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RESEARCH ARTICLE

Light traps based-control threshold: An alternative method for hot pepper pests' management

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ABSTRACT

Crop damage-based control threshold of 12.5% has been used to reduce the excessive use of insecticides while controlling *Spodoptera litura* and *Helicoverpa armigera* in hot peppers (*Capsicum annuum* L.) cultivation systems. However, it is necessary to develop an easy, practical, inexpensive control threshold to increase farmer eagerness in reducing pesticide use. The study aimed to evaluate a light trap captured based-control threshold for both hot pepper pests. The activity was conducted at Lembang (*ca*. 1250 m a.s.l.), West Java, Indonesia, from September 2022 to April 2023. Six treatments and four replicates were arranged in a randomized block design. The treatments included the use of four light trap captured based-control thresholds, i.e., ≥ 30, ≥ 25, ≥ 20, ≥ and 15 moth trap^{-1} wk^{-1}; crop damage based-control threshold of 12.5%; and once per week insecticide application as a control treatment. The study found that the implementation of pests' control threshold of ≥ 25 moth trap^{-1} wk^{-1} could reduce 75% insecticide use compared to the plant damage-based control threshold. The use of this approach could maintain high crop production and generate a return rate of 1.26. The findings will be beneficial for farmers in reducing insecticide use.

Key words: Armyworm, *Capsicum annuum* L., economic feasibility, technical feasibility, tomato worm.

INTRODUCTION

Hot pepper (*Capsicum annuum* L.) is one of the most prominent vegetables with high economic value in tropical and subtropical regions, including Indonesia (Syafruddin, 2017; Han et al., 2018; Chakrabarty et al., 2019; Barchenger et al., 2020) and commonly consumed as a supply of nutrients, minerals, and vitamins (Kerketta et al., 2018; Saleh et al., 2018).

Pests' attacks in hot pepper cultivation could be detrimental and lead to yield losses. Armyworm (*Spodoptera litura* F.) and tomato worm (*Helicoverpa armigera* H.) are two of hot pepper key pests in many Asian countries and cause severe damage (Meena et al., 2017; Bragard et al., 2019; Ramadhan et al., 2020; Prabaningrum et al., 2022). *Spodoptera litura* infestation could cause more than 75.0% yield losses in hot pepper (Sarkar et al., 2015), and 25.8%-100.0% yield lost in bell pepper (Nagal et al., 2016). Growers typically heavily rely on chemical insecticides to control those pests and apply an average of 12 kg ha^{-1} pesticide in a 3- to 4-mo cultivation season. Pesticides are commonly applied around 23 times during each growing season. However, yield losses remained relatively high in the intensive use of this chemical treatments (Kumar et al., 2017; Mariyono, 2017; Tuan et al., 2017; Patra and Samanta, 2018).

Integrated pest management (IPM) is a valuable and ecologically delicate effort in controlling pest population and has been an emphasis of crop protection research over the past decades. The implementation of IPM can reduce costs and pesticide use (Peterson et al., 2018; Krupke and Tooker, 2020; Zhao and Gao, 2020;

Isaac, 2021). The economic threshold (ET) is one of foundational IPM principles and it aims to prevent the increasing pest population from reaching the point where its damage causes the equivalent level of economic loss and management cost. However, ET is barely used by farmers and agricultural specialists (Seiter, 2018; Hoidal and Koch, 2021). Indonesians have applied crop damage based-control threshold of 12.5% to control *S. litura* infestation in hot pepper cultivation. However, farmers found this approach difficult since it requires significant cost and time for conducting pest observations. Therefore, it is necessary to develop more practical and economical control thresholds of hot pepper pests including *S. litura* and *H. armigera* that could be quickly adopted and implemented by farmers.

Both, *S. litura* and *H. armigera*, are nocturnal insects, and they are drawn to sources of light that produce a lot of ultraviolet emissions. Light traps were then created based on this behaviour and this tool was used for monitoring, forecasting pest outbreaks, and controlling insect pests (Meena et al., 2018; Punithavalli, 2018; Abbas et al., 2019; Bjerge et al., 2021). Since the quantity of damaged leaves was correlated to the quantity of moths captured by the light trap (Otuka et al., 2020), thus, this study proposed the use of the number of moths that captured in light traps as control threshold for *S. litura* and *H. armigera* in hot pepper crops cultivation system.

