sex pheromone or synthetics pheromones in the atmosphere that luring the male moth into the traps hence reduce the reproduction of the insects (Weinzierl *et al*. 2012). However, this method is limited and not very common among farmers in Malaysia. In addition, light traps can also be used to monitor and reduce the populations of rice stem borers. Monitoring tasks can be carried out by counting the number of adult moths trapped and, if they reach a dangerous level, control action is needed (Baehaki, 2017).

The most popular method among farmers is the use of chemical insecticides in the management of rice stem borer because of it rapid impact on the reduction of the rice stem borers population and the level of damage. The use of right insecticides not only reduces the population of rice stem borer, but also minimizes the chance of harm to other non-target insects (Rahaman, 2019). Adult moths should be eliminated with contact insecticides before the larval stage appears. Contact pesticides may kill moths when the moth is exposed to insecticides. However, due to the damage that occurs inside the stem, contact insecticides are ineffective in controlling the larvae. The functional insecticide is systemic insecticide, which is absorbed into the rice stem and kill the larvae after they have eaten the stem tissue.

Another developing method involved in the management of rice stem borer in the world recently is the use of resistance rice variety. The study on the resistance variety of rice was initiated by Chaudhary since 1982 in Philippine and the selected varieties (IR20, IR36, IR50, Ratna and Chandina) were observed to show moderately resistance (Chaudhary, 1984). Saljoqi (2003) in his study reported that variety KS-282 was found as resistant while Gomal-6 and Gomal-7 showed moderate resistance, although none of the tested varieties were free from the attack of rice stem borer. Although no resistance rice variety to the rice stem borer is launched in Malaysia, but the effort is initiated.

2.6 Insecticide application and resistance in paddy plantation

Pesticide use is usually higher for particular harvests, such as rice, corn, and vegetables. Pesticide use by farmers is often excessive and in higher dosages than recommended, resulting in high levels of pesticide resistance (Chauhan & Singhal, 2006). In the tropical paddy field biological system, the substantial use of pesticides has affected the ecosystem of other non-target living organisms, such as natural enemies and fishes (Abdullah *et al*., 2009). Insecticide resistance occurs when the inherited sensitivity of a pest population is changed and resulted in the repeated failure of a product to control the targeted pest at expected level when applied according to the label recommendation as defined by the Insecticide Resistance Action Committee (IRAC).

The insecticides not only being used in agriculture, but they also were applied in other field. In agriculture stream, fipronil for example is a broad spectrum agent used as an insecticide, formicide and termiticide, especially in rice, sugarcane, cotton, potato, corn and soybean crops (AGROFIT, 2007). Besides that, fipronil also was an important agents in veterinary medicine that used against fleas, ticks, lice and other insects (Mohamed *et al*., 2004; Le Faounder *et al*., 2007). Other than that, it also played a role in public hygiene sector as the cleaning agent against ants and cockroaches (Zhao *et al*., 2005).

On the other hand, the phthalic diamide, flubendiamide (1,2-benzenedicarboxamide) was co-developed by Nihon Nohyaku and Bayer CropScience, (Masaki *et al*., 2006 and Nauen, 2006). Flubendiamide was mostly used in crop protection, less was found in other field. Flubendiamide is mainly effective for controlling lepidopteron pests in agriculture especially in rice, cotton, corn, grapes, other fruits and vegetables. The example of the lepidopteran pest treated by flubendiamide are rice stem borer, rice leaf folder and bagworms. It is more specific in targetting the insect pest and less harmful to the non-target insect. For example, the application of flubendiamide in oil palm can reduce the *Metisa plana* population but it only caused 27% of lethality index to *Elaeidobius kamerunicus,* a pollinator weevil that belongs to Curculionidae (Norhayu, 2020).

Chlorantraniliprole also has becoming an important insecticide in agriculture crop. It is belonging to the anthranilic diamide class of chemistry and was intended for the control of lepidopteran, coleopteran, and some dipteran pests in commercial agriculture on both perennial and annual crops (Ashfaq *et al.*, 2011). It was also the first anthranilic diamide insecticide registered for use on turf-grass and landscape ornamental. Both diamide insecticides exhibits excellent differential selectivity for insect ryanodine receptors over mammalian ryanodine receptors (Whalon *et al*., 2008). This mammalian safety selectivity was the important feature of the insecticide to be put in the cart by the farmers to choose the insecticide.

