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IFPRI Discussion Paper 01866

September 2019

Economic and Health Impacts of Genetically Modified Eggplant

Results from a Randomized Controlled Trial of Bt brinjal in Bangladesh

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Key words: GMOs, eggplant, economic impacts, health, Bangladesh

JEL classification: Q16, Q12, O13

Running head: Impacts of genetically modified eggplant in Bangladesh

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Acknowledgements: We thank the Bangladesh Agricultural Research Institute (BARI), the Department of Agricultural Extension (DAE), and the Agricultural Policy Support Unit (APSU) of the Ministry of Agriculture, Government of the People's Republic of Bangladesh, for their guidance and support for this study. We are particularly grateful to A.S.M. Mahbubur Rahman (BARI), Kazi Md. Shaiful Islam (DAE), and Masuma Younus (APSU) for their assistance. At IFPRI, research support was provided by Julie Ghostlaw, Md. Latiful Haque, Md. Aminul Islam Khandaker, Aklima Parvin, M. Tahsin Rahaman, Md. Redoy, Waziha, Rahman, Salauddin Tauseef, and Shabnaz Zubaid. We acknowledge with thanks the dedication and hard work of the survey enumerators and other staff from Data Analysis and Technical Assistance (DATA); special thanks go out to Md. Zahidul Hassan, Mohammad Zobair, and Md. Imrul Hassan. Lesley Perlman, Tracy Powell, and Paul Tanger from the United States Agency for International Development (USAID) Bureau for Food Security (BFS), Tony Shelton from Cornell University, and workshop participants in Dhaka provided helpful comments on our preliminary findings. We thank Pamela Stedman-Edwards for her overall editorial review and Samita Kaiser for her help with the production of this report. Funding for the intervention came from the Government of Bangladesh. We gratefully acknowledge USAID for funding this study through the Policy Research and Strategy Support Program (PRSSP) in Bangladesh under USAID Grant Number EEM-G-00-04-00013-00; and the CGIAR Research Program on Policies, Institutions, and Markets (PIM). Any opinions stated herein are those of the authors and are not necessarily representative of or endorsed by the U.S. Agency for International Development (USAID) or IFPRI.

Abstract

In this paper, we assess the impacts of genetically modified eggplant, Bt brinjal, on economic and health outcomes in Bangladesh using a cluster randomized controlled design. Bt brinjal cultivation reduces the cost of pesticide use by 47 percent. This is driven by reductions in the use of pesticides with adverse ecological impacts by 82 percent, and reductions in the use of pesticides with adverse effects on farmer health by 23 percent. Individuals who had a pre-existing chronic condition consistent with pesticide exposure and who lived in villages randomly selected to grow Bt brinjal were 11.5 percentage points less likely to report a symptom of pesticide exposure and were 11 percentage points less likely to incur cash medical expenses to treat these symptoms. Net yields were 42 percent higher for Bt brinjal farmers, and our descriptive distributional work suggests that these yield gains are widespread. The differences in net yields were driven by two outcomes: the quantity harvested was higher on Bt brinjal fields, by 114 kilograms per farmer; and after harvesting, fewer fruits were discarded because of damage due to pests and diseases, by 40 kilograms per farmer. Increased production, together with a 14 percent increase in price and a 10 percent reduction in costs, leads to a substantial increase in profits from cultivating Bt brinjal for treatment farmers compared with conventional brinjal produced by control farmers. Bt brinjal is a publicly developed GMO that conveys significant health benefits, both human and ecological, while raising farmer incomes.

1. Introduction

Genetically modified (GM) crops are controversial. While there is strong scientific consensus that GM crops are safe for human consumption (see, for example, National Academies of Sciences, Engineering, and Medicine 2016), even the most cursory internet search quickly reveals a myriad of criticisms. For example, the website of the Non-GMO Project includes the following statements: "Most GMOs are a direct extension of chemical agriculture and are developed and sold by the world's largest chemical companies." "Biotechnology companies have been able to obtain patents to control the use and distribution of their genetically engineered seeds … Genetically modified crops therefore pose a serious threat to farmer sovereignty." "There is no evidence that any of the GMOs currently on the market offer increased yield, drought tolerance, enhanced nutrition, or any other consumer benefit." And, "The safety of GMOs is unknown" (Non-GMO Project, 2019).

In this paper, we report the results of a randomized controlled trial assessing a relatively new GM crop, a genetically modified version of eggplant called Bt brinjal. Brinjal is grown and consumed widely across South and East Asia. It is a lucrative cash crop that can be grown on small plots of land. But in countries like Bangladesh, brinjal is susceptible to the fruit and shoot borer (FSB) pest, which is reported to affect up to 86 percent of plants (Ali, Ali, and Rahman 1980). Consequently, farmers apply pesticides frequently, ranging from 23 to as many as 140 times per season (Rashid, Mohiuddin, and Mannan 2008; Dey 2010; Sabur and Molla 2001; Ahsanuzzaman and Zilberman 2018; Raza 2018). Few farmers take protective measures while applying pesticides, and these frequent sprays could have negative health effects (Sabur and Molla 2001; Rashid, Mohiuddin, and Mannan 2008; Dey 2010).

Given these concerns, starting in 2005, scientists at the publicly funded Bangladesh Agricultural Research Institute (BARI), with support from Cornell University, embarked on a program to develop a genetically modified brinjal—brinjal spliced with a gene from the soil bacterium *Bacillus thuringiensis* to make it resistant to FSB. After eight years of breeding and testing, in 2013 four varieties were approved for cultivation by Bangladesh's National Committee on Biosafety (APAARI 2018). In 2014, 20 farmers received seedlings of the four varieties of Bt brinjal from the Ministry of Agriculture to grow on a trial basis (Shelton et al.

2018). Three observational studies, one with approximately 100 farmers[1], a second on a research farm (Prodhan et al. 2018), and a third (Rashid, Hasan, and Matin 2018) with a larger sample size (505 Bt brinjal farmers and 350 farmers growing conventional brinjal) all provided evidence that Bt brinjal can reduce FSB infestation, requires fewer pesticides, and results in higher yields with lower production costs.[2]

In this paper, we go beyond these helpful observational studies. The setting for our work is four districts in northwestern Bangladesh, not the controlled setting of a research farm. We use a randomized controlled design to assess impacts, so concerns regarding observational studies (such as selection bias) do not apply. Like previous studies, we assess impacts on pesticide use, cost of production, and yields. But we go beyond this literature to include assessments on the impact on the toxicity of pesticides used, on self-reported farmer health, and on sales, prices, and profitability. As such, we speak directly to the criticisms of those opposed to GM crops. Bt brinjal is a publicly available crop not controlled by private corporations. We assess whether it makes smallholder farmers better off in terms of health and income while reducing the use of toxic pesticides.

Section 2 describes our study and intervention design, and section 3 outlines our data and estimation strategy. Results on pesticide use, toxicity, and health are found in section 4. Section 5 reports our impact estimates on yield and production, price, and profit. Section 6 summarizes our findings. A supplementary appendix provides additional results.

2. Study and Intervention Design

Study Design

We begin with our statistical power calculations. These are based on the two primary outcomes identified in our registered pre-analysis plan:[3] brinjal yields per hectare and total cost of pesticide use per hectare. Our sample size is designed to provide an 80 percent chance of correctly rejecting the null hypothesis that no change occurred, with a 0.05 level of significance.

[1] These data come from an unpublished 2014 BARI report by Rashid et al. Tony Shelton (personal communication) provided these details.

[2] An earlier ex-ante study by Islam and Norton (2007), based on data collected from 60 farmers, indicated that there were likely to be positive economic benefits of cultivating Bt brinjal.

[3] Our pre-analysis plan is available at: http://ridie.3ieimpact.org/index.php?r=search/detailView&id=682

Using these parameters and data on mean, standard deviations, and intra-cluster correlations of brinjal cultivation taken from a nationally representative sample of households residing in rural areas (Ahmed 2013), a minimum total sample size of 180 clusters (villages) and 1,046 farm households is required to detect a statistically significant increase in brinjal yields per hectare of 30 percent between treatment and control groups, with 523 farm households for the treatment group and 523 households for the control group. For reduction of pesticide cost per hectare, 187 clusters and 1,120 farm households (560 treatment and 560 control households) are needed to detect a minimum of 40 percent reduction in pesticide cost. Additionally, the sample size must be large enough to assess both impacts and account for the possibility that some households would attrit. Accordingly, we planned on a sample of 200 clusters/villages (100 treatment and 100 control villages). Each cluster would include six farm households, yielding 1,200 farm households (600 treatment and 600 control households) in our sample.

The Bt brinjal varieties released by BARI are best suited to winter cultivation, with sowing of seeds beginning in September/October and seedlings transplanted in November. For this reason, we concentrated on localities where farmers largely cultivated brinjal in the winter. Given interest in assessing Bt brinjal as a cash crop (rather than one simply for home consumption), we needed to work in areas characterized by good physical infrastructure and well-functioning markets for brinjal. Accordingly, in consultation with officials from BARI and the Department of Agricultural Extension (DAE), we purposively selected four districts in the northwestern region that satisfy these criteria: Bogura, Gaibandha, Naogaon, and Rangpur. Within these four districts, DAE officials provided us with lists, by upazilas (sub-districts), of villages where brinjal is cultivated predominantly in the winter season and with the number of brinjal farmers in each village. Using these lists, we purposively selected 10 upazilas with a high concentration of villages with a substantial number of brinjal farmers.[4] For each selected upazila, we generated a list of the villages that had at least 15 brinjal farmers. We gave this list to the survey firm, Data Analysis and Technical Assistance Ltd (DATA), which undertook the data collection, DATA randomly assigned 100 villages to the treatment group and 100 villages to

[4] These were: Shahjahanpur, Gaibandha Sadar, Gobindoganj, Palashbari, Dhamoirhat, Manda, Gongachara, Mithapukur, Pirgacha, and Pirganj.

the control group.[5] This approach meant that randomization was undertaken independently of both the program implementers and the evaluators.

Next, we conducted a census in all 200 villages, generating a list of all farmers in these villages who had grown brinjal in the preceding 24 months. We identified and listed farmers willing to grow either conventional or Bt brinjal on 10-decimal plots (equivalent to 0.10 acres or 0.04 hectares) during the planting season beginning in November 2017. From these lists, DATA randomly selected 10 farmers from each village, of whom 6 farmers belong to the study group and 4 farmers belong the reserve group.[6]

We received letters of authorization to conduct the survey from the Ministry of Agriculture, Government of Bangladesh, and our study protocol was approved by the Institutional Review Board of the International Food Policy Research Institute.

Intervention Design

DAE assigned a sub-assistant agricultural officer (SAAO) to each village. All SAAOs received training on brinjal cultivation, both conventional and GM varieties, prior to the start of the intervention. Using an instructional manual and curriculum developed for brinjal cultivation by DAE, SAAOs trained all treatment and control farmers on agronomic practices relating to brinjal cultivation over a 10-day period before the start of the winter planting season. This included information on when to plant, the size of plot (10 decimals), when to apply fertilizer and irrigation, addressing weed infestation, and when to harvest. Particular attention was paid to the safe handling of pesticides and integrated pest management (IPM). Both treatment and control farmers received information on how to manage pests including FSB, leaf hoppers/jassids, beetles, and red spiders. Treatment farmers received additional training on the importance of planting a refuge border around Bt brinjal plots and the need to follow BARI's biosafety rules and guidelines.

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[5] Specifically, DATA: (1) used a random number generator to generate a number for each village; (2) ordered villages from smallest to largest number; and (3) allocated the first 100 villages to the control group and the remaining 100 villages to the treatment group.

[6] Farmers' willingness to participate was reconfirmed in September and November 2017. Out of 1,200 farmers in the original study group, 16 farmers declined to participate, so they were replaced by farmers in the reserve group.

