The effect of high-yielding variety on rice yield, farm income and household nutrition: evidence from rural Bangladesh

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Abstract

Background: High-yielding variety (HYV) seed breeding has been one key approach to improving agricultural productivity and to reduce global hunger and poverty. This paper explores the causal relationship between high-yielding rice variety, rice productivity, farm income and household nutrition. A challenge with evaluating the impact of changes such as crop varieties on yield is self-selection and endogeneity. This article robustly identifies marginal input contributions, correcting for self-selection potential by applying matched Difference in Difference method.

Results: We found that the farms that switched from local to HYV, experienced around 35% higher yield and 76% higher profit from Aman rice than non-adopting farms. More calorie intake, more protein and especially higher fruit and vegetable intake meant less calorie poverty for adopted households.

Conclusion: This recent evidence suggests improved seed remains a high potential return investment for regions of the world where smallholder farming and malnutrition is a wider phenomenon.

Keywords: High-yielding rice variety, Yield increase, Rice productivity, Farm income, Household nutrition

Introduction

In developing countries, nutritional deficiencies are still among the major causes of premature deaths, infectious diseases, physical and mental growth retardation in children, and other types of health problems [37]. Over the last few decades, agricultural productivity and food production growth has helped to reduce global hunger considerably [35, 51, 66]. And rice is the most important staple food for more than half of the population in the world particularly in developing countries [8, 73]. Hence, rice production and productivity increase are important for ensuring food security, reducing hunger and a vital prerequisite to sustainable economic growth [62].

A number of technologies have been identified as potential for increasing rice yield including high-yielding rice varieties, efficient agronomic management techniques, enhancing nutrient and water availability and controlling weeds [39, 60]. Among these technologies improved or high-yielding varieties [21, 29, 46, 64, 67] is a particularly successful intervention used to increase yields. Since 1980 rice yield has increased globally by threefold [52] and yield gain from the development of new varieties have played a big part in this gain [10, 21, 64, 84].

Empirical studies find positive HYV impact on yield [3, 24, 30, 61, 72] or that using HYV can maintain yield from reduced input [5, 63]. Generally, modern varieties have more yield potential and more response to chemical fertilizer resulting in higher yield [60].

Yield growth can also contribute to the nutritional outcome of families. There are a number of pathways through which agriculture can influence nutritional
outcomes such as by increasing food available to households for own consumption or increasing income available to households to buy additional or higher quality food [33, 38, 78, 81]. But the evidence is mixed. Some studies show agricultural growth is important for reducing malnutrition by allowing households to consume more calories and diversify their diets [20]. On the other hand, [41] found that agricultural growth had no (statistically significant) impact on child stunting. Other literature shows that poor farmers directly benefit from adopting new agricultural technologies through increases in farm household income, and indirectly, through reduced unemployment, and higher wage rates of functionally landless labourer, and by lowering the price of food staples [23, 45, 47, 69, 82].

Previous study on agricultural technology adoption and poverty [55], improved rice technology and poverty [58], agriculture, nutrition and green revolution in Bangladesh [43], improved rice technology adoption and farmer’s well-being [48] have been constrained either by methodology or data they used. Mendola [55] used data from two rural regions of Bangladesh, Nguezet et al. [58] used cross-sectional data from 481 farmers on some selected areas in Nigeria, [43] a simple conceptual linkage model to show the impact of food productivity on nutritional outcome.

A challenge with evaluating yield, nutrition, and economic return impacts of technologies like improved varieties that most of the above studies fail to treat is that farmers who self-select into groups of adopters and non-adopters often also differ systematically in other attributes that can potentially influence yield. We found only one study that did: Islam [48] investigate the impact of improved rice technology on small farmer’s well-being by using matching techniques and subsequently DID regression with a matching method to construct similar treatment group and control group samples. Our objective is to expand the empirical literature that robustly identifies marginal yield, income and food intake impacts of HYV adoption, given self-selection tendency by applying a matched DID method with control for time-varying variables. The research used nation-wide panel survey data for farm households including fields that switched from local to HYV between survey periods 2012 and 2015. During this period uptake of HYV seeds in Aman rice grew from a high level of 73% of Aman rice farmers to a near population Saturation level of 80% leading some authors to question whether further expanding area under HYV technology will eventually result in diminishing returns to this strategy [50]. Moreover, Adesina and Djato [4] and Craig, Pardey and Roseboom [22] mentioned that Constant or increasing return to scale (RTS) is often observed for developed countries’ agriculture and diminishing RTS is predominant in the developing countries’ agriculture. This evaluation provides an opportunity to empirically evaluate whether in fact diminishing returns to further uptake of HYV seeds is setting in for Aman rice in Bangladesh or not. The rest of the article is structured as follows: section 2 presents case study details, section 3 presents the data and summary statistics, section 4 describes methodology, section 5 explains the results and section 6 presents discussion and conclusions.

