**A REVIEW**

# INSECT PESTS OF VEGETABLES IN MALAYSIA AND THEIR MANAGEMENT USING ENTOMOPATHOGENIC FUNGI

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**ABSTRACT**

The domestic economy in Malaysia is dominated by agriculture, which accounts for about 10% of the Gross Domestic Product (GDP), and contributed more than 23% of the total export earnings. Vegetable comprises about 15% of the daily food intake of the Malaysian population. Vegetables in Malaysia are mostly produced by smallholder farmers and this industry provides millions of employments for the peoples, especially the rural dwellers. Insect pest is one of the major constraints of vegetable production in Malaysia. During growth, different species of insect pests such as armyworms, caterpillars, beetles, aphids, whiteflies, mites, and thrips cause serious damage to different vegetable crops, which reduce yield and make it unsuitable for human consumption. Integrated Pest Management (IPM) has been internationally recognized approach to pest control. IPM programme for insect pest of vegetable include, cultural control, physical control, mechanical control, biological control (parasitoids, predators, and entomopathogens), Plant Resistance to insects (PRI), and chemical control. Comparably, entomopathogenic fungi has demonstrated advantageous performance in infecting hosts directly through the integument. This paper aims to review some of the available literature on the IPM of insect pests of vegetables in Malaysia with more emphasis on insect pathogenic fungi as a contribution to components of IPM.

**Keywords:** Entomopathogenic fungi, insect pests, IPM, Malaysia, vegetables.

## ABSTRAK

Ekonomi domestik di Malaysia melalui sektor pertanian menyumbang sekitar 10% dari Keluaran Dalam Negara Kasar (KDNK) dan menyumbang lebih dari 23% dari jumlah pendapatan eksport. Sayur-sayuran merangkumi sekitar 15% daripada pengambilan makanan harian penduduk Malaysia. Sayur-sayuran di Malaysia kebanyakan dihasilkan oleh petani dan pekebun kecil serta industri ini menyediakan peluang pekerjaan untuk masyarakat, terutama penduduk luar bandar. Serangga perosak adalah salah satu cabaran utama pengeluaran sayur-sayuran di Malaysia. Semasa pertumbuhan, pelbagai spesies perosak serangga seperti ulat ratus, ulat beluncas, kumbang, kutu daun, lalat putih, hama, dan thrips menyebabkan kerosakan serius pada tanaman sayuran menyebabkan pengurangan hasil dan tidak sesuai untuk pengguna. Pada masa kini, Pengurusan Perosak Bersepadu (PPB) menjadi pendekatan yang diakui di seluruh tempat sebagai satu pendekatan mengawal perosak. Program PPB untuk serangga perosak sayuran termasuklah kawalan kultur, kawalan fizikal, kawalan mekanikal, kawalan biologi (parasitoid, pemangsa, dan entomopatogen), Ketahanan Tumbuhan terhadap serangga (PRI) dan kawalan kimia. Sebagai perbandingan, kulat entomopatogenik telah menunjukkan prestasi yang baik dalam memasuki perumah secara langsung melalui sistem dalaman. Semakan ini bertujuan untuk mengkaji beberapa literatur yang ada mengenai PPB serangga perosak sayuran di Malaysia dengan lebih menekankan kepada kulat patogenik serangga sebagai sumbangan kepada komponen PPB.


**Kata Kunci:** Entomopatogen fungus, serangga perosak, PPB, Malaysia, sayur-sayuran.

## INTRODUCTION

Vegetables are important food crops that play a key role in improving diets as well as restoration of some micronutrient deficiencies, especially in under developed nations around the world (FAO 2004). Vegetable has been reported to reduce some certain diseases associated with the heart, eye, digestive tract, and cancerogenic diseases (Kunjwal & Srivastava 2018). Researchers have recommended human being to consume not less than 200g of vegetables in a day. But, the majority of resource-poor persons do not take or consume below 200g per day, leading to a considerable rise in malnutrition rate (Phophi & Mafongoya 2017). Southeast Asia was among the countries that were recently ranked as the most suffering high rates of associated stroke deaths because of the poor intake of fruit and vegetables (Hionas 2019).

