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Impact of training vegetable farmers in Bangladesh in integrated pest management (IPM)

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ABSTRACT

This study quantifies the impact of training vegetable farmers in integrated pest management (IPM) in Bangladesh. Data come from a random sample of 300 trained and 300 non-trained farmers producing either bitter gourd (*Momordica charantia* L.) or eggplant (*Solanum melongena* L.). Propensity score matching and inverse probability weighting was employed to correct for selection bias in observable characteristics. A range of outcome indicators along the impact pathway was used. The study finds that trained farmers had better knowledge about insect pests and the proper use of pesticides, adopted more IPM practices, and reduced the frequency of spraying and mixing different pesticides. For eggplant, but not for bitter gourd, trained farmers reduced the quantity of pesticide use and achieved a significantly higher crop yield and gross margin. The effect on consumptive expenditures, which we used as a proxy of income, was insignificant. We conclude that further promotion of IPM adoption among farmers is needed and that it should be a priority to increase the profitability of IPM practices for gradual reduction in synthetic pesticide misuse and a sustainable agricultural production.

1. Introduction

Farmers in low income countries are overly reliant on synthetic pesticides to manage crop pests and diseases (Schreinemachers et al., 2017; Pretty, 2005; Ecobichon, 2001). Although average quantities are not necessarily greater than in high income countries, environmental and human health risks tend to be much higher because of incorrect pesticide use (overuse, unsafe use, and use of obsolete products) and the fact that a large section of the population is engaged in farm work and therefore directly exposed to pesticides (Schreinemachers and Tipraqsa, 2012). The development and promotion of alternative pest control methods is an important component of a wider effort to reduce pesticide risk and to promote a more sustainable form of agricultural production.

Such alternatives are usually packaged in the form of integrated pest management (IPM), which aims at a more rational deployment of a variety of pest control methods designed to complement, reduce or replace the application of synthetic pesticides (Pretty and Bharucha, 2015). IPM methods typically include regular scouting of plants for pests and diseases, preventive measures such as the use of proper crop rotation and resistant varieties, healthy seedlings, use of biopesticides, and biocontrol agents. IPM is not a straightforward concept to apply and requires farmer training and a supportive environment that makes knowledge and inputs available to farmers.

Evidence for the impact of IPM on pesticide use, crop yields and household wellbeing remains patchy and there is lack of sound impact evaluation. Van den Berg and Jiggins (2007) reviewed 25 studies of IPM training through farmer field schools and found relatively strong evidence for pesticide reductions, particularly in Asia. Pretty and Bharucha (2015) reviewed 85 IPM projects from 24 countries in Africa and Asia for their effect on crop yield and pesticide use. They also found relatively strong evidence that IPM projects reduced pesticide use, but concluded that the impact on crop yield is more complex, depending, among other factors, on pest incidence and severity. There is therefore a need for sound

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impact studies that also go beyond the effect on pesticide use.

This study contributes to strengthening the evidence basis of IPM in low income countries. The study objective is to quantify the impact of IPM training of vegetable farmers in Bangladesh on a broad range of outcome indicators from pesticide use and handling to profitability and income. The study does this by applying a quasi-experimental method to evaluate the impact of IPM training in Bangladesh for eggplant (*Solanum melongena* L.)—more commonly referred to as brinjal in South Asia—and bitter gourd (*Momordica charantia* L.). These are summer (*kharif*) season vegetables with known problems of pesticide misuse.

Bangladesh has experienced a fivefold increase in agricultural pesticide use (insecticides, fungicides and herbicides) between 1990 and 2010 (Pretty and Bharucha, 2015). The use of pesticides in Bangladesh is particularly high on vegetables. Bentley (2009) and Rashid et al. (2003) reported that farmers producing eggplant sprayed nearly every day. Health and environmental risks associated with high levels of synthetic pesticide use in Bangladesh have been well-documented (e.g. Dasupta et al., 2005; 2007; Rahman and Alam, 1997). Pesticide problems have also led other countries to consider restricting vegetable imports from Bangladesh (Rahman, 2016).

It is therefore of utmost importance to Bangladesh to reduce pesticide use in vegetables. Bangladesh has successfully introduced IPM farmer field schools in rice and later expanded these to vegetables. The country has worked intensively with international organizations such as World Bank, FAO and World Vegetable Center to reduce pesticide use and promote IPM in vegetables and other crops. In 2002, the government approved a national IPM policy and in 2010 it opened a new registration system for biocontrol products, which has increased the availability of a wider range of biocontrol products (Srinivasan, 2012).

