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An economic evaluation of Integrated Pest Management against the invasive fall armyworm (FAW) in Malaysia

[Penilaian ekonomi kawalan serangga *fall armyworm* (FAW) menggunakan *Integrated Pest Management* (IPM)]

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Abstract

The fall armyworm (FAW), *Spodoptera frugiperda*, is known worldwide as a destructive pest of various agricultural crops and is widely distributed in Europe, Africa, Asia and Australia. In 2019, the pest was reported to be affecting corn plantation in Vietnam, Thailand, Myanmar, Indonesia and Malaysia. Controlling pests using a single method is generally less effective. The integrated pest management (IPM) approach is one of the methods that grain and sweet corn farmers use to control FAW. MARDI studied the introduction of pheromones from Costa Rica to control adult FAW moths and investigated the introduction of pesticides with the active ingredients *Chlorantraniliprole* and *Emamectin benzoate*. Therefore, this study aims to evaluate the cost benefit of IPM recommendations in controlling FAW in corn fields. Using IPM for FAW control in grain corn resulted in an increase amounting RM96 more than not using the IPM method, even assuming the yield increases by 300 kg. In sweet corn, using IPM for FAW control provides an advantage of RM3, 363.19 more than not using IPM method with a yield increase of 12%. Both type of corn were tested with MARDI's technology in handling and following SOP for IPM-FAW control. The aim of the IPM is to bring FAW below the economic damage threshold. Therefore, the use of IPM for FAW control is suitable for implementation in areas where the SOP proposed by MARDI has never been practiced to achieve higher sweet corn yields. However, for grain corn, further research needs to be carried out to ensure that the IPM can generate a significant financial return, and to ensure the sustainability of the IPM recommendations on site in line with efforts to minimise the use of chemical based pesticides.

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Introduction

The fall armyworm (FAW), *Spodoptera frugiperda* is recognised worldwide as a destructive pest of various agricultural crops, spreading across Europe, Africa, Asia and Australia (Goergen et al. 2016; Early et al. 2018; Kebede & Shimalis 2019; Ginting et al. 2020; Hang et al. 2020; Jamil et. al 2021). The pest was first detected at the African continent in 2016 (Goergen et al. 2016). A few years later, the pest spread throughout South Asia (Kalleshwaraswamy et al. 2018) and later, reached Southeast Asia. In 2019, the pest was reported to affect corn in Vietnam, Thailand, Myanmar and Indonesia (Yee et al. 2019; Ginting et al. 2020; Hang et al. 2020).

The *S. frugiperda* was first detected in Malaysia in February 2019 in the northern states of Peninsular Malaysia (Kedah and Perlis). By the end of the calendar year, the insect had spread to all states in Malaysia, including the Borneo states of Sabah and Sarawak (Jamil et al. 2021). To date, numerous studies have been recommended on various management practices in the Americas and Africa to reduce the damage and losses caused by *S. frugiperda* (Midega et al. 2018; Prasanna et al. 2018; Harrison et al. 2019). However, due to the recent infestation of this pest into Malaysia, there is an obvious knowledge gap in the information and management of *S. frugiperda* in the field. There is not much information and reports on the tolerability and effectiveness of chemical pesticides suitable for use in IPM to control FAW in Malaysia. Therefore, the integrated pest management (IPM) approach is one of the management methods used by corn farmers to control FAW.

In IPM, the priority is to control FAW so that its population remains below the threshold level of economic damage. In other words, the control of FAW won't be able to control at 100% level but rather to ensure that the number of FAW present does not cause losses to farmers while also being able to conserve the presence of beneficial insects in the area. It should be noted that mechanical, cultural, biological, and chemical spray control approaches are among the components of IPM. In this article we will focus on insect control in the FAW area.

