PROMOTION OF BIOLOGICAL CONTROL FOR SAFER VEGETABLE PRODUCTION IN SOUTHEAST ASIA: IS THE ENVIRONMENT CONDUCIVE NOW?

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ABSTRACT

In this paper, presents case studies on vegetable legumes and leafy brassicas – the two most important crops in Southeast Asia – especially from Cambodia, Lao PDR and Vietnam. Since the pesticide misuse has been documented on these crops, it has become highly imperative to develop, validate and scale-out effective alternatives to reduce pesticide misuse in vegetable production. Integrated pest management (IPM) packages have been developed using pheromones, bio-pesticides and need-based applications of selective pesticides. They were validated in on-station as well as farmer participatory trials in Cambodia, Lao PDR and Vietnam. Multi-location trials confirmed that the performance of the IPM package was on par with farmers' practices (calendar-based application of chemical pesticides) in reducing the infestation by target pests, without compromising yield. In addition, the IPM package also supported the proliferation of natural enemies in vegetable production systems. Furthermore, these IPM packages can play a greater role in safer vegetable production. However, majority of the farmers in Southeast Asia still do not have access to most of the IPM inputs including bio-pesticides. Hence, a public-private partnership has become inevitable to introduce and promote IPM products, considering also the recent progress made on the harmonization of regulatory procedures for registration of bio-control agents across Southeast Asia, which can expedite the introduction of IPM products in this region.

Keywords: vegetables, pesticide misuse, biological control, regulatory environment, public-private partnership.

1. INTRODUCTION

Vegetables are an important component in the Agrifood systems in Southeast Asia. Vegetables are cultivated in an area of 4.02 million ha in Southeast Asia with an annual production of about 45.59 million t (FAO, 2018). They are grown by a large number of small-holder farmers, since vegetables can generate more revenue per unit area than cereals (Joshi *et al.,* 2006; Safi *et al.,* 2011; Joosten *et al.,* 2015). In addition, vegetable farming provides more employment per hectare than cereals (Weinberger and Lumpkin, 2007). However, the vegetable productivity in Southeast Asia is comparatively lower (11.35 t/ha) than the Asian average (20.04 t/ha) (FAO, 2018). Although several factors contribute for reduced yield, biotic stresses especially pests and diseases are one of the most important limiting factors in vegetable production in Southeast Asia.

Vegetable legumes and leafy brassicas are the two most important crops in Southeast Asia. Yard-long bean (*Vigna unguiculata* subsp. *sesquipedalis*) and leafy brassicas such as Chinese cabbage

(*Brassica rapa* var. *pekinensis*), pak-choi (*B. rapa* var. *chinensis*), choisum (*B. rapa* var. *parachinensis*) and Chinese kale (*B. oleracea* var. *alboglabra)* are among the most important vegetables in Cambodia, Lao PDR and Vietnam and most of the production is for home consumption and local markets. Cambodia imports vegetables from Thailand and Vietnam and Lao PDR is mostly dependent on Thailand for its vegetable supply during the rainy season (Kethongsa *et al.,* 2004; Tim Vutha, 2012). Chinese kale, Chinese mustard, pak-choi and yard-long bean dominate these imports (Kethongsa *et al.,* 2004). Yard-long bean and leafy brassicas contribute protein, vitamins, minerals and dietary fiber to diets. In addition to nutrition, these crops also have the potential to lift farmers out of poverty due to their high market value. For instance, the average sales value of yard-long bean is US$ 4,400/ha per cropping cycle in Lao PDR, while the value of Chinese kale in Cambodia is US$ 6,900/ha (Genova *et al.,* 2006 a, b; Genova *et al.,* 2010). Since these vegetables account for 64-75% of the total vegetable area in Cambodia, Laos and Vietnam, their contribution to overall livelihoods is significant (Genova *et al.,* 2010). However, their productivity is limited, mainly due to insect pests and plant diseases.

Insect pests severely limit the productivity of yard-long bean and leafy brassicas and trigger the overuse of pesticides. Although legume pod borer (*Maruca vitrata*) is rated as the major pest of yard-long bean, common armyworm (*Spodoptera litura*), aphid (*Aphis craccivora*) and thrips (*Megalurothrips* sp.) are also serious pests. Yield losses of up to 30% in yard-long bean due to *M. vitrata* damage alone are reported in Laos and Vietnam, if the crop is left unprotected. Aphids and thrips cause up to 60% yield losses in green beans including yard-long bean (Ngu *et al.,* 2009). Diamondback moth (*Plutella xylostella*) is the dominant pest of brassicas, although *S. litura,* cabbage butterfly (*Pieris rapae*) and striped flea beetle (*Phyllotreta striolata*) cause marketable yield losses of up to 100% in leafy brassicas in Cambodia, Laos and Vietnam (Ungsa and Vanharn, 1995; Nhung *et al.,* 2008).