Insecticide resistance in rice stem borer has been reported in many countries around the world. In China, an insecticide resistance control study was in full swing, concentrating on a range of insecticides. Since 2005, insecticide resistance to rice stem borer has been discovered, with low or middle levels of resistance to fipronil, which has shown excellent results since its introduction in the 1990s (Jiang *et al*., 2005). One of the factor involving in the insecticide resistance mechanism in insects was the mode of action of the insecticides. The mode of action of fipronil involved the GABA-receptor. The mutation of the at two site mutations in RDL subunit of GABA-receptor caused the high level of resistance to fipronil in *Drosophila simulans* (Goff, 2005). Other than that, the resistance mechanism also involved in the low permeability of the cuticle, monooxygenase metabolism, and/ or the increased activity of detoxification enzymes as been reported in *Musca domestica* and *Plutella oxylostella* (Kristensen *et al*., 2004). From the reports, it was predicted that the fipronil resistance in *C. polychrysus* will be developed with the mutation of GABA-receptor dan the incerase of detoxification enzyme activities.

While, the diamide insecticides attacked the ryanodine receptor (RyR) modulator that lead to the insecticide resistance. In *P. xylostella*, chlorantraniliprole resistance is mediated by metabolic detoxification mechanisms such as P450 monooxygenases, glutathione S-transferases and esterases (Nauen, 2016). A study was conducted in a population in China, where RyR mutation in *P. xylostella* impairs diamide insecticide binding site caused the resistance to occur. However, the mutation frequency was only 23.75% even including resistant homozygous in the population. It was reported that high level of field-evolved resistance to chlorantraniliprole in *P. xylostella* was unstable, as shown by a decline in resistance ratios from 2040- to 25-fold during a period of six generations without selection (Yao *et al*., 2016). The unstability of the insecticide resistance towards both diamide insecticides was predicted to happen to *C. polychrysus* (Troczka, 2017).

CHAPTER 3

ABUNDANCE AND INFESTATION OF RICE STEM BORER AT SEVERAL DIFFERENT LOCALITIES

3.1 Introduction

Rice stem borer, one of the most major rice insect pests in most rice-countries especially in Asia. It has caused serious damage to the paddy fields based on the acreage of infected area in Malaysia as reported by Noorazura (2019). Previously, the rice stem borer infestation was reported to constantly infesting the rice field, however on the beginning of 2017, the severity of the rice infestation eventually increased drastically (Emi Faizal, 2019). In 2018, the infestation intensity was 30.30%, and the damage acreage involved was 7933.76 ha (Emi Faizal, 2019). Under field conditions, heavy stem borer infestations can cause rice grain yield losses up to 80% (January, 2020). The abundance, distribution, and damage caused by these stem borer species differ between various stages of crop development, climatic factors and geographic location of the rice field (Leonard, 2015).

The destructive stage by the rice stem borer is during the larvae stage which destroy the paddy stems by cutting off the stem (Shamik, 2020). The cut stem is due to the feeding behaviour of the rice stem borer larvae has prevented the movement of the nutrients from root to leaf (Muralidharan, 2006). As a result, during the vegetative phase, the central tillers of the paddy seedlings became dry and died or called deadheart. At reproductive stage, the panicle become unfilled or known as whitehead (Bandong, 2005). The severity infestation of rice stem borer at different stage of paddy plants give different result to the yield (Pallavi, 2017). The rice field with DH damage at vegetative stage did not affected the yield directly and could recover for the infestation that lower than 30% (Rubia *et al*. 1990). On the other hand, yield loss was almost proportional to the WH in the reproductive stage of rice where yield loss was as much as 1-3% higher than the percentage of the whitehead (Suharto, 2005).

Other than crop development, biotic and abiotic factors are the causes of the fluctuation of insect population dynamics (Singh, 2009). The factors such as temperature, rainfall, and relative humidity are the abiotic factors in the insect population outbreak (Heong *et al*., 2007 and Hussain *et al*., 2018). Rice stem borer population dynamics are subject to change depending on the dynamic state of its environment (Khaliq, 2014).

Understanding seasonal abundance and population growth trends is essential for timely preparation to deal with threatening pest problems and prevent crop losses. (Das *et al*., 2008). In Malaysia, four common species of rice stem borer were recorded by Nik Mohd Noor (2012) and they were yellow stem borer (*Scirpophaga incertulas*), black-headed stem borer (*Chilo polychrysus*), pink stem borer (*Sesamia inferens*) and striped stem borer (*Chilo suppressalis*). The abundance and distribution of rice stem borer species at specific geographic location provided a proper management to the insect pest (Arbab, 2014). Therefore, the aims of this study includes determining the abundance and percentage infestation of rice stem borer in the north regions of Peninsular Malaysia with specific localities, damage symptoms, rice planting seasons and weather parameter influences.