MARDI has worked on a study on the introduction of pheromones from Costa Rica to control adult FAW moths and on the introduction of pesticides with the active ingredients *chlorantraniliprole* and *emamectin benzoate*. They were selected as a chemical control component for the control of FAW using the IPM approach. The control of FAW must include an economic assessment to measure the effectiveness of the financial impact of the use of IPM. The production economics for controlling FAW insects using IPM includes production costs and returns as well as cost and benefit analyses. A partial budget analysis was conducted to determine the differences between the benefits and impacts of FAW insect control using this IPM. Therefore, the main objective of the study is to evaluate the cost benefit of IPM recommendations in controlling FAW in corn fields.

Background

The Food and Agriculture Organisation (FAO) of the United Nations has declared FAW as one of the world's major invasive pests, emphasizing that close attention must be paid to FAW as its polyphagous nature may threaten global food security (FAO 2017). This pest has several characteristics to be a successful invader. An adult moth can go through several generations, it can lay up to 1,000 eggs during its lifetime (CABI 2019). Once hatched, large numbers of newborn FAW larvae, tenacious as an army, can cause severe damage to corn, especially the leaves. The larvae of FAW may feed on more than 350 plant species, including several economically important crops such as corn, sugarcane, and rice (Montezano et al. 2018). The worst damage typically occurs in fourth to sixth instar larvae, where they cause injuries to the corn whorl, stalk, and ear through excessive feeding. In addition to the larvae, adults are also strong fliers and can fly over 100 km/night (Johnson 1987). All these characteristics directly contribute to the success of the spread of FAW as a global pest.

Several approaches have been proposed to combat FAW at the earliest stage of infestation, including the introduction of FAW control agents such as *Emamectin benzoate, Cypermethrin* and *Spinosad* (Nor Amna A'liah et al. 2020). It was widely used by farmers as a solution to the fighting with FAW. Later, with the increasing research on FAW, several solutions to deal with FAW were introduced includes using the IPM.

IPM involves the simultaneous use of multiple pest control strategies in combination to maintain pest populations below economic damage levels without negative impacts on soil health and the environment. IPM practices include not only curative measures but also prophylactic measures taken before an infestation occurs (Lamsal et al. 2020). For smallholder farmers, IPM represents a range of cost-effective agricultural control measures and is an optimal option to implement as part of an effective control strategy against FAW. IPM approaches exploit the complex interactions between organisms and their environment to develop techniques to minimise pest damage to crops (Jing et al. 2021). Scientists have proposed five IPM approaches for Asia to successfully minimise the FAW population. The lists are as following:

1. Traditional pre-planting with some measures such as deep plowing before sowing (Prasanna et al. 2018);
2. Cultivation of transgenic/Bt insect-resistant corn varieties (Jing et al. 2021);
3. Mechanical methods such as hand picking, light traps and pheromone baits to monitor and control the pest (Bhusal & Bhattarai 2019);
4. The use of intercropping of pulses with corn and the use of push and pull strategy (Bhusal & Bhattarai 2019; Jing et al. 2021);
5. Synthetic chemicals. if possible should be avoided, but can be used if the damage is severe or more than 50% (Chhetri & Acharya 2019).

Out of the five approaches, two were used by MARDI to solve FAW in Malaysia. The use of mechanical methods such as pheromone baits are some options suggested by MARDI to monitor and control the pest (Maziah et al. 2022). MARDI have tested three types of commercial pheromones for their ability to attract adult male FAW moths in the laboratory and field, namely the P061-90Lure (ChemTica International, Costa Rica), FAW Lure (Pest Control Pvt. Ltd., India) and Trece Pherocon® Fall Armyworm (Trece Incorporated Oklahoma, US).

In the laboratory test, all three pheromones demonstrated the ability to attract adult FAW without significant differences, suggesting that all three pheromones have equivalent effectiveness in attracting adult FAW in the laboratory. A field study later was conducted in the grain corn cultivation area at MARDI Bachok Station in Kelantan. Pheromones from Costa Rica have 3.5 times greater potential to attract male FAW butterflies and have a longer lifespan in the field than pheromones from USA and India. No significant differences were found among the grain corn varieties. The field evaluation shows that the P061-90 bait pheromone from Costa Rica has high potential for monitoring the FAW population in Malaysia. Therefore, Costa Rican pheromone was selected as a recommendation component for FAW control in corn crops.