**Case study context**

Bangladesh is the fourth largest rice-producing and consuming country of the world [31, 80]. Agriculture is the key economic sector of Bangladesh [14] and rice is the main crop which covers around 77% of the total agricultural land [6]. In recent decades the irrigated area has increased and cropping patterns have changed with increases in area in short duration high-yielding varieties of rice [54, 68]. In Boro (dry) season rice is mostly high-yielding varieties. In Aman (monsoon) season both local varieties and high-yielding varieties are cultivated.

Over the past several decades rice yield in Bangladesh grew considerably mainly due to increased use of high-yielding rice variety, groundwater irrigation, chemical fertilizer and pesticides [11, 27, 57]. Rice cultivation accounts for 48% of total rural employment and provides two-thirds of the calorific needs along with half the protein consumed in Bangladesh [70]. Hence, for ensuring food security most farmers cultivate rice. During the period 1977 to 2011, average yield growth of rice in Bangladesh was 3.6% per annum mainly backed by the adoption of high-yielding varieties and expansion of irrigation in the dry season [42].

Bangladesh has made significant progress over the past several decades in terms of economic growth, poverty reduction, and human development [14]. A number of studies have shown that agricultural growth is the key to reducing poverty and hunger in Bangladesh [53, 76, 77]. Bangladesh is comparatively a late adopter of green revolution which is characterised by rapid expansion of irrigation, high-yielding variety, fertilizer that contributed to agricultural yield [17] and poverty reduction. Still comparatively little is known about how green revolution productivity improvement impacts on nutrition [42]. Yosef et al. [85] notes that while extensive review literature on agriculture and nutrition exists, much is theoretical work and there is limited evidence from observational and experimental research studies documenting this impact, particularly for Bangladesh. Bhagowalia [16] investigated the linkage among agriculture, income and nutrition in India and concluded that irrigation and livestock substantially influence household food diversity. Headey
also argued in their article on agriculture and undernutrition in India that many researchers and policymakers have high expectations of agriculture’s potential to reduce undernutrition, but there is a lack of substantive evidence. This dearth of quality studies motivated us to empirically evaluate the impact of an agricultural technology, HYV seed breeding, on agricultural productivity, household income and nutrition in Bangladesh.

Data and summary statistics

Data

This study uses data from the Bangladesh Integrated Household Survey-BIHS (2012 and 2015) administered by IFPRI (International Food Policy Research Institute). Data were collected in 2 time periods: from October 2011 to March 2012 and from January to June 2015. IFPRI senior researchers designed and supervised the survey. Statistically, this is a nationally representative data which cover all administrative divisions of Bangladesh. The survey covers 5500 households. The BIHS questionnaire comprises several modules with question related to multiple aspects of living standards, including individual-level education, employment, household demographics, assets and their values, income, expenditure, microcredit, disaster mitigation, migration and remittance. However, the primary focus of the surveys was to collect data on agricultural production and cost at the plot level. This includes data on crop farming activities including yield, input use for seed, fertilizer, pesticide, technology used, land characteristics, management and other issues. For investigating the impact of high-yielding variety, we considered the treatment group to be plots that were planted to local variety in 2012 and converted to HYV by 2015. The rest of the sample, plots planted to local varieties plots in both 2012 and 2015 were our control group.