Still there is only limited evidence for the impact of IPM on reduced pesticide use in Bangladesh and neighboring countries. A study on IPM training in cauliflower, cabbage and okra in India didn't find a significant adoption of non-chemical practices other than pheromone traps used by okra growers (Sharma and Peshin, 2016). Van den Berg (2004) and Rashid et al. (2003) reported that eggplant IPM in Bangladesh reduced spraying frequency and pesticide expenditure and increased yield and income. However, Ahsanuzzaman (2015) found that IPM neither increased crop yield nor reduced input expenditures in sweet gourd production. This study therefore contributes to strengthening the evidence basis for the impact of IPM in Bangladesh and elsewhere.

The remainder of the paper is organized as follows. The next section describes the intervention studied as well as the statistical matching method we applied and data we collected to quantify impact. We then present the results, organized in intermediate indicators (IPM adoption, knowledge and attitudes, pesticide use), primary outcomes (crop yield, profit, and income) and pesticide risk (safe handling practices). We then discuss our results in the wider context of IPM adoption globally and conclude with major implications for policy and research.

2. Materials and methods

2.1. Intervention studied

The intervention that is studied here was implemented by the World Vegetable Center and the Bangladesh Agricultural Research Institute (BARI), which have a long-term collaboration on the development, testing and scaling of vegetable IPM methods. The IPM strategy for eggplant is based on sanitation (prompt removal and destruction of infested fruits and shoots) without pesticide use, installation of pheromone traps, inundative release of egg and larval parasitoids and application of bio-pesticides. Cucurbit IPM includes weekly removal and destruction of infested fruits from the field, baiting with kairomone lures (cue-lure) and inundative release of egg and larval parasitoids. Over 2500 farmers were trained in the use of IPM methods for eggplant and a range of cucurbits (bitter gourd, pumpkin, and bottle gourd) between 2012 and 2014 in the context of a project funded by the United States Agency for International Development (USAID).

The intervention included farmer participatory trials backstopped by BARI, farmer field days, and day-long hands-on training organized in groups of 25–30 farmers per village. Training topics included the identification of harmful and beneficial insects, threshold levels for various pests and pest management decision making, adverse effects of pesticides to human and environment health, importance of cultural practices including sanitation, the use of pheromone/kairomone lures and traps as well as bio-control agents. The training events included lecturing, screening of documentaries and discussion sessions, followed by hands-on practices. The field days included lecturing and sharing of experiences by IPM adopters, followed by field visits as well as discussion. The trainings and field days were mainly organized by BARI staff. Trainees received samples of traps and lures one time after the training together with extension publications in Bengali that explained the identification of pests and how to apply IPM for eggplant and cucurbits. BARI staff would visit the farmers and their fields two to three times at the critical stages of the crop production in the season after the training. The support described above was only provided for one season after the training. However, private sector engagement in manufacturing and/or marketing the IPM products continued to make available these inputs for adoption.

2.2. Statistical matching

Selection bias is the main concern when using observational data for impact evaluation. It occurs when farmers with favorable characteristics self-select by adopting a technology earlier than other farmers. Selection bias potentially exaggerates the measured impact because early adopters are likely to have a better farm performance than late adopters, even without the intervention. We minimized the effect of selection bias through our sampling strategy and the use of statistical matching methods.

We applied two matching methods: propensity score matching (PMS) and inverse probability weighting (IPW). These methods are commonly applied to evaluate the impact of agricultural interventions (e.g. Mendola, 2007; Ochieng et al., 2017; Sanglestsawai et al., 2015; Schreinemachers et al., 2016).

Both methods start by regressing program placement (trained *vs.* non-trained) on a set of independent farm characteristics that simultaneously influence program placement and outcomes. We included ten covariates that were conceptually related to program placement: farm managers' age, education level, membership in a political party or farmers' group, years of experience producing vegetables, travel time to the nearest extension office, value of agricultural land and other household assets owned before the intervention, the percentage of adult women in the household and the percentage of household members working on the own farm. Parameters were estimated using a logit model and the predicted values—the propensity scores—were calculated from all covariates independent of their significance levels (Heckman et al., 1998). Severe outliers in the data were replaced before estimating the propensity scores.

Farm households were ranked according to their propensity score. We used nearest neighbor matching as our matching algorithm, which finds for every trained farmer the nearest ranked non-trained farmer, and for every non-trained farmer the nearest ranked trained farmer. The difference in outcomes is calculated for each matched pair, after which these differences are averaged over the entire sample to obtain the average treatment effect. It is also possible to match each trained farmer to more than one non-trained farmer and vice versa, which we did this for the purpose of sensitivity testing.