Brinjal seedlings were provided to all farmers in both treatment and control groups in a similar manner. DAE collected Bt brinjal and conventional (ISD-006) brinjal seeds from BARI. SAAOs distributed these seeds to one farmer (the "lead" farmer) in each treatment and control village, who then raised seedlings. Once the seedlings were mature, the lead farmers, with the assistance of SAAOs, distributed them to the other treatment and control farmers to transplant on their respective 10-decimal plots. Per BARI's instructions, treatment farmers included a four-sided non-Bt brinjal refuge, or boundary, to slow the development of Bt resistance; the existence of these boundaries was confirmed during field visits. Although seedling production was delayed by 10 to 15 days due to heavy rainfall and wet field conditions in some areas, BARI and DAE indicated that most seedlings were transplanted at the optimum maturity and around the same time in all study districts.

All farmers (treatment and control) received an input package worth approximately US$25. The package included fertilizer, netting (to prevent birds from eating the brinjal), and support posts for plants. This package did not include pesticides. Finally, all farmers received visits from SAAOs throughout the growing season.

Summarizing, all treatment and control farmers received training on similar topics at the same time. They all received brinjal seedlings in the same fashion and they all received the same input package. Access to extension services (SAAOs) during the growing season was the same for both groups. Treatment farmers received Bt brinjal instead of the conventional variety received by the control group (ISD-006) and received additional training on the cultivation of Bt brinjal.

3. Data and Model Estimation

Survey Implementation

Baseline quantitative data were collected from November 25 to December 13, 2017. The endline survey was conducted from July 4 to 17, 2018, after harvesting was complete. A short qualitative survey (primarily focus group discussions and key informant interviews with implementers, farmers, and traders buying and selling brinjal) was also conducted in July 2017.

Survey instruments were peer reviewed and pilot tested before being fielded. Data were collected using tablets. GPS units were used for geo-referencing, including plot area estimation.

Sample Characteristics

Table 1 shows baseline household characteristics. Average household size is 4.6. Nearly all households, 95 percent, are male-headed. Males and females older than age 15 have an average of 6.3 years of schooling. Adult males and females with no schooling make up 23.6 and 29.5 percent of the sample, respectively, with minimal variation between treatment and control groups. Farming is the main occupation for most surveyed households (84.1 percent), followed by business and trade (9.1 percent of treatment households and 7.9 percent of control households). Most surveyed farmers (81.6 percent) have access to electricity. Nearly all (95.1 percent) surveyed households live in houses with roofs made of tin. Mobile phone ownership is nearly universal (98.1 percent). About four-fifths (80.8 percent) of all surveyed households own a pesticide sprayer, which is unsurprising given brinjal's susceptibility to pest infestations.

Around 48 percent of treatment farmers and control farmers cultivate their own lands. It is common for our sampled farmers to augment their landholdings through rental arrangements. Nearly one-half of surveyed farmers are sharecroppers (46.7 percent of treatment farmers and 44.1 percent of control farmers), including those who do not own any cultivable land (pure tenants), as well as those who own land and sharecrop others' land. Cash lease is also a land tenure arrangement among the surveyed farmers (10 percent and 13.1 percent of treatment and control farmers, respectively), either as pure tenants or as those with their own land plus cash-leased land.

At baseline, brinjal occupied only 10 percent of total cropped area for surveyed farmers (9.5 percent and 10.7 percent for treatment and control farmers, respectively). Over one-half of total cropped area was under rice (63.1 percent and 57.2 percent for treatment and control farmers, respectively), with nearly all farmers having cultivated rice at baseline. In addition to brinjal and rice, farmers also diversified agricultural production into other crops. For instance, about one-fifth of surveyed farmers cultivated maize, which is mainly used for fish and livestock feed in Bangladesh. Farmers also cultivated a variety of other high-value vegetables, fruits, and spices, including potatoes, jute, chili, *patal*, bittergourd, and arum and other leafy vegetables.

Table 1 Baseline household characteristics, by treatment status

	Treatment mean	Control mean	All
Characteristics used as control variables			
Years of education of the brinjal grower	5.8	5.3	5.6
Age of brinjal grower	46.1	46.2	46.2
Years of working as a farmer	26.9	26.6	26.8
Size of operated land (acres)	1.6	1.4	1.5
Wealth Index	0.020	-0.025	0.0
Other characteristics			
Household size (number)	4.7	4.5	4.6
Years of schooling, adult male aged 15 and above	6.9	6.7	6.8
Years of schooling, adult female aged 15 and above	6.0	5.6	5.8
No schooling, adult male (percent)	22.9	24.3	23.6
No schooling, adult female (percent)	28.8	30.2	29.5
Head principal occupation: Farming (percent)	82.5	85.7	84.1
Head principal occupation: Business/Trade (percent)	9.1	7.9	8.5
Dwelling has electricity (percent)	82.4	80.8	81.6
Dwelling roof is tin sheets (percent)	94.1	96.1	95.1
Own mobile phone (percent)	98.2	98.1	98.1
Own pesticide sprayer (percent)	77.8	83.8	80.8
Own land (percent)	47.9	48.5	48.2
Sharecrop (percent)	46.7	44.1	45.4
Cropped area, rice (percent)	63.1	57.2	60.2
Cropped area, brinjal (percent)	9.5	10.7	10.1
Primary outcomes			
Brinjal yield in baseline (kg per ha)	27,893	33,746	30,819
Cost of pesticides used in baseline (Tk per ha)	28,605	31,620	30,112

Source: 2017 Baseline survey.

Supplementary Tables S1.1-S1.5 provide additional descriptive statistics on household characteristics.

Attrition

Our actual baseline survey consisted of 1,196 households (598 treatment households and 598 control households). We successfully traced and re-interviewed 1,176 households, 593 treatment households, and 583 control households, losing only 20 households (5 treatment and

15 controls), an attrition rate of 1.7 percent.[7] In our pre-analysis plan, we specified that if an omnibus test of joint orthogonality rejects the null hypothesis that these baseline values are uncorrelated with attrition status and if attrition exceeds 10 percent, we will assess the robustness of our findings to the use of inverse-probability-of-attrition weights (Fitzgerald et al. 1998). Accordingly, we estimated a model where the outcome variable equals one if the household was lost to follow-up for any reason, zero otherwise. Our regressors include treatment status, the control variables we include in all extended model specifications (age of household head; education of household head; wealth status; land operated during the previous 12 months, and number of years working as a farmer), and our two primary outcomes, namely brinjal yield at baseline and cost of pesticides.[8] Standard errors account for clustering at the level of randomization, the village. A Wald test does not reject the null hypothesis that the regressors are jointly equal to zero (Table 2). Households randomized into Bt brinjal cultivation were less likely to attrit, but while this coefficient is statistically significant, the magnitude is small (1.6 percentage points). Given these results and given the very low level of attrition, we do not implement the weighting methodology proposed by Fitzgerald et al. (1998). Attrition is not a concern for this study.

Balance

Bruhn and McKenzie (2009) note that there are both beneficial and problematic aspects associated with testing for randomization. In our case, randomization was undertaken by an independent third party trained by us in how to implement randomized selection. Further, this was a straightforward randomization exercise, involving neither multiple phases nor stratification. Given all this, we follow McKenzie (2015) by undertaking an omnibus test of joint orthogonality. We use the same set of variables that we used to test for sample attrition (see above) as well as two primary outcomes: brinjal yields (kg/ha) and pesticide costs (Tk/ha).

Table 2 shows no association between any baseline characteristic and treatment status except that, at baseline, yields were higher in control households. However, a Wald test does

[7] Seven control and two treatment households decided not to continue growing brinjal, four control households switched to another non-GM variety, two households migrated, and five could not be traced.
[8] The official exchange rate for the taka (Tk), the currency of Bangladesh, was Tk 84.13 per US$1.00 on March 31, 2019.

not reject the null hypothesis that the regressors are jointly equal to zero, implying that imbalance between treatment and control households in baseline characteristics is not a concern for this study.

Table 2 Attrition and balance

	(1) Dependent variable: Household lost to follow up		(2) Dependent variable: Treatment status	
Baseline characteristics	Marginal effects	SE	Marginal effects	SE
Treatment status is Bt brinjal	-0.016**	0.008	-	-
Years of education of the brinjal grower	0.001*	0.0006	0.007	0.004
Age of brinjal grower	0.0002	0.0004	-0.001	0.002
Years of working as a farmer	-0.0003	0.0003	0.002	0.002
Size of operated land (in acres)	-0.002	0.004	0.020	0.017
Wealth Index	-0.001	0.001	-0.003	0.010
Brinjal yield in baseline (kg/ha)	-2.07×10^{-7}	1.40×10^{-7}	-2.11×10^{-6}**	1.04×10^{-6}
Cost of pesticides used in baseline (Tk/ha)	5.68×10^{-8}	6.14×10^{-8}	-2.45×10^{-7}	7.25×10^{-7}
	Joint test of orthogonality		Joint test of orthogonality	
Wald chi^2	12.70		10.91	
p-value	0.12		0.14	

Source: 2017 Baseline and 2018 endline surveys.
Note: Column (1): Dependent variable equals one if the household was lost to follow up, zero otherwise. Column (2): Dependent variable equals one if household was in a treatment village at endline, zero otherwise. Standard errors clustered at the village level. *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level. Sample size is 1,196 for (1) and 1,166 for (2).

Estimation Strategy

We use our randomized design to estimate an intent-to-treat (ITT) analysis using the ANCOVA specification described in McKenzie (2012). We estimate the following base model:

$$Y_h = \propto + \beta T_h + \gamma Y_{h,base} + \varepsilon_h$$

where Y_h is the outcome of interest (e.g., Bt brinjal yields) for farm household h at follow-up and $Y_{h,base}$ is the outcome of interest at baseline. T is an indicator for whether household h is in the treatment group (treatment = 1, control = 0). β and γ are parameters to be estimated; our focus is on β, which captures the impact of being randomized into the treatment group. We also estimate an "extended" ANCOVA specification. The extended specification includes additional baseline covariates to improve precision as well as to further address any baseline imbalances between arms. We chose a parsimonious list of baseline covariates for the extended specification, including variables that we believed a priori to be associated with our primary outcomes (Bruhn and McKenzie 2009). As specified in our pre-analysis plan, these are: age of household head; education of household head; wealth status (based on a principal components analysis of ownership of consumer durables and housing quality); land operated during the prior 12 months (November 2016 to October 2017), and number of years working as a farmer.[9] Standard errors are adjusted for clustering at the unit of randomization, the village. We have two domains of primary outcomes, pesticide use and yields. Within each domain, we defined a single outcome; accordingly, we do not adjust for multiple hypothesis testing. We assess the robustness of our findings by comparing results from the basic model and the extended model, and where appropriate, winsorizing our outcome variables (setting the values of the bottom two percentiles equal to the second percentile and by setting the values of the top two percentiles equal to the 98th percentile to assess robustness to outliers) and, where appropriate, taking the log of the dependent variable. We explore whether there are differential effects by subgroups based on farmer characteristics: age, sex of head, schooling, and land cultivated. Note that because of the criteria for inclusion in the study, this sample of households may be relatively homogeneous and thus there may be limited scope for heterogeneous effects.