The second option is using the synthetic chemicals. Research into how effective commercial insecticides and biopesticides are in controlling FAW had being conducted by MARDI. Formulated commercial insecticides and biopesticides as well as plant extracts were evaluated for their effectiveness in FAW control. The insecticides are: *Emamectin benzoate* (T1), *Cypermethrin* (T2); *Spinosad* (T3); *Indoxacarb* (T4), *Chlorantraniliprole* (T5), *Infenuron* (T6), *Cyantraniprol* (T7), *Chlorfenapyr* (T8), *Malathion* (T9), *Flubendiamide* (T10), *Deltamethrin* (T11), *Fipronil* (T12) and *Carbofuran* (T13). Biopesticides used are Neem oil (T14); fresh garlic extract (T15), Bacillus thuringiensis (T16) and crude extracts were *Citrus hystrix* extracts (T17) and control (T18) using filtered tap water with finding show 100% mortality of FAW larvae was observed in the *Emamectin Benzoate, Chlorantraniliprole, Infenuron, Cyantraniprol* and *Cypermethrin* treatments.

A field experiment was carried out in a grain corn and sweet corn crop plot at MARDI Kluang, Johor on a three ha area. The area had attack of FAW was almost 100% and had the level of more than 50% with a maximum score of five (severe damage). Plots treated with *Chlorantraniliprole*, *Infenuron*, *Cyantraniliprole*, *Cypermethrin* and *Emamectin benzoate*, had the highest average mortality percentage (100%) for both grain and sweet corn. Pesticides with the active agents *Chlorantraniliprole* and *Emamectin benzoate* have been selected for the chemical control component as a recommendation component for FAW control in corn crops.

Thus, the use of both the recommendation are suggested in controlling FAW with the recommended practices. The installation of pheromone traps (from Costa Rica) must be made 14 days before planting as a preliminary determination of the presence of FAW. For an one ha farm, it is recommended to install a total of 8 pheromone trap units, with 50 m spacing between traps along the property perimeter. Regular monitoring and inspection of plants in the field begins as early as seven days after planting and continues at least once a week throughout growth to detect early FAW attacks. To combat FAW in the field, a bioinsecticide based on *Bacillus thuringiensis* is recommended as early as 7 – 14 days after planting at an infestation level of 5 – 20%. However, if the infestation is more than 20%, the use of a chemical poison with the active ingredient *Emamectin benzoate* is recommended. Spray the poison *Emamectin* or *Chlorantraniliprole* 15 – 28 days after planting and 29 – 49 days after planting if FAW infestation exceeds 5%. In IPM, pesticides rotation should be performed to avoid pesticides resistance to FAW. It is not recommended to spray chemical pesticides at any time beyond 49 days after planting (from harvest to harvest) to avoid the presence of pesticide residues in corn products.

Methodology

Data collection

Data collection was carried out from grain corn and sweet corn farmers in Chuping, Kedah and Tanjong Karang, Selangor, respectively. The data obtained from farmers on yield and cost of insecticides, where the conventional system involves the use of chemical pesticides while the IPM system involves the use of pheromones along with the chemical pesticides. Farmers participated in the study that was conducted using questionnaires. In addition to the data collected from farmers the technical team from Agrobiodiversity and Environment Research Centre, Industrial Crop Research Centre, Horticulture Research Centre and Soil Science Research Centre also provided technical data on the aspects of pheromones, chemical pesticides and corn live cycle.