The IPW method does not directly match trained and non-trained farmers, but uses the inverse of the propensity score to give a higher weight to farmers with a high predicted probability of being selected for training and a low weight to those with a low predicted probability. The average treatment effect is then calculated as the difference between the weighted averages of trained and non-trained farmers.

2.3. Sample selection

The project trained farmers in 23 villages of Jessore district in southwestern Bangladesh and we randomly selected 14 villages for our study. Within each village, households were selected randomly from the list of all farmers trained. If the selected household had not grown eggplant or cucurbits in the past *kharif* season then it was replaced with another randomly selected household. The total sample of trained farmers included 150 households producing eggplant and 150 producing bitter gourd (Table 1).

Twelve control villages were selected purposively from the same sub-districts where the intervention had taken place but which had not been included in the project or in any other vegetable IPM project. The separation of control from intervention villages was to minimize possible spillover effects as these are more likely to occur between farmers in the same village than between different villages. The survey team visited the selected control villages and met with key informants to explain the purpose of the study and to find out if there was a large enough sample of farmers that had produced eggplant or bitter gourd in the *kharif* season. Production areas were visited and a list of farmers was constructed by asking around for names of farmers who had grown the crops in question.

2.4. Outcome variables

Data were collected in October 2015 at the end of the *kharif* season after the harvest of eggplant and bitter gourd. A range of outcome indicators were used to compare trained and non-trained farmers:

Knowledge and attitude score: This score was based on 10 knowledge and 12 attitude questions. These two aspects were combined into a single score because the total number of questions was few and all were binary choice. The knowledge test showed farmers photos of common insects (e.g. caterpillar, bee, and spider) and asked to tell if it was harmful or beneficial to crop production. In addition, knowledge about insect life cycle was tested by asking the farmers to match photos of adult stage insects with their larvae or nymphs using photos. These tests were taken from Schreinemachers et al. (2017). Attitudes were tested using 12 statements about the perceived need, health risk and satisfaction with synthetic pesticides to which respondents could either agree or disagree (see Annex Table A1). The total score was expressed as a percentage of correct answers or benign attitudes.

IPM adoption: Respondents were presented with 20 IPM practices (Table 3) and had to indicate which of these they had applied in eggplant or bitter gourd production. The score ranged from 0 to 20.

Lures: The number of pheromone/kairomone lures the respondent had used divided by the planted area in hectares (ha).

Pesticides mixing: The average number of different pesticides mixed in a single spray.

Pesticide sprays: The number of times that the farmers had sprayed chemical pesticides.

Pesticide quantity: The quantity of undiluted pesticides (excluding biopesticides) used divided by the crop area and converted to kg/ha.

Crop yield: The harvested quantity divided by the crop area converted to tons/ha.

Gross Margin: Total value of output minus the total value of inputs divided by the crop area and converted to US$/ha.

Pesticide safety score: Respondents were asked about their use of 14 different pesticide handling practices (e.g. use of protective gear, safe disposal of empty containers, time lag to re-enter the field after spraying, and the time lag between spraying and harvesting). The score was expressed as a percentage.

Pesticide related incidences: Number of different pesticide poisoning symptoms experienced immediately after spraying, selected from a list of 15 possible symptoms (e.g. eye burn, vomiting, and dizziness).

Consumptive expenditures: Household expenditures on food and non-food items divided by the household size and converted to US$/capita/year, used as a proxy for income.

3. Results

3.1. Matching of trained and non-trained farmers

A comparison of observable characteristics between trained and non-trained farmers showed several to be significantly different (Table 2). In the sample of eggplant producers, trained farmers had on average a higher (pre-intervention) value of household assets and had a slightly larger percentage of adults working on the own farm. In the sample of bitter gourd producers, the trained farmers also had a higher value of assets, owned more agricultural land, and were slightly older than the non-trained farmers. These differences confirm the need to correct for selection bias using matching methods.

Table 1
Sample distribution of trained and non-trained (control) farm households.

Crop	Upazila	Trained			Non-trained		
		Unions	Villages	House-holds	Unions	Villages	House-holds
Eggplant	Bagarpara	1	1	9	0	0	0
	Chaugachha	2	3	110	1	1	28
	Sadar	3	3	31	1	6	122
Bitter gourd	Bagarpara	1	7	101	2	2	81
	Chaugachha	2	2	14	0	0	0
	Sadar	1	1	35	2	3	69
Total		10	14	300	6	12	300

Notes: All samples collected from upazilas (subdistricts) in Jessore district. Unions are the smallest rural administrative unit in Bangladesh and typically consist of nine villages.

Table 2
Characteristics of the sample of trained and non-trained farm households in Bangladesh, 2015, means with standard deviations in brackets.

