Study Brief 32: Impact

Impact of integrated pest management in rice and maize in the Greater Mekong Subregion

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Summary

Between 2011 and 2016, CABI and the Institute of Plant Protection, Chinese Academy of Agricultural Sciences (IPP-CAAS) led two integrated pest management (IPM) projects in Southwestern China, Laos and Myanmar, which promoted the adoption of biological pest control among rice and maize farmers. The project focused on the establishment of *Trichogramma* rearing facilities (TRFs) for the production of *Trichogramma* egg-cards, which act as an effective biocontrol agent for maize and rice, as well as

training farmers in IPM practices. At the end of 2017, CABI conducted an extensive assessment of the sustainability of TRFs and the impact of the interventions on IPM adoption in the target areas. The study found that the projects had led to significant reductions in chemical pesticide use among target rice farmers, as a result of the adoption of alternative IPM practices. The assessment also revealed the integral role of government policy in promoting the sustainable adoption of IPM in the Greater Mekong Subregion (GMS).

Key highlights

- At the end of the two projects in mid-2016, 20 TRFs were still producing *Trichogramma* egg-cards; by the end of 2017 this number had dropped to 11.
- The key reason for the termination of TRF production was a shortage of funds. After the projects came to an end, TRFs were reliant on government funding as none had yet transitioned to commercial production.
- Farmers using egg-cards significantly decreased the amount spent on pesticide by appx 37% and almost halved the numbers of times crops were sprayed.
- During the study, 45% to 100% of maize farmers reported an increase in yields whilst applying *Trichogramma* egg-cards.
- Farmers expressed willingness to pay for *Trichogramma* egg-cards, but not at commercially sustainable prices. Government subsidies therefore appear to be necessary to support sustainable production of *Trichogramma*.
- It is important to consider the economic and ecological context when selecting a target area to introduce biocontrol agents. Commercial markets for the widespread adoption and application of biocontrol agents do not exist in many GMS areas.

Context

Rice and maize are the two most important crops in Southwestern China, Laos and Myanmar, which make up part of the GMS. Rice is not only the primary source of food in the region, but also provides work and income for 80% of the population (Johnston *et al*., 2010). Similarly, maize is a staple crop for both human consumption and animal feed, and is produced by around 19 million farmers in the above mentioned countries. Despite significant improvements in rice production in the GMS over the past 15 years, irrigated rice yields have remained low, averaging 3-4 t/ha, in Laos and Myanmar (Heinrichs and Muniappan, 2017). One of the key reasons for these relatively low yields is the impact of pests, diseases and weeds.

To date, where pest control measures are implemented in the GMS, farmers have predominantly relied on the intensive use of broad spectrum pesticides, particularly in China where half of all pesticides applied globally are used (Pretty and Bharucha, 2015). This has led to increased pesticide resistance and more frequent outbreaks of secondary pests, such as plant hoppers in rice (Heong and Hardy, 2009). There is therefore an urgent need for more sustainable and economically viable pest management approaches for rice and maize in the GMS. In both maize and rice, the key pests come from the order of Lepidoptera insects (e.g. the Asian Corn Borer). Many of the major pests from this group have been successfully targeted worldwide by releasing the egg parasitoid *Trichogramma*, which acts as a biocontrol agent. Biocontrol is commonly used in IPM, which encompasses a variety of pest monitoring and control practices, and is widely accepted as an economically viable and sustainable approach to pest management.

However, farmers in the GMS had no prior experience of using *Trichogramma* egg parasitoids as a biocontrol agent and IPM knowledge was limited, particularly on use and production of suitable biocontrol agents (Babendreier *et al*., 2016). In 2011, CABI and IPP-CAAS launched two IPM projects, funded by EuropeAid, with partners in China, Laos and Myanmar to address this challenge and support smallholder farmers in the GMS to improve the region's livelihoods and food security. The projects aimed to increase smallholder farmers' maize and rice yields and reduce input costs by introducing IPM methods for both crops and reducing use of pesticide treatments. Overall, 137 training sessions on rice IPM practices were provided to more than 6,400 GMS farmers and approximately 10,000 farmers were trained in maize IPM practices.