Table 1 Summary statistics of attributes of HYV and local variety adopter

| Item                                               | Overall sample | HYV     | Local variety | t-test (HYV vs local) |
|----------------------------------------------------|----------------|---------|---------------|-----------------------|
| Mean                                               | Mean           | Mean    |               |                       |
| Yield/hectare                                      | 2.56           | 3.48    | 2.24          | − 1.24***             |
| Land area (decimal)                                | 31.55          | 29.92   | 32.12         | 2.20                  |
| Household head’s age                               | 50.22          | 49.94   | 50.32         | 0.38                  |
| Education of the farmer                            | 3.47           | 3.40    | 3.49          | 0.09                  |
| Household head’s gender                            | 0.93           | 0.94    | 0.92          | − 0.02                |
| Agriculture as the main occupation                 | 0.04           | 0.04    | 0.04          | − 0.00                |
| Per hectare fertilizer cost (BDT)                  | 3900           | 6268    | 3086          | − 3182***             |
| Per hectare machinery cost (BDT)                   | 6049           | 6523    | 5886          | − 636**               |
| Per hectare total labour hours                      | 674            | 857     | 611           | − 245***              |
| Access to credit                                   | 0.78           | 0.70    | 0.81          | 0.10***               |
| Extension service                                  | 0.12           | 0.08    | 0.14          | 0.06***               |
| Have Livestock                                     | 0.92           | 0.91    | 0.93          | 0.01                  |
| Have fisheries                                     | 0.10           | 0.10    | 0.10          | − 0.00                |
| Non-farm income (BDT)                              | 3725           | 1932    | 4341          | 2408*                 |
| Per capita total calorie intake                     | 2782.30        | 2895.28 | 2743.40       | − 151.88*             |
| Per capita calorie intake from grain                | 1550.09        | 1626.00 | 1523.95       | − 102.05***           |
| Per capita calorie intake from protein              | 601.60         | 606.51  | 599.91        | − 6.59                |
| Per capita calorie intake from oil-fat              | 210.24         | 203.14  | 212.69        | 9.55                  |
| Per capita calorie intake from fruits and vegetables| 348.72         | 389.41  | 334.71        | − 54.70               |
| Per capita calorie intake others food               | 71.64          | 70.21   | 72.13         | 1.91                  |
| No of observations                                 | 1624           | 416     | 1208          |                       |

HYV: high-yielding varieties

Data source: IFPRI Bangladesh Integrated Household Survey 2015

*Significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level
Summary statistics

Summary statistics for variables included in probit regression to identify matched treatment and control samples, and for DID\(^1\) regression, including t-tests for differences in the treatment and control group are shown in Table 1.

In our sample, 1204 plots were with local variety both in 2012 and 2015 which is our control group, and 416 plots were local variety in 2012 and converted to improved variety in 2015 which is our treatment group. Hence, we see that around 26% of plots converted from local to HYV from 2012 to 2015. For summary statistics, we have considered only 2015 as in 2012 all our sample was plots with local variety. Summary statistics tell us that local and HYV plots are similarly sized, had a similar percentage of livestock and fisheries and had similar human capital measured as farm household head education, age and gender. Plots with local variety had more non-farm income, and interestingly had more access to credit and had more access to extension service. On the other hand, plots with HYV: had more per hectare yield, more irrigated plots, spent more labour hours in the field, had higher fertilizer cost and had more similar machinery cost. In case of nutritional outcome, t-test showed that farm households who adopted HYV had more overall calorie intake and more calorie intake from grains. However, t statistics shows that there was no significant difference in calorie consumption from fruits–vegetables protein, oil-fat and other food categories.

Methodology

To investigate the impact of HYV on monsoon season rice yield and family nutritional and income outcomes the difference in difference (DID) method was applied, which is increasingly popular for estimating causal relationships \([15, 26, 34, 79]\). One of the advantages of DID is potential to deal with endogeneity problems in the comparison between heterogenous observations \([56]\). To implement DID, we constructed a treatment group and a control group. The treatment group is the plots that were converted from local variety to HYV from 2012 to 2015, and the control group is the plots which did not convert, i.e. the plots which were local variety in 2012 and remained in local variety in 2015. Unbiased estimation requires that the treatment group and control group be similar (i.e. the counterfactual should be as similar as possible to the treatment group). A challenge with evaluating yield impacts of technologies like seed is that farmers self-select into groups of adopters and non-adopters in a nonrandom way that is likely to be influenced by other unobserved attributes like farmers’ motivation, risk attitude, innate skill \([2]\). One way to address this selection bias is to use Propensity Score Matching-PSM \([1, 7, 44, 75]\). Essentially PSM is a method to identify a subpopulation of non-adopters sufficiently similar to the population of adopters to assume that the distribution of unobservable characteristics is the same or at least not so different for both groups that it possibly induces a bias \([13]\). The propensity score used in such matching is simply the probability that a household has access to the treatment \([26]\):

$$P(T = 1|X).$$  \hspace{1cm} (1)

Propensity scores are estimated using a probit model where a vector of household characteristics, \(X\) are regressed on \(P\), a binary variable with a value of 1 indicating that a household had adopted high-yielding rice varieties and zero otherwise, to obtain predictions of household propensity scores.