MATERIALS AND METHODS

The study was conducted at the Margahayu Research Field Station of Indonesian Vegetable Research Institute (IVegRI), Lembang (1250 m a.s.l.), West Java, Indonesia, from September 2022 to April 2023. Six treatments and four replicates were arranged in a randomized block design. The treatments included the use of four light trap captured based-control thresholds, i.e., ≥ 30, ≥ 25, ≥ 20, and ≥15 moth trap^{-1} wk^{-1}, (e) 12.5% crop damage based-control threshold, and once per week insecticide spraying as a control treatment. Accordingly, spinosad (0.1 mL L^{-1}) was applied to the crops in the certain treatment plot if the number of moths caught in the light traps reached threshold level.

Five light traps were positioned diagonally in the experiment field (Figure 1) on the day of hot pepper (*Capsicum annuum* L.) seedlings transplantation. The light trap was constructed using a wavelength of 365-400 nm lamp that powered using a solar cell panel. Locally produced lamp trap (West Java, Indonesia) with 5.5 V solar panel current source specs, powered by Panasonic 18650 type battery 3.7 V and LED lamp with wavelength 365-400 nm and output of 0.5 W. The lamp was positioned above a plastic basin containing 2 L diluted detergent (Figure 1). The diluted detergent was made by combining 10 g detergent (Rinso, Unilever, London, UK) with 1 L water. The diluted detergent was changed in each observation time to maintain the water freshness and prevent the damage of captured pests. The height of the traps was continually adjusted accordingly to ensure that the trap positioned above the crop' canopy (Figure 1).

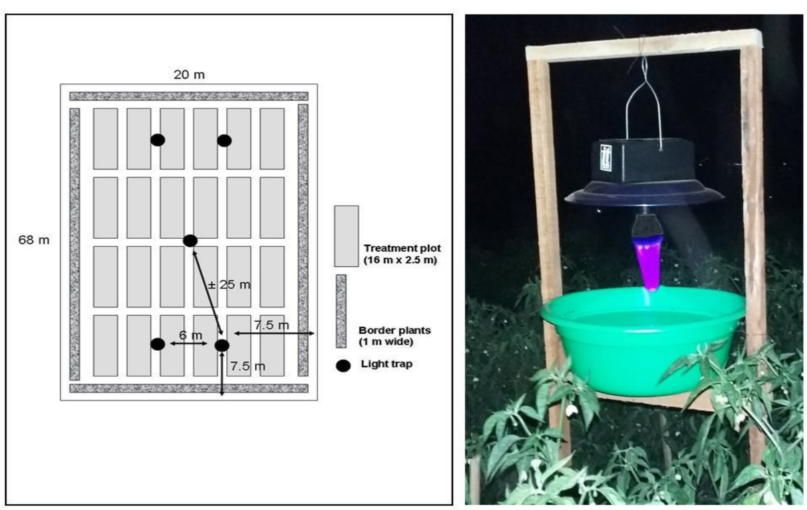

Figure 1. Light trap arrangement in the experiment field (left) and trap position among crop (right).

The hybrid hot pepper 'Kastilo' was cultivated in treatment plot, each one 40 m^2 (16 m × 2.5 m). The hot pepper seedlings were transplanted in 50 cm × 60 cm double-row configurations to meet 128 plants in each plot. The basic fertilizer was chicken manure (20 t ha^{-1}) applied along with other fertilizers including N (110 kg ha^{-1}), P_2O_5 (110 kg ha^{-1}), and K_2O (180 kg ha^{-1}). Observations were conducted every week starting from week two after transplanting. Ten systematically selected plant samples were carefully observed on the observation day. The intensity of crop damage caused by both pests was determined using Equation 1 (Prabaningrum and Moekasan, 2021) as follows:

$$P = \frac{\Sigma (n \times v)}{N \times Z} \times 100\% \qquad (1)$$

in this formula P represents plant damage intensity (%); v is damage value (score) for each plant determined by the area of its leaves that has been attacked, specifically: 0 (no damage), 1 (> 0%-≤ 20%), 3 (> 20%-≤ 40%), 5 (> 40%-≤ 60%), 7 (> 60%-≤ 80%), 9 (> 80%); n represents the quantity of plants with the same value for v (plant damage); Z represents the greatest damage score (9); and N represents the quantity of plants observed.