A major component of the projects was the establishment of large-scale TRFs for *Trichogramma* egg-card production. In Laos and Myanmar, the maize IPM project promoted a village-level enterprise model to develop commercial TRFs with capacity to produce and sell egg-cards for 500-1,000 ha of maize. Farmer groups were established to run these TRFs and provided with business training, as well as training in practical rearing techniques. Project funding, supplemented by small-scale farmer enterprises, was used to construct new buildings and cover other start-up costs for the village-led TRFs. In China, the maize TRFs, which were largely government funded, were established in village buildings and run by paid community individuals with a view to developing a sustainable system. The long-term aim was to cover the production costs by charging farmers a small fee for egg-cards; however, the facilities are considered a community asset rather than profit-making enterprises.

The rice IPM project was more research focused, so developing a sustainable business model for the TRFs was not a priority and government partners saw provision of *Trichogramma* egg-cards as a service that fitted within their remit. By the end of the projects, 12 rice TRFs had been established, four in each country, while 8 out of 10 maize TRFs were still operational, four in China, three in Myanmar and one in Laos.

What we did

To assess the impact of the two interventions in introducing IPM practices to maize and rice farming in the GMS, CABI conducted an in-depth examination of how the TRFs were performing and the adoption of IPM practices, including *Trichogramma* egg-cards, during October-December 2017 – 18 months after project activities had come to an end. The study employed quantitative and qualitative data collection tools, including key informant interviews (KIIs), focus group discussions (FGDs) and a farm household questionnaire survey (HHS) to collect information in selected GMS areas.

The TRFs were seen as key intervention sites in so far as the IPM training and release of *Trichogramma* egg-cards took place in their vicinity. A pre-survey interview was therefore conducted with project managers in the three target countries in order to select 13 representative TRFs to collect information from for the subsequent assessment of project outcomes. In each country, at least one rice TRF and one maize TRF was selected for the assessment (see Table 1). The selected TRFs included both those that had high *Trichogramma* egg-card production and those that had stopped operations.

Table 1. Locations where TRFs were established and the year that mass *Trichogramma* rearing started

SW China – village/township	Laos - districts	Myanmar
Maize		
Dehong prefecture Yunnan Province • **Tuanging** (2014) [50T; 10C] *2F* • Husa (2015) • **Sudian** (2015) *2F* • **Mengdian** (2015)	Vientiane Province • **Sanakham** (2015) 2F • Xaiaboury • Paklai (N/A)	Southern Shan State • **Thanlun** (2014) • **Pinphit** (2015) 1F Northern Shan State • Kharshi (2016) • Sakhanthar (2016)
Rice		
Dehong prefecture, Yunnan Province: • **Tuanqing** (2014) • **Mangshi PPQS** (2014) [51T; 11C] 2F Xing'an county, Guangxi Province • ***Maiyuan*** (2014) • **Hejiatang** (2015) [54T; 19C] 2F	Vientiane Capitol Province, • **Vientiane** PPC (2013) 4F Sayabouri Province • ***Phieng*** (2015) • Sayabouri (2015) • Xienghou (2015)	Yangon region • **Yangon PPD** (2015) 4F Sagaing region (2015) • Paleik (2015) Mandalay region • ShweBo (2015) Naypyidaw Union Territory • Yezin Agriculture University (2016)

*Note: T = no. of farmers in the HHS treatment group; C = no. of farmers in the HHS control group; F = no. of FGDs. On-site visits to implement KIIs were carried out in locations in **bold** or with individuals from locations in **bold italics** travelling to a central location.*

Key informant interviews

Seven different types of key informants were interviewed, including staff from the country project implementation team; local agricultural authorities; local IPM trainers/extension staff; TRF managers and staff; village committee members or village heads in the *Trichogramma* release area; TRF customers; and agro-input dealers. In total, 61 KIIs were carried out in China, Laos and Myanmar (see table 2). In China, all KIIs were conducted by an independent impact assessment team member, whilst in Laos and Myanmar, country project managers acted as interpreters for some KIIs. The questions were primarily directed at the sustainability of TRFs.