There are some potential exogenous variables which can influence the farmers propensity for HYV adoption. For example, if agriculture is the main occupation, farmers are often more concern about the yield; for HYV more inputs like fertilizer, pesticide is often applied which requires more money, hence access to credit or other sources of income be different for treatment and control groups. We used the following characteristics to estimate propensity score: (1) land area; (2) main occupation-agriculture or not; (3) gender of head of household; (4) access to credit v. has fisheries with the probit regression:

$$\text{PS} = \text{Prob}(\beta_0 + \beta_1 L + \beta_2 O + \beta_3 G + \beta_4 C + \beta_5 \text{Fi} + \epsilon),$$ \hspace{1cm} (2)

where \(\text{PS}\) = propensity score, \(L =\) land area, \(O =\) occupation, \(G =\) gender of the household head, \(C =\) access to credit, \(\text{Fi} =\) having fisheries, and \(l =\) non-farm income.

The region of common support is established by eliminating the observations from the comparison or non-adopter group with a p-scores (propensity score) lower than the minimum p-score in the treatment group. Observations from the control group with a p-score higher than the maximum p-score of the comparison group are also eliminated \([79]\). The region of common support is shown in Fig. 1.

After propensity score matching, we applied DID to the modified sample. For the case of yield as the dependent variable, the difference in outcome (\(Y\)) for the treatment group before and after treatment is calculated as:

$$\left[ Y_{t1}^1(x) - Y_{t0}^1(x) \right].$$ \hspace{1cm} (3)

The difference in outcome (\(Y\)) for the control group in before and after treatment is calculated as:

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\(^1\) DID = Difference in difference.
Then the difference in difference between the treatment group and the control group is calculated as:

\[
\Delta = \left[ Y_{t_1}(x) - Y_{t_0}(x) \right] - \left[ Y_{t_0}(x) - Y_{t_0}(x) \right].
\]

In a regression format Eq. 5 can be written as [9]:

\[
Y = \beta_0 + \delta_0 d_2 + \beta_1 d_T + \delta d_2 d_T + \epsilon,
\]

where \( Y \) is the yield per hectare, \( d_2 \) is the dummy variable for the second time point, \( d_T \) is equal to unity for those in the intervention or treatment group \( T \).

**Dealing with treatment and control group time-varying differences**

DID is only unbiased when the assumption of equal trends in time-varying effects for control and treatment groups applies. This assumption implies that all things being equal, both groups are changing over time in the same way, except that the treatment group is exposed to the treatment. However, if any time-varying differences do exist between the treatment group and control group, DID estimation will produce biased estimates [32].

In fact, over the time period 2012 and 2015 many attributes influencing yield outcomes did change. For example, irrigation, fertilizer, pesticide, compost, machinery use levels could be changed. Not controlling for these time-varying effects can produce biased estimation [9]. We addressed the issue by first testing for time-varying differences in attributes for the treatment and control group with DID. We found that six variables were time-varying with a time different trend for control and treatment groups: total labour hours, fertilizer cost, pesticide cost, machinery cost, irrigation and extension service. This indicates that these variables followed a different trend between the two periods for the control and treatment groups in ways that have potential impact on the yield outcome variable. We also tested whether time trends differed across the two groups for the variables: compost cost, and other income and found these variables were not time-varying in different ways for the two groups. We did not control land type, farmers...
educational level, age and other human capital variables as these did not change over time in a different fashion for the treatment and control groups. For these attributes the 'equal trend' assumption held.

Our ultimate yield DID regression equation can be written as:

\[ Y = \beta_0 + \delta_0 d_2 + \beta_1 dT + \delta_2 dT + \sigma_1 U_i + \varepsilon, \quad (7) \]

where \( Y \) is yield, \( T \) is a time variable, \( I \) is a binary intervention variable, \( U_i \) are time-varying variables: fertilizer cost, irrigation, total labour hours, pesticide cost, machinery cost and extension service.