The severity of fruit damage caused by *S. litura* and *H. armigera* at harvest time was determined based on the number of fruits attacked by those pests and the number of healthy fruits per treatment. The damage intensity was calculated using the Equation 2 (Prabaningrum and Moekasan, 2021):

$$\text{Fruit damage intensity (\%)} = (\text{Number of damaged fruit per plot}/\text{Total fruit per plot}) \times 100\% \qquad (2)$$

The number of *S. litura* and *H. armigera* moths caught in traps were counted separately and recorded two times per week to prevent damage of moth. If left in the traps for more than 3 d, the captured moth will become a wreck and will be hard to be identified. Since both pests caused similar damage symptoms in both leaves and fruits, the decision of control treatment was determined based on the total number of both pests caught in the trap per week. Additionally, the number of insecticide applications in each treatment was recorded. The efficiency of pesticide application was calculated using the following formula:

$$E (\%) = [(TA - TT)/TA] \times 100\% \qquad (3)$$

in this formula, E represents the efficiency of pesticide application, TA corresponds to the number of pesticide applications in control and TT is the number of pesticide applications in certain treatment. The observation data were analysed using PKBT-STAT 1.0 software (Center for Tropical Horticulture Studies, IPB University, Bogor, Indonesia). The least significant difference (LSD) test at 5% was used to further evaluate the difference among treatments.

Until recently, the application of pest captured in light trap based-control thresholds is categorized as an innovative approach to control hot pepper pests and reduce the pesticide use in this system in Indonesia. Thus, it is important to evaluate whether this innovative approach is more feasible than earlier techniques. Partial budged analysis was widely used to evaluate the significant impact of the newest technologies (El-Deep Soha, 2014). Based on this analysis a new technique could be recommended to replace the old technology if the new approach can increase net income or generate a return rate (R) greater than 1 (El-Deep Soha, 2014). The partial budget analysis calculates the magnitude of changes in revenue, variable costs, and net income due to changing technology. The following Equations 4 and 5 (El-Deep Soha, 2014) were used to analyse the economic data generated from the implementation of the new pest control threshold.

$$\Delta NI = \Delta TR - \Delta VC \qquad (4)$$

$$R = \Delta NI/\Delta VC \qquad (5)$$

in this formula TR represents the total revenue (USD ha^{-1}) that was calculated by yield (kg ha^{-1}) × yield price (USD kg^{-1}). The VC is total variable cost (USD ha^{-1}), calculated by quantity of input used (unit ha^{-1}) × input price (USD $unit^{-1}$). The NI is revenue, determined by total revenue – total cost changes. The Δ means the difference of change. The ΔNI represents the difference between the net income generated from the application of control thresholds based on moth catches using light traps, and the net income generated from the application of control thresholds based on 12.5% plant damage. The ΔTR signifies the difference of the hot pepper yield between the crops protected using the application of control thresholds based on moth catches using light traps and control thresholds based on 12.5% crop damage. The ΔVC represents the difference of the variable cost between the red chili grown using the application of control thresholds based on moth catches using light traps and the application of control thresholds based on 12.5% plant damage; and R represents the rate of return.

Criteria used in decision-making includes if NI stays unchanged or drops, the recent technology will be dismissed; if NI rises and VC stays the same or declines, then the new technology can be adopted; if NI and VC increase, the R-value is calculated. If the R-value is ≥ 1.0, then the recent technology can be adopted or the higher the NI and R, the more economically attractive it is to be adopted. For partial budget analysis, the sales results, observation costs, light trap costs, pesticide spraying costs, and pesticide costs were recorded.