Previous reports showed that several factors greatly reduce vegetable production in Malaysia. Among these limiting factors are insect pests and diseases which were observed to cause serious destruction on vegetables (Jipanin et al. 2001; Zurina et al. 2015). It has been estimated that each year, phytophagous insects are responsible for damaging more than one-fifth of the total world's crop production (Kunjwal & Srivastava 2018).

Up to this time, chemical control is the most efficient option to protect vegetable crops against pests and diseases in Malaysia (Mispan et al. 2015). Disappointingly, many kinds of literature have reported several problems related to chemical pesticides which include elevated costs, health problems in humans, development of pest resistance and weeds, and destruction of non- target organisms (Abdelghany 2015). The situation has become to the extent that some neighbouring countries have rejected Malaysian vegetable exports for failing to pass their pesticide residue tests (Vijian 2001).

In recent years, IPM has been recognized as safe, effective, and modern methods of managing insect pests of vegetables. Biological control using natural enemies (pathogens, parasitoids, and predators) are one of the major components of Integrated Pest Management (IPM) techniques and entomopathogenic fungi are among the organisms used for biological control in developed and developing countries (Dauda & Maina 2018). It has been reported that insect pests find it very difficult to develop resistance on entomopathogenic fungi due to their complex action (Khan et al. 2012).

To date, many genera of entomopathogenic fungi that belong to either class Entomophthorales in the phylum Zygomycota or class Hyphomycetes in the phylum Deuteromycota are under research. However, three species have been identified as the most common and potentially important in biological control namely *Beauveria* spp., *Metarhizium anisopliae* (Metchnikoff) Sorokin, and *Isaria* spp. (formally known as *Paecilomyces*) (Esparza Mora et al. 2016).

Despite the benefits associated with entomopathogenic fungi, there has been little information on the use of indigenous fungal pathogens for the control of insect pests attacking vegetables in Malaysia. But several studies from different parts of the world have found that entomopathogenic fungi (Hyphomycetes) significantly control species of insects that attacked vegetables. This paper aims at reviewing the findings of some previous works on the control of vegetables insect pests in Malaysia using entomopathogenic fungi.

## VEGETABLE PRODUCTION IN MALAYSIA

In Malaysia, vegetables are one of the leading food that comprises about 15% of the daily food intake of the peoples (Jinius et al. 2001). The country has about 44,000 hectares of total land area planted with vegetables with an export value of US $122.5 million to mainly Singapore (Mohamed & Rokiah 2006). However, there is a recent report of Asia and Pacific Seed Association (APSA) in 2018 that shows Malaysia is one of the leading vegetable importers in Asia which values at about $900 million. Vegetable production rose by more than 4.5% per annum in 2015 and it is estimated that by the year 2020, at least 2.4 million tons of products will be required to meet Malaysian demand (Noorlidawati & Rozhan 2016). It has been estimated that around 46,000 or 8.18% of the total Malaysian farmers are involved actively in vegetable farming (Ng 2016). The production and harvesting are being carried out on a very small area of land that accounts for only 1% of the total agricultural land used in Malaysia (Yusoff 2016).

Vegetables grown in Malaysia could be either lowland or highland vegetables. The former is grown around the coastal areas 900 ft above sea level and the later one is grown in areas at around 3000-5000 ft above sea level (Jinius et al. 2001). The most common and popular vegetables grown in Cameron Highland, Pahang are cabbage, lettuce, chili, and tomato while, different types of vegetables can be grown in lowland, some of which are leaf mustard, long bean, cucumber, water convolvulus, spinach, chili, lady’s finger (Mohamed & Rokiah 2006), (Syed et al. 2000). The largest area of growing vegetables is in Johor with a total of 11,880 hectares (ha) and 31% of national hectarage. Pahang is the second-largest state with 6,540 ha. The third-largest producer was Kelantan (3,940 ha) followed by Sarawak (3,890 ha) and Sabah (2,650 ha) (Anim 2010).

