Rahman and Connor
Agriculture & Food Security (2022) 11:35
https://doi.org/10.1186/s40066-022-00365-6

Agriculture & Food Security

RESEARCH

Open Access

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

Mohammad Mahbubur Rahman* and Jeffery D Connor

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

*Correspondence: rahmm009@mymail.unisa.edu.au
University of South Australia, Business School, Centre for Markets, Values and Inclusion, University of South Australia, 37–44, North Terrace, GPO Box 2471, Adelaide, SA 5001, Australia

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 adaption 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 caloric 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

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

Item	2015			
	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

[40] 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.

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]:

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

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:

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

where PS = propensity score, L = land area, O = occupation, G = gender of the household head, C = access to credit, Fi = having fisheries, and I = 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:

$$\left[\overline{Y}^1_{t_1}(x) - \overline{Y}^1_{t_0}(x)\right]. \tag{3}$$

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

[1] DID = Difference in difference.

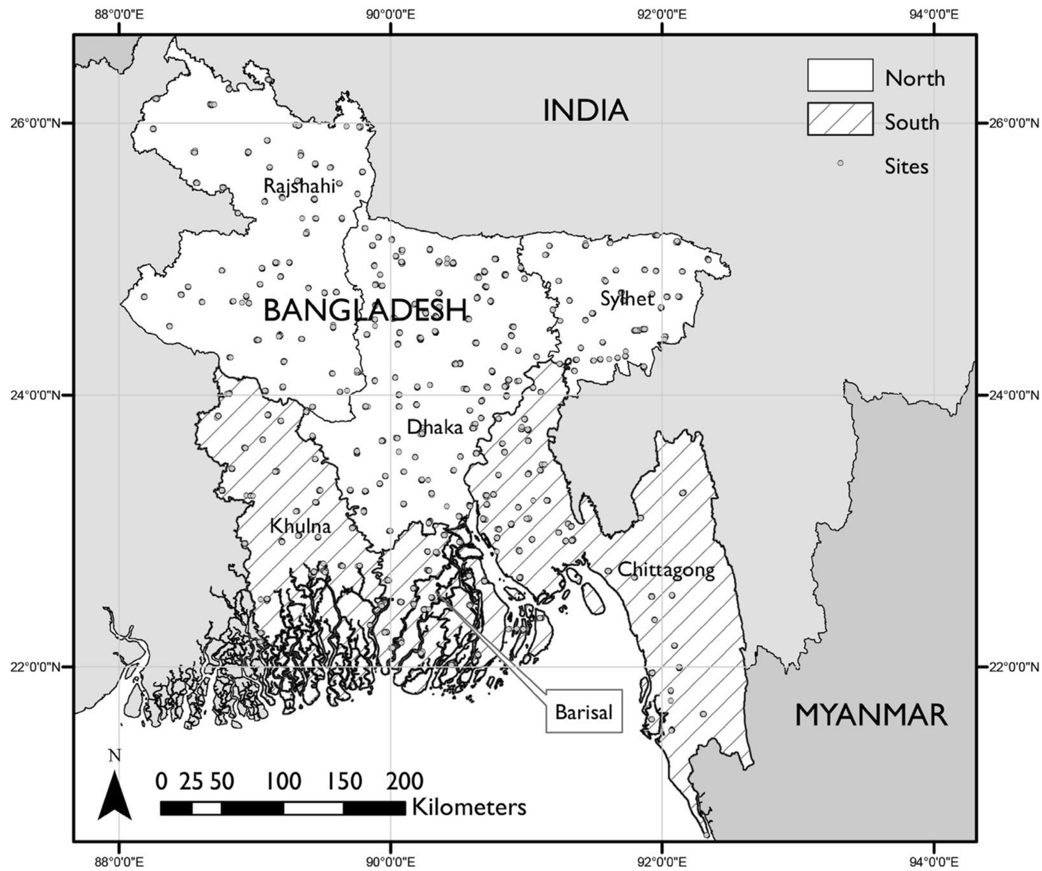

Fig. 1 Map showing the data collection points in Bangladesh

$$\left[\overline{Y}^{0}_{t_1}(x) - \overline{Y}^{0}_{t_0}(x)\right]. \quad (4)$$

Then the difference in difference between the treatment group and the control group is calculated as:

$$\hat{\Delta} = \left[\overline{Y}^{1}_{t_1}(x) - \overline{Y}^{1}_{t_0}(x)\right] - \left[\overline{Y}^{0}_{t_1}(x) - \overline{Y}^{0}_{t_0}(x)\right]. \quad (5)$$