Table 2. No. of key informant interviews

	China		Laos		Myanmar	
	Maize	Rice	Maize	Rice	Maize	Rice
Project implementation team	1	3	1	1	1	1
Local agricultural authorities	0	2	1	2	1	0
Local IPM trainers/extension staff	3	1	1	2	1	1
TRF managers and staff	3	4	1	2	1	1
Village committee members or village heads	3	2	0	1	2	1
Customers	0	2	0	0	1	3
Agro-input dealers	3	4	1	1	1	1
Total KIIs	**13**	**18**	**5**	**9**	**8**	**8**

Farmer focus group discussions

Between one and four FGDs were carried out in at least one maize and one rice TRF site per country. Approximately 10 rice or maize farmers attended each FGD. At each site where the FGDs were carried out, the assessment aimed to have at least one farmer group, which had applied *Trichogramma* egg-cards in 2017 (the treatment group), and one group of farmers who had not applied the egg-cards in 2017 or ever, which made up the control group (see Table 1). A total of 19 FGDs were carried out in the three countries, involving 69 maize and 116 rice farmers, with the main questions focusing on the effect of the interventions on farmers' fields and farming practices.

Farm household questionnaire survey

For a subset of selected TRFs in two regions in China, where substantial production and release of *Trichogramma* egg-cards was ongoing in 2017, a farm HHS was conducted. Farmers were selected for the survey from villages supplied with *Trichogramma* egg-cards (the treatment group) and others with similar agro-ecological conditions where egg-cards had not been provided to act as the control group. A total of 195 farmers responded to the household survey in China, including 105 rice farmers using *Trichogramma* egg-cards, 30 control group rice farmers, 50 maize farmers using the egg-cards and 10 control group maize farmers (see Table 1). Differences between treatment or control farmers were analysed based on t-tests or Chi2 -tests.

What impact was achieved?

The focus of the assessment was on short-term impacts, i.e. reduction of pesticide use, increase of yields and uptake of sustainable pest management practices. Long-term impacts, such as the sustainability of biocontrol agent production and use, were also considered. The results of the impact assessment suggest that the IPM project interventions meet the needs of all countries regarding their agricultural development strategies, for example, the 'Green Control & Professional Unified Control' and 'Pesticide and Fertilizer Zero Growth Action Plan (2015-2020)' in China or the 'Clean Agriculture' programme in Laos. This was highlighted repeatedly by national and local agricultural authorities involved in the projects.

Sustainability of TRFs

When the projects ended in mid-2016, 20 TRFs were still running (12 TRFs from the rice IPM project and 8 from the maize IPM project). Since then, the projects' national partners have made considerable efforts to sustain TRF activities. As a result, by the end of 2017, 11 TRFs were still producing *Trichogramma* egg-cards for ongoing releases (eight rice TRFs and three maize TRFs), whilst four TRFs continued rearing *Trichogramma* stock (see Table 3).

Table 3. Operation of TRFs established during the last year of the rice and maize IPM projects (mid-2016) and by the end of 2017.

Projects and countries		No. of TRFs running mid-2016	No. of TRFs running end 2017	No. of TRFs only stock rearing in 2017	No. of TRFs producing *Trichogramma* for release 2017	Area treated (ha) with *Trichogramma* in 2017
Rice Project	Laos	4	4	2	2	222
	Myanmar	4	4	0	4	416
	China	4	2	0	2	415
	Sub- total	**12**	**10**	**2**	**8**	**1,053**
Maize Project	Laos	1	1	0	1	270
	Myanmar	3	1	1	0	0
	China	4	3	1	2	554
	Sub- total	**8**	**5**	**2**	**3**	**824**
Sum total		**20**	**15**	**4**	**11**	**1,877**

The main reason that TRFs ceased producing *Trichogramma* egg-cards was a shortage of stable funds to cover TRF running costs, i.e. costs of water and electricity, rearing materials, and staff salaries. Technical capacities for rearing *Trichogramma* was only an issue for one maize TRF in Myanmar, which was run by a farmer group without any technical support from the local governmental extension in 2017. To support sustainable TRF operations, business plans and owner agreements (outlining partner responsibilities) were developed in both projects. However, most TRFs still producing egg-cards in 2017 only partly followed the business plans – the marketing component, for example, was largely ignored – and owner agreements were not widely implemented.