Vegetable farmers generally resort to indiscriminate, repeated application of chemical pesticides in their attempts to prevent crop losses by pests and diseases. A study found that Vietnamese farmers on average sprayed pesticides on yard-long bean weekly as a prophylactic measure, using a mixture of two to three pesticides (Schreinemachers *et al.,* 2014). Cambodian growers mixed an average of four pesticides together in a single spray (Schreinemachers *et al.,* 2017). Surprisingly, farmers in Laos sprayed more frequently than in Cambodia and Vietnam. In Cambodia and Laos, much of the pesticides sold comes from neighbouring countries and mostly has foreign language labels (CEDAC, 2004; Escalada *et al.,* 2006; Phanith, 2011). A recent study also showed that the highest level of pesticide overuse was in Vietnam with 100% of vegetable farmers overusing pesticides, followed by Cambodia with 73% and Laos with 59% of the sampled vegetable farmers spending more on pesticides than needed (Schreinemachers *et al.,* 2020). Indiscriminate pesticide use can lead to potential health hazards, food safety concerns and environmental problems, including high human health risk in vegetable production and high-risk perception among consumers due to high pesticide residues in the harvested vegetables (Praneetvatakul *et al.,* 2013; Nguyen *et al.,* 2020). In addition, insect pests subjected to indiscriminate pesticide use increases the likelihood of developing resistance to the pesticides. Resistance of *M. vitrata* and/or *P. striolata* to commonly used pesticides has been reported in other South- and Southeast Asian countries (Feng, 1990; Ulrichs *et al.,* 2001; Sreelakshmi *et al.,* 2015).

In Cambodia and Vietnam, pesticides are often applied to vegetables until close to harvest (Middleton *et al.,* 2004; Hoi, 2010), leaving a harvest interval too short for pesticide residue to reduce to safe levels. Hence, the harmful effect on consumer health is likely to be high. Among vegetables sampled from multiple markets in Phnom Penh, 15% of yard-long bean and 95% of kale contained detectable levels of organophosphate and carbamate pesticides (Neufeld *et al.,* 2010). An increasing concern about food safety in Vietnam is perceived among consumers, which consider chemical pesticides as a higher safety hazard compared to biological contamination or nutritional imbalance, since chemicals could bring health issues of unknown consequence (Ha *et al.,* 2019). Urban consumers, especially the emerging middle-classes in Southeast Asia, are increasingly demanding vegetables with minimal pesticide residue and are willing to pay higher prices for these products. But, for example, the supply of vegetables with reduced pesticide residue can only meet 30% of the demand in Ho Chi Minh City (Simmons and Scott, 2007). Thus, excessive pesticide residue on vegetables excludes farmers from high-value domestic and export markets (Hoi, 2010) and limit potential for economic development.

In addition, pesticide misuse can adversely affect the health of women and children who are engaged in farm operations as family labourers, especially in Cambodia and Vietnam, where 20% of agricultural households are headed by women (FAO, 2010a, b). In intensive yard-long bean and leafy brassicas production areas of Cambodia, Laos and Vietnam, a large majority of farmers have experienced a range of pesticide poisoning symptoms after spraying (Schreinemachers *et al.,* 2017).

Unless complex biotic constraints in vegetable production are addressed in a comprehensive integrated pest management (IPM package), it will not be possible to significantly reduce overall pesticide use. However, private input dealers typically promote the use of chemical pesticides due to liberal policies and windfall profits and tend to neglect bio-pesticides. Hence, IPM has not been widely adopted in Cambodia, Laos and Vietnam (Srinivasan *et al.,* 2019a). In recent years, IPM packages were developed using pheromones, bio-pesticides and need-based application of selective pesticides and then piloted in on-station as well as farmer participatory trials. In this paper, we present IPM case studies on vegetable legumes and leafy brassicas from Cambodia, Laos and Vietnam.

2. SAFER VEGETABLE PRODUCTION IN SOUTHEAST ASIA

Safer vegetable production can be achieved by reducing the over-reliance on harmful chemical pesticides and through the adoption of sustainable pest management approaches such as bio-pesticides. However, application of a single bio-pesticide or chemical pesticide may impose a huge selection pressure on insect pests and thus leading to the evolution of resistance. In addition, it may not provide sufficient control of different key insect pests on a particular crop. Hence, we evaluated an IPM strategy based on sequential application of various bio-pesticides and chemical pesticides against major insect pests on yard-long bean and leafy brassicas in Cambodia, Laos and Vietnam.