RESULTS

Number of *S. litura* and *H. armigera* moths captured in light traps

The number of *S. litura* and *H. armigera* moths caught in light traps started to increase on the 35 d after transplanting and fluctuated throughout the growing season (Figure 2). *Spodoptera litura* (armyworm) is well known as major hot pepper in West Java, Indonesia, this study confirmed that this pest population was consistently higher than that of *H. armigera*. Spinosad was applied in the plots of control threshold ≥ 15 moths $trap^{-1}$ wk^{-1} since an average of 16 moths (*S. litura* + *H. armigera*) was caught in trap on the 35 d after transplanting.

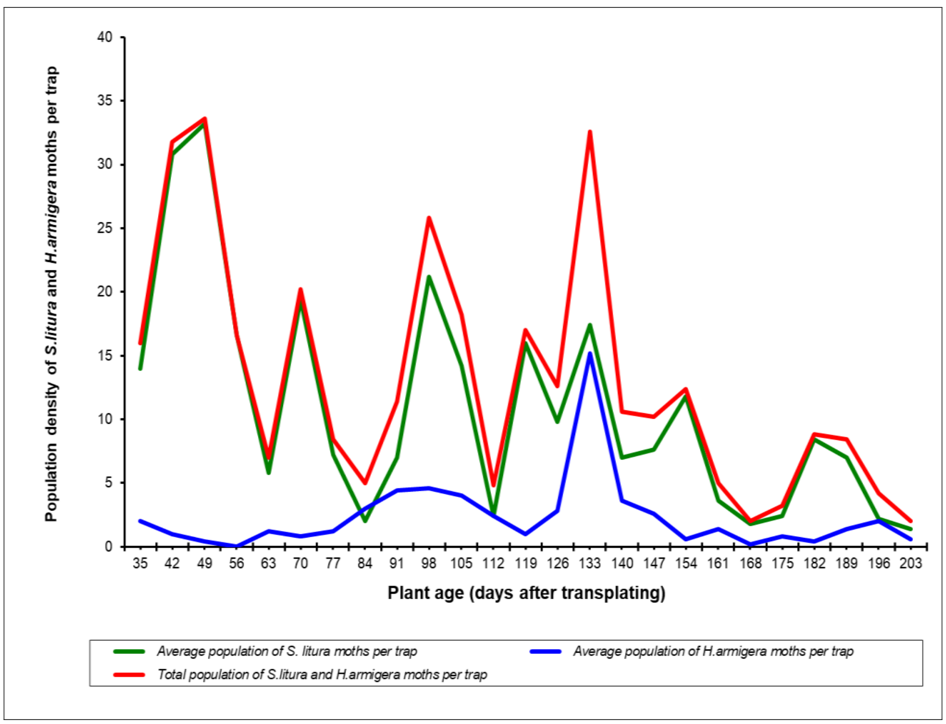

Figure 2. Number of *Spodoptera litura* and *Helicoverpa armigera* moths caught in trap wk^{-1}.

Plant damage and number of insecticide applications

Figure 3 depicts crop damage data that emphasizes the significance of applying moth catch-based management thresholds. Plant damage had only reached 5% at 35 d, even though the number of moth catches had reached an average of 16 individuals $trap^{-1}$. Because the crop damage was less than the control level (12.5% damage), no pesticide was applied in 12.5% plant damage treatment. As a result, plant damage under this treatment increased at 42 d after transplanting.

The insecticide was applied accordingly when the number of moths caught in the trap reached the established control threshold level. The number of insecticide applications in each light trap treatment is presented in Table 1. The number of insecticide applications in the treatments ≥ 15, ≥ 20, ≥ 25 and ≥ 30 moths $trap^{-1}$ wk^{-1} were 9, 5, 4 and 3 times, respectively.