4. Results (1): Pesticide Use, Toxicity, and Health

Pesticide Use

We begin with one of our primary outcomes, pesticide cost per hectare (ha) of brinjal cultivated. This is defined as the cost of pesticides (in taka) per ha, where area is defined as the area under brinjal cultivation. This is calculated over the period November 2017 to June 2018. As discussed above, Bt brinjal should reduce, but not eliminate, spending on pesticides, because although farmers no longer need to spray for FSB, they do need to spray for other

[9] As more than 95 percent of households are male-headed, we did not include this characteristic in our extended specification. As a robustness check, we included it as an additional control; doing so does not change our results.

pests. However, there are three reasons why we might not obtain this finding: (1) farmers might simply not believe the information they receive from SAAOs about Bt brinjal's resistance to FSB; (2) farmers might use the money saved from reduced spraying for FSB by increasing their expenditures on pesticides that kill other pests affecting brinjal; and (3) both treatment and control farmers received training on non-pesticide methods, both preventive and combative (for example, the use of yellow sticky traps), for addressing pest infestations. If this knowledge could be used to reduce the need for pesticides, then we would see no difference in endline use of pesticide costs between treatment and control farmers.

Results are found in Table 3. Column (1) shows that the cultivation of Bt brinjal reduces expenditures on pesticides by Tk 7,175 per ha. When we include spending on pesticides per ha in the previous season and selected farmer and household characteristics as control variables, we obtain a near identical coefficient, a reduction in pesticide expenditures of Tk 7,196 (column 2). When we express this outcome variable in logs, we see that Bt brinjal cultivation reduces per ha costs of pesticide use by 46 percent (column 3) with no controls and by 47 percent when we add in baseline pesticide use and control variables (column 4). All impacts are statistically significant at the 1 percent level.

Table 3 Impact of Bt brinjal cultivation on cost of pesticides

Outcome	(1) Cost of pesticides used (Tk/ha)	(2) Cost of pesticides used (Tk/ha)	(3) Log of cost of pesticides used (Tk/ha)	(4) Log of cost of pesticides used (Tk/ha)
Treatment: Bt brinjal	-7,174.6*** (1,213.3)	-7,196.3*** (1,209.7)	-0.46*** (0.06)	-0.47*** (0.06)
Controls				
Baseline outcome	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes
Observations	1,166	1,166	1,137	1,137
Endline mean, control group (Tk/ha)	21,714	21,714	-	-

Source: 2017 Baseline and 2018 endline surveys.

Note: Household characteristics include characteristics of the individual responsible for brinjal production (age, education, years working as a farmer), land operated by the household and household wealth index derived from principal components (using number of rooms in the dwelling; whether the dwelling has electricity; physical states of the dwelling and ownership of the following consumer durables: wrist watch, color tv, bicycle, tri van, motorcycle and solar panels). Standard errors clustered at the village level. *** significant at the 1 percent level; ** significant at the 5% level; * significant at the 10% level.

One question that arises is whether this reduced use of pesticide was accompanied by a reduction in pest infestation. Table 4 provides information on this. At both baseline and endline, farmers were asked if their brinjal plots were affected by FSB and other pests, and if so, what percentage of plants were affected. At baseline, treatment farmers reported that 98.4 percent of their brinjal plots were infested by the FSB pest, and on these plots 35.5 percent of plants were affected. Thus, 34.9 percent (0.984 x 0.355 = 0.349) of all brinjal plants grown by treatment farmers in the previous season were infested by FSB. For the control group, at baseline 98.9 percent of all plots were infested by FSB, and 36.4 percent of the plants were infested in those plots; thus, 36.0 percent (0.989 x 0.364 = 0.360) of their brinjal plants were infested by FSB. At endline, plot-level infestation of FSB for the treatment group fell to 10.6 percent. The percentage of plants affected by FSB in those infested plots was 17.2 percent; thus, only 1.8 percent (0.106 x 0.172 = 0.018) of all Bt brinjal plants grown by the treatment farmers were infested by FSB, indicating that Bt brinjal was resistant to FSB infestation. By contrast, 90.3 percent of all plots of the control group and 37.5 percent of the plants in those plots were infested by FSB; thus 33.9 percent (0.903 x 0.375 = 0.339) of all ISD-006 brinjal plants grown by the control farmers were infested by FSB.

Table 4 Plant level infestation by pest, treatment status and survey round

	Baseline		Endline	
	Treatment	Control	Treatment	Control
Name of Pest				
	(percent)			
Fruit and shoot borer	34.9	36.0	1.8	33.9
Leaf eating beetles	21.7	22.9	8.7	15.8
Thrips, white fly, jassid or aphids	16.5	19.1	9.1	14.3
Mites, mealy or leaf wing bugs, or leaf roller	10.9	13.8	6.3	13.1

Source: 2017 Baseline and 2018 endline surveys.

Table 4 also reports plant-level infestation by secondary pests—leaf-eating beetles, thrips, white flies, jassids, aphids, mites, leaf bugs, and leaf rollers—for treatment and control farmers at baseline and endline. Unlike FSB, infestation of a number of these (leaf-eating beetles, thrips, white fly, jassid or aphids) fall for both treatment and control farmers. This suggests that the training that farmers received in IPM had some effect on reducing some types of pest infestations, but not FSB.[10]

In addition, we wondered if the reduction in pesticide use resulted from farmers spraying less often or using less pesticide. The first two columns of Table 5 address this. Column (1) shows that, controlling for baseline outcome levels and household characteristics, the cultivation of Bt brinjal reduced the number of pesticide applications by 7.3; column (2) shows that in log terms, this corresponds to a 51 percent reduction in the number of sprays. Column (3) shows that, controlling for baseline outcome levels and household characteristics, the cultivation of Bt brinjal reduced the quantity of pesticide sprayed by 4,617 grams (milliliters) per ha; column (4) shows that in log terms, this corresponds to a 39 percent reduction in the quantity of pesticide sprayed. These impacts are statistically significant at the 1 percent level.[11]

Table 5 Impact of Bt brinjal cultivation on pesticide use, additional results

Outcome	(1) Number of pesticide applications	(2) Log of number of pesticide applications	(3) Quantity of pesticides used (ml or gm per ha)	(4) Log of quantity of pesticides used (ml or gm per ha)
Treatment: Bt brinjal	-7.37***	-0.51***	-4,616.7***	-0.39***
	(1.22)	(0.06)	(1,093.7)	(0.07)
Controls				
Baseline outcome	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes
Observations	1,166	1,137	1,166	1,137
Endline mean, control group	21.5	-	16,270	

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

[10] Temperatures during the endline winter season were lower than the baseline winter season, which may have also contributed to lower pest infestation.
[11] Disaggregating by median farmer age, education, and total landholdings showed no evidence of differential impacts related to pesticide application.

Toxicity

Table 5 tells us that farmers reduced the quantity of pesticide that they used. But pesticides differ markedly in their toxicity, ranging from those that are fatal if ingested, inhaled, or contacted to those that may be harmful. Because the farmers in our study were asked to name the pesticides that they applied to brinjal, we can assess the impact of Bt brinjal on pesticide toxicity. We do so in two ways.

First, the trade names of these pesticides (as reported by farmers) were matched with the *DAE List of Registered Agricultural Bio Pesticides and Public Health Pesticides in Bangladesh* (DAE 2016) to obtain their active chemical ingredients. For eight pesticides used by 43 percent of farmers (treatment and control) at baseline to control for FSB, we could match their ingredients to the database used by Kovach et al. (1992) to construct Environmental Impact Quotient (EIQ) scores. There are three components to the EIQ score: Farm worker risk = (Applicator Exposure + Picker Exposure) × Chronic Toxicity; Consumer (end user of the product) = Consumer Exposure Potential + Potential Ground Water Effects; and Ecological = Sum of effects of chemicals on fish, birds, bees, and beneficial arthropods. Each component receives equal weight. To account for different formulations of the same active ingredient in various pesticides, and differences in rate of application, we use the following suggested adjustment to calculate the EIQ Field Use Rating (EIQ-FUR): EIQ-FUR = EIQ × % Active Ingredient × Rate of Application (Kniss and Coburn 2015). A higher EIQ-FUR implies greater potential adverse impacts on people and the environment. Supplementary Appendix 2 provides additional details on how we constructed these EIQ-FUR values.

Impact results are shown in columns (1)–(4) of Table 6. Our dependent variables are in logs and our estimated models include baseline values and control variables. (Supplementary Appendix 2 includes results in levels and logs with and without controls.) Column (1) shows that cultivation of Bt brinjal reduces the toxicity of pesticide use, as measured by EIQ-FUR, by 56 percent. This change is driven by reductions in use of pesticides with adverse ecological impacts (as measured by EIQ-ecological), which falls by 82 percent (column 4), and reductions in the use of pesticides with adverse effects on farmer health, which falls by 23 percent (column 3).

Table 6 Impact of Bt brinjal cultivation on pesticide toxicity

Outcome	(1) Log of EIQ-FUR	(2) Log of EIQ-Consumer	(3) Log of EIQ-Farm Worker	(4) Log of EIQ-Ecological	(5) PUTS
Treatment: Bt brinjal	-0.56***	-0.04	-0.23***	-0.82***	-7.17***
	(0.09)	(0.05)	(0.06)	(0.11)	(1.57)
Controls					
Baseline outcome	Yes	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes	Yes
Observations	1,165	1,165	1,165	1,165	1,166
Endline mean (levels), control group	7.03	0.90	1.63	18.66	17.0

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

Our EIQ analysis focuses on pesticides used for FSB. We complement this with a second approach in which we matched the pesticides (and their chemicals) used by farmers in our study to the *Globally Harmonized System (GHS) Acute Toxicity Hazard Categories* database constructed by the World Health Organization (United Nations 2011). The GHS ranks the chemicals in these pesticides on a scale from one to five where category 1 is fatal if swallowed, inhaled, or contacts the skin, and category five is potentially harmful. We use this information to construct a toxicity score, the Pesticide Use Toxicity Score (PUTS), which assigns a score based on the GHS Oral Hazard category of the selected pesticides and the frequency of use of the respective pesticides. In the GHS Hazard Classification scale, lower levels (1,2) correspond to more severe levels of toxicity. For PUTS to be easily interpretable, the GHS scale is inverted so that higher values correspond to higher toxicity levels. The toxicity score was calculated as:

$$PUTS = Inversed\ GHS\ Oral\ Hazard\ Classification \times Number\ of\ times\ the\ respective\ pesticide\ was\ applied\ in\ a\ season$$

Supplementary Appendix 2 provides additional details on how we constructed PUTS. Table 6, column (5) gives the impact of growing Bt brinjal on log PUTS, controlling for baseline values and farmer characteristics. It shows that Bt brinjal lowers PUTS by 7.2 points, a 41 percent decline relative to the endline mean for the control group.

Health

We have shown that cultivation of Bt brinjal reduces the use of pesticides, including those that are particularly hazardous to human health. Are these changes large enough to improve health outcomes? Our unit of observation for these health outcomes is the individual. In both survey rounds, individuals who reported undertaking work on any field crops were asked if during the last agricultural season they had experienced eye irritation, headaches, dizziness,; nausea or vomiting, diarrhea, fever, convulsions, shortness of breath, wheezing, or coughing, skin disease, or joint pain (stiffness, swelling). We also asked how long (in days) these symptoms persisted, the number of days during the agricultural season that these symptoms prevented the individual from working, and the amount of cash medical expenses associated with treating these symptoms.

We have data on 2,531 individuals who engaged in any crop cultivation at baseline. Their average age was 40. Somewhat more than half of the sample (62 percent) were male and 38 percent were female. About a third of the sample (31 percent) were the spouses of the household head, 18 percent were children, sons- or daughters-in-law, or grandchildren of the head, 5 percent were other relatives of the head, and the remainder (46 percent) were household heads. Most (69 percent) reported at least one symptom consistent with pesticide exposure and, on average, respondents reported experiencing 1.8 such symptoms. A third (34 percent) reported that they missed a day's work because of these symptoms; days missed averaged 1.8 days. Just under half (42 percent) reported that they sought medical attention to address these symptoms and 58 percent stated that they had incurred cash expenses to deal with these. On average, individuals spent Tk 675 on fees, tests, transport, and medicines when treating these symptoms. Note that the variation in these expenses (standard deviation is 3,457) is high relative to the mean. Supplementary Appendix 3 provides full descriptive statistics on these individuals at baseline.