2.1. Cambodia

The effectiveness of microbial pesticides (*Bacillus thuringiensis* and *Metarhizium anisopliae* formulations) and neem leaf extract alone and in combination (as an IPM package) were evaluated against aphids, thrips and pod borer on yard-long bean in three different provinces of Cambodia during 2015-2018. Initially, six bio-pesticides [Xentari® (*B. thuringiensis* subsp. *aizawai*), Crymax® (*B. thuringiensis* subsp. *kurstaki*), E"911® (*B. thuringiensis* subsp. *kurstaki*), Real M-62® (*M. anisopliae*), Real M-69® (*M. anisopliae*) and neem] were tested along with abamectin (positive control) and an untreated check, during July–October 2015 and January–May 2016 in Kandal, Kampong Chhnang, Svay Rieng and Prey Veng provinces of Cambodia. Each treatment was replicated for three times, following a randomized complete block (RCB) design. The results showed that the bio-pesticides reduced the incidences of thrips, the infestation by the aphid and the pod-borer to the levels equivalent to abamectin during trials in 2015 and 2016. Although the yield was significantly higher in bio-pesticide treated plots than in untreated plots in 2015, the yield did not differ significantly among the treatments in 2016 trials (Srinivasan *et al.,* 2019b). In line with this, combined (sequential) application of these bio-pesticides in an IPM package was subsequently validated, since the IPM components might have synergistic or additive effects in reducing the pest damage as well as increasing the crop yield.

Subsequently, 12 field trials were conducted in Kandal, Kampong Chhnang and Prey Veng provinces of Cambodia during 2016-2018 to evaluate the efficacy of an IPM package against aphid, thrips and pod borer on yard-long bean. IPM treatment was a sequential application of bio-pesticides (*B. thuringiensis* subsp. *aizawai*, *B. thuringiensis* subsp. *kurstaki* and *M. anisopliae* formulations) along with the chemical pesticide and the spraying order was designed based on the incidences of target pests in a given season and the location. The IPM package was compared with the Farmers' practice (calendar-based application of abamectin and cypermethrin alternatively) and an untreated control. The trials were conducted in an RCB design with six replications for each treatment. The performance of the IPM package was on par with Farmers' practice in reducing the infestations by target pests, without compromising yield. Specifically, the pod infestation was reduced by 38-75% in the treated plots compared to the untreated control plots (Srinivasan *et al.*, 2019b). Thus, the IPM package was shown to be a better alternative to chemical pesticides in managing the insect pests on yard-long bean in Cambodia.

Similar approaches were also used to screen the bio-pesticides against key insect pests of Chinese mustard and subsequently an IPM package was developed and piloted. Six field trials were conducted in Kandal, Kampong Chhnang, Svay Rieng and Prey Veng provinces of Cambodia to assess the effectiveness of *B. thuringiensis* and *M. anisopliae* formulations, as well as neem leaf extract against diamondback moth (DBM), common armyworm, cabbage webworm (*Hellula undalis*) and striped flea beetle (SFB) during 2015-2016. Each treatment was replicated for three times, following an RCB design. All the bio-pesticides reduced the incidence of DBM, common armyworm, *H. undalis* and the damage by SFB to the levels equivalent to abamectin. However, the yield was significantly higher in bio-pesticide treated plots than in untreated plots in 2015, but it did not differ among the treatments in 2016 trials (Srinivasan *et al.*, 2020). Again, it necessitated the sequential application of various bio-pesticides in an IPM package in Chinese mustard.

Subsequently, six field trials were conducted in Kandal, Kampong Chhnang and Prey Veng provinces of Cambodia during September 2016 – January 2018 to evaluate the efficacy of an IPM package against DBM, *H. undalis*, *S. litura* and SFB on Chinese mustard. IPM treatment was a sequential application of bio-pesticide formulations, along with the chemical pesticide and the spraying order was designed based on the incidences of target pests in a given season and the location. The IPM package was compared with the Farmers' practice (calendar-based application of abamectin and cypermethrin alternatively) and an untreated control. The trials were conducted in an RCB design with six replications for each treatment. The IPM treatment significantly reduced the larval population of DBM, *S. litura* and *H. undalis* and the feeding damage by SFB on Chinese mustard compared to the untreated control plots. The marketable yield was also significantly higher in IPM treated plots than the untreated control plots (Srinivasan *et al.*, 2020). Thus, the bio-based IPM package was also shown to be a better alternative to chemical pesticides in managing the insect pests on Chinese mustard in Cambodia.