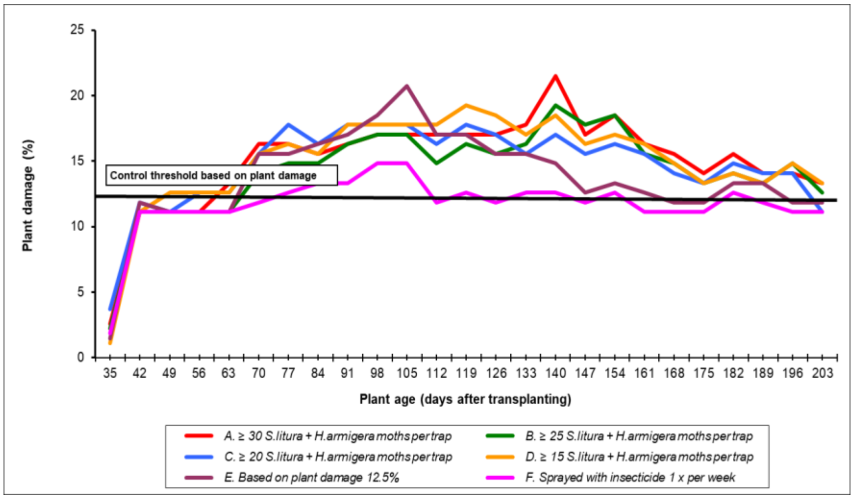

Figure 3. Plant damage due to *Spodoptera litura* and *Helicoverpa armigera* attacks.

Table 1. Number of insecticide applications and percentage of the reduction of insecticide applications.

Treatments	Number of insecticide applications	Percentage of reduction in insecticide applications in each treatment compared to that in... 12.5% plant damage	Once per week insecticide application
≥ 30 *Spodoptera litura* + *Helicoverpa armigera* moths trap^{-1} wk^{-1}	3	81.2	89.2
≥ 25 *S. litura* + *H. armigera* moths trap^{-1} wk^{-1}	4	75.0	85.7
≥ 20 *S. litura* + *H. armigera* moths trap^{-1} wk^{-1}	5	68.7	82.1
≥ 15 *S. litura* + *H. armigera* moths trap^{-1} wk^{-1}	9	43.7	67.8
12.5% plant damage	16	-	42.8
Once per week insecticide application	28	-75.0	-

Crop yield

The yield of crops protected based on pest control threshold of more than 30 moths trap^{-1} wk^{-1} experienced the significantly lowest yield (51.0 kg 40 m^{-2}) compared to the yields in other treatment plots (Table 2). This lowest yield was caused by the significantly higher attacks of *S. litura* and *H. armigera* on the crops compared to those in other treatments (Table 3). The percentage of unmarketable fruit (7.8%) in this treatment was also significantly different from other treatments, and consequently affected the farmer' income.

Table 2. Hot peppers yield in various treatments. The mean values at the same column followed by the same letters are not significantly different according to the least significant difference (LSD) test at the 5% level.

Treatments	Marketable fruits		Unmarketable fruits (kg 40 m^{-2})
	kg 40 m^{-2}	t ha^{-1}	%
≥ 30 *Spodoptera litura* + *Helicoverpa armigera* moths trap^{-1} wk^{-1}	51.0^{b}	10.2	4.4^{a}
≥ 25 *S. litura* + *H. armigera* moths trap^{-1} wk^{-1}	72.2^{a}	14.2	1.5^{b}
≥ 20 *S. litura* + *H. armigera* moths trap^{-1} wk^{-1}	72.4^{a}	14.4	1.5^{b}
≥ 15 *S. litura* + *H. armigera* moths trap^{-1} wk^{-1}	71.5^{a}	14.3	4.4^{a}
12.5% plant damage	71.3^{a}	14.2	4.0^{a}
Once per week insecticide application	72.2^{a}	14.4	2.9^{b}
LSD 5%	12.4		2.0
CV, %	10.0		15.4

Table 3. Intensity of pest and disease attacks on the harvested hot pepper. Mean values in the same column followed by the same letters are not significantly different according to the least significant difference (LSD) test at the 5% level.