The Yangon TRF in Myanmar is the only TRF where local farmers paid for egg-cards. The farmers paid 50 kyat/card (3.7 USD) for the release of 100 egg-cards on 1 ha. The price was calculated without charging for facility staff salaries, water and electricity, indicating that the TRF could not run commercially based on this low egg-card price. The key informants in China noted that biocontrol products, even when delivered by commercial companies, are generally given away for free by the government, or at least heavily subsidised. To achieve competitive prices for *Trichogramma* egg-cards the key informants felt that the TRFs needed more modern technology and infrastructure to increase efficiency and reduce running costs. For instance, in the facility in Guangxi, China, there is just one air conditioner, which makes it impossible to maintain the optimum temperature and humidity.

To generate additional profits to support TRF operation, innovative community-based approaches for long-term sustainability were piloted in the maize IPM project in one TRF in Laos and three in Myanmar. For instance, a sweet maize processing room was established in Sanakham, Laos to add value to the maize harvested; a post-harvest maize centre (including a maize thresher and drying facility) was established in Pinphit, Myanmar; and input supply centres were established in Sakhanthar and Kharshi, Myanmar. On-site visits during the impact assessment in December 2017, revealed that these small innovation projects, managed by the rural communities, have created income for the farmer groups and are still running well. However, the income has been used to further scale up these side businesses, rather than to support TRF operations, which were not perceived by the farmers to be as beneficial.

The rice TRF in Maiyuan, Xing'an county, China, was still running semi-commercially in 2018 after the Xing'an county Plant Protection Station (XAPPS) – who own the facility – outsourced investment from a local entrepreneur, who set up a private sector company to take over the facility's operations. According to the financial management rules and procedures in China, XAPPS cannot use government funds to directly support TRF production. However, with this alternative arrangement, XAPPS still provides necessary technical support for the facility and helps the company to promote *Trichogramma* egg-cards to other government institutions, as well as acting as the company's main customer. This public-private partnership has improved the TRF sustainability and enabled the company to generate a profit in 2018.

Farmer-level impacts related to *Trichogramma* adoption

HHS results

When comparing yields reported from the last 2017 harvest, the average rice yield was about 7 t/ha. Despite farmers in the treatment group reporting 300 kg more in rice yields, there is no significant difference in the yield obtained compared to the control group of farmers (see Table 4). Slightly higher maize yields were also observed among the treatment group of farmers compared to the control group, but again no significant difference was found.

Table 4. Summary statistics of farm-level benefits reported by rice and maize farmers during household surveys in the last cropping season 2017.

	Treatment		Control	
	Mean	SD	Mean	SD
Rice yield (kg/ha)	7213.3	2590.2	6932.3	1328.7
Maize yield (kg/ha)	5011.2	1726.2	4535.0	2200.6
Household applied pesticides to rice (%)	99.1		100	
Household applied pesticides to maize (%)	66.0		70.0	
Amount spent on chemicals for rice (USD/ha)	148.9**	112.5	201.6	139.9
Amount spent on chemicals for maize (USD/ha)	144.9	110.5	178.6	90.9

*Note: SD = standard deviation. For results related specifically to rice, n=105 and 30 for treatment and control, respectively; and for maize, n=50 and 10 for treatment and control, respectively. ** indicates that there was a significant difference between treatment and control farmers, based on t-tests, at the 5% significance level.*

Virtually all rice farmers and two-thirds of maize farmers applied pesticides to their crop with no difference between the treatment and control groups of farmers. However, a significant difference was found in the decrease in the average amount of money the treatment group of rice farmers spent on pesticides during the 2017 cropping season, compared to farmers in the control group (Table 4). Most of the treatment group rice farmers reported a decrease in pesticide use, while the majority of control farmers reported no change in pesticide use between 2015 and 2017 (see Figure 1). Although fewer maize farmers in the treatment group (15%) reduced pesticide use compared to control farmers (28%) the difference was not significant. Interestingly, there is no significant relationship between crop yields and the amount spent on pesticides per hectare, neither for the treatment groups of farmers (r=-0.020, P=0.82, n=155) nor for the control groups of farmers (r=-0.017, P=0.92, n=40), indicating that higher pesticide inputs do not necessarily translate into higher yields.