The cost of production and income

The cost of production calculation is a fundamental component in evaluating the financial performance and efficiency of businesses engaged in manufacturing or providing goods and services. This computation entails the comprehensive assessment of all expenditures associated with the production process. It encompasses both variable costs, such as raw materials, labour and utilities. This fluctuates with production levels and fixed costs, including rent, equipment depreciation and salaried personnel, which remain constant regardless of output. The summation of these direct and indirect expenses is vital for enterprises, serving as a cornerstone for pricing strategies, resource allocation decisions and the identification of opportunities for cost optimisation. Accurate cost of production analysis plays a pivotal role in strategic business planning and sustainable operations.

Partial budgeting analysis

This study uses a partial budget analysis for the mechanised production system of plant materials and integrated control plants. Partial budget analysis is widely used in evaluating changes in either crops or technology. (Lowenberg-DeBoer et al. 2019). Partial budget analysis is applied if there are two options to consider and the results of the analysis are only based on indicators of increase and decrease in net income or increase and decrease in costs and separate the positive and negative effects into several sections

To determine the benefits or implications, the estimated production costs and income at the cultivation scale will be evaluated. The analysis carried out looks at the cost of reduced or introduced pesticides and any additions to natural control.

Results and discussion

The cost of production and income

The cost of producing grain corn and sweet corn includes service provider costs, plant material costs, fertiliser costs and pest control costs. There is an increase in cost which is the cost of drying for grain corn because the final product is corn kernels that are dried compared to sweet corn that is sold wet in the form of corn cobs. *Table 2* shows a comparison of grain corn production costs between conventional methods and IPM and *Table 3* also shows a comparison of the cost of sweet corn using FAW insecticides and IPM as a control for FAW.

This production cost is calculated assuming that all the costs of using the conventional cultivation method (control using FAW poison) are the same as the system using the IPM approach.

Table 1. The concept of the partial budgeting approach

Benefits	Value	Implications	Value
Return increase Increased income due to change	RM XX	Return decrease Reduced income due to change	RM XX
Cost decrease Reduced costs due to change	RM XX	Cost increase Increased costs due to change	RM XX
Total benefits	RM XX (**A**)	Total Implications	RM XX (**B**)
Net Income [(A)-(B)] = – (value)/ + (value)			

Table 2. Estimated cost of production and income of grain corn

Item	Grain corn conventional[1] (2020)	Grain corn IPM (2022)
Yield (ton)	6.2[2]	6.5[2]
Selling price (RM/ton)	1,000.00	1,000.00
Total revenue	6,200.00	6,500.00
Variables costs:		
1) Service provider		
Disc plow, comb plough, rotary plough, planting machinery, boom sprayer	2,335.00	2,335.00
2) Plant material		
Seeds (20 kg x RM15)	300.00	300.00
3) Fertiliser		
Green NPK (RM/kg)	920.00	920.00
Urea (RM/kg)	286.00	286.00
4) Pest control		
Herbicide: *Altrazine*	75.00	75.00
Herbicide: *Metalachlor*	328.60	328.60
FAW control: *Emamectin benzoate*	480.00[2]	240.00[2]
FAW control: *Chlorantraniliprole*		140.00[2]
IPM: Pheromone Set (P061-90Lure, ChemTica)		496.00[3]
5) Drying (mobile dryer) (RM0.13/kg)	845.00	845.00
Total variable costs	5,569.60	5,965.60
Gross margin	630.40	534.40
Production cost/kg	0.90	0.92

[1]Production costs are based on practices used at the start of the FAW outbreak in 2019 except for yield and pest control
[2]Production results and costs are based on practices used at the time of the 2021 study
[3]The production cost is for 16 units of pheromone, spikes, and pheromone holder containers, for use throughout 1 growing season. This set of pheromones is recommended by MARDI (2022)