3.2 Materials and method

3.2.1 Sampling sites

Rice stem borer incidence was recorded in four districts in MADA areas for two rice planting seasons (Plate 3.1). The first sampling session started at season one (Season 1/2019) which began from June to September 2019 and the second sampling session two (season 2/2019) started from November 2019 until February 2020. The sampling areas followed the regions divided geographically by MADA (MADA, 2021) where four regions were stated. The regions were divided into Region 1, Region 2, Region 3 and Region 4 which involved several districts (Table 3.1). From the four regions, ten districts were selected and each districts had three replications of sampling sites where they were located in at least 1 kilometre from each other. The sampling sites were marked as sampling plots in one acre in size and planted with rice variety MARDI Siraj 297. Each planting season, a total of thirty sampling plots were recorded for rice stem borer incidence data collection. The sampling plots were managed by selected farmers by transplanting (Plate 3.2) or direct seeding (Plate 3.3). The paddy fields were maintained in conventional paddy ecosystem with proper agronomic practices such as good weeds management, scheduled fertilizer and application of pesticides when needed. The data recording were repeated in two planting seasons with another 30 sampling plots .

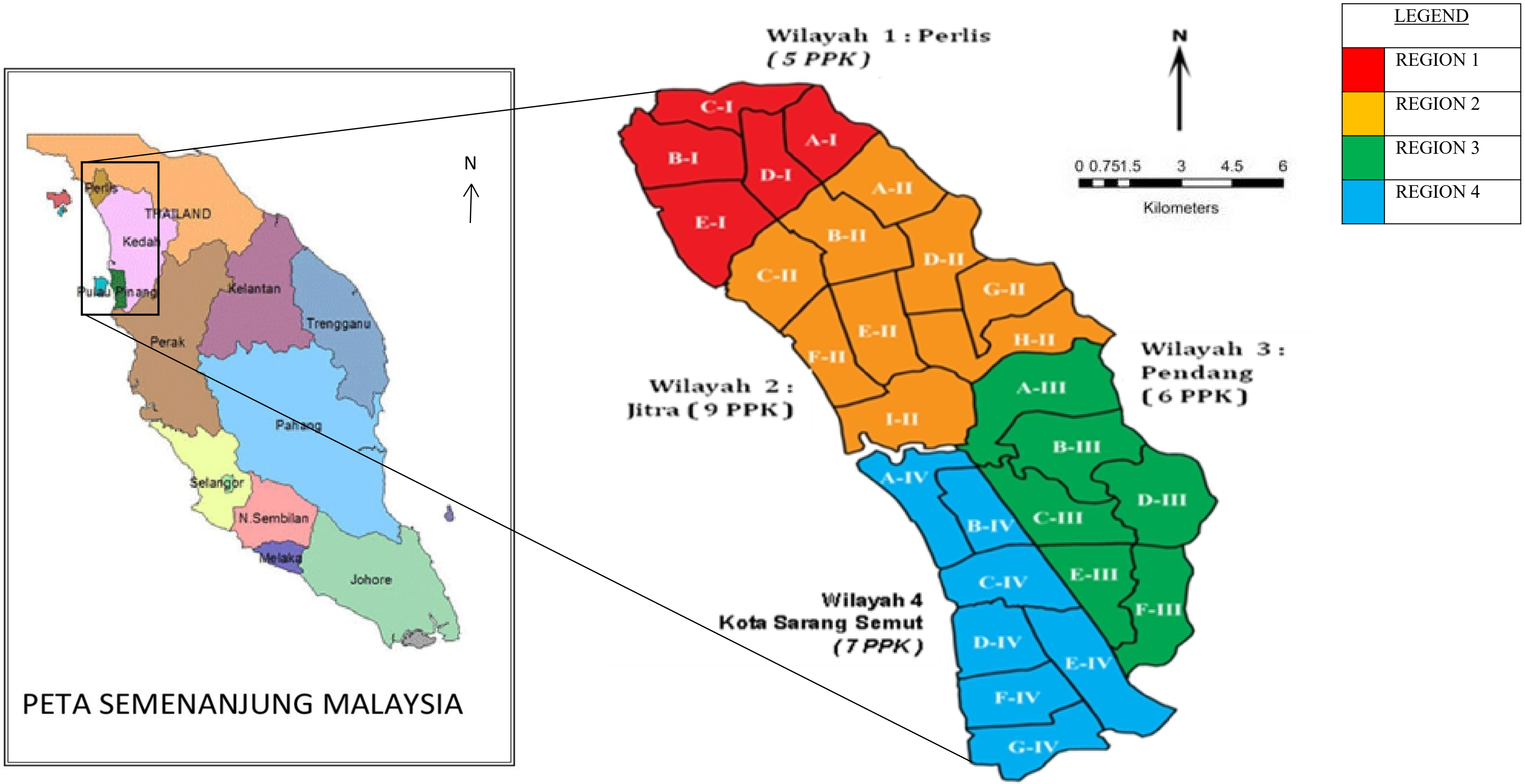


Plate 3.1. Location of four MADA Regions in Peninsular Malaysia

Table 3.1: Thirty sampling sites planted with rice variety MARDI Siraj 297 for rice stem borer incidence data recording per season.

No	Region	District	Method of planting	Specific location	Longitude	Latitude
1	R1	Arau	Direct seeding	A	6°23'49.0"N	100°15'23.9"E