## INSECT PESTS OF VEGETABLES IN MALAYSIA

Each stage of growth of vegetables, from germinating seeds to roots and stems has one or more genuine insect pests that can result in severe damage ranging from reducing plant yield vigour to plants death (Stansly 2011). Wireworms attack vegetables especially at root stages, cutworms at the young seedlings, caterpillars, and beetles attack foliage and stems. While pests like aphids, whiteflies, and mites infested young leaves and flowers of the plants. Otherwise, thrips are the major insect pests of vegetables attacking flowers (Sarwar 2014a). The classification and biology of major insect pests attacking vegetables in Malaysia are briefly discussed in the following subsections. However, the major insect pest of vegetable in Malaysia and parts of plants attacked are presented in table 1.

**Cutworm, *Agrotis ipsilon* (Hufnagel) (Noctuidae: Lepidoptera)**
This is the larvae of moths related to armyworms that attack young seedling of nearly all vegetable plants (Stansly 2011), and also feeds on cotton, rice, sorghum, strawberry, tobacco, and in some cases grains and grasses (Capinera 2018). In Malaysia, cutworms have been recognized to infest vegetable crops over the last 5 decades (Gholson 1978). Moth belongs to this family and is nocturnal insects that are well distributed in Asia (Kunjwal & Srivastava 2018). An adult has hindwings with darker scales and uniformly light brown forewings with black dashes extend distally from the bean-shaped wing spot. The size is fairly large, with a wingspan of 40 to 55 mm (Capinera 2018).

Eggs are round (0.5–0.7 mm diameter) and become slightly tinted before hatching (Kunjwal & Srivastava 2018). Eggs incubate for about 3-6 days and females may deposit 1200 to 1900 eggs. Larvae develop through several instars before pupating in the soil at a depth of 3 to 12 cm. Duration of the pupal stage is normally 12 to 20 days (Capinera 2018).

**Caterpillar pests, *Plutella xylostella* L., and *Spodoptera exigua* Smith (Lepidoptera: Plutellidae, Noctuidae,)**
Caterpillars are the larval stages of moths and butterflies. There are several species of caterpillars and many of which have smooth skins, while some have soft hairs with a long cylindrical body from 10–315 mm in length and range in colour (Maier et al. 2011). Caterpillars have a well-defined head, three thoracic segments, and ten abdominal segments. Each thoracic segment has one pair of true legs (Sparks & Liu 2001). Some of the caterpillars that are found feeding on vegetables are the armyworms (*Spodoptera exigua***)**, Diamondback moth (DBM) (*Plutella. xylostella*), cabbage loopers (*Tricoplusiani*), and tomato hornworm, (*Manduca quinquemaculata*) (McLeod 2008). Two species of caterpillars; *P. xylostella* and *Spodoptera exigua* had a global distribution and found in Europe, America, Australia, New Zealand, Africa, and Asia including Malaysia (Kunjwal & Srivastava 2018). In Malaysia, DBM, *P. xylostella* is considered to be the major insect pest attacking cabbage and other crucifers vegetables (Fatimah et al. 2019).

Over the last two decades Beet armyworm, *S. exigua* has become an important pest of various economic crops in Malaysia and has caused extensive damage to crops such as onions, brinjal, legumes and crucifers (Hussain & Annamalai 2003). *S. frugiperda* or Fall army worm is one of the serious caterpillar pests attacking more than 80 species of plants including several vegetable crops. These pests have not yet been officially reported in Malaysia but has recently become invasive pests attacking several crops in neighbouring countries such as Thailand and Indonesia (Ginting et al. 2020)

It has been demonstrated that all members within the order Lepidoptera, the butterflies and moths, progress through a four-stage life cycle, or complete metamorphosis, that is egg, larva, pupa, and adult (Hadley 2018).Upon hatching from eggs, the caterpillars start feeding on the young leaves, by making leaf nests inside the leaf. Older caterpillars of both species make larger nests. The pupa is found inside the nest or covered with silk on the surface of the leaf (Maier et al. 2011). Adult moths and butterflies may or may not feed in the same way and on the same plants as caterpillars, they have mouthparts designed for siphoning and are unable to damage plants (Sarwar 2014b).