Table 3. Estimated cost of production and income of sweet corn

Item	Sweet corn conventional[1] (2020)	Sweet corn IPM (2022)
Yield (cob/ha/season)	26,500[2]	29,680[2]
Selling price (RM/cob)	0.75	0.75
Total revenue	19,875.00	22,260.00
Variable costs		
1) Service provider:		
Disc plow, comb plough, rotary plough, planting machinery, boom sprayer	2,335.00	2,335.00
2) Plant material		
Seeds (10 kg x RM160)	1,600.00	1,600.00
3) Fertiliser	1,372.00	1,372.00
4) Pest control		
Herbicide: *Altrazine*	75.00	75.00
Herbicide: *Metalachlor*	328.60	328.60
FAW control: *Emamectin benzoate*	432.00[2]	432.00[2]
FAW control: *Chlorantraniliprole*		123.10[2]
FAW control: *Lufenuron*	1,296.45[2]	
FAW control: *Acetamiprid*	300.85[2]	
IPM: Pheromone set (P061-90Lure, ChemTica)		496.00[3]
Total variable costs	7,739.90	6,761.70
Gross margin	12,135.10	15,498.30
Production cost/kg	0.29	0.23

[1] Production costs are based on practices used at the start of the FAW outbreak in 2019 except for yield and pest control
[2] Production results and costs are based on practices used at the time of the 2021 study
[3] The production cost is for 16 units of pheromone, spikes, and pheromone holder containers, for use throughout 1 growing season. This set of pheromones is recommended by MARDI (2022)

Replacement of variable costs does not consider other costs and only involves the cost of insecticides where for the conventional system, the use of chemical pesticides is used while for the system using IPM, the use of pheromones from Costa Rica is used together with the poison *Emamectin benzoate* and *Chlorantraniliprole* as biological control for this system.

Partial budget analysis

Partial budget analysis that shows the difference between benefits and implications in production costs and results that focus on the impact on farmers' income. The results of the analysis (*Tables 4* and *5*) show that with the change from conventional (control using FAW poison) to using IPM that has an impact on yield and cost. For grain corn, the implications outweigh the benefits, while for sweet corn, the benefits outweigh the implications.

For the cultivation of grain corn with IPM, farmers can increase their income by RM300 with an increase in yield of 300 kg. This increase is not significant because the agricultural practices that have been used by farmers resemble the SOP recommendations for FAW control practices developed by MARDI (2022) compared to the practices practiced in 2019, in addition to reducing the cost of insecticides by RM240. However, the use of pheromones with the cost of RM496 and the addition of *Chlorantraniliprole* (RM140), could not offset the existing variable cost expenses, causing the implication costs to exceed the benefits of RM96 (*Table 4*).

In contrast to the cultivation of sweet corn, cultivation with the use of IPM succeeded in increasing the yield by 12 % (3,180 cobs = RM2,385) and reducing the use of *Lufenuron* and *Acetamiprid* insecticides by RM1,596.30. This reduction is supported by the FAW control practice SOP developed by MARDI which helps to reduce the use of pesticide spray rates from using four types of poison (*Emamectin benzoate, Cypermethrin, Lufenuron* and *Acetamiprid*) to only two types (*Emamectin benzoate* and *Chlorantraniliprole*) with the spray rate reduced from 18 times to only five times in sweet corn fields. Although there is an increase in the cost of Pheromone (RM496) and the cost of *Emamectin benzoate* poison of RM123.10, the benefits received exceed the implications of RM3,363.19 (*Table 5*).

Recommendation and conclusion

The use of this IPM system provides benefits in two forms, namely financial and environmental. In the use of IPM for grain corn, IPM provides more environmental than financial benefits. The results of the research in the grain corn field, the participation of farmers as experimenters using this IPM method in the farmer's experiment plot to apply the MARDI SOP. The economic or financial results are not significant, but as a long-term effort it is difficult to implement since it is difficult for farmers to continue using it without economic benefits except with government intervention financial incentives or legislation to maintain environmental sustainability from IPM practices.

Unlike sweet corn farmers, they benefit more in both financial and environmental aspects where after using the IPM method and MARDI SOP in controlling FAW, they can obtain financial benefits of RM3,363.19 because of an increase in yield by 12% and a reduction the use of insecticides from 18 times to five times of spraying.