We use an ANCOVA specification and the same household controls used to assess outcomes in other domains. Because illness is reported at an individual level, we control for individual characteristics (age, sex, relationship to household head). We use linear probability models when the outcome is dichotomous and Poisson estimators for count outcomes.

Table 7a tells us that individuals engaged in crop cultivation that included Bt brinjal were 6.2 percentage points less likely to report symptoms consistent with pesticide exposure. Individuals in households growing Bt brinjal were 6.5 percentage points less likely to report that they needed to seek medical care for these symptoms. We do not find statistically significant impacts on numbers of work days lost or on the cost of treatment.[12]

Table 7a Impact of Bt brinjal cultivation on self-report of symptoms consistent with pesticide exposure

Outcome	(1) Any symptom of pesticide exposure	(2) # symptoms of pesticide exposure	(3) Sought medical treatment for any of these symptoms?	(4) Incurred cash expenses associated with treating symptoms?
Estimator	LPM	Poisson	LPM	LPM
Treatment: Bt brinjal	-0.062**	-0.103	-0.065*	-0.048
	(0.032)	(0.068)	(0.034)	(0.031)
Controls				
Baseline outcome	Yes	Yes	Yes	Yes
Individual characteristics	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes
Observations	2,531	2,531	2,531	2,531

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

Our pre-analysis plan specified that we would assess whether these impacts differed by age, sex, and relationship to the household head. These disaggregations (available on request) do not show any evidence of differential impact. However, many individuals in our sample have worked as farmers for decades, have been exposed to pesticides for a long period of time, and consequently may have developed chronic conditions consistent with pesticide exposure. We wondered if the presence of pre-existing chronic conditions might affect our results. To assess this, we did the following. At baseline, approximately 20 percent of our sample (522/2,531) reported suffering from either persistent respiratory problems or from persistent skin disease.

[12] We run three checks on model specification: (1) For our core results, the reduction in reported symptoms and the seeking of medical care, we re-estimate using a probit and calculate marginal effects. This produces near identical results to those generated by the linear probability model; (2) We winsorize the number of days lost because of these symptoms and the cash costs associated with treatment. Re-estimating with the winsorized data does not produce statistically significant impacts; and (3) For days lost and cash costs, we run Powell's (1984) censored least absolute deviations estimator (CLAD); this does not produce statistically significant impacts either.

We disaggregated our sample, putting all such individuals into one group and everyone else into a second group.

Results are reported in Table 7b for four outcomes. Individuals who had a pre-existing chronic condition consistent with pesticide exposure and who lived in villages randomly selected to grow Bt brinjal were 11.5 percentage points less likely to report a symptom of pesticide exposure, reported 0.2 fewer such symptoms, were 12 percentage points less likely to seek medical care for these symptoms, and were 11 percentage points less likely to incur cash medical expenses to treat these symptoms. All impacts are statistically significant at the 5 percent level.[13] For each of these outcomes, while the impact of Bt brinjal cultivation is larger for individuals with pre-existing chronic conditions than it is for individuals without these conditions, we come close but do not reject the null hypothesis that these impacts are equal across the two groups.

Table 7b Selected impacts on self-reported health outcomes, by chronic disease status

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Outcome	Any symptom of pesticide exposure	Any symptom of pesticide exposure	# symptoms of pesticide exposure	# symptoms of pesticide exposure	Sought medical treatment for any of these symptoms?	Sought medical treatment for any of these symptoms?	Incurred cash expenses associated with treating symptoms?	Incurred cash expenses associated with treating symptoms?
	Chronic respiratory or skin disease	No chronic respiratory or skin disease	Chronic respiratory or skin disease	No chronic respiratory or skin disease	Chronic respiratory or skin disease	No chronic respiratory or skin disease	Chronic respiratory or skin disease	No chronic respiratory or skin disease
Estimator	LPM	LPM	Poisson	Poisson	LPM	LPM	LPM	LPM
Treatment: Bt brinjal	-0.115***	-0.050**	-0.215**	-0.068	-0.122**	-0.050	-0.109**	-0.033
	(0.038)	(0.021)	(0.093)	(0.073)	(0.050)	(0.036)	(0.044)	(0.034)
p-value on equality of coefficients	0.14		0.10*		0.15		0.10*	
Observations	522	2,012	522	2,012	522	2,012	522	2,012

Source: 2017 Baseline and 2018 endline surveys.
Note: Individual characteristics are age, sex and relationship to household head. For household characteristics and additional notes, see Table 3.

[13] There were no statistically significant impacts for either group for symptoms that prevented person from working and level of cash expenses associated with treating symptoms.

Finally, we note that both treatment and control households received training on the safe handling of pesticides. If treatment households were more likely to adopt these practices, then the differences in self-reported illness could reflect this training, not the cultivation of Bt brinjal. To assess this possibility, at baseline and endline, we asked farmers cultivating brinjal to describe how they handled pesticides. The following patterns emerge (full results are reported in Supplementary Appendix 4). There are some correct practices that virtually all farmers, irrespective of treatment status, undertook at both baseline and endline: washing after spraying; changing clothes; wearing long-sleeved clothing; and wearing trousers. There were some practices that more farmers undertook at endline compared to baseline: reading and following instructions; not using bare hands when mixing pesticides; and checking for wind direction before spraying. These improvements were observed in both treatment and control households. Finally, there were some practices that few farmers undertook at baseline and which showed little change at endline: mixing pesticides with a stick and wearing gloves; and wearing eye protection, gloves, or sandals/shoes while spraying. We see little evidence of change in either treatment or control households. Crucially, looking across these practices, we see that they are similar across treatment and control households at baseline. Where we observe changes, we observe them for both groups. This suggests that differences in pesticide handling practices does not account for the reduction in the self-reported symptoms described above.

5. Results (2): Yield and Production, Price, and Profit

Yield and Production

We have seen that Bt brinjal reduces the use of pesticides (Table 3) while also reducing pest infestation (Table 4). Does this result in an increase in yield?

At endline, farmers were asked to identify the months during which they harvested brinjal. For each month, they then indicated how much they had: harvested (including fruit that they harvested, but on inspection had to discard because of pest infestation or disease); retained for home consumption; paid out to owners of leased plots; paid to hired labor; gave away as a gift; discarded for any reason, including damage due to pests or diseases; and how much they had sold. All quantities were recorded in kilograms. While a few farmers indicated some harvesting in November and December 2017, nearly all harvesting took place between January and June 2018.[14] As described above, farmers agreed to grow brinjal in 10-decimal plots. At endline, we measured these plots using GPS. Using these data, we calculate gross yields per hectare (quantity harvested in kilograms divided by area planted in hectares) and net yields per hectare (quantity harvested in kilograms minus fruit discarded for any reason, including damage due to pests or diseases). This net yield variable is a primary outcome defined in our analysis plan.

Table 8 provides descriptive statistics on endline brinjal production by treatment status. Comparing the unconditional endline means, farmers growing Bt brinjal produced, on average, 113.2 kg more brinjal (600 kg vs. 487 kg for control farmers) over the period November 2017 to June 2018. Fewer brinjal (40 kg) were discarded by Bt brinjal farmers. Consequently, after accounting for amounts paid out and retained for home consumption or seed stock, Bt brinjal farmers were able to sell more brinjal. They did so on slightly smaller plot areas (remember, Bt brinjal farmers were supposed to plant a border around their fields). Gross and net yields per hectare were, on average, higher for Bt brinjal farmers.

[14] A similar method was used to collect baseline data. While this approach is consistent with what we described in our pre-analysis plan, it introduced an unexpected complication. For baseline, this recall period (November to June) captures not only brinjal planted in October but also brinjal planted earlier in the year. As a result, for some baseline farmers, their baseline data captures two harvests on the same plot of land, rather than one. This is seen, most notably, in the number of farmers reporting harvesting in November, December, and January. At baseline, 494, 597, and 689 households respectively reported harvesting in these months. At endline (remembering that transplanting of seedlings took place largely in November), the number of farmers harvesting were 7, 29, and 340 in November, December, and January, respectively.

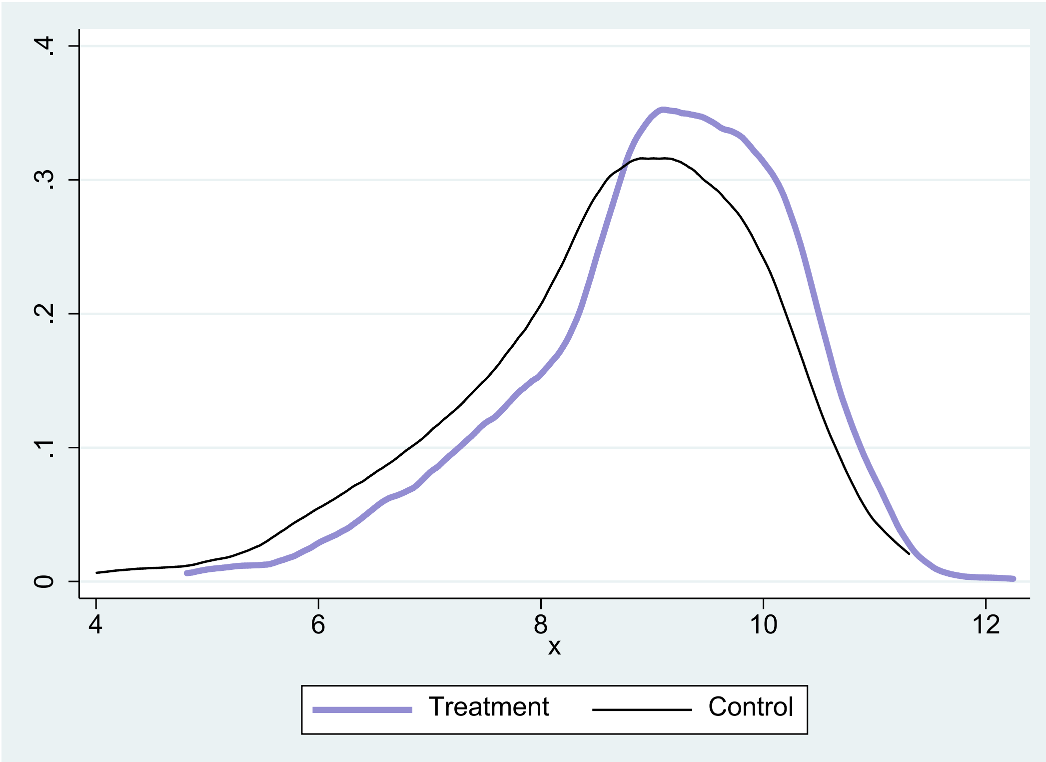
Table 8 Mean levels of endline brinjal production and yield, by treatment status

	Treatment	Control	Difference
Quantity harvested (kg)	599.9	486.7	113.2
Quantity discarded (kg)	33.0	73.3	-40.3
Quantity paid out (kg)	38.1	31.9	6.2
Quantity retained for home consumption or seed stock (kg)	29.1	22.1	7.0
Quantity sold (kg)	499.7	359.4	140.3
Plot area (ha)	0.042	0.040	0.002
Gross yield (kg per ha)	14,700.3	12,456.1	2,244.2
Net yield (kg per ha)	13,914.3	10,483.1	3,431.2

Source: 2018 Endline survey.