**Beetle, *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae)**
This is a member of the family Chrysomelidae and commonly called the flea beetle. This is an insect pest that has been reported to cause serious damage to cruciferous vegetables such as cabbage, cauliflower, and radish (Kumaranag et al. 2014). Adult flea beetles are in various sizes and colours, but they all have enlarged hind legs that allow them to jump like a flea when disturbed (Sarwar 2014a). Female flea beetles lay their eggs in or on the soil near host crop plants or crevice. Eggs are too small to be seen and usually incubate for about 7 to 10 days (Stansly 2011). There are several larval instars and there is an increase in size in each instar. Pupation is usually occurring in the soil. The duration of the immature stages varies among species of flea beetles, but the entire life cycle from egg to adult takes 6 to 10 weeks (Hoffmann et al. 1999).

**Aphids, *Brevicoryne brassicae* (Homoptera: Aphididae)**
Adult aphids can be winged or wingless (apterous). Winged forms generally have slimmer bodies and transparent wings. The winged form of the green peach aphid has dark spots on its green body (Cannon et al. 2017). Aphids hosted on several plants such as tomato, potato, pepper, eggplant, cucumber, mustards, cabbage (Kunjwal & Srivastava 2018). The life cycle of aphids can be complex and differs among species. The adult female gives birth to 20-130 nymphs. Young aphids (nymphs) look like adults, except smaller in size. Nymph grows very fast and full fed in 7-10 days. About 45 generations are completed in a year (Kumaranag et al. 2014).

**Whiteflies, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae)**
Adult whiteflies are minute (about 1 mm in length) and white (Stansly 2011). Whiteflies were found in several vegetables grown in Malaysia and distributed throughout the country, both in the highland and lowland areas. Tomato, eggplant, bell pepper, chili, and cucumber were reported to host whiteflies (Syed et al. 2000).

Generally, whiteflies have a life cycle that consists of three stages; an egg stage, four nymphal stages, and an adult form (Sani et al. 2020; Stansly 2011). White (2013) reported that the entire whitefly life cycle of whitefly takes about 3 weeks under favourable conditions. Females lay eggs in leaf tissue of plants and first nymphal instar (crawler) emerge and feed by extracting sap from plants (McLeod 2008). However, only the crawler is mobile. older nymphs lose their ability to walk and remain in the same location for the rest of their development until they pupate and emerge as winged adults (Stansly 2011).

**Mites, *Polyphagotarsonemus latus* (Acari: Tarsonemidae),**
Mites are not true insects, they are more closely related to spiders and are one of the major vegetable pests that remove plant juices from the leaves of beans, corn, tomato, and eggplant. (Foster & Obermeyer 2017). The mite is very small, red, and adults resemble spiders. Adult females lay up to about 100 eggs on the foliage which hatches into larvae in a few days as 3

days. Upon hatching, the larvae begin to feed. Adults emerge within about 1 week and the cycle is repeated (McLeod 2008).

**Flies, *Bactrocera latifrons* and *B. cucurbitae* (Diptera: Tephritidae)**
Fruit flies are important pest of several crops that are not only threat to fruits but also several vegetable crops around the tropical, subtropical and temperate regions of the world (Ansari et al. 2012). *Bactrocera latifrons* is one of the species that are native to south -east Asia such as Malaysia, Thailand, Taiwan, India and China, and it has been reported to causes 60-80% infestation on red peppers crop in Malaysia (Wingsanoi & Siri 2012). The melon fruit fly, *B. cucurbitae* is a major cucurbitaceous crops that distributed worldwide with annual loss ranging between 30-100% depending on the host plant and season (Ansari et al. 2012). The time required for *Bactrocera* spp. to complete development from egg to adult was significantly influenced by the host plant on which the fruitflies are reared. The entire development from eggs to adult ranged between 14 to 23 days (Salmah et al. 2019)

**Thrips, *Frankliniella occidentalis, Thrips palmi* and *T. tabaci* (Thysanoptera: Thripidae)**
Thrips (Thysanoptera) are minute insects with slender-bodied and piercing-sucking mouthparts (Iftikhar et al. 2016). There are at least 6,200 species of thrips in the world, out of which the thripinae subfamily is the most economically important pest species (Ng 2016). Thrips found on several vegetable crops, including cucumber, onion, pepper, potato, lettuce, and tomato (Capinera 2001; Jamian et al. 2019). In Malaysia, *Thrips palmi* and *T. parvispinus* were reported to feed on flowers of eggplant, chili, and bell pepper in Cameron Highlands (Tan et al. 2016). Meanwhile, Jamian et al. (2019), has observed thrips infestation on the surface of lettuce grown in commercial hydroponic farm located in Perak, Malaysia.