Therefore, the use of IPM for FAW control is suitable to be implemented in areas that have never practiced the SOP suggested by MARDI to obtain higher yields for sweet corn, but for grain corn, further research needs to be carried out to ensure that the IPM that is implemented is capable provide a significant financial return to ensure the sustainability of IPM use recommendations in the field in line with efforts to ensure environmental preservation.

Table 4. Partial budget analysis of grain corn

A) Benefits	RM	B) Implications	RM
a) Additional revenue		c) Additional costs	
• Increase in yield by 5% (≈300kg)	300.00	• Increased insecticide *Emamectin benzoate*	
		• ChemTica pheromone set	496.00
b) Cost reduction		d) Reduction of revenue	
• Cost reduction of *Chlorantraniliprole* insecticide	240.00	• None	0.00
Total interest	540.00	Total implications	636.00
Benefits/implications	RM - 96.00	/season	

Table 5. Partial budget analysis of sweet corn

A) Benefits	RM	B) Implications	RM
a) Additional revenue		c) Additional costs	
• Increase in yield by 12% (3,180 cobs)	2,385.00	• Increased insecticide *Emamectin benzoate*	123.10
		• ChemTica pheromone set	496.00
b) Cost reduction		d) Reduction of revenue	
• Cost reduction of *Lufenuron* and *Acetamiprid* insecticides	1,597.30	• None	0.00
Total interest	3,982.30	Total implications	619.10
Benefits/implications	RM3,363.19/season		

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Abstrak

Fall armyworm (FAW), *Spodoptera frugiperda*, dikenali sebagai perosak pelbagai tanaman pertanian di sekitar Eropah, Afrika, Asia dan Australia. Pada 2019, perosak ini dilaporkan menjejaskan tanaman jagung di Vietnam, Thailand, Myanmar, Indonesia dan Malaysia. Kawalan FAW menggunakan satu kaedah kawalan lazimnya kurang berkesan. Pendekatan pengurusan perosak bersepadu (IPM) merupakan salah satu kaedah pengurusan yang dicadangkan untuk petani jagung bijian dan jagung manis untuk mengawal FAW. MARDI telah menjalankan kajian tentang penggunaan feromon dari Costa Rica untuk mengawal FAW dewasa dan pengenalan racun perosak dengan bahan aktif *Chlorantraniliprole* dan *Emamectin benzoate*. Melalui pengenalan kawalan tersebut, kajian ini bertujuan untuk menilai kos pengeluaran dan pulangan serta analisis kos dan faedah dalam mengawal FAW di kedua-dua ladang jagung. Penggunaan IPM untuk kawalan FAW dalam jagung bijian menyebabkan peningkatan kos sebanyak RM96 berbanding dengan tidak menggunakan kaedah IPM, namun masih berupaya meningkatkan hasil meningkat sebanyak 300 kg. Bagi jagung manis, menggunakan IPM untuk kawalan FAW memberikan kelebihan RM3,363.19 lebih daripada tidak menggunakan kaedah IPM dengan peningkatan hasil sebanyak 12%. Kedua-dua jagung mengaplikasikan amalan MARDI dalam pengendalian dan SOP untuk kawalan IPM-FAW. Penggunaan kaedah IPM bertujuan untuk membawa kerosakan akibat FAW di bawah ambang kerosakan ekonomi. Oleh itu, penggunaan IPM untuk kawalan FAW adalah sesuai dilaksanakan di kawasan yang SOP MARDI tidak pernah diamalkan untuk mencapai hasil yang baik terutama di kawasan jagung manis. Walau bagaimanapun, bagi jagung bijian, kajian lanjut perlu dijalankan bagi memastikan kaedah IPM dapat menjana pulangan kewangan yang setara di samping memastikan penggunaan IPM berupaya untuk memastikan kemampanan di samping memastikan perlindungan alam sekitar terjaga.