Characteristics	Eggplant		Bitter gourd	
	Non-trained (n = 150)	Trained (n = 150)	Non-trained (n = 150)	Trained (n = 150)
Household size (persons)	4.71	4.71	4.97	5.01
	(1.48)	*(1.53) ns*	*(1.86)*	*(1.89) ns*
Dependents in household (%) (other than 16–60 years)	34.30	31.81	33.78	31.13
	(19.41)	*(19.75) ns*	*(19.53)*	*(20.48) ns*
Value of total household assets in 2010 ('000 US $)	22.23	30.12	23.96	41.24
	(21.34)	*(39.91)* **	*(21.52)*	*(40.00)****
Value of house and residential land in 2010 ('000 US $)	6.96	10.23	16.89	29.76
	(4.35)	*(8.05)* ***	*(19.89)*	*(38.10)***
Value of agricultural land in 2010 ('000 US $)	14.08	18.61	16.89	29.76
	(19.28)	*(35.88) ns*	*(19.89)*	*(38.10)***
Agricultural land (ha)	0.29	0.24	0.29	0.59
	(0.32)	*(0.40) ns*	*(0.32)*	*(0.73)****
Female household members (%)	47.96	44.54	46.59	46.22
	(16.94)	*(14.66)**	*(15.35)*	*(14.91) ns*
Adults working on own farm (%)	29.53	33.29	30.00	31.87
	(12.52)	*(13.78)***	*(13.29)*	*(13.76) ns*
Age of farm manager (years)	42.06	41.91	42.10	45.72
	(10.34)	*(11.41) ns*	*(11.51)*	*(11.27)* ***
Years of education completed by farm manager	5.34	5.18	5.33	6.00
	(4.15)	*(3.87) ns*	*(4.01)*	*(4.20) ns*
Years of experience in vegetable cultivation	10.45	11.22	8.39	9.15
	(6.94)	*(6.42) ns*	*(5.56)*	*(6.26) ns*
Travel time to nearest extension office (minutes)	13.25	13.12.	14.93	16.45
	(10.45)	*(5.26) ns*	*(4.94)*	*(14.38) ns*

Notes: *, **, *** denote significance of mean difference at the 10%, 5%, and 1% level, respectively; ns = not significant at 10%.

Table 3
Adoption of chemical pesticides and IPM methods among trained and non-trained farmers in the sample, in percent of all farmers per group.

	IPM method	Trained (n = 300)	Non-trained (n = 300)
1	Use chemical pesticides	90	98
2	Use resistant variety	25	14
3	Use seed treatment	18	7
4	Raise seedlings in net house	8	12
5	Buy healthy seedlings	31	21
6	Use pheromone traps	84	2
7	Use biopesticides (e.g. neem)	27	5
8	Use naphthalene balls	1	1
9	Grow crop under insect net or net house	3	7
10	Regular scouting of plants for pests and diseases	80	60
11	Pesticide spraying based on economic thresholds	27	26
12	Adjust planting/harvesting dates to reduce pest damage	41	27
13	Adjust planting density to reduce pest damage	63	41
14	Adjust irrigation timing/amount to reduce pest damage	67	49
15	Adjust fertilizer rate to reduce pest damage	67	45
16	Pick and destroy infected plant or plant parts	82	67
17	Rotate with non-host crop	32	17
18	Release or promote natural enemies	6	1
19	Use of trap crop or light trap	4	0
20	Barrier crop	26	6

The variables listed in Table 2 jointly explained 8–11% of the variation in program placement. After matching, this decreased to 1–2% and the overall standard percentage bias was less than 10% while none of the covariates had a bias greater than 20%, which are benchmarks for matching suggested by Rosenbaum and Rubin (1983). An unpaired *t*-test of the covariates after matching also shows no significant ($p < 0.05$) differences between the two groups after matching. These results indicate that the use of propensity score estimators has eliminated selection bias in observable characteristics. Finally, plotting the propensity score distribution of the trained and non-trained groups shows that the two samples have a large enough area of common support (Fig. 1). It should thus be possible to find for every trained farmer a similar non-trained farmer, and vice versa.