It has been demonstrated that most members within the order Thysanoptera have a remarkable characteristic life cycle that consists of six stages: an egg, two active larval stages, and inactive and non-feeding pupal stage and adult stage (Mound 2018). Under the favourable condition, the development of thrips from egg to adult takes about 19 days and adult thrips live for about 23 days or less (Sani & Umar 2017). Females insert eggs into plant tissue with a structure called the ovipositor (Mound 2018). The incubation period takes approximately three days, depending on the species. Nymphs thrips feed for four to five days and then stop feeding, drop from the plant into the soil and pupate (Cote & Day 2015). First to second larval instar stages take 10–14 days to complete, while the pre-pupa and pupa stages can last approximately a week. Adults emerge after two days of pupation at 30 °C (Riley et al. 2018).

Table 1. Insect pest of vegetable and major crops attack in Malaysia

| Insect pest | Common name: Order and family | Major vegetable and part attack | Reference |
|---|---|---|---|
| *Plutella xylostella* | Diamond back moth (Lepidoptera: Plutellidae) | Crucifer vegetables like cabbage, cauliflower. Larvae feeds on the leaves | (Kunjwal & Srivastava 2018) |
| *Spodoptera exigua* | Beet armyworm, (Lepidoptera: Noctuidae) | Onions, brinjal, legumes, and crucifers | (Hussain & Annamalai 2003) |
| *Agrotis ipsilon* | Cutworm (Noctuidae: Lepidoptera) | Nearly all vegetables. Adults feed on nectar from flowers | (Capinera 2018) |

| | | | |
|---|---|---|---|
| *Phyllotreta cruciferae* | crucifer flea beetle (Coleoptera: Chrysomelidae) | Brasssicaceae crops such as Cualiflower, radish, mustard and leafy vegetable. | (Mayoori & Mikunthan 2009) |
| *Brevicoryne brassicae* | Cabbage aphids (Homoptera: Aphididae_ | Cabbage. Feed on Leaf | (Kunjwal & Srivastava 2018) |
| *Bemisia tabaci* | Silverleaf whitefly (Hemiptera: Aleyrodidae) | Nearly all vegetables grown in Malaysia | (Shadmany et al. 2013; Sani et al. 2020) |
| *Frankliniella occidentalis,* | Western flower thrips (Thysanoptera: Thripidae) | Eggplant, chili and bell pepper | (Tan et al. 2016) |
| *Thrips palmi* | Melon hrips (Thysanoptera: Thripidae) | Eggplant, chili and bell pepper | (Tan et al. 2016) |
| *Thrips tabaci* | Onion thrips (Thysanoptera: Thripidae) | Eggplant, chili and bell pepper | (Tan et al. 2016) |
| *Polyphagotarsonemus latus* | Broad mites (Acari: Tarsonemidae), | Tomato, and eggplant. Feed on the leaves | |
| *Bactrocera latifrons* | Solanum fruit fly (Diptera: Tephritidae) | Solanaceae (Solanum specie). Feed in fleshy vegetables | (Clarke et al. 2001) |

## DAMAGES CAUSED TO VEGETABLES BY INSECT PESTS

Over the past few decades, many researchers have investigated a lot of damages on vegetable crops caused by different species of insect pests. Most of these insect pests have been reported to cause serious damage on different vegetable crops in Malaysia and different parts of the world, for instant Diamondback Moth, *P. xylostella* has been reported to be the major pest of cruciferous vegetables grown in Cameron Highland that may completely defoliate the plant due to feeding on it by the caterpillar (Ooi 2015). However, *P. xylostella* global damage and control have been estimated to cost up to 1 billion US$ per year. The most prevalent areas are mostly in Asia and Africa (Grzywacz et al. 2010). Mayoori & Mikunthan (2009) reported that cabbage flea beetle, *P. cruciferae*, is a serious insect pest of Brassicaceae plant. However, laboratory assessment of foliage damage of some brassica plants shows that damage caused by *P. cruciferae* was significant (greater than 50%) in the cauliflower, radish, mustard, and cabbage.