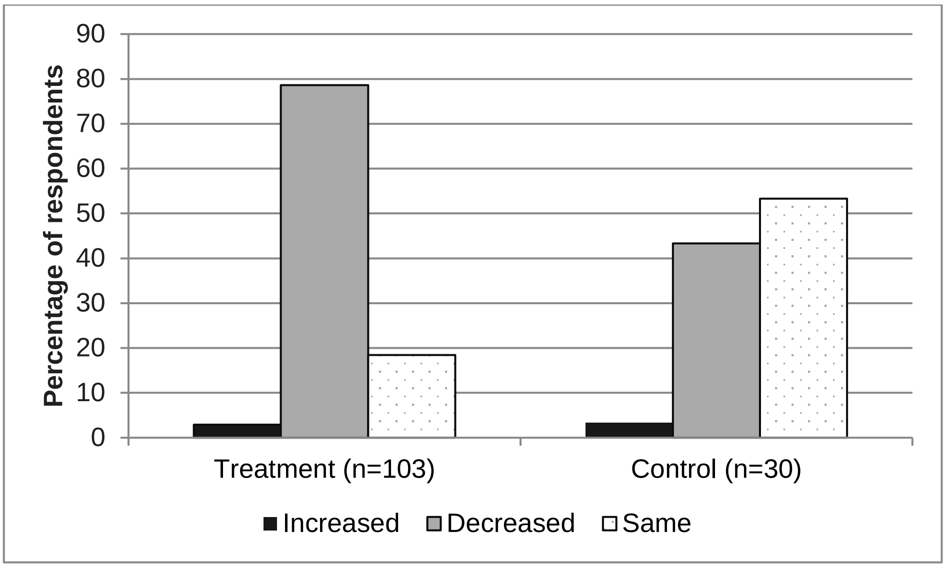

Figure 1. **Trend in pesticide use from 2015 and 2017 for rice farmers in the project implementation areas in Southwestern China, based on farmers' reports from the HSS (*Chi*^{2}=14.9, P<0.001).**

Farmers were also asked for potential reasons for reducing pesticides (Table 5). According to the responses, adoption of alternative IPM methods, particularly application of *Trichogramma* egg-cards; provision of unmanned aerial vehicle (UAV) pest control free-of-charge; and training or information on improved control methods were the main drivers for reduction in pesticide use among sampled households. Significantly fewer farmers in the treatment group reported pest and disease outbreaks compared to control farmers.

Table 5. Reasons for decrease in pesticide use reported by rice and maize farmers during HHS between 2015 and 2017.

Reason	Percentage of treatment farmers (n=86)	Percentage of control farmers (n=15)
1. I learnt from project trainings or other information resources to improve the control methods	37.2	20.0
2. Control effects of pesticide was good compared to last year	18.6	6.7
3. Less pest and disease outbreaks	17.4***	53.3
4. Have alternative IPM methods promoted by other projects (e.g. light traps, pheromone traps)	63.9*	40.0
5. I have applied *Trichogramma* egg-cards	94.2***	20.0
6. It is not up to me to make the decision on pesticide use	1.2	6.7
7. Government provided pest control services free of charge	5.8	0
8. UAV pests control twice, free-of-charge	41.9	46.7

*Note: *** and * indicate that there are significant differences between treatment and control farmers, based on t-tests, at the 1% and 10% significance level, respectively.*

Evidence from the self-reported benefits observed by treatment farmers in the HHS, before and after applying egg-cards, suggests a significant decrease in the number of times insecticides were sprayed by about 40-50%, for both rice and maize farmers (Table 6). Correspondingly, there was a significant decrease in the costs incurred on insecticides by 35-40% once the egg-cards were applied, for both maize and rice farmers.

Table 6: Benefits of egg-card application reported by farmers in the HHS

	Before applying egg-cards		After applying egg-cards	
	Mean	SD	Mean	SD
No. of insecticide sprays on rice (93)	4.24***	1.20	2.23	1.20
No. of insecticide sprays on maize (29)	1.93***	1.51	1.14	1.16
Cost (¥) of insecticides used on rice (86)	620.3***	546.1	386.0	430.8
Cost (¥) of insecticides used on maize (30)	248.3***	261.7	153.5	213.0

*Note: Sample size is provided in brackets. *** indicates that the mean values before applying egg-cards are significantly different to the mean values after applying egg-cards at the 1% significance level, based on t-tests.*

FGD results

During the FGDs, most farmers in the treatment groups reported an increase in yield and a decrease in pesticide application. In the sites assessed, 45% to 100% of the maize farmers reported a crop yield increase whilst applying *Trichogramma* egg-cards. At the same time, chemical spray reductions were noted for 0 to 30% of the treatment group of maize farmers, with chemical costs decreasing for 0 to 35% of these farmers. Yields increased for 0 to 46% of treatment group rice farmers assessed in the FGDs, with a decrease in chemical use from 29% to 35%. Agricultural input costs decreased among these rice farmers by 0 to 65%.