While Table 8 suggests differences in mean values, we are also interested in the distribution of yields across Bt brinjal and control households. To assess these, we plot the density functions of log net yields for treatment and control farmers. Figure 1 shows that, relative to control households, the distribution of (log) net Bt brinjal yields per hectare is shifted to the right. This suggests that mean differences between treatment and control groups are not being driven by a small number of households but rather that Bt brinjal yields are generally higher than those from conventional varieties such as ISD-006. A Kolmogorov-Smirnov test rejects the null hypothesis that the two distributions are equal at the 1 percent level.

Figure 1 Kernel density functions for net yields per ha, by treatment status



Source: 2018 Endline survey.

Table 9 gives our impact estimates using our extended ANCOVA specification. On a per hectare basis, net yields are 3,622 kg higher when farmers grow Bt brinjal. These results are robust to expressing the outcome variable as gross or net yields, including or excluding control variables apart from baseline values, winsorizing the data to account for outliers, or expressing our dependent variable in logs (see Supplementary Appendix S5). The log results indicate that net yields are approximately 42 percent higher for Bt brinjal farmers. As columns (3)–(7) show, net yields rise because, relative to the control farmers, Bt brinjal farmers produced 114 kg more brinjal (column 3) per farmer. After harvesting, they discarded 42.9 kg less than control farmers (column 4). Consequently, even though Bt brinjal farmers retain more brinjal for home consumption than control farmers, they also sold 143.8 kg more brinjal. All impacts are statistically significant at the 5 percent level.[15]

[15] We undertook a limited exploration of sample disaggregations, by median farmer age, education and total land holdings but find no evidence of differential impact.

Table 9 Impact of Bt brinjal on yields and production

	Yield		Production				
Outcome	(1) Net yield per ha	(2) Log net yield per ha	(3) Harvest kg	(4) Qty discarded kg	(5) Qty paid out kg	(6) Qty retained for home consumption kg	(7) Qty sold kg
Treatment: Bt brinjal	3,622.1***	0.420***	113.6 **	-42.92***	5.67	6.46***	143.8***
	(1,234.6)	(.119)	(54.0)	(10. 36)	(4.94)	(2.09)	(49.3)
Controls							
Baseline outcome	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,166	1,114	1,166	1,166	1,166	1,166	1,166

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

Price and Profit

Higher yields do not necessarily imply higher profits. For example, if Bt brinjal sells for a lower price than conventional varieties or if there are higher non-pesticide costs associated with Bt brinjal production, then net profits would not be higher.

We begin with price. At endline, farmers were asked to identify the months during which they sold brinjal, the quantity sold, and the revenue they received. We also asked them to describe who purchased their brinjal, where the brinjal was sold, and why they contracted with that buyer. Nearly all farmers (88.4 percent of treatment and 85.7 percent of control) sold brinjal. Most (65.4 percent of treatment and 61.5 percent of control) sold to wholesalers. These sales took place at the district wholesale market (44 percent of farmers) or the local retail market (43.1 percent). The main reason for choosing a particular buyer was that they were willing to pay a high or fair price (38.3 percent), pay immediately (30.3 percent), or buy in bulk (19.6 percent). Sale locations and reasons for choosing buyers do not differ between treatment and control farmers, suggesting that Bt brinjal cultivation did not cause farmers to change sales practices (see Supplementary Appendix 6).

The first two columns of Table 10 provide our impact estimates on farmers' sales price of brinjal using our extended ANCOVA, conditional on selling any brinjal. The sale price for Bt brinjal was 0.96 Tk/kg higher than for conventional varieties (column 1), corresponding to a 14.3 percent higher sales price; these impacts are statistically significant at the 5 percent level. (If we include farmers not selling brinjal, this increase falls to 10 percent.) We note that traders purchasing Bt brinjal knew that it was a GM crop, and, to the best of our knowledge, consumers knew that they were purchasing a GMO food. A consequence of reduced pesticide application was that the skin of the brinjal was much softer, making the food easier to prepare and, according to the respondents in our qualitative fieldwork, tastier. The following quotation from a market trader illustrates these points in a manner consistent with our impact estimates on price.

> *At the beginning, I could not sell this brinjal in this market; I forced them to take it, especially those who are known to me to come every day. I told them no problem if you do not pay money. Then, when they took the brinjal home and ate it, they told me to give them more brinjal. Since then, demand is getting higher. In fact, it was not sold for two or three days at the beginning. After that, I enticed all of them to buy this. Since then, I did not have any problems.*

Table 10 Impact of Bt brinjal on prices, revenues, costs and net profits

	Prices		Revenues		Costs		Profits	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Outcome	Unit price Taka per kg	Log unit price Taka per kg	Revenue Taka	Log revenue	Log cost per ha	Cost per kg	Profit per kg	Profit per ha
Treatment: Bt brinjal	0.963**	0.143***	1,962.2***	0.548***	-0.106***	-8.50 **	9.30 **	38048.4***
	(0.416)	(0.053)	(465.7)	(0.116)	(.028)	(4.09)	(4.09)	(10,858.3)
Controls								
Baseline outcome	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	980	980	1,166	980	1,166	1,116	1,116	1,166

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

The next two columns of Table 10 show impact on revenue of Bt brinjal cultivation, controlling for baseline characteristics (see Supplementary Appendix 6 for results without these controls). Given that Bt brinjal increases the amount of brinjal sold in the market (Table 9, column 7) and the price received (Table 10, columns 1 and 2), it is not surprising that Bt brinjal increases revenues by Tk 1,962 (column 3), a 54.8 percent increase when expressed in log terms (column 4) conditional on sales, with both impacts statistically significant at the 1 percent level.

Next we consider cost. We collected plot-level data on the input costs for seed/seedlings, fertilizer, irrigation, pesticides, machinery, and hired labor. At endline, on a per hectare basis, the cash costs of production of Bt brinjal are lower than conventional varieties (Tk 72,109 for treatment vs. Tk. 81,902 for control farmers) largely because Bt brinjal farmers incurred a considerably lower cost for pesticides compared with control farmers (see Supplementary Appendix 6). Note that we exclude a valuation of family labor used for brinjal cultivation given the challenges associated with valuing this labor; as we show in Supplementary Appendix 6, however, less family labor was used for Bt brinjal cultivation largely because less time was needed for pesticide application.

Columns (5) and (6) in Table 10 show impacts based on the extended ANCOVA model for log cost per hectare and cost per kilogram of brinjal produced. Bt brinjal reduces the cost of brinjal production per hectare by 10.6 percent (column 5) and cost per kg of brinjal by 8.50 Tk/kg (column 6). Both impacts are statistically significant at the 1 percent level. Additional results based on alternative model specifications are found in Supplementary Appendix 6.

Finally, we look at profits. Given that the cultivation of Bt brinjal reduces the cost of production by 8.50 Tk/kg (Table 10, column 6) and given that the sales price of Bt brinjal was 0.96 Tk/kg higher (Table 10, column 1), not surprisingly profits per kg are Tk 9.30 higher when Bt brinjal is cultivated (Table 10, column 7). Across all farmers, Bt brinjal increases farm profits by 38,048 Tk/ha (though note that this falls to 33,827 Tk/ha if we winsorize this outcome; see Supplementary Appendix 6). These impacts are statistically significant at the 5 percent level. As with our other findings, they do not differ when we disaggregate by farmer age, education, or landholdings.

6. Summary and Conclusions

In this paper, we assess the impact of genetically modified eggplant, Bt brinjal, on economic and health outcomes in Bangladesh using a cluster randomized controlled design.

We find that Bt brinjal cultivation reduces the cost of pesticide use by 47 percent; this impact is statistically significant at the 1 percent level. Our two measures, EIQ-FUR and PUTS, both show that Bt brinjal reduced the toxicity of pesticides used. This is driven by reductions in use of pesticides with adverse ecological impacts (as measured by EIQ-ecological), which falls by 82 percent, and reductions in the use of pesticides with adverse effects on farmer health (as measured by EIQ-farm worker), which falls by 23 percent. We assessed a potential consequence of the reduction in pesticide use, namely reductions in the reporting of symptoms and illness consistent with pesticide exposure. Individuals growing Bt brinjal were 6.2 percentage points less likely to report symptoms consistent with pesticide exposure. Individuals who had a pre-existing chronic condition consistent with pesticide exposure and who lived in villages randomly selected to grow Bt brinjal were 11.5 percentage points less likely to report a symptom of pesticide exposure, reported 0.2 fewer such symptoms, were 12 percentage points less likely to seek medical care for these symptoms, and were 11 percentage points less likely to incur cash medical expenses to treat these symptoms. All impacts are statistically significant at the 5 percent level.

Net yields are 42 percent higher for Bt brinjal farmers; this impact is also statistically significant at the 1 percent level. Our descriptive distributional work suggests that these yield gains are widespread. These differences in net yields are driven by two outcomes: quantity harvested is higher on Bt brinjal fields, by 114 kg per farmer; and after harvesting, fewer fruits were discarded because of damage from pests and diseases, by 40 kg per farmer. Consequently, Bt brinjal production raised sales of brinjal by 143 kg per farmer. This increase in production, together with a 14 percent increase in price and a 10 percent reduction in costs, leads to a substantial increase in profits from cultivating Bt brinjal for treatment farmers compared with conventional brinjal produced by control farmers. All these impacts are statistically significant at the 5 percent level.

These results provide a strong counternarrative to those with concerns regarding the cultivation of GM crops. Bt brinjal is a publicly developed GMO that conveys significant health benefits, both human and ecological, while raising farmer incomes.

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Appendix S1
Profile of Survey Households

Table S1.1 Characteristics of Survey Household

Item	Treatment	Control	All
Household size (number)	4.7	4.5	4.6
Dependency ratio (percent)	56.5	59.0	57.7
Primary school-age children (6-11 years) who never went to school (percent)	2.5	3.3	2.9
Secondary school-age children (12-18 years) who never went to school (percent)	1.5	0.8	1.2
Years of schooling, male household head	5.5	5.3	5.4
Years of schooling, wife of household head	5.2	5.0	5.1
Years of schooling, adult male aged 15 and above	6.9	6.7	6.8
Years of schooling, adult female aged 15 and above	6.0	5.6	5.8
No schooling, adult male (percent)	22.9	24.3	23.6
No schooling, adult female (percent)	28.8	30.2	29.5
Principal occupation of household head (percent)			
Agricultural day laborer	1.5	0.7	1.1
Nonagricultural day labor	0.8	0.5	0.7
Salaried	1.3	2.2	1.8
Self Employed	2.2	1.5	1.9
Business/Trade	9.1	7.9	8.5
Farming	82.5	85.7	84.1
Non-earning occupations	1.8	0.8	1.3
Total	100.0	100.0	100.0

Source: 2017 Baseline survey.

Table S1.2 Electricity and structure of dwelling

Characteristics	Treatment	Control	All
		(percent)	
Household has electricity	82.4	80.8	81.6
Structure of walls			
Permanent*	84.7	89.2	87.0
Roofing material			
Concrete/brick	5.6	3.7	4.6
Tin	94.1	96.1	95.1
Other	0.3	0.2	0.3

Source: 2017 Baseline survey.
Note: *Permanent materials include field bricks, concrete, wood and tin sheets.