3.2. Intermediate outcomes

Table 3 shows the adoption of pesticides and 19 other IPM methods among trained and non-trained farmers. Chemical pesticide use was more common in non-trained group (98%) than in trained group (90%). Some of the most commonly used pesticides by both trained and non-trained farmers (in both crops) included emamectin benzoate (used against shoot and fruit borer), tebuconazole and difenoconazole (used against powdery mildew), and

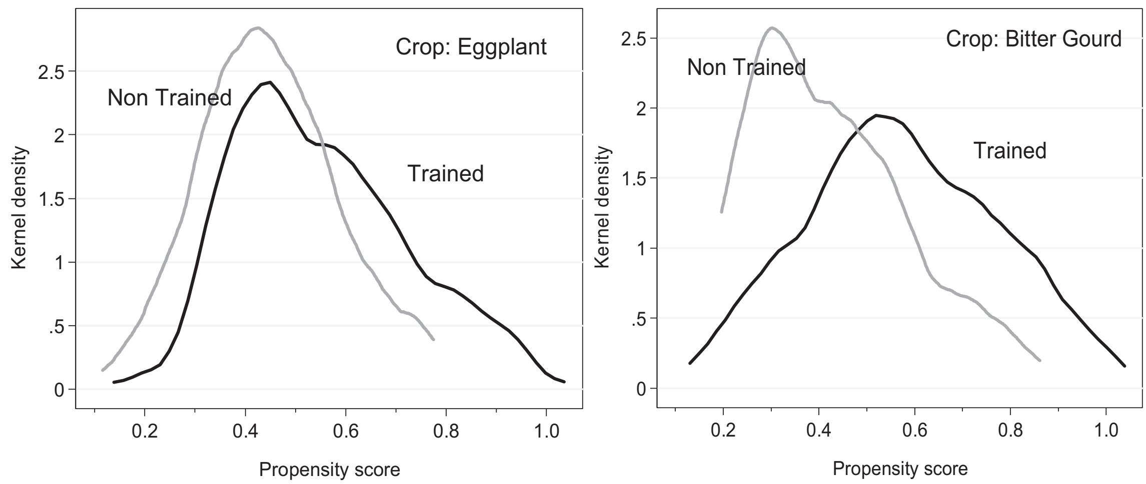

Fig. 1. Overlap between trained and non-trained farmers in kernel density distribution. Note: Epanechnikov kernel with bandwidth 0.555 (left) and 0.0639 (right).

chlorpyrifos (an organophosphate pesticide used against a broad range of insect pests). Of the other 19 IPM methods, 16 methods were more commonly used by trained farmers, especially the use of pheromone traps, other bio-pesticides, timing and amount of irrigation and pesticide application, and scouting for pests and diseases. The use of insect nets or net houses was uncommon in both groups, but a slightly higher percentage of non-trained farmers used it.

The results of the impact assessment in Table 4 also confirm that trained farmers had adopted a larger number of IPM practices (+56% for eggplant and +87% for bitter gourd) than non-trained farmers. For both crops, trained farmers used significantly more lures per hectare than non-trained farmers. Trained farmers also had significantly better knowledge of insect pests and more benign attitudes toward non-chemical pest control methods (+40% for eggplant and +55% for bitter gourd).

The results furthermore confirm that IPM training reduced the frequency of pesticide spraying (−22% for eggplant and −28% for bitter gourd). For eggplant, trained farmers used 29% less pesticides in terms of total quantity than non-trained farmers, but for bitter gourd the difference was not significant. The effect size and significance levels of the IPW and PSM methods are in agreement.

3.3. Impact on yield, profit and income

Eggplant farmers that received the IPM training obtained significantly higher crop yields (+6.3–7.4 tons/ha) than non-trained farmers (Table 5). There was no significant difference in production costs between trained and non-trained farmers. As a result, trained farmers obtained a significantly higher gross margin

Table 4
Average treatment effect of IPM training on indicators of pest management.

Outcome	Method	ATE		SE	PO mean	ATE as % of PO mean
Eggplant:						
Knowledge and attitude score	IPW	12.93	***	1.18	32.60	39.7
	PSM	12.12	***	1.30	32.33	37.5
Number of IPM methods used	IPW	2.55	***	0.28	4.56	55.9
	PSM	2.45	***	0.43	4.54	54.0
Lures/ha	IPW	126.95	***	7.51	1.00	12,695
	PSM	115.14	***	10.37	1.00	11,514
Spraying frequency	IPW	−8.67	***	1.79	39.34	−22.0
	PSM	−12.35	***	3.03	39.35	−31.4
Pesticide quantity (kg/ha)	IPW	−10.10	***	2.50	35.31	−28.6
	PSM	−11.02	***	3.24	34.76	−31.7
Bitter gourd:						
Knowledge and attitude score	IPW	18.27	***	1.51	33.02	55.3
	PSM	17.92	***	1.76	32.27	55.5
Number of IPM methods used	IPW	3.10	***	0.25	3.58	86.6
	PSM	3.25	***	0.29	3.63	89.5
Lures/ha	IPW	128.54	***	9.75	5.38	2389.2
	PSM	130.12	***	12.07	5.35	2432.2
Spraying frequency	IPW	−5.89	**	1.30	20.81	−28.3
	PSM	−4.51	**	1.54	20.70	−21.8
Pesticide quantity (kg/ha)	IPW	−0.20	ns	1.14	11.39	−1.8
	PSM	−1.51	ns	1.08	11.51	−13.1

Notes: IPW = inverse probability weighting; PSM = propensity score matching. ATE = Average treatment effect. PO mean = Potential outcome mean (the mean for the control group). SE=Standard error. *, **, *** denote significance of mean difference at the 10%, 5%, and 1% level, respectively; ns = not significant at 10%.