2.2. Lao PDR

Three field trials were conducted on yard-long bean, two at Clean Agriculture Standards Center (CASC) (August–October 2014 and February–April 2015) and one at Viengkham district during January–May 2015. Three treatments, (i) IPM [sequential application of Zitarback F.C.® (*B. thuringiensis* subsp. *aizawai*), Thai neem 111®, abamectin and Redcat® (*B. thuringiensis* subsp. *kurstaki*)], (ii) abamectin and (iii) an untreated control were used in the trials. The experiments were conducted in an RCB design with four replications for each treatment. The recommended dose of each chemical or bio-pesticide was applied weekly until the final harvest. Pod damage by *M. vitrata* and *A. craccivora* and yield at every harvest were recorded. In the first trial at CASC and the trial in Viengkham district, the mean pod borer damage (15-22% and 24-26%), aphid damage (0.50-4% and 3-6%) and yield (7 t/ha and 8-9 t/ha) did not differ significantly among the treatments. However, the mean pod borer damage in the IPM treatment (13%) was lowest (F=6.92; p=0.02) in the second trial at CASC. The aphid damage was also significantly lower in the IPM treatment (25%) compared to the untreated check (54%) (F=7.31; p=0.02). The yield in IPM treatment and abamectin was on par (4-6 t/ha) and significantly higher than untreated check (2 t/ha) (F=19.82; p=0.001).

The fourth and the final IPM trial was conducted on yard-long bean at Phaxay village, Kasi district in Vientiane province during September–November 2016. The IPM package (sequential application of Zitarback F.C.®, Thai neem 111®, abamectin and Redcat®) was compared with the farmers' practice (calendar-based spraying of abamectin). The experiments were conducted following RCB design, with eight replications for each treatment. The mean pod borer damage was significantly lower in IPM plots (10%), compared to the farmers' practice (18%) (F=49.72; p=0.0002) and the yield was similar in both the treatments. Thus, the IPM package for yard-long bean demonstrated its effectiveness in reducing the pest damage and providing similar yield like farmers' usual practice of calendar-based pesticide application.

In cabbage, four IPM trials were conducted at Phaxang village, Kasi district in Vientiane province during January–March 2016. Three treatments, (i) IPM (sequential application of Zitarback F.C.®, Thai neem 111®, abamectin and Redcat®, plus installation of *P. xylostella* and *S. litura* pheromone lures), (ii) abamectin and (iii) an untreated control were used in these trials. The experiments were conducted following RCB design, with four replications for each treatment. Incidences of DBM, *S. litura,* cabbage cluster caterpillar (*Crocidolomia pavonana*), cabbage butterfly and damage by SFB and yield at harvest were recorded. The results showed that *S. litura* incidence did not differ significantly among the treatments in all the field trials. SFB damage and the incidence of *C. pavonana* were significantly lower than untreated control in only one trial. However, farmers' practice recorded the lowest DBM and cabbage butterfly larval populations, which was followed by IPM, while untreated control recorded the highest larval populations. The yield was also significantly higher in farmers' practice (50-54 t/ha), followed by IPM (46-50 t/ha) in all the trials (Srinivasan *et al.,* 2019c). Thus, IPM strategy was found to be effective in managing the major insect pests (DBM and cabbage butterfly), but the slightly lower yield in IPM plots than in the farmers' current practice should be compensated by the premium price for the safer cabbages, which would encourage the farmers to adopt IPM packages. In addition, application of bio-pesticides based IPM package was found to enhance the proliferation of natural enemies such as *Pteromalus puparum* (parasitizing *Pieris rapae*) in cabbage fields in Laos (Srinivasan *et al.,* 2017).

2.3. Vietnam

Two field trials, one at Thanh Tri district, Hanoi (May–July 2015) and the other at Mai Son district, Son La province (May–July 2015) were conducted on yard-long bean to validate an IPM package. The treatments were (i) IPM [sequential application of *M. anisopliae* and *B. thuringiensis* subsp. *kurstaki* formulations and Virtako® (20% chlorantraniliprole and 20% thiamethoxam), sex pheromone traps for *S. litura*, blue and yellow sticky traps], (ii) famers' practice (calendar-based application of Virtako®) and (iii) an untreated control. The experiments were conducted in a RCB design with 10 replications for each treatment in Hanoi and five replications in Son La. The recommended dose of each chemical or bio-pesticide was applied weekly until the final harvest. Pod damage by *M. vitrata* and yield at every harvest were recorded. The results confirmed that there was no significant difference between the IPM strategy and the farmers' practice in pod damage (6-9% in Hanoi and 3-5% in Son La) and yield (12-14 t/ha in Hanoi and 15-16 t/ha in Son La). Hence, the IPM strategy was effective in reducing the pod damage and in increasing the yield in farmers' fields.