According to observations from local extension workers and FGD feedback, farmers involved in the IPM projects not only learnt about the release of *Trichogramma* egg-cards, but also about many other IPM methods, pest monitoring, etc. HHS data confirms that not only are farmers in the treatment groups implementing biocontrol methods, but significantly more rice farmers in the treatment groups are applying physical control methods (e.g. the project was providing rice farmers in Guangxi province with pheromone traps) and field sanitation practices, when compared to rice farmers in the control groups (Figure 2a and b). However, for a number of measures recommended during the project (e.g. balanced fertilisation or alternative wetting and drying), no difference was observed between treatment and control groups.

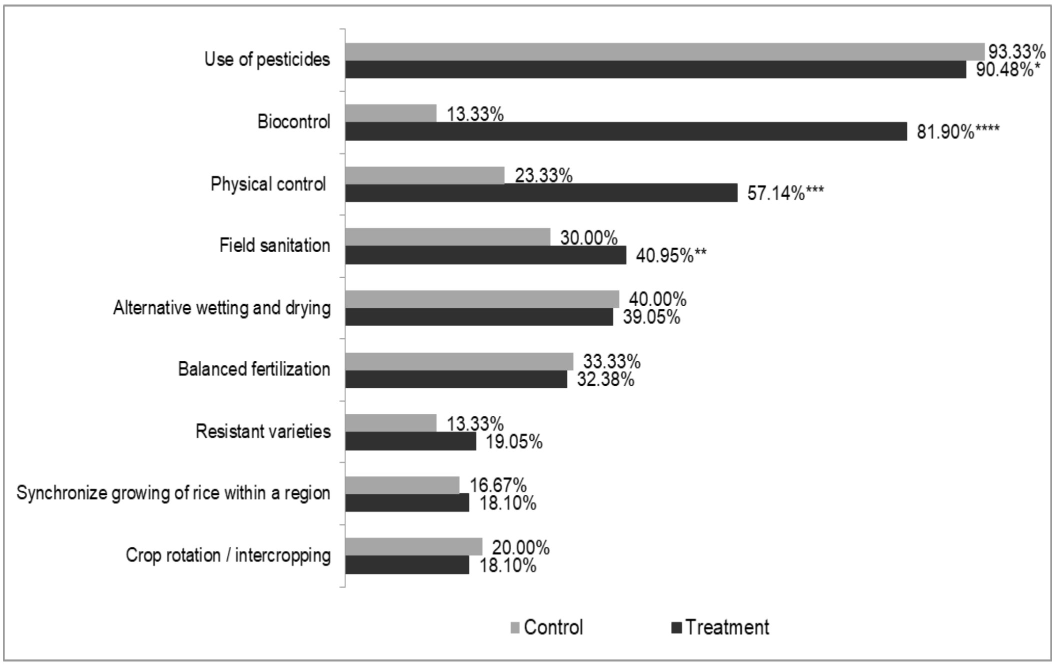

Figure 2a. Adoption of rice IPM practices as reported by farmers during HHS in the last 2017 cropping season (treatment n=105; control n=30). *Note: ***, ** and * indicate that there are significant differences between treatment and control farmers, based on t-tests, at the 1%, 5% and 10% significance level, respectively.*