Thrips have been recognized as one of the most serious insect pests of solanaceous vegetables (tomato, eggplant chili, lettuce and sweet potato) that either cause damage by direct feeding on leaves or flowers or indirectly through the transmission of plant viruses (Ng & Zaimi 2018; Jamian et al. 2019).

Whitefly, *B. tabaci*, was also reported to damages a large number of crops by feeding on their phloem sap and secreting honeydew and also by transmitting more than 200 viral diseases (Lu et al. 2019). Yield loss ranging from 20 to 100% have been recorded due to *B. tabaci*- transmitted begomoviruses (Jones 2003). In Malaysia, it was first recorded since over the last eight decades as an unimportant pest but *B. tabaci* has recently become one of the devastating insect pests of many vegetables' crops including tomato, chili, and brinjal (Saad et al. 2015). Green peach aphid, *M. persicae* Sulzer is one of the major global pests of vegetable crops that are found to attacks more than 800 plant species. The insect has a sucking mouthpart that used to take in plants cell sap and nutrients, it also transmits many viral diseases (Nazir et al. 2018).

## INTEGRATED PEST MANAGEMENT (IPM) ON INSECT PESTS OF VEGETABLE SPECIES IN MALAYSIA

Integrated Pest Management (IPM) is an internationally recognized approach to pest and disease control. IPM was first introduced into Malaysia in the 1960s to combat the surging problem of pest resistance and resurgence in the 1970s, however, the implementation of IPM principles and practices in Malaysia was the gradual and continual process (Juni 2005; Tey & Cheong 2013). The present IPM strategists in vegetable production include Plant Resistance to insects (PRI), cultural control, physical and mechanical control, biological control and chemical control (Abrol & Uma 2012). Meanwhile, the study of the IPM package has shown effective in managing insect pests of sweet pea in Sabah, Malaysia. The package consisted of spraying ivermectin, yellow sticky traps, spraying of *Bacillus thuringiensis,* and the use of parasitoids (Jipanin 2008).

In Malaysia, there are over 30 local and foreign companies developing, manufacturing, and distributing pesticides with an over RM500 million markets (Borneo 2014). It has been observed that farmers rely heavily on chemical pesticides and those with good pesticide knowledge showed good practices in pesticides used and were more inclined to apply pesticides according to recommended guidelines for protective measures and sustainability (Sharifzadeh et al. 2018). Farmers in Malaysia used up to 11 types of insecticides to control insect pests of cabbage, and each farmer usually uses 3-4 types of insecticides per season (Mazlan & Mumford 2005). However, chemical control measures should only be applied when the pest population is above the economic threshold (Tey & Cheong 2013). The immature stages must be targeted because it is the most vulnerable to the chemical, and since nymphs of many insect pests begin to destroy plants immediately after hatching (Leong et al. 2019). Thus, the IPM principle does not prohibit application of chemical pesticide, but rather should be the last option to be used prudently by the farmers if other alternatives are not effective against pest infestation on the crops (Halimatunsadiah et al. 2016).

Several vegetable varieties have been screened to be less tasty to an insect pest or to possess certain properties that discourage insect feeding or egg-laying, or to be able to host insects pest population without much damage on it (Robinson 2009). According to Ministry of Agriculture and Agro-Based Industry Malaysia (MOA 2007), Malaysian Agricultural Research Development Institute have successfully released some improved varieties of vegetable such as MC11 and MC12 chili with good fruit qualities and high, stable yield.

Cultural and physical methods are some of the earliest sustainable methods of pest control in Malaysia. The techniques emphasized more on creating an environment that is unfavourable to pests. This includes removing pest breeding sites, healthy seedling, and resistant variety (Hamid et al. 2002). Mechanical controls include hand removal of pests or their eggs, barriers, and traps. Many pests can be controlled simply by removing them and killing them (Allen 2014). Physical methods such as heat or cold treatment, humidity manipulation and light trapping are also some of the sustainable methods prove to be promising in reducing the rate of pest and disease colonization (Hamid et al. 2002). Crop rotation, cover crops, and manipulation of sowing and harvesting dates are cultural methods that were also used to prevent the build-up of pest numbers (Bale et al. 2008). A study revealed that about 40% of vegetable farmers used crop rotation for pest management in highland. Yellow floodlight is also one of the most important techniques used by vegetable farmers to control lepidopteran pests in Malaysia (Juni 2005). Mulching and intercropping are some of the important methods used to reduce the large number of winged aphid that vector several viruses of chili plants (Hamid et al. 2002).