Farm income DID

In this part, farm income is our dependent variable. Farm income from Aman rice is calculated by subtracting the cost of production from the product revenue. Hence, the DID regression equation to estimate how it relates to HYV can be written as:

\[ I = \beta_0 + \delta_0 d_2 + \beta_1 dT + \delta_2 dT + \varepsilon, \quad (8) \]

where \( I \) is the farm income expressed in Bangladeshi Taka (BDT), \( d_2 \) is the dummy variable for the second time point, and \( dT \) is the equal unity for observations in the intervention or treatment group \( T \).

Household nutrition DID

In this part, per capita total calorie consumption and calorie consumption by different food category has been used as dependent variables. Per capita calorie consumption, i.e. calorie adequacy is a popular indicator for household food and nutritional security [36]. Per capita calorie consumption is calculated by dividing household's total calorie consumption (a sum of the calorie intake of all food items including homemade food and in-kind food donations) by the total number of family members.²

The survey collects food consumption information over 7 days; we converted this to daily consumption. We also regressed household food intake on outcome determinants for the following categories: (1) grains or carbohydrate; (2) fish–meat–milk–egg–pulses or protein; (3) oil-fat; (4) fruits–vegetables, and (5) others. Hence, our outcome variables in nutrition regressions were calorie intake per day per person, calorie intake from food groups: carbohydrate, protein, fruits and vegetable, oil fat and other food item.

For household food calorie variables DID did not require inclusion of time-varying effects, as the human capital of household head like education which can potentially affect the nutritional outcome hold ‘equal trend’ assumption and other potential household nutrient influencing variable like income from livestock and income from fisheries followed the similar trend for both groups between 2012 and 2015 (details shown in Table 3).

Results

In order to capture the net effect of HYV on yield, household nutrition and poverty, we analysed the DID effect. To get unbiased estimation we matched the control group and the treatment group from an estimated propensity score regression model (probit model) reflect correlation but does not depict a causal relationship. The purpose of the probit model is to estimate the propensity score that assesses the probability that a household will have access to the high-yielding rice crop. For this reason, as many relevant observable household characteristics from the dataset were chosen that could influence high-yielding rice crop access to create propensity scores that satisfy the balancing property (Table 2).

The algorithm for selecting the control sample is based on the balancing property which ensures that a control group is constructed with observable characteristics distributed equivalently across quintiles in both the treatment and control groups, as described by [25, 75]. After that region of common support/matched region was established. Figure 1 shows the probability score of the treatment and control group, before and after matching condition (Fig. 2).

² This methodology followed the official poverty calculation from the data obtained by Bangladesh household Survey in 2005 and earlier (BBS, 2010).

| Table 2 | Probit regression on treatment (2012) |
|---------|-------------------------------------|
| **Household characteristics (2012)** | **HYV adoption** |
| Land area (decimal) | 0.00017 (− 0.00101) |
| Household head’s gender | 0.0521 (− 0.168) |
| Agriculture as main occupation | 0.219** (− 0.065) |
| Access to credit | 0.276*** (− 0.0842) |
| Have fisheries | − 0.0777 (− 0.109) |
| Constant | − 0.533*** (− 0.172) |
| Observations | 1780 |

Standard errors in parentheses

***p<0.01, **p<0.05, *p<0.1
Before DID regression, we checked the time-varying attributes of variables, machinery cost, pesticide cost, fertilizer cost, compost cost, labour hour, other income and irrigation as, if these variables do not follow the 'equal trend' then these variables might have an impact on our outcome variables. The results of these checks are shown in Table 3.