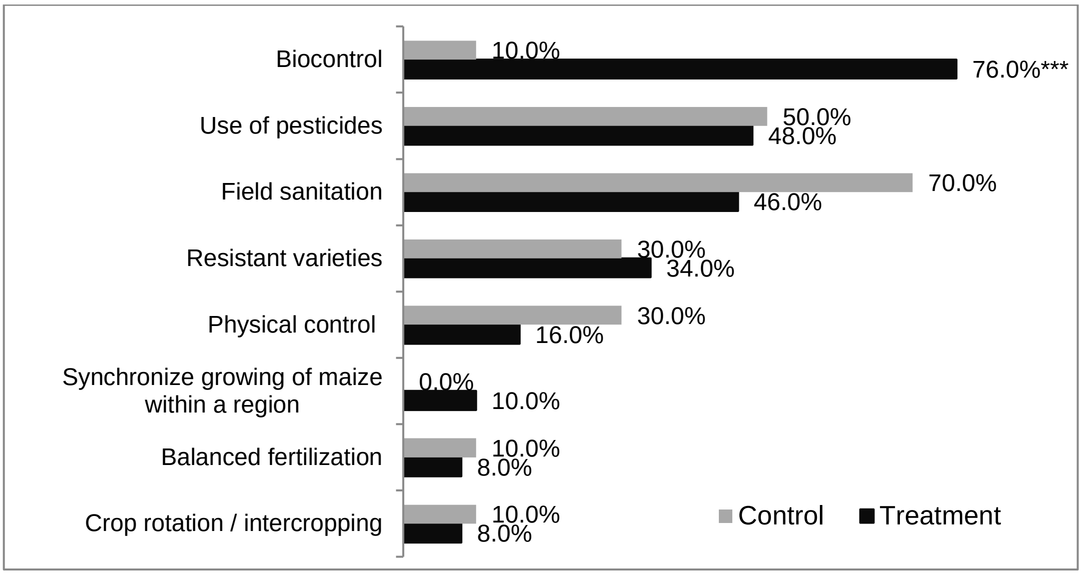

Figure 2b. Adoption of maize IPM practices as reported by farmers during HHS in the last 2017 cropping season (treatment n=50; control n=10). *Note: *** indicates that there are significant differences between treatment and control farmers, based on t-tests, at the 1% significance level.*

In general, farmers' feedback in all target countries indicate that *Trichogramma* cards were applied correctly in maize and rice fields. However, most farmers reported 1-2 releases of egg-cards per season, for both maize and rice, which is less than the 3 releases recommended for full pest control. The majority (61%) of egg-card users applied *Trichogramma* only once during the last cropping season and only about 27% and 11% of the egg-card users applied the cards two and three times, respectively. In China, egg-card placements were supported by partners or extension staff, which obviously helped to get good releases in terms of timing and placements.

During the maize FGDs, 100% of the farmers in the treatment groups in China expressed their willingness to buy *Trichogramma* egg-cards at a price range of 0.4-0.56 USD per card (100 cards are needed per hectare). In Laos, 80% of the farmers in the treatment groups were interested in buying the cards at 0.12 USD per card. Among the treatment group rice farmers involved in the FGDs in China, 75% asserted that they would like to buy *Trichogramma* egg-cards, but at a lower price ranging between 0.08-0.31 USD per card. All rice farmers interviewed in the FGDs in Laos showed willingness to buy egg-cards, again for a lower price of 0.06 USD per card. In Myanmar, farmers involved in the FGDs were unsure of the effects of *Trichogramma* on their fields, only 25% of treatment group farmers said that they would like to buy the egg-cards at a price of 0.04 USD per card. It was generally agreed that farmers are interested in buying egg-cards, as long as the price is lower than for pesticides. However, the actual costs of *Trichogramma* egg-card production (staff salaries, water and electricity charges etc.) was sometimes three times the price that farmers said they would pay.

Behaviour change among other stakeholders

Results from the KIIs

Behaviour changes were reported in the KIIs among all the other stakeholders involved in the IPM projects in the three countries, including the country project implementation team, local agricultural authorities, local extension workers, and TRF managers. In 2017, the two projects won the 2nd Science & Technology award of Dehong Prefecture, Yunnan Province, China, due to their achievements in reducing pesticide use in the project implementation area and the manifold spill-over effects to the whole Prefecture.

All stakeholders interviewed also reported improvements in IPM-based biocontrol knowledge, particularly among local extension workers, who were personally involved in training of trainer (TOT) and farmer training organised by the projects. After attending TOTs, key IPM components, such as preventative cultural control methods, pest monitoring and non-chemical control methods (e.g. biocontrol), became an integral part of extension workers' daily activities. The country partners unanimously agreed that the projects had increased their confidence to promote biocontrol to farmers. This was helped by the establishment of TRFs, which received a high-profile and repeated visits and inquiries from farmers, universities and plant protection organisations outside of the designated coverage areas, in all three countries.