The first successful biological control in Malaysia is when two parasitoids namely *Diadegma semiclausum* Hellen (Hymenoptera, Ichneumonidae), and *Diadromous collaris* Gravenhurst (Hymenoptera, Ichneumonidae) imported from New Zealand. This led to the first successful biological control in Malaysia and this success encouraged the biological control of the Diamondback moth in Vietnam, Thailand, and even in Tanzania (Ooi 2015). In addition, Jamian et al. (2017) reported the use of predatory insects can be an alternative to pest control compared to chemical control in agriculture systems.

Over the last three decades, some scientists explain in detail the success and failures of some biological control trials in Malaysia. Based on the researchers found, there were 23 biological control agents imported to control 11 pest problems in Malaysia. Six of them were able to establish. The researchers also concluded that the strategy to import exotic natural enemies was good for control exotic pests (Hamid et al. 2002).

Two species of parasitoids: *Bassus* sp. (Braconidae) and *Trathala flavoorbitalis* (Cam.) (Ichneumonidae) were reported to control larvae of cabbage webworm, *Hellula undalis* (Fabr.) (Pyralidae: Glaphyriinae) infesting various cruciferous plants in Malaysia. The study was also reported fire-ant, *Solenopsis geminata* (F.), a predator of the prepupae and pupae of *H. undalis* (Sivapragasam & Chua 1997). In the late 1980s and early 1999s, there has been a decrease in using pesticides and a high level of adoption of *B. thuringiensis* (*Bt*) products by farmers in the Cameron Highlands. But, currently, there has been resistance to *Bt* due to continuing use of it without adherence to insect resistance management (IRM) (Grzywacz et al. 2010). However, neem tree (*Azadirachta indica*), garlic *(Allium cepa*), and *Citronella* spp, are the three plant species that are currently used as sources of botanical pesticides registered in Malaysia (Sivapragasam 2009).

## BIOLOGICAL CONTROL OF INSECT PESTS OF VEGETABLES WITH ENTOMOPATHOGENIC FUNGI

Entomopathogenic fungi are a group of insects biological control agents that have a significant role among all known biological control agents due to their ability to infect host through the integument and wide host range (Sani et al. 2020; Khan et al. 2012). The deliberate use of fungal pathogens as a biological control against pests was first considered in the latter part of the nineteenth century by the Russian scientist Metchnikoff. He used *M. anisopliae,* (green muscadine fungus) against the wheat cockchafer, *Anisopliae austriaca* (Abdelghany 2015). Since then, researchers from different part of the world has recorded many success in using entomopathogenic fungi to control different insect pests attacking different crops in a different part of the world.

However, there have been several studies that revealed the potential of entomopathogenic fungi against insect pests of vegetables. Abdel-Raheem & Al-Keridis (2016) demonstrated the effectiveness of three entomopathogenic fungi; *M. anisopliae, B. bassiana,* and *Verticillium lecanii* in the whitefly, *B. tabaci* infecting tomato plant, where the results showed 100% mortality over 6 days under laboratory condition. Huang et al. (2010) tested the effect of *Isaria fumosoroseus* on mortality and fecundity of immature stages of whitefly (*B. tabaci*) and Diamondback moth (*P. xylostella*) on eggplant. The result shows *I. fumosoroseus* to be significantly reduced the longevity and fecundity of *B. tabaci* and *P. xylostella*.