**Table 3** Investigation of time-varying attributes of variables

| Variable                          | Comparison group | Treatment group | Difference in Difference |
|-----------------------------------|------------------|----------------|-------------------------|
| Per hectare machinery cost (BDT) | 2040             | 5888           | 3848                    | 1919             | 6521           | 4602          | 754***       |
| Per hectare pesticide cost (BDT) | 302              | 813            | 511                     | 318              | 1489           | 1171          | 660***       |
| Per hectare fertilizer cost (BDT)| 1502             | 3093           | 1591                    | 2130             | 6278           | 4148          | 2556***      |
| Per hectare compost cost (BDT)   | 126              | 3              | −123                    | 142              | 48             | −94           | 28           |
| Other income (BDT)               | 6260             | 4354           | −1906                   | 3796             | 1937           | −1859         | 46           |
| Per hectare total labour hour    | 324              | 612            | 288                     | 299              | 856            | 557           | 269***       |
| Irrigation                       | 0.176            | 0.078          | −0.098                  | 0.281            | 0.33           | 0.049         | 0.147***     |
| Extension service                | 0.104            | 0.145          | 0.041                   | 0.150            | 0.082          | −0.068        | −0.109***    |
| Having income from livestock     | 0.904            | 0.933          | 0.029                   | 0.921            | 0.918          | −0.03         | −0.032       |
| Having income from fisheries     | 0.100            | 0.104          | 0.004                   | 0.94             | 0.101          | 0.007         | 0.003        |

*Significant at the 10% level, **significant at the 5% level, ***significant at the 1% level

Yield results

We see that except compost cost and other income, all dependent variables are time-varying in different ways for the treatment and control samples. Hence, we controlled for time-varying pesticide cost, fertilizer cost, tools cost, total labour hour used in DID regression and found the results summarised in Table 4.

Table 4 tells us that in the treatment group's actual production increase attributable to HYV seed adoption is estimated to be 0.85 ton per hectare. The base production

**Table 4** Impact of HYV on per hectare yield in DID

| Variables                  | Co-efficient | p-value |
|----------------------------|--------------|---------|
| Time                       | −0.123***    | 0.008   |
| Var                        | 0.190***     | 0.001   |
| Difference in difference   | 0.850***     | 0.000   |
| Per hectare fertilizer cost| 2.64e-05***  | 0.000   |
| Irrigated or not           | 0.249***     | 0.000   |
| Per hectare labour hour    | 9.29e-05**   | 0.010   |
| Per hectare pesticide cost | 7.59e-05***  | 0.000   |
| Per hectare Machinery cost | 1.39e-05**   | 0.010   |
| Constant                   | 0.339***     | 0.000   |
| Observations               | 3399         |         |
| R-squared                  | 0.176        |         |

***p < 0.01, **p < 0.05, *p < 0.1
of treatment group is 2.45 ton/ha, which means that a 35% yield increase is attributable to adopting HYV. Household farm income DID results are shown in Table 5. 

The result clearly indicates that the farm households who adopted high-yielding varieties enjoyed more farm income. Here, we can see in 2015, the average income of control group is 1471 BDT and the average income of treatment group is 2598.84 BDT. After adopting HYV the treatment group enjoyed a 76% more income than the control group.

**Nutrition impacts**

As with income and yield, for food intake regression we also checked the extent to which there were differences in time-varying variables for treatment versus control groups which potentially influence the calorie intake and intake of calories by food group for carbohydrates, proteins, oils-fats, fruits–vegetables and other foods. The human capital of head of the households grows in the same fashion for the control group and treatment group. We checked other potential influencing variables like other income, having money from fisheries and livestock and found these variables also follow ‘equal trends’ for control and treatment groups (Table 3). Hence, we do not have any variables to control in the DID. The nutritional outcome of different food groups between the control group and treatment group is shown below in Table 6.

The results indicate that observed higher agricultural production associated with HYV adoption allowed the adopting households to take in more calories than those who did not adopt high-yielding varieties. Without DID adopters were estimated to have less protein intake. However, the DID estimate was higher for the treatment group. The treatment group was also estimated to taking in more calories from fruits and vegetables. Calorie intake differences for the two groups from the oils-fats and other food groups were statistically insignificant. We conclude that HYV adoption brought positive nutrition changes to the households that adopted HYV seed.

**Discussion and conclusion**

Our study found that in the monsoon season, farms adopting high-yielding rice varieties between 2012 and 2015 experienced 35% higher yield. This increased production also translated into more income for the farms that had adopted high-yielding rice varieties. Farm income increased by more than yield, it was 73% more for adopting farms than non-adopted farms.

Households that had not adapted HYV in 2012 but had in 2015 (the treatment group) also experienced statistically significantly higher calorie consumption and had statistically significantly more fruits and vegetable consumption than non-adopters which is a key source of vitamins, minerals and fibre [74]. Compared to non-adopters their total calorie intake increased by 6.14%, carbohydrate intake increased by 5.19% and fruits–vegetables intake increased by 20.07%. On the other hand, the oil-fat consumption and other food or outside food
consumption did not increase which is also considered positive nutrition outcome [59].