One set of field trials was conducted on yard-long bean at Duyên Ha commune, Thanh Tri district, Hanoi during April–July 2016. The treatments were (i) IPM (sequential application of *M. anisopliae*, *B. thuringiensis* subsp. *kurstaki* and *B. thuringiensis* subsp. *aizawai* formulations and Virtako®, Match® (lufenuron), sex pheromone traps for *S. litura*, blue and yellow sticky traps) and (ii) farmers' practice (calendar-based application of Virtako® and Match® alternatively). IPM was implemented in ten farmers' fields, whereas farmers' practice was tested in five fields and each field was considered as a replication and data was analyzed using Student's *t* test. The results confirmed that there was no significant difference between the IPM strategy and the farmers' practice in reducing the pod damage (8.92% and 8.07%, respectively) (t=0.84; p=0.42) and increasing the yield (13.46 t/ha and 13.96 t/ha, respectively) (t=0.93; p=0.37). Thus, the IPM strategy was effective in reducing the pod damage and in increasing the yield in the farmers' fields, which can be scaled out among the yard-long bean farmers in Vietnam.

2.4. Conclusions from the IPM Trials

Multi-location trials of all the three Southeast Asian countries confirmed that the performance of the IPM package in both yard-long bean and brassicas was on par with farmers' practice (calendar-based application of chemical pesticides) in reducing the infestation by target pests, without compromising yield. In addition, the IPM package also showed to proliferate the natural enemies in a few vegetable production systems. Based on these results, the evaluated IPM packages can play a greater role in safer vegetable production.

3. STATUS AND OPPORTUNITIES FOR BIO-CONTROL BASED SAFER VEGETABLE PRODUCTION IN SOUTHEAST ASIA

Although several projects have developed, piloted and scaled up IPM packages for various crops in Southeast Asia (Shepard *et al.*, 2009), a majority of the growers still do not have access to most of the IPM inputs including bio-pesticides. For instance, no farmer was using bio-pesticides in yard-long bean and leafy brassicas in Laos, whereas only one percent of the surveyed respondents were using some bio-pesticides in Cambodia (Schreinemachers *et al.*, 2017). However, this study showed that 74% of the sampled farmers in Vietnam were using bio-pesticides. This reveals the development of bio-pesticide industry and adoption of IPM in a few countries such as Indonesia, Thailand and Vietnam (Jäkel, 2017), whereas it is almost non-existing in countries like Laos. Although the bio-pesticide industries are present in a few SE Asian countries, they are mostly small and medium sized enterprises, producing and/or marketing only a very few products, that too in a limited geography within the country or region. In addition, most of these companies are importers of bio-pesticide products and their investment for developing their own local bio-pesticide products is almost negligible.

However, several countries have developed the standards for good agricultural practices (GAPs) as a response to food safety and environmental concerns and started promoting them among the farmers in Southeast Asia in the recent decade. For instance, Laos expects an increase of Lao GAP farms to 100,000 in 2020 from 300 farms in 2016. In contrast, Vietnamese Good Agricultural Practices (VietGAP) introduced to farmers in 2008 has been adopted by less than 5% of farmers nationwide (Hoang, 2020). Hence, it has become imperative to understand the major barriers for the adoption of GAPs. This will enable the vegetable farmers in Southeast Asia to adopt the concept of GAPs, which results in food products that are safe and wholesome for consumers, besides contributing to the improved productivity, in particular for the small-scale farmers (Laosutsan *et al.,* 2019), as well as for a better environment. IPM products, bio-pesticides in particular can fill the gap in the adoption of GAPs, if these products are made available at affordable prices within the reach of the vegetable producers. Hence, a public-private partnership has become inevitable to introduce and promote IPM products in Southeast Asian countries. The recent progress made on the harmonization of regulatory procedures for registration of bio-control agents across Southeast Asia under the ASEAN Sustainable Agrifood Systems (SAS) project can expedite the introduction of IPM products in this region. In fact, 2500 bio-inputs have been registered for ASEAN trade (https://www.asean-agrifood.org/download/results-at-a-glanceas-of-september-2017/?wpdmdl=10508). Moreover, it is expected that bio-control products will expand its niche in the plant protection market in the near future and thus enable safer vegetable production across Southeast Asia.

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