2	R1	Arau	Direct seeding	B	6°24'33.9"N	100°17'00.3"E
3	R1	Arau	Direct seeding	C	6°24'50.5"N	100°15'19.7"E
4	R1	Simpang Empat	Transplant	A	6°16'15.1"N	100°11'31.7"E
5	R1	Simpang Empat	Transplant	B	6°21'19.5"N	100°11'15.1"E
6	R1	Simpang Empat	Direct seeding	C	6°19'40.4"N	100°10'00.7"E
7	R2	Kodiang	Transplant	A	6°21'03.9"N	100°18'07.5"E
8	R2	Kodiang	Transplant	B	6°20'50.5"N	100°18'06.1"E
9	R2	Kodiang	Transplant	C	6°21'32.3"N	100°17'22.4"E
10	R2	Jerlun	Direct seeding	A	6°10'28.6"N	100°16'39.5"E
11	R2	Jerlun	Direct seeding	B	6°10'50.4"N	100°16'47.9"E
12	R2	Jerlun	Direct seeding	C	6°13'18.3"N	100°16'45.7"E
13	R3	Hutan Kampung	Direct seeding	A	6°11'24.6"N	100°24'32.3"E
14	R3	Hutan Kampung	Direct seeding	B	6°11'00.2"N	100°24'28.9"E
15	R3	Hutan Kampung	Direct seeding	C	6°10'37.2"N	100°24'21.8"E
16	R3	Tajar	Direct seeding	A	6°04'26.3"N	100°23'22.0"E
17	R3	Tajar	Direct seeding	B	6°04'51.9"N	100°23'35.2"E
18	R3	Tajar	Direct seeding	C	6°05'09.0"N	100°23'36.6"E
19	R3	Pendang	Direct seeding	A	5°58'34.8"N	100°31'15.0"E
20	R3	Pendang	Direct seeding	B	5°58'47.7"N	100°29'55.4"E
21	R3	Pendang	Direct seeding	C	5°59'01.6"N	100°29'56.6"E

22	R4	Batas Paip	Direct seeding	A	6°02'07.9"N	100°20'53.1"E
23	R4	Batas Paip	Direct seeding	B	6°01'57.5"N	100°21'03.9"E
24	R4	Batas Paip	Direct seeding	C	6°02'29.6"N	100°21'32.6"E
25	R4	Permatang Buluh	Direct seeding	A	5°57'08.7"N	100°21'42.1"E
26	R4	Permatang Buluh	Direct seeding	B	5°56'45.2"N	100°23'38.9"E
27	R4	Permatang Buluh	Direct seeding	C	5°56'48.6"N	100°24'05.1"E
28	R4	Guar Chempedak	Direct seeding	A	5°51'28.1"N	100°24'46.7"E
29	R4	Guar Chempedak	Direct seeding	B	5°49'56.7"N	100°22'13.0"E
30	R4	Guar Chempedak	Direct seeding	C	5°50'20.6"N	100°24'57.8"E

R1 - Region 1
R2 - Region 2
R3 - Region 3
R4 - Region 4