Treatments	Intensity of fruit damage due to pest and disease attacks		
	Spodoptera litura and *Helicoverpa armigera**	*Bactrocera* sp.	*Colletotrichum* sp.
	%		
≥ 30 *S. litura* + *H. armigera* moths $trap^{-1}$ wk^{-1}	4.5[a]	5.1	3.6
≥ 25 *S. litura* + *H. armigera* moths $trap^{-1}$ wk^{-1}	2.3[b]	4.6	2.4
≥ 20 *S. litura* + *H. armigera* moths $trap^{-1}$ wk^{-1}	2.0[b]	4.5	2.4
≥ 15 *S. litura* + *H. armigera* moths $trap^{-1}$ wk^{-1}	2.2[b]	4.7	2.2
12.5% plant damage	2.3[b]	4.1	2.8
Once per week insecticide application	1.9[b]	3.9	2.0
LSD 5%	0.7	-	-
CV, %	15.3	21.6	32.4

Partial budget analysis

The implementation of use of 25 moths catches in light traps-based control threshold was considered as the best method to reduce pesticide used in hot pepper cultivation compared to other treatments. However, the changes in crop protection from the use of 12.5% crop damage based-control threshold to the use of 25 moths catches in light traps-based control threshold caused the differences in revenue and costs as presented in Table 4.

Table 4. Change in revenue and variable cost due to the control techniques changing. [1]Cost and revenue change due to the alteration of crop protection technique from the application of 12.5% crop damage based-control thresholds to the application of 25 moths captured in light traps based-control threshold. The cost and revenue were calculated for hot pepper cultivation in 1000 m^2.

Description	Change in crop protection technique[1]		
	12.5% crop damage based-control thresholds	Number of moths captured in light traps based-control threshold	Change (Δ)
I. Yield			
Weight (kg 1000 m^{-2})	0.11	0.12	-0.001
Price (USD kg^{-1})	1.49	1.49	0.00
Total revenue (USD 1000 m^{-2}) (TR)	2657.43	2691.32	33.89
II. Variable cost per 1000 m^2 (USD 1000 m^{-2})			
Light trap depreciation	0.00	17.82	-17.82
Labour for observation	44.91	6.42	38.50
Labour for pesticide spraying	51.33	12.83	38.50
Cost of insecticide	59.03	1.48	57.56
Capital cost (1.67% mo^{-1} for 8 mo)	20.75	5.15	15.60
Total variable cost (USD 1000 m^{-2}) (VC)	176.02	43.70	132.32
Income (USD 1000 m^{-2}) (NI)	2481.41	2647.62	-166.22
Rate of return (R)		1.26	

DISCUSSION

The results showed that at 42 and 49 d after transplanting, more than 30 individuals trap^{-1} wk^{-1} were caught in the light traps installed in the field, thus insecticide was applied in all treatment plots. The insecticides could be effectively used to manage both pests as indicated by the declining number of pest population in the following week after the insecticide application. The use of light traps might indirectly reduce the populations of *S. litura* and *H. armigera* larva by suppressing larva population in the field. Previous studies found a significant negative correlation between the larval population and the number of moths caught in light traps. If the moth catches in light traps increased, the population of pest larvae declined (Abbas et al., 2019).

The adoption of catchment-based control thresholds is critical and can be used to forecast future crop loss. In 12.5% plant damage treatment of this study, no pesticide was applied in the field. As a result, plant damage under this treatment increased at 42 d after transplanting. Light traps could be used to monitor pest populations and predict the possible pest outbreak (Meena et al., 2018; Punithavalli, 2018; Abbas et al., 2019; Bjerge et al., 2021). The number of pest moths caught in traps is highly correlated to the increased level of plant damage (Otuka et al., 2020). The hot peppers damage in this study reached more than 12.5% starting from 70 d after transplanting until harvesting period. Consequently, in the treatment plots of 12.5% plant damage-based control threshold, insecticide was applied sixteen times throughout the crop season.