Table 5
Average treatment effect of IPM training on indicators of farm performance.

Outcome	Method	ATE		SE	PO mean	ATE as % of PO mean
Eggplant:						
Crop yield (tons/ha)	IPW	6.3	***	1.4	26.3	23.8
	PSM	7.4	***	1.8	26.4	28.0
Cost of production (US$/ha)	IPW	−75	ns	417	3972	−1.9
	PSM	−42	*	521	4043	−1.0
Gross margin (US$/ha)	IPW	1371	**	694	5724	24.0
	PSM	1909	**	893	5641	33.8
Consumptive expenditures (US$/year)	IPW	−8.1	ns	17.6	399.4	−2.0
	PSM	−27.5	ns	19.0	399.5	−6.9
Bitter gourd:						
Crop yield (tons/ha)	IPW	−2.0	**	0.8	19.9	−10.1
	PSM	−1.4	ns	0.9	19.8	−7.1
Cost of production (US$/ha)	IPW	−145	ns	217	2453	−5.9
	PSM	−73	ns	279	2440	−3.0
Gross margin (US$/ha)	IPW	165	ns	392	4260	3.9
	PSM	773	ns	472	4211	18.4
Consumptive expenditures (US$/year)	IPW	24.7	ns	16.7	362.7	6.8
	PSM	20.7	ns	18.9	345.3	6.0

Notes: IPW = inverse probability weighting; PSM = propensity score matching. ATE = Average treatment effect. PO mean = Potential outcome mean (the mean for the control group). SE=Standard error. *, **, *** denote significance of mean difference at the 10%, 5%, and 1% level, respectively; ns = not significant at 10%.

in eggplant production (+34%). However, this higher gross margin did not translate into a measurable change in consumptive expenditures.

Bitter gourd farmers that received the training obtained a significantly lower crop yield (−2.0 tons/ha), but the difference was only significant for the IPW method, not for PSM. There was also no significant difference in production costs between trained and non-trained farmers. Consequently, the results did not show a significant difference in the gross margin in bitter gourd production or household consumptive expenditures.

We tested for the sensitivity of average treatment effects to alternative matching algorithms and hidden bias using the Rosenbaum's bounds tests (Rosenbaum, 2002 and implemented in STATA by DiPrete and Gangl, 2004). The results in Annex Table A2 show that the variation between matching algorithms is low for intermediate outcomes, but relatively high for outcomes variables such as profit and consumptive expenditures. The Rosenbaum's bounds test shows that the crop yield variable is sensitive for both crops while other variables were not very sensitive (Table A3). The impact on crop yields must therefore be interpreted with caution.

3.4. Pesticide handling and risk

Pesticide risk is a function of dose, toxicity and exposure. In terms of exposure, the results show that eggplant and bitter gourd farmers trained in IPM had a better score in terms of pesticide safety (Table 6). This suggests that the IPM training improved the safe handling of pesticides by 20% among eggplant farmers and 32% among bitter gourd farmers. Trained farmers also mixed fewer pesticides in a single spray and the results suggest that the training reduced this practice by 16%. The practice of mixing pesticides nonetheless remained common even among trained farmers. Perhaps as a result of significant but incomplete improvements in pesticide safety, as well as the fact that farmers also grow other crops than eggplant and bitter gourd, there was no significant difference in the perceived number of pesticide related incidences.

Table 6
Average treatment effect of IPM training on indicators of pesticide risk.