The way forward

Commercially sustainable TRF operations had not been realised at the time of this assessment (18 months after the projects came to an end). The operational funds for the 11 TRFs still producing *Trichogramma* egg-cards in 2017 all came from the governments of the countries in which the TRFs were situated. The reasons for the TRFs' failure to achieve commercial sustainability varied between countries. In China, the TRFs had very basic and low-cost equipment, which resulted in relatively small production capacity and a lower level of competitiveness compared to other natural enemy factories. To reduce running costs and improve potential for commercialisation, TRFs should be standardised and automation should be introduced where possible to increase their production efficiency.

Many non-chemical pest control products (biocontrol agents, light traps, etc.) have been distributed free of charge to farmers in recent years to meet the Chinese government's targets on pesticide reduction. Although this free delivery is positive for short-term reduction of chemical pesticide use, it reduces farmers' incentive to pay for *Trichogramma* egg-cards and therefore inhibits TRF sustainability. In Myanmar and Laos, agricultural production is less intensive than China, and most maize and rice farmers do not apply pest control measures. It is therefore difficult to persuade farmers to invest in

Trichogramma egg-cards when they have not previously incurred input costs for pest management. A combination of these challenges meant that farmers did not perceive enough benefits from the *Trichogramma* releases to incentivise them to pay a price for the egg-cards that would allow sustainable production.

Biocontrol agents are more widely and easily adopted by high-value crop farmers, such as citrus farmers, whose net unit income in Xing'an, China, is 25 times that of rice farmers in the region. In an attempt to commercialise *Trichogramma* egg-cards, at the end of the project national partners promoted the release of the cards in high value crops like citrus fruits, for which farmers are more willing to invest in agro-inputs. However, *Trichogramma* species reared in the TRFs are not necessarily best matched to controlling pests in these different crops and a number of factors still need to be adapted, including the release strategy, before the egg-cards are sold commercially to these farmers. Despite this, initial results for the release of *Trichogramma* cards, targeting swallowtails and noctuid moths, in 13.3 ha of citrus fields in Guangxi Province, China, have been positive.

In developed countries, IPM is most commonly used for high value crops, in relatively simple agro-ecosystems where mono-cropping is practised over large areas of land. Morse and Buhler (1997) have demonstrated that resource-poor farmers often do not match the necessary economic and ecological criteria for the successful implementation of IPM programmes. It is important to consider the context of IPM project interventions – including the socio-economic situation of farmers, current availability and cost of agricultural inputs, and climatic conditions in the target area – to ensure the biocontrol agent has potential for widespread adoption and effective pest control. For instance, *Trichogramma* egg-cards are not effective when applied on an individual basis, to 1 ha or less, by smallholder farmers. In Laos and Myanmar, the projects therefore aimed to promote adoption of the egg-cards by all the farmers in a particular village to avoid dispersal of *Trichogramma* wasps. But this was not fully achieved.

More support should be given to running field demonstrations and marketing promotions to cultivate potential customers for biocontrol agents and nurture the local market for TRFs. Such promotional activities should specifically target large farmers, planting companies or contract farmers, and government extension agencies, as they are more likely to be profitable customers for TRFs. During the KIIs, all national partners suggested that, if the projects had funded an additional 1-2 years of field demonstrations and marketing promotions, it would have helped to commercialise the running of TRFs. However, efforts also need to be made to encourage private sector involvement in TRF operation, as in Maiyuan, China, where a local entrepreneur has successfully taken over running the TRF.

The IPM training provided by the projects appeared to influence farmers to make changes to their pest management practices. By introducing farmers to biocontrol methods, as well as several other IPM practices in the target areas, the two interventions have paved the way for more sustainable maize and rice production, which will benefit the environment and health of the farm households involved. However, more intensive training and widespread awareness raising, including the production of illustrated factsheets, may help to further increase adoption of improved IPM practices in the GMS. But without appropriate incentives, training and awareness raising alone are insufficient to drive significant change. Government policy is crucial for incentivising adoption of environmentally-friendly farming practices such as IPM, particularly when such practices exceed the costs of pesticides. For instance, the provision of subsidies to ensure biocontrol is cost-effective at both a smallholder farm level (including subsistence farmers) and for commercial producers. Globally, biocontrol in field crops tends to be subsidised by governments.

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