The previously established control threshold for *S. litura* and *H. armigera* attack in hot pepper cultivation in Indonesia was based on 12.5% plant damage (Prabaningrum and Moekasan, 2021). In this study, pest attacks reached its crop damage based-control threshold 16 times throughout the crop season, consequently pesticide should be applied to the crop 16 times to control pest attacks. The use of crop damage based-control threshold could reduce insecticide applications by 42.8% compared to farmer' pesticide application practices (once a week spraying time). However, this was considerably still less than the 67.8%-89.2% reduction in the number of insecticide applications based on moth caught in light trap. Additionally, the application of the number of moths captured in light trap-based control thresholds could reduce the frequency of insecticide applications by 43.7%-81.2% compared to the application of 12.5% plant damage based-control threshold. Similarly, Kumar et al. (2013) reported that light traps use could reduce 90.0% insecticide applications commonly applied to control *Manduca sexta* in North Carolina.

The attacks of *Bactrocera* sp. (fruit fly) and *Colletotrichum* sp. (anthracnose) were evenly distributed in each treatment plot and insignificantly different among treatments. This indicated that the low hot pepper yield in the treatment based on control threshold of ≥ 30 individuals caught trap^{-1} wk^{-1} was caused primarily by the *S. litura* and *H. armigera* attacks.

Various research reported the advantages of using light traps for monitoring and controlling insect pests, such as the utilization light traps in different pest-infested areas, the capacity of traps to capture a vast number of insect species in a short amount of time and to reduce pest populations, its cost-effective use in terms of the labour and skills required. Additionally, this technique is safe for humans, animals, and natural enemies; and it does not cause pest resistance, chemical residue, and pollution, and more importantly it is easy to be implemented by farmers in the field (Kammar et al., 2020). Light traps are also important in the pull function of the push-pull strategy because they lure pests away from the main crop and make pest control easier. The push-pull strategy is the most effective approach for lowering insect density and dispersal (Guera et al., 2023). Thus, the use of light traps is considered as the safest and most efficient IPM technique used to control *S. litura* and *H. armigera* in hot pepper cultivation system.

A partial budget analysis was conducted to evaluate whether the implementation of this new technique was technically and economically feasible to be implemented by farmers. This economic evaluation is important since the crop yield in the implementations of new treatment was insignificantly different compared to the previous crop protection technique. The variable costs for applying the new control threshold-based crop protection included light trap depreciation, labours for pest observations, labours for insecticide spraying, pesticides, and bank interest. The application of new control thresholds resulted in an increase farmer income (USD 33.89) due to the increase of hot pepper production (23.25 kg).

The altering costs in the application of control thresholds based on the catches of *S. litura* and *H. armigera* moths in light trap^{-1} wk^{-1} (USD 132.32) were due to reductions in observation labour costs, insecticide spraying labour costs, insecticide purchase costs, and bank interest. The rate of return on applying the control thresholds based on 25 moths captured trap^{-1} wk^{-1} was 1.26. If a recent technology has a rate of return of ≥ 1, that technology could be considered as a profitable technology (El-Deep Soha, 2014) and therefore it could be suggested to be implemented.

CONCLUSIONS

Control thresholds based on *Spodoptera litura* and *Helicoverpa armigera* moth catches in light traps of 25 individuals trap^{-1} wk^{-1} generated the maximum pesticide application effectiveness of 75%. The partial budget analysis indicated that the implementation of this control threshold is profitable with return rate of 1.26; thus, farmers could use this prospective technique to reduce pesticide use in hot pepper cultivation.

Author contribution

Conceptualization: T.K.M., Methodology: T.K.M., L.P., W.S., Validation: T.K.M., W.S. Investigation: R.M., A.M., T.K.M., W.S., A.H., I.S., N.G., E.K., A.K.K., B.K.U., A.S. Resources: R.M., A.M., T.K.M., A.H., I.S., N.G., E.K., B.K.U., N.G., A.K.K., W.A., R.T., A.S. Data analysis: T.K.M., R.M., A.S. Writing-original draft: T.K.M., R.M., W.S. Writing and editing: N.G., R.M., A.M., W.S., W.A., A.S. Supervision: T.K.M. All co-authors reviewed the final version and approved the manuscript before submission.

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