Our yield conclusions are supported by other research showing rice production increase in Bangladesh was mainly due to changes away from lower-yielding to higher-yielding seasonal varieties. Our HYV adoption and total calorie findings are also similar to conclusions by Headey and Hoddinott [43], who find a positive association between yield growth and calorie availability for farm households in rural Bangladesh. Results are also consistent with past studies on agricultural yield growth and poverty [28, 55] in Bangladesh, which finds poor farmers benefitted from adoption of high-yielding varieties through reduced poverty.

For a country with land constraints and high population like Bangladesh, agricultural production growth and food security remains a huge challenge. Some authors suggest that the potential to realise greater yield through further uptake of key technologies is likely to reach a limit where further uptake results in diminishing marginal returns [50]. However, Wu et al. [83] showed that the effect of technology on well-being shows a diminishing impact over time unless new technology is generated and promoted continuously to replace older technologies. Notably, even among fields and farms listed as using high-yielding varieties in the survey, we evaluated there is a wide variation in yield performance and opportunity for seed improvement. Bangladesh Rice Research Institute has invented more than 100 rice varieties and Bangladesh Institute of Nuclear Agriculture (BINA) has invented more than 22 rice varieties. In many cases, the yield potential of newly invented rice varieties is much higher than the earlier varieties. For example, the yield potential of Aman variety BR-5 is 3 ton/ha, whereas the yield potential of Aman variety BRRI dhan 49 is 5.5 ton/ha, which is 54% higher than BR-5 (BRRI) and Binadhan-17’s yield potential is 7.5 ton/ha in Aman season (Bilu November 6, 2019). In 2015, at the national level HYV Aman production was 2.69 ton/ha and local Aman production was 1.64 ton/ha [12] both of which are much lower than the production potential of BRRI dhan 49, 5.5 ton/ha and Binadhan-17, 7.5 ton/ha. This notion has been expressed by Kabir et al. [49] that the genetic gains (i.e. productivity) associated with hybrid and HYV rice have not reached their full, country-wide potential due to a lack of adoption—leaving a significant on-farm yield gap. Hence, Our study suggests that uptake of improved variety hasn’t reached diminishing returns for Aman rice in Bangladesh, the recent addition uptake seems to have been strong driver of higher yields indicating that there is still opportunity for rice production growth by converting from local variety to HYV in monsoon season rice cultivation, despite an already high (80%) level of uptake and replacing the early higher yielding varieties with the newer higher yield variety could have significant impact nationally. Similar idea is expressed by Shew et al. [71] that still, many rice producers have yet to adopt improved varieties in Bangladesh despite their ability to increase yields and the adoption has been especially weak in the Aman season, and given the improved economic, food security, and environmental efficiency, this could be a strong focus in supportive policies for HYV adoption. HYV adoption increased rice consumption by 12.6% the equivalent of meal for additional 26 million people annually between the year 2012 and 2015 [71]. Our study findings suggest that investments to further improve rice variety and adoption of recently invented more yielding varieties remains a very effective and high benefit technology investment to continue boosting the Bangladesh agriculture. Results also add to global evidence relevant to many developing countries suggesting that further plant breeding and seed subsidy/adoptions support can be a very effective investment for food security, improving household nutrition and farm income.

One of the limitations of our study is that we used DID with only two years of data, using long time series panel data would be ideal. We focussed on HYV impacts on Aman rice outcomes. Further evaluation of HYV uptake on other crops would also be valuable. Another area where further research would be helpful would be worked to understand the pathways through which HYV uptake is influencing farm income, yields and nutritional outcomes. For example, is farm income influencing yield by enabling more machinery, fertilizer, irrigation and hired labour use? More work to understand details of how effective particular HYV seed types are at improving yields, incomes and nutrition outcomes would also be useful. An area of particular interest is how outcomes of HYV introduction may vary across climatic and socioeconomic contexts particularly in any isolated pockets of relatively low uptake.

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Authors’ contributions
First author has the greatest contribution and second author has substantially contributed to the paper. Both authors read and approved the final manuscript.

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