Table S1.3 Household asset ownership

Asset	Treatment	Control	All
		(percent)	
Consumer Assets			
Electric fan	85.4	82.8	84.1
Radio	1.0	0.7	0.8
Audio cassette/CD player	0.5	1.0	0.8
Television (B/W)	3.4	3.9	3.6
Television (color)	40.2	39.4	39.8
Sewing machine	9.6	8.2	8.9
Bicycle	75.5	76.9	76.2
Motorcycle	16.5	12.0	14.2
Mobile phone set (functioning)	98.2	98.1	98.1
Fishing net	47.7	48.5	48.1
Solar energy panel	15.3	16.3	15.8
Hand tubewell	23.4	23.7	23.6
Cow	83.4	84.3	83.9
Buffalo	0.7	0.0	0.3
Goat/sheep	45.7	46.1	45.9
Duck/hen	87.7	88.4	88.1
Productive Assets			
Plough and yoke	25.9	23.6	24.7
Pesticide sprayer	77.8	83.8	80.8
Equipment for showering plant (*Jhorna/Jhajhara*)	10.6	7.6	9.1
Net for covering field/seedbed	15.0	11.8	13.4
Insect trap (Pheromone trap)	4.7	3.5	4.1
Jerry can (container) for mixing pesticide	11.4	8.1	9.8
Wheelbarrow	0.5	0.0	0.3
Tractor	0.3	0.5	0.4
Power tiller	9.4	10.6	10.0
Thresher	17.0	19.7	18.3
Swing basket	8.1	5.6	6.8
Don	1.2	0.7	0.9
Low lift pump (LLP) for irrigation	13.5	14.5	14.0
Shallow tubewell (STW)	32.3	33.3	32.8
Deep tubewell (DTW)	0.5	0.3	0.4
Electric motor pump	5.4	4.9	5.1
Diesel motor pump	2.9	5.2	4.0

Source: 2017 Baseline survey.

Table S1.4 Land tenure arrangements

	Treatment	Control
	(percent)	
Pure tenant	6.2	6.7
Sharecropping	62.2	65.0
Cash lease	27.0	15.0
Both	10.8	20.0
Own land	47.9	48.5
Mixed tenant	45.9	44.8
Sharecropping	83.5	75.9
Cash lease	8.1	14.3
Both	8.5	9.8
All sharecroppers	46.7	44.1
All cash lease	10.0	13.1

Source: 2017 Baseline survey.

Table S1.5 Share of crops on total cropped land at baseline

	Farmers who grew this crop		Total cropped area under this crop	
Crop	Treatment	Control	Treatment	Control
		(percent)		
Rice	93.6	92.1	63.1	57.2
Wheat	5.5	2.7	0.7	0.4
Maize	20.7	21.9	3.9	3.9
Pulse	4.0	2.5	0.3	0.2
Oilseed	5.5	3.9	0.6	0.5
Potato	40.3	42.6	6.1	6.5
Brinjal	99.2	99.3	9.5	10.7
Patal (pointed gourd)	14.1	18.4	1.6	1.9
Bittergourd	8.6	11.6	1.2	1.6
Arum	10.9	10.3	0.9	0.9
Bean	5.2	9.4	0.5	1.1
Other vegetable	19.5	30.8	2.8	4.3
Leafy vegetable	9.9	11.4	1.1	1.6
Banana	8.7	14.8	1.2	2.5
Onion	7.9	5.2	0.5	0.4
Chili	14.6	18.5	1.3	1.7
Other spice	10.4	10.6	0.8	1.0
Jute	18.2	16.7	2.4	2.0

Source: 2017 Baseline survey.

Appendix S2
Pesticide Toxicity: EIQ and PUTS

EIQ

Kovach et al. (1992) developed the EIQ as a measure of the environmental effect of specific pesticides. They constructed a database showing the health, ecological, and environmental effects of pesticides on dermal toxicity, chronic toxicity, systemicity (the uptake and distribution of pesticides in the leaves and roots, Goertz and Mahoney 2012), fish toxicity, leaching potential, surface loss potential, bird toxicity, soil half-life, bee toxicity, beneficial arthropod toxicity, and the plant surface half-life of specific pesticides. From this, they generate three components of the EIQ score:

1. Farm worker risk = (Applicator Exposure + Picker Exposure) × Chronic Toxicity
2. Consumer (end user of the product) = Consumer Exposure Potential + Potential Ground Water Effects
3. Ecological = Sum of effects of chemicals on fish, birds, bees and beneficial arthropods

Consumer exposure potential and picker exposure are functions of the residue potential in soil and plant surfaces, which is the time required for one-half of the chemical to break down. The residue factor accounts for the erosion of pesticides that occur in agricultural systems (Kovach et al. 1992). Each component is given equal weight. Across all pesticides in their data base, EIQ ranges from 6.7 to 226.7 (Kniss and Coburn 2015). To account for different formulations of the same active ingredient in various pesticides, and differences in rate of application, the EIQ Field Use Rating (EIQ-FUR) is calculated as:

EIQ-FUR = EIQ × % Active Ingredient × Rate of Application

Our calculation of EIQ-FUR is based on the pesticides most frequently used by farmers in our study to combat FSB. These are: Alba 1.8 EC, Dursban 20 EC, Ripcord 10 EC, Volium Flexi 300 SC, Wonder 5 WG, Actara 25 WG, Guilder 5 SG, and Shobicron 425 EC. These pesticides were used by 43 percent of all treatment and control farmers at baseline and 23 percent of all farmers at endline. Table S2.1 describes the chemical name, percent of active ingredient, Field Use EIQ, and EIQ component scores of the selected pesticides.

Table S2.1 Pesticides used to calculate EIQ

Sl. No.	Trade/brand name	Active Ingredients	Field Use EIQ (1000 ml per ha)	Field Use EIQ Components (1000 ml per ha)		
				Consumer	Field worker	Ecological
1	Alba (1.8 EC)	Abamectin: 18 gm/liter (1.8%)	0.5	0.1	0.2	1.3
2	Dursban (20 EC)	Chlorpyrifos (20%)	4.6	0.3	1	12.4
3	Ripcord (10 EC)	Cypermethrin (10%)	3.1	0.5	1.2	7.6
4	Volium Flexi (300 SC)	Thiamethoxam: 200 gm/liter (20%)	5.7	2.1	1.8	13.3
		Chlorantraniliprole: 100 gm/liter (10%)	1.6	0.6	0.6	3.6
		Weighted Average	4.3	1.6	1.4	10.1
5	Wonder (5 WG)	Emamectin Benzoate (5%)	1.1	0.2	0.4	2.8
6	Actara (25 WG)	Thiamethoxam: 250gm/kg (25%)	7.1	2.6	2.2	16.6
7	Guilder (5 SG)	Emamectin Benzoate (5%)	1.1	0.2	0.4	2.8
8	Shobicron (425 EC)	Profenofos: 400 gm/liter (40%)	20.4	1	2.8	57.3
		Cypermethrin: 25 gm/liter (2.5%)	0.8	0.1	0.3	1.9
		Weighted Average	19.2	0.9	2.7	54.0

Source: Calculated from Eshenaur et al. (2015).

The EIQ values in Table S2.1 are based on an application rate of 1,000 ml per ha. We adjusted the EIQ values according to the application rate (in ml/ha) on individual plots based on our survey data collected at baseline and endline. Table S2.2 presents descriptive statistics on EIQ values of pesticides used in treatment and control plots by survey round.

Table S2.2 Descriptive statistics of EIQ-FUR and EIQ components, by round and treatment status

	Baseline				Endline			
	Treatment n=630		Control n=628		Treatment n=603		Control n=589	
	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev
EIQ-FUR	8.66	35.41	8.70	24.60	2.52	14.29	7.03	19.97
EIQ Components								
Consumer	1.06	2.83	1.33	3.21	0.19	0.86	0.90	2.49
Farm Worker	2.10	5.99	2.48	5.78	0.45	2.15	1.63	3.81
Ecological	22.95	98.47	22.48	66.42	6.93	40.02	18.66	54.70

Source: 2017 Baseline and 2018 endline surveys.
Note: n = number of plots

Tables S2.3 gives our full set of impact estimates.

Table S2.3 Impact of Bt brinjal cultivation on EIQ-FUR and EIQ component values

Outcome	(1) EIQ-FUR	(2) EIQ-FUR	(3) Log of EIQ-FUR	(4) Log of EIQ-FUR
Treatment: Bt brinjal	-4.67***	-4.63***	-0.56***	-0.56***
	(1.57)	(1.62)	(0.09)	(0.09)
Controls				
Baseline outcome	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes
Observations	1,166	1,165	1,166	1,165

Table S2.3 Impact of Bt brinjal cultivation on EIQ-FUR and EIQ component values, *continued*

Outcome	(5) EIQ-Consumer	(6) EIQ-Consumer	(7) Log of EIQ-Consumer	(8) Log of EIQ-Consumer
Treatment: Bt brinjal	-0.71***	-0.70***	-0.04	-0.04
	(0.13)	(0.13)	(0.05)	(0.05)
Controls				
Baseline outcome	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes
Observations	1,166	1,165	1,166	1,165

Table S2.3 Impact of Bt brinjal cultivation on EIQ-FUR and EIQ component values, *continued*

Outcome	(9) EIQ-Farm Worker	(10) EIQ-Farm Worker	(11) Log of EIQ-Farm Worker	(12) Log of EIQ-Farm Worker
Treatment: Bt brinjal	-1.20***	-1.18***	-0.23***	-0.23***
	(0.25)	(0.25)	(0.06)	(0.06)
Controls				
Baseline outcome	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes
Observations	1,166	1,165	1,166	1,165

Table S2.3 Impact of Bt brinjal cultivation on EIQ-FUR and EIQ component values, *continued*

Outcome	(13) EIQ-Ecological	(14) EIQ-Ecological	(15) Log of EIQ-Ecological	(16) Log of EIQ-Ecological
Treatment: Bt brinjal	-12.17***	-12.08***	-0.83***	-0.82***
	(4.38)	(4.53)	(0.11)	(0.11)
Controls				
Baseline outcome	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes
Observations	1,166	1,165	1,166	1,165

Source: 2017 Baseline and 2018 endline surveys.

Note: See main text, Table 3.

PUTS

We constructed our PUTS (Pesticide Use Toxicity Score) measure in the following fashion.

In both survey rounds, farmers were also asked to name the pesticides used for different brinjal pests. We matched the trade names of these pesticides to the DAE List of Registered Agricultural Bio Pesticides and Public Health Pesticides in Bangladesh (DAE 2016) to obtain their respective chemical names. The toxicity levels of the chemicals in these pesticides were checked against the Globally Harmonized System (GHS) Acute Toxicity Hazard Categories. GHS toxicity classification is an internationally recognized classification and labeling scheme of chemical substances and mixtures of chemicals according to their physical, health, and environmental hazards (United Nations 2011); see Table S2.4. Combining information primarily from these two sources, a list of pesticides widely used against common brinjal pests was compiled, along with information on DAE's recommendation for which types of pests and crops they are appropriate for and their GHS toxicity classification; see Table S2.5.

Table S2.4 Globally Harmonized System of Classification and Labelling of Chemical (GHS)

Categories	Oral Hazard Statement	Dermal Hazard Statement	Inhalation Hazard Statement
1	Fatal if swallowed	Fatal in contact with skin	Fatal if inhaled
2	Fatal if swallowed	Fatal in contact with skin	Fatal if inhaled
3	Toxic if swallowed	Toxic in contact with skin	Toxic if inhaled
4	Harmful if swallowed	Harmful in contact with skin	Harmful if inhaled
5	May be harmful if swallowed	May be harmful in contact with skin	May be harmful if inhaled

Source: United Nations (2011).
Note: Although categories 1 and 2 have the same hazard labels, the lethal dose (expressed in mg per kg of bodyweight) is lower for chemicals classified under category 1 compared to those under category 2.