Outcome	Method	ATE	Sign.	SE	PO mean	ATE as % of PO Mean
Eggplant:						
Pesticide safety score	IPW	1.27	***	0.17	5.99	21.2
	PSM	1.18	***	0.20	5.98	19.7
Number of different pesticides mixed per spray	IPW	−0.49	***	0.09	3.11	−15.8
	PSM	−0.50	***	0.12	3.09	−16.2
Pesticide-related incidences	IPW	−0.12	ns	0.24	5.22	−2.3
	PSM	0.30	ns	0.28	5.21	5.8
Bitter gourd:						
Pesticide safety	IPW	1.70	***	0.17	5.32	32.0
	PSM	1.73	***	0.19	5.29	32.7
Number of different pesticides mixed per spray	IPW	−0.42	***	0.09	2.52	−16.7
	PSM	−0.38	***	0.12	2.46	−15.5
Pesticide-related incidences	IPW	−0.11	ns	0.22	4.58	−2.4
	PSM	−0.10	ns	0.26	4.56	−2.2

Notes: IPW = inverse probability weighting; PSM = propensity score matching. ATE = Average treatment effect. PO mean = Potential outcome mean (the mean for the control group). SE=Standard error. *, **, *** denote significance of mean difference at the 10%, 5%, and 1% level, respectively; ns = not significant at 10%.

Table 7
Difference in average treatment effect between farmers trained in IPM in 2012/13 and farmers trained in 2014, t-values in brackets.

Outcome variable	Eggplant	Bitter gourd
Pesticide quantity (l/ha)	−8.98	−7.11
	(-1.95)*	(-3.24)***
Gross margin ('000 US$/ha)	3.69	0.98
	(2.75)**	(1.31)ns
Cost of production ('000 US$/ha)	1.43	−32.70
	(1.56)ns	(-0.087) ns
Consumptive expenditures (US$/capita)	−68.99	−30.40
	(-1.84)*	(-0.92) ns

Notes: Negative signs indicate that the treatment effect is larger for the group trained in 2012/13 than in the group trained in 2014. *, **, *** denote significance of mean difference at the 10%, 5%, and 1% level, respectively; ns = not significant at 10%.

3.5. Heterogeneous effect

Trained farmers received the IPM training in three different years from 2012 to 2014. We assessed whether the intervention's impact has been sustained by comparing the average treatment effect between farmers trained in 2012/2013 and those trained in 2014. It shows that eggplant and bitter gourd farmers trained earlier achieved a significantly greater reduction in pesticide quantity (Table 7). This suggests that it takes a few years for reductions in pesticide use to materialize after IPM training. For eggplant, but not for bitter gourd, farmers trained in the earlier year obtained higher profits. Surprisingly, we found that total consumptive expenditures of eggplant farmers trained in 2012/13 were US$70 lower than those trained in 2014, but the difference was only significant at the 90% confidence interval.

4. Discussion

Our study shows that IPM training of vegetable farmers in Bangladesh increased farmers' knowledge of insect pests and their positive attitudes toward IPM. The training reduced the spraying frequency and contributed to a safer handling of pesticides. For eggplant, but not for bitter gourd, IPM training reduced the average quantity of pesticides applied and increased the average profit. However, there was no measureable impact on household consumptive expenditures (as a proxy for income).

These results confirm the earlier study by Rashid et al. (2003) which reported that eggplant IPM in Bangladesh reduced spraying frequency and pesticide expenditures and increased yield. Our findings also align with those previously reported by Srinivasan (2008) who showed that eggplant IPM reduced pesticide use and increased revenues. However, our findings did not confirm that IPM training increased total household income. Our results also confirm those of Ahsanuzzaman (2015), who found that sweet gourd IPM in Bangladesh neither increased crop yield nor reduced input expenditures. The available evidence therefore shows that eggplant IPM has a greater impact on reducing farmers' pesticide use and increasing their profits than cucurbit IPM. More research is needed to optimize the IPM package for bitter gourd (and other gourds affected by the same pests and diseases).

A possible reason for the lack of impact of IPM on bitter gourd is the limited local availability of biocontrol products. Our intervention focused on the use of pheromone/kairomone lures and traps, but these traps and lures were initially not widely available in rural areas of Bangladesh, which may have limited farmers to practice what they had learned during the training. The authors of this study observed that this situation has gradually improved after introduction of a new registration system for biocontrol products in 2010, and it is therefore possible that the IPM training has a greater impact now than five years ago.

More generally, our results confirm the findings of reviews by Van den Berg and Jiggins (2007) and Pretty and Bharucha (2015), which showed that IPM are effective at reducing agricultural pesticide use, though not always at increasing crop yields and profits. We agree with these authors that yields—and profit and income even more so, are complex outcomes that are driven by many factors other than IPM.

The use of quasi-experimental methods in our study is an improvement on many past studies that have evaluated the impact of IPM. However, quasi-experimental methods have limitations. The main limitation is that the method controls for observable farm and household characteristics (e.g. farmers' age, land size) but not for unobservables such as farmers' skills and aptitudes in vegetable growing or enthusiasm in the use of new technologies. This shortcoming can be overcome by collecting data before and after the intervention period for trained and non-trained farmers and then applying a double difference estimator. The use of such method, ideally in combination with random assignment of farmers to the trained and non-trained groups, is still uncommon in IPM impact studies and is a shortcoming in the literature.