In Malaysia, many published studies revealed the potentials of indigenous isolates of entomopathogenic fungi against different insect pests of vegetables. Islam et al. (2016) found that *M. anisopliae* isolated from *Coptotermes gestroi* (Rhinotermitidae: Isoptera) has a pathogenic effect on *B. tabaci* on eggplant, that causes mortality up to 97% under osmotic condition. Meanwhile, Rahim et al. (2013) reported the susceptibility of newly to isolate of *Isaria fumosorosea* on all stages of *B. tabaci* infesting eggplants in Universiti Putra Malaysia glasshouse. A similar study was conducted with 10 isolates of *P. fumosoroseus* against egg and nymph of *B. tabaci* (Rahim et al. 2015). In the field trial, it was found that wettable powder formulations of *B. bassiana*, *Paecilomyces* spp. and *M. anisopliae* can significantly reduce the mite population in the field of one-month-old *Capsicum annum* (chili) plants (Ihsan & Yusof 2007). Similarly, Panyasiri & Poehling (2007) tested the effect of thirty-three isolates of entomopathogenic fungi against thrips (*Ceratothripoidesclaratris*), mealybug (*Pseudococcus cryptus*) and whitefly (*B. tabaci*) on tomato in Thailand. The result showed that *Paecilomyces fumosoroseus* is the most virulent against thrips and *M. anisopliae* is the most effective against mealybug.

A synergistic field experiment of entomopathogenic fungi; *B. bassiana* and *Lecanicillium lecanii* with farmyard manure, neem cake and *Pseudomonas fluorescens* against sucking pests of chili, aphids (*M. persicae*), chili thrips (*Thrips dorsalis*), and muranai mite (*P. latus*) were shown promising in reducing the population of sucking pests of chili in the field (Chinniah et al. 2016).

## BENEFIT, CHALLENGES, AND PROSPECTS OF ENTOMOPATHOGENIC FUNGI UTILIZATION IN MALAYSIA

Although entomopathogenic fungi consider being an alternative to synthetic chemical pesticides in controlling insect pests, there are also several drawbacks of using it in insect pest control. Sivapragasam (2009) and Ramlah et al. (2013) outlined some of the benefits and problems of bio-pesticides in Malaysia. They also suggested some strategic solutions to the problems which would possibly enhance the sustainable use of bio-pesticides under the framework of IPM. Some of the major benefits, limitations and the suggested solutions are discussed below.

Butt et al. (2001) reported that some compound isolated from fungal biocontrol agents has led to the development of some pharmaceutical drugs and safer agrochemicals. However, entomopathogenic fungi have different ways of infection. Hence insect resistance cannot be developed, and they can be used as prolonged pest control (Khan et al. 2012).

One of the limitations of entomopathogenic fungi is taking a long time to kill the insect population, usually 2-3 weeks when compared with the synthetic insecticides that need only 2-3 days (Sani et al. 2020; Khan et al. 2012). Another limitation is the environmental factors such as sunlight, temperature, humidity, and UV exposure which influence the insecticidal activity of entomopathogenic fungi against insect pests in an open field of tropical regions (Cheong et al. 2013). Additionally, there is relatively little investment in the research and development of microorganisms compared with that spent on the discovery of chemical pesticides (Butt et al. 2001).

To address this limitation, the IPM techniques with a specific focus to microbial control agents should be adopted and effectively used in controlling insect pests. Also, advancement and investment in plant protection research could help to address these problems. Kamarulzaman et al. (2012) conducted a survey that revealed that the majority of the Malaysian farmers believed that biopesticides are natural chemicals that can be used for pest control and few of them used to apply it because it would not harm the environment. Because of this, farmers need to be educated on the benefit associated with the use of biopesticides in the control of insect pests. The Malaysian government should also effectively enlighten farmers on the strategists that involve in an IPM approach to reduce ecological and health damage caused by the chemical pesticides.

## CONCLUSION

Vegetables in Malaysia are largely produced by small scale farmers especially those in the rural areas. However, an insect pest of a different kind is one of the major constraints that can significantly reduce yield and cause a threat to food security. Synthetic chemical pesticides are the most widely used for control of these insect pests despite their toxicity and hazardous effects to human, non-target organisms, and the environment. However, there are some sustainable control measures such as cultural, used of resistance varieties and biological that have been developed as alternatives to synthetic chemical insecticides. Although Malaysia has noteworthy success in controlling insect pests of vegetables through conventional, and some non-conventional technologies, it needs to adopt environmentally sustainable methods of crop protection through IPM and cutting-edge technologies to keep pace with global advancements. As a first step to achieve this goal, identification, and isolation of biological control agents such as bacteria, fungi, and nematodes, will be critical. It is therefore recommended to conduct broad research on the use of microbial control agents in the management of insect pests of vegetables and other insect pests on agricultural production.

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