Table S2.5 Frequently used pesticides used in brinjal production

Trade/ Brand Name	Generic/ Chemical Name	Name of Registration Holder	Recommended Pests	GHS Hazard Classification
Actara (25 WG)	Thiamethoxam	Syngenta Bangladesh Limited	BPH, Aphid, Jassid, Termite, Hopper, Beetle, Helopeltis	4 (Oral)
Alba (1.8 EC)	Abamectin	SAMP Limited	Brown Planthopper (BPH), Hispa	2 (Oral); 1 (Inhalation)
Basuden (10 GR)	Diazinon Organophosphate	Raven Agro Chemicals Limited	Aphid	4 (Oral)
Dursban (20 EC)	Chlorpyrifos Organophosphate	Auto Crop Care Limited	BPH, Hispa, Stem Borer (SB), Leafroller (LR), Grasshopper (GH), Rice bug, Termite, Cutworm, Bollworm, Aphid, Jassid	3 (Oral); 3 (Dermal); 4 (Inhalation)
Furadan (5G)	Carbofuran	Padma Oil Company Limited	Stemborer, BPH, Ufra Nematode, White grub, Top and Early Shoot borer, Cutworm	2 (Oral); 2 (Inhalation)
Guilder (5 SG)	Emamectin Benzoate	Aama Gree Care	Pod borer, Termite	3 (Oral); 4 (Dermal)
Imitaf (20 SL)	Imidacloprid	Auto Crop Care Limited	BPH, Hispa, Aphid, Jassid, Whitefly, Bollworm, Termite	4 (Oral)
Licar (1.8 EC)	Abamectin	Corbel International Limited	BPH, Hispa	2 (Oral); 1 (Inhalation)
Pegasus (500 SC)	Diafenthiuron	Polo/Pegasus	Whitefly, mites, aphids, jassids	4 (Oral); 3 (Inhalation); 2 (Dermal)
Ripcord (10 EC)	Cypermethrin	BASF Bangladesh Limited	Bollworm, Hopper, Hairy caterpillar, Field cricket, Semilooper, Shoot and fruit borer	3 (Oral); 4 (Inhalation); 1 (Skin Sensitization)

Shobicron (425 EC)	Profenofos (40%) + Cypermthrin (2.5%)	Syngenta Bangladesh Limited	Fruit fly, Shoot and Fruit Borer, White fly, Aphid, Jassid, Bollworm, Hopper, Beetle	Profenofos: 4 (Oral); 4 (Dermal); Cypermethrin: 3 (Oral); 4 (Inhalation); 1 (Skin Sensitization)
Tundra (20 SP)	Acetamiprid	Auto Crop Care Limited	Aphid, Jassid, White fly	4 (Oral); 2 (Inhalation)
Vertimec (1.8 EC)	Abamectin	Syngenta Bangladesh Limited	Red spider mite, mite	2 (Oral); 1 (Inhalation)
Volium Flexi (300 SC)	Thiamethoxam (20%) + Chloraniliprole (20%)	Syngenta Bangladesh Limited	Fruit borer, Shoot and fruit borer	4 (Oral); The toxicological properties have not been thoroughly investigated for Chloraniliprole
Wonder (5 WG)	Emamectin Benzoate	Asia Trade International	Bollworm	3 (Oral); 4 (Dermal)

Source: WHO (2010); United Nations (2011); DAE (2016).
Note: Pesticide Formulation Abbreviations. EC: Emulsifiable Concentrate; SC: Suspension Concentrate; WG: Water Dispersible Granule; SG: Soluble Granule; SP: Soluble Powder Formulation; SL: Soluble Liquid; GR: Granule.

Table S2.6 summarizes data on the percentage of total brinjal plots that used these pesticides and the quantity applied (ml or gm) per ha, disaggregated by treatment status at baseline and endline. Note that some pesticides are used for multiple pests.

Table S2.6 Pesticides commonly used by treatment and control farmers

GHS Hazard Classification	Name of Pesticides	Percentage of total plots that used this pesticide: Baseline Treatment	Baseline Control	Endline Treatment	Endline Control	Quantity (ml or gm) per ha: Baseline Treatment	Baseline Control	Endline Treatment	Endline Control
		Pesticides for Fruit and Shoot Borer Infestation							
4 (Oral)	Actara 25 WG	3.5	3.5	1.2	5.8	85.1	53.8	14.3	96.9
2 (Oral); 1 (Inhalation)	Alba 1.8 EC	15.4	12.6	2.5	9.3	1,270.0	1,506.0	76.8	376.5
3 (Oral); 3 (Dermal); 4 (Inhalation)	Dursban 20 EC	7.9	6.5	2.8	8.3	247.2	174.6	66.1	269.4
3 (Oral); 4 (Dermal)	Guilder 5 SG	1.1	3.5	1.2	8.0	22.5	105.7	42.1	286.4
3 (Oral); 4 (Inhalation); 1 (Skin Sensitization)	Ripcord 10 EC	13.3	14.0	1.3	5.4	545.5	914.7	34.0	233.4
(3-4 Oral); (4 Dermal); 4 (Inhalation); 1 (Skin Sensitization)	Shobicron 425 EC	3.8	3.2	2.7	4.9	209.0	139.1	98.7	167.8
4 (Oral)	Volium 300 SC	4.0	5.1	0.3	3.4	93.0	218.7	6.2	105.0
3 (Oral); 4 (Dermal)	Wonder 5 WG	3.8	5.6	0.2	6.1	136.8	176.0	3.1	189.4
		Pesticides for White Flies/White Insects							
4 (Oral)	Actara 25 WG	3.2	6.7	3.8	5.3	85.1	128.5	51.2	88.0
2 (Oral); 1 (Inhalation)	Alba 1.8 EC	4.4	1.3	2.5	2.9	222.9	85.4	76.5	108.2
3 (Oral); 3 (Dermal); 4 (Inhalation)	Dursban 20 EC	5.1	4.1	6.0	3.9	168.8	110.4	146.7	124.4
4 (Oral)	Imitaf 20 SL	1.4	1.8	7.8	2.2	92.4	87.3	405.8	110.8
3 (Oral); 4 (Inhalation); 1 (Skin Sensitization)	Ripcord 10 EC	5.2	5.1	5.3	5.3	249.0	107.5	175.6	155.0
(3-4 Oral); (4 Dermal); 4 (Inhalation); 1 (Skin Sensitization)	Shobicron 425 EC	5.4	4.6	2.7	3.7	248.2	216.9	79.4	156.2
4 (Oral); 2 (Inhalation)	Tundra 20 SP	4.8	4.9	6.5	4.9	214.9	215.1	133.7	166.8
4 (Oral); 3 (Inhalation); 2 (Dermal)	Pegasus 500 SC	Not used in baseline		5.1	1.0	Not used in baseline		163.0	23.4

Table S2.6 Pesticides commonly used by treatment and control farmers (*continued*)

		Popular Pesticides for Beetles, Spiders and Worms							
4 (Oral)	Actara 25 WG	1.8	3.2	4.3	6.6	17.8	58.8	73.5	130.8
2 (Oral); 1 (Inhalation)	Alba 1.8 EC	2.7	0.6	5.5	3.6	220.2	16.6	137.3	234.0
4 (Oral)	Basudin	1.9	1.9	1.2	1.2	274.1	293.0	169.5	266.4
3 (Oral); 3 (Dermal); 4 (Inhalation)	Dursban 20 EC	5.2	4.6	2.5	3.4	281.2	228.7	94.1	177.3
2 (Oral); 2 (Inhalation)	Furadan 5G	1.6	2.6	3.7	3.6	187.3	276.2	862.7	864.1
2 (Oral); 1 (Inhalation)	Licar 1.8 EC	1.9	3.5	3.8	6.5	140.9	130.1	124.2	239.9
3 (Oral); 4 (Inhalation); 1 (Skin Sensitization)	Ripcord 10 EC	2.4	2.2	2.0	3.4	99.1	60.8	55.7	90.0
(3-4 Oral); (4 Dermal); 4 (Inhalation); 1 (Skin Sensitization)	Shobicron 425 EC	1.6	3.2	0.8	1.5	150.1	224.2	26.1	59.8
2 (Oral); 1 (Inhalation)	Vertimec 1.8 EC	3.0	4.3	4.3	9.0	182.7	274.0	137.7	338.6
4 (Oral); 3 (Inhalation); 2 (Dermal)	Pegasus 500 SC	Not used in baseline		4.8	1.5	Not used in baseline		122.4	34.5

Source: 2017 Baseline and 2018 endline surveys.

Note: Pesticide Formulation Abbreviations. EC: Emulsifiable Concentrate; SC: Suspension Concentrate; WG: Water Dispersible Granule; SG: Soluble Granule; SP: Soluble Powder Formulation; SL: Soluble Liquid; GR: Granule.

Next, we group their prevalence and use by the GHS Oral Hazard classification, see Table S2.7.[16] This shows that fewer treatment farmers applied pesticides of high toxicity levels (levels 2 and 3) compared to control farmers at endline. The mean number of times highly toxic (levels 2 and 3) pesticides were applied by endline was also lower for treatment farmers.

Table S2.7 Disaggregation of pesticide toxicity

Toxicity Scale	Frequency				Mean Sprays			
	Baseline		Endline		Baseline		Endline	
	Treatment	Control	Treatment	Control	Treatment	Control	Treatment	Control
Pesticides used for all pests								
1	N/A				N/A			
2	31.4	34.1	34.2	43.0	3.8	4.1	1.7	3.1
3	45.7	46.7	28.0	45.2	4.1	5.2	1.7	3.5
3.5 (avg. scale)	11.8	10.8	6.8	11.2	1.2	1.0	0.4	0.8
4	32.2	36.2	43.8	42.8	3.0	3.8	3.5	3.0
5	N/A				N/A			
Pesticides used for fruit and shoot borer								
1	N/A				N/A			
2	17.8	17.0	5.1	14.1	2.0	2.5	0.2	0.9
3	24.3	26.4	5.3	24.6	1.8	2.6	0.2	1.7
3.5 (avg. scale)	3.8	3.2	2.7	4.9	0.3	0.2	0.1	0.3
4	9.7	11.0	5.5	13.8	0.6	0.8	0.3	0.9
5	N/A				N/A			

Source: 2017 Baseline and 2018 endline surveys.
Note: N/A indicates that none of the pesticides selected for this analysis corresponded to the respective toxicity scale. Toxicity scale is based on GHS Oral Ingestion Hazard level. Frequency: Percentage of farmers using pesticides of corresponding toxicity level. Mean Sprays: Average number of times pesticides of corresponding toxicity level were applied.

We summarize pesticide use adjusting for toxicity by constructing a Pesticide Use Toxicity Score (PUTS). This is based on the GHS Oral Hazard category of the pesticides used as well as their frequency of use. In the GHS Hazard Classification scale, lower levels (1,2) correspond to more severe levels of toxicity. For PUTS to be easily interpretable, the GHS scale is inverted so that higher values correspond to higher toxicity levels. The toxicity score was calculated in the following method:

$$PUTS = Inversed\ GHS\ Oral\ Hazard\ Classification \times Number\ of\ times\ the\ respective\ pesticide\ was\ applied\ in\ a\ season$$

Summary statistics are shown in Table S2.8 and the full set of impact results are shown in Table S2.9.

[16] Although the inhalation hazard classification would have been more appropriate, this information is not available for all the pesticides identified during these surveys.

Table S2.8 Pesticide use toxicity score (PUTS) summary statistics

	Baseline		Endline	
	Treatment	Control	Treatment	Control
Mean	22.3	24.5	9.5	17.0
St. Dev.	29.4	32.5	14.1	23.2
Min	0.0	0.0	0.0	0.0
Max	207.0	177.5	150.0	247.0

Source: 2017 Baseline and 2018 endline surveys.

Note: Range for PUTS: 0 to 438 (max. based on highest toxicity level times maximum number of sprays recorded in baseline).

Table S2.9 Impact of Bt brinjal cultivation PUTS

	(1)	(2)	(3)	(4)
Outcome	PUTS	PUTS	Log of PUTS	Log of PUTS
Treatment: Bt brinjal	-7.20***	-7.17***	-0.42***	-0.41***
	(1.57)	(1.57)	(0.09)	(0.09)
Controls				
Baseline outcome	Yes	Yes	Yes	Yes
Individual characteristics	No	Yes	No	Yes
Household characteristics	No	Yes	No	Yes
Observation	1,166	1,166	634	634

Source: 2017 Baseline and 2018 endline surveys.