5. Conclusion

The misuse of chemical pesticides is widespread in Bangladesh and elsewhere and is a large problem in vegetable production in particular. Pesticide misuse exposes consumers and farm workers to substantial health risks, contributes to unsustainable farming practices, and limits agricultural exports. This study showed that short-term training of farmers in vegetable IPM methods improved farmers' knowledge and attitudes in pest management, led to safer use of pesticides, and reduced the number of pesticide sprays. However, IPM training was more effective in eggplant than in bitter gourd in reducing the quantity of pesticide used and in increasing crop yields and farm profits. Biocontrol products are increasingly available in Bangladesh and in other countries and supplied by the private sector, but public sector investment is needed to expand IPM training to reach more farmers and to develop and test new and improved IPM methods. To enable widespread adoption it is important that researchers focus on the development of IPM methods that reduce costs and increase profits.

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Annex

Table A1
IPM and pesticide related attitude statements, in % of farmers that agreed with statement.

	Statement	Trained	Non-trained
1	Using pesticides increases the profit from the farm	77	97
2	Mixing different pesticides can make them more effective	77	94
3	I prefer using pesticides that kill all insects immediately	76	92
4	I am satisfied with the level of control offered by chemical pesticides	65	87
5	Pesticides can enter the body through the skin	67	48
6	Herbicides are not dangerous to humans	35	23
7	It is OK to reuse empty pesticide containers for other purposes	3	22
8	Sometimes I use my mouth to open a pesticide package or bottle	0	13
9	Bio-pesticides are not as effective as chemical pesticides	53	63
10	Pheromone traps are not as effective as chemical pesticides	48	66
11	I am worried about getting cancer because of pesticide spraying	76	43
12	I am worried about pesticide residues when eating vegetables from my farm.	85	50

Table A2
Sensitivity of average treatment effects to alternative matching methods.

Outcome variable	IPW	nn = 1	nn = 3	nn = 5	radius	Kernel density	CV (%)
Eggplant:							
Knowledge and attitudes	12.93	12.33	12.27	12.35	12.63	13.08	2.7
IPM adoption	2.55	2.73	2.68	2.72	2.54	2.60	3.2
Pesticide quantity	−10.10	−10.05	−9.41	−9.13	−9.42	−9.96	−4.2
Crop yield	6.27	5.53	7.17	6.70	6.12	6.43	8.7
Gross margin	1371	2106	1997	1810	1509	1579	16.8
Consumptive expenditure	−8.12	−26.35	−2.14	−1.87	−3.01	−7.19	−114.1
Bitter gourd:							
Knowledge and attitudes	18.27	18.46	18.08	18.06	19.09	17.97	2.3
IPM adoption	3.10	3.16	3.22	3.17	3.16	3.12	1.3
Pesticide quantity	−0.20	−0.60	−0.88	−0.34	−0.68	−0.47	−46.3
Crop yield	−2.00	−1.12	−1.55	−1.90	−1.56	−1.88	−19.6
Gross margin	165.00	615.97	371.04	89.70	431.66	198.13	63.2
Consumptive expenditure	24.69	23.93	27.51	30.68	51.87	31.64	32.6

Note: nn = nearest neighbor method. CV=Coefficient of variation (%). The PSMatch2 command was used to estimate the average treatment effect (ATE) for the nn, radius and kernel density methods while the ATE in Tables 4–6 was estimated using the t-effects command, which shows a small difference.

Table A3
The "Rosenbaum bounds" analysis for hidden bias, *p*-values (upper bound).

Gamma	Knowledge attitude score		IPM adoption		Pesticide quantity		Crop yield	
	Eggplant	Bitter gourd	Eggplant	Bitter gourd	Eggplant	Bitter gourd	Eggplant	Bitter gourd
1.0	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.006
1.2	0.000	0.000	0.000	0.000	0.000	0.000	0.073	0.063
1.4	0.000	0.000	0.000	0.000	0.000	0.000	0.258	0.233
1.6	0.000	0.000	0.000	0.000	0.000	0.000	0.517	0.485
1.8	0.000	0.000	0.001	0.000	0.000	0.000	0.743	0.716
2.0	0.000	0.000	0.004	0.004	0.000	0.000	0.885	0.868
2.5	0.000	0.000	0.050	0.050	0.000	0.000	0.955	0.988
3.0	0.000	0.000	0.198	0.198	0.000	0.000	0.998	0.998

*gamma - log odds of differential assignment due to unobserved factors.

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