Note: See Table 3.

Appendix S3
Health

Table S3.1 Descriptive statistics, self-reported health status, baseline

	Mean	Standard Deviation
Demographic characteristics		
Age	40.8	14.2
Female	0.38	0.49
Head of household	0.46	0.50
Spouse of head	0.31	0.46
Child, son/daughter-in-law or grandchild of head	0.18	0.39
Other relation	0.05	0.22
Self-reported health status		
Any symptom consistent with pesticide exposure	0.69	0.46
Number of symptoms	1.85	1.78
Any work days lost because of symptoms	0.34	0.47
Number of days lost because of symptoms	1.89	4.53
Sought treatment for symptoms	0.42	0.49
Incurred expenses to address symptoms	0.58	0.49
Medical expenses incurred to address symptoms (Taka)	675	3,457
Self-reported health status by treatment status	Mean	
	Control	Treatment
Any symptom consistent with pesticide exposure	0.66	0.72
Number of symptoms	1.77	1.93
Any work days lost because of symptoms	0.30	0.38
Number of days lost because of symptoms	1.47	2.28
Sought treatment for symptoms	0.39	0.45
Incurred expenses to address symptoms	0.55	0.61
Medical expenses incurred to address symptoms (Taka)	519	827

Source: 2017 Baseline survey.
Note: Sample size is 2,531.

Appendix S4
Pesticide Handling Practices

Table S4:1 Pesticide handling practices by treatment status and survey round

	Baseline		Endline	
	Treatment	Control	Treatment	Control
	Do you read the labels on pesticide bottles/packs? (percent)			
Yes	62.8	62.2	69.0	68.3
Cannot read, have someone else read it	8.8	12.4	19.7	20.9
No	23.1	21.0	10.8	9.2
Cannot read, do not have someone else read it	5.3	4.4	0.5	1.5
	Do you follow the instructions on the label?			
Yes	36.8	38.5	67.3	67.7
Yes, sometimes	34.1	34.8	21.8	22.9
No	5.9	5.8	0.2	0.2
No, do not read label	23.1	21.0	10.8	9.3
	How do you prepare pesticide?			
With bare hands	71.1	74.2	59.9	61.7
Wearing gloves	11.4	9.3	7.1	11.1
With a stick (but bare hands)	85.1	80.7	81.8	83.5
With a stick wearing gloves	12.7	9.5	9.1	14.1
	Spraying practices			
Wears long sleeves	92.5	93.2	95.8	97.1
Wears long trousers	91.7	92.7	96.0	97.1
Shields face	67.9	63.7	67.8	69.2
Covers head	58.5	54.0	61.2	68.8
Wears eye protection	13.7	12.2	8.9	10.6
Wears gloves	12.2	8.0	8.8	11.2
Wears sandal/shoes	11.5	10.0	16.2	19.9
	Do you determine the wind direction before spraying?			
Yes	89.5	89.5	95.8	97.5
	Do you spray when it is windy?			
Yes	5.4	7.3	4.7	4.9
	After applying pesticides			
Wash hands after spraying	97.5	98.1	96.3	97.1
Wash face after spraying	96.6	96.7	95.6	97.1
Take bath/shower after spraying	95.1	96.4	96.1	97.3
Change clothes after spraying	96.1	97.4	95.8	97.6

Source: 2017 Baseline and 2018 endline surveys.

Appendix S5
Yield and Production

Table S5.1 Impact of Bt brinjal on yields

Outcome	(1) Gross yield per ha	(2) Gross yield per ha	(3) Net yield per ha	(4) Net yield per ha	(5) Net yield per ha Winsorized	(6) Net yield per ha Winsorized	(7) Log net yield per ha	(8) Log net yield per ha
Treatment: Bt brinjal	2,420.1*	2,355.6*	3,624.1***	3,622.1***	3,367.2***	3,372.9***	0.417***	0.420***
	(1,319.9)	(1,318.4)	(1,241.8)	(1,234.6)	(1,129.6)	(1,129.7)	(.117)	(.119)
Controls								
Baseline outcome	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes	No	Yes	No	Yes
Observations	1,166	1,166	1,166	1,166	1,166	1,166	1,114	1,114

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

Table S5.2 Impact of Bt brinjal on harvest, plot area, quantity discarded, paid out, retained for consumption and sold

Outcome	(1) Harvest kg	(2) Harvest kg	(3) Area planted ha	(4) Area planted ha	(5) Qty discarded kg	(6) Qty discarded kg	(7) Qty paid out Kg	(8) Qty paid out kg	(9) Qty retained for home consumption kg	(10) Qty retained for home consumption kg	(11) Qty sold kg	(12) Qty sold kg
Treatment: Bt brinjal	117.7**	113.6 **	.002**	.002**	- 40.54***	- 42.92***	5.54	5.67	6.85***	6.46***	145.1***	143.8***
	(54.0)	(54.0)	(.001)	(.001)	(9.88)	(10. 36)	(4.91)	(4.94)	(2.19)	(2.09)	(49.3)	(49.3)
Controls												
Baseline outcome	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Observations	1,166	1,166	1,166	1,166	1,166	1,166	1,166	1,166	1,166	1,166	1,166	1,166

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

Appendix S6
Price and Profit

Table S6.1 Marketing of brinjal at endline

	Treatment	Control	All
		(percent)	
Main buyer of brinjal			
Wholesaler	65.4	61.5	63.4
Retailer	10.9	10.6	10.8
Consumer	9.2	8.9	9.1
Village collector	2.4	4.7	3.5
Others	0.5	0.0	0.3
Did not sell	11.6	14.3	13.0
Main reason for the choice of buyer			
Pays high/fair price	39.7	36.7	38.3
Makes immediate payment	31.8	28.9	30.3
Buys in bulk	18.8	20.4	19.6
Buys limited quantity	5.5	8.1	6.8
Lives nearby	2.1	3.0	2.5
Makes advance payment	0.2	0.8	0.5
No other option	1.9	2.2	2.0
Location of sales			
District wholesale market	44.3	44.4	44.4
Local retail market	43.4	42.8	43.1
Farmer's field / own	10.5	10.6	10.5
Another district wholesale market	1.3	1.6	1.5
Other wholesale market	0.0	0.6	0.3
Others	0.6	0.0	0.3
Price agreed upon over phone	39.0	33.3	36.6

Source: 2018 Endline survey.

Table S6.2 Impact of Bt brinjal on price for those who sold

Outcome	(1) Unit price Taka per kg	(2) Unit price Taka per kg	(3) Log unit price Taka per kg	(4) Log unit price Taka per kg
Treatment: Bt brinjal	1.01**	0.963**	0.148***	0.143***
	(0.418)	(0.416)	(0.053)	(0.053)
Controls				
Baseline outcome	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes
Observations	980	980	980	980

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

Table S6.3 Impact of Bt brinjal on revenue

Outcome	(1) Value of sales Taka	(2) Value of sales Taka	(3) Log Value of sales Taka	(4) Log Value of sales Taka
Treatment: Bt brinjal	1,963.7***	1,962.2***	0.565***	0.548***
	(475.7)	(465.7)	(0.115)	(0.116)
Controls				
Baseline outcome	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes
Observations	1,166	1,166	980	980

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

Table S6.4 Input costs per hectare for Bt Brinjal and ISD-006 cultivation at endline

Cost	Treatment	Control
	(Taka per hectare)	
Seed/seedling	5,461	5,539
Fertilizer	30,326	32,026
Irrigation	11,241	11,867
Pesticide	14,852	22,145
Machinery	7,600	8,097
Total hired labor	2,505	2,227
Total cash cost	72,109	81,902

Source: 2018 Endline survey.

Table S6.5 Endline labor use in brinjal cultivation: Days per hectare by cultivation activities, labor type and treatment status

Activity	Family labor						Hired labor						Total labor				
	Treatment			Control			Treatment			Control							
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Total male labor	Total female labor	Total labor (Treatment)	Total labor (Control)	Total labor (Treatment+ Control)
	(Labor days)						(Labor days)						(Labor days)				
Land preparation	18.8	0.9	19.7	19.2	1.4	20.7	6.8	0.2	7.0	7.7	0.2	7.8	52.5	2.7	26.7	28.5	55.2
Transplanting	20.2	2.6	22.8	21.0	2.2	23.3	12.5	1.0	13.5	11.9	0.1	12.0	65.7	5.9	36.3	35.3	71.6
Fertilizer application	10.9	0.1	11.0	13.3	0.3	13.6	0.6	0.0	0.6	0.6	0.0	0.6	25.3	0.4	11.5	14.2	25.7
Pesticide application	23.1	0.3	23.4	35.4	0.5	35.9	3.6	0.0	3.6	2.7	0.0	2.7	64.8	0.8	27.0	38.5	65.5
Weeding	59.1	5.8	64.9	63.6	5.2	68.8	61.4	10.8	72.2	59.6	6.8	66.5	243.7	28.6	137.0	135.3	272.3
Irrigation	4.2	0.1	4.3	4.2	0.1	4.3	0.6	0.0	0.6	0.4	0.0	0.4	9.4	0.2	4.9	4.7	9.6
Harvesting	45.5	19.9	65.4	48.3	21.9	70.2	0.9	0.7	1.6	2.2	1.6	3.7	96.9	44.1	67.1	73.9	141.0
Sorting and packing	13.5	11.3	24.9	13.6	12.1	25.6	0.3	0.2	0.6	0.1	0.1	0.2	27.6	23.7	25.5	25.9	51.3
Plant uprooting	13.2	1.2	14.3	15.4	1.2	16.6	4.3	0.2	4.4	4.5	0.2	4.7	37.3	2.8	18.8	21.3	40.1
Total	208.4	42.4	250.7	234.1	44.8	278.9	91.0	13.1	104.1	89.7	9.0	98.7	623.1	109.2	354.8	377.6	732.3

Source: 2018 Endline survey.

Table S6.6 Impact of Bt brinjal on cost

Outcome	(1) Cost per ha	(2) Cost per ha	(3) Cost per ha Winsorized	(4) Cost per ha Winsorized	(5) Log cost per ha	(6) Log cost per ha	(7) Cost per kg	(8) Cost per kg	(9) Log cost per kg	(10) Log cost per kg
Treatment: Bt brinjal	-9,260.5***	-9,260.4***	-8,214.6***	-8,265.5***	-0.105***	-0.105***	-8.17 **	-8.31 **	-0.309***	-0.310***
	(2131.8)	(2129.5)	(1995.0)	(1996.8)	(.028)	(.028)	(4.04)	(4.06)	(0.102)	(0.103)
Controls										
Baseline outcome	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Observations	1,174	1,174	1,174	1,174	1,174	1,174	1,122	1,122	1,122	1,122

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

Table S6.7 Impact of Bt brinjal on profit

Outcome	(1) Profit per ha	(2) Profit per ha	(3) Profit per ha Winsorized	(4) Profit per ha Winsorized	(5) Profit per kg	(6) Profit per kg
Treatment: Bt brinjal	38,967.6***	38,063.4***	34,359.0***	33,827.0***	9.00**	9.11 **
	(10,806.5)	(10,815.0)	(9,156.3)	(9,216.9)	(4.04)	(4.06)
Controls						
Baseline outcome	Yes	Yes	Yes	Yes	Yes	Yes
Household characteristics	No	Yes	No	Yes	No	Yes
Observations	1,174	1,174	1,174	1,174	1,122	1,122

Source: 2017 Baseline and 2018 endline surveys.
Note: See Table 3.

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