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

$$Y = \beta_0 + \delta_0 d2 + \beta_1 dT + \delta.d2.dT + \varepsilon, \quad (6)$$

where Y is the yield per hectare, $d2$ is the dummy variable for the second time point, dT 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:

$$Y = \beta_0 + \delta_0 d2 + \beta_1 dT + \delta.d2.dT + \sigma_i U_i + \varepsilon, \quad (7)$$

where Y is yield, T is a time variable, I is a binary intervention variable, Ui 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:

$$I = \beta_0 + \delta_0 d2 + \beta_1 dT + \delta.d2.dT + \varepsilon, \quad (8)$$

where I is the farm income expressed in Bangladeshi Taka (BDT), $d2$ 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). Hence our equation for calorie consumption and calorie consumption from (1) grains or carbohydrate; (2) fish–meat–milk–egg–pulses or protein; (3) oil-fat; (4) fruits–vegetables; (5) others food groups can be written as:

$$C = \beta_0 + \delta_0 d2 + \beta_1 dT + \delta.d2.dT + \varepsilon, \quad (9)$$

where C is the per day per capita calorie consumption, $d2$ is the dummy variable for the second time point, and dT is unity for observation in the treatment group T.

[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	

***$p<0.01$, **$p<0.05$, *$p<0.1$

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. It is important to note that the 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).

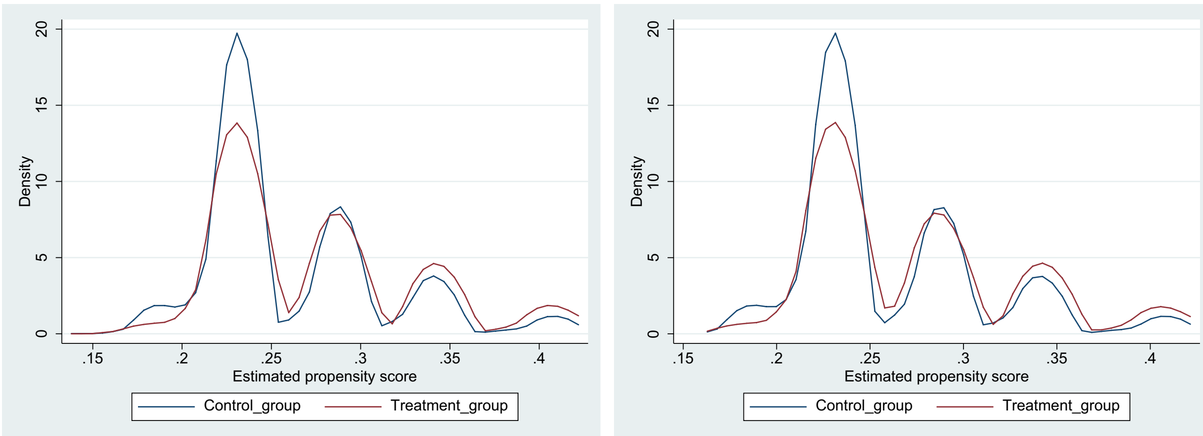

Fig. 2 Propensity score before matching and after matching

Table 3 Investigation of time-varying attributes of variables

Variable	Comparison group			Treatment group			Difference in Difference
	2012	2015	Difference	2012	2015	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

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

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	

***$p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5 Estimated impact of HYV on farm income

	2012			2015			
	Control group	**Treatment group**	**Difference**	**Control group**	**Treatment group**	**Difference**	**Difference in difference (DID)**
Household farm income (BDT/acre)	2385.10	2583.11	198.01	1471	2598.84	1127.83***	929.82***

Table 6 Estimated impact of HYV on food intake by food group and in total

Per day per capita calorie intake	2012			2015			
	Control group	**Treatment Group**	**Difference**	**Control group**	**Treatment Group**	**Difference**	**DID**
Total calorie	3201	3142	− 59	2847	2981	134**	193**
Carbohydrate	1892	1944	51*	1524	1626	101***	49
Protein	746	676	− 70***	702	691	− 11	58**
Oil-fat	195	178	− 1***	212	203	− 9	8
Fruit–vegetable	291	274	− 16	336	391	55**	71**
Other foods	77	69	− 8	72	70	− 2	6

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

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 HVY 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/adoption 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 socio-economic contexts particularly in any isolated pockets of relatively low uptake.

Acknowledgements

We are grateful to Professor Lin Crase, and Dr. Bethany Cooper for their valuable comments on this paper. Besides this, this paper has been presented in AARES (Australian Agricultural and Resource Economics Society) annual conference 2021 and in regular seminar in University of South Australia, Business School. We are grateful to all professors, Senior Researchers/Lecturers, and participants of the seminar for their valuable comments to improve this paper.

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.

Authors' information

First Author: Mohammad Mahbubur Rahman is a PhD candidate in University of South Australia.

Second Author: Professor Jeff Connor specializes in quantitative economic, environmental and social integrated systems modelling often working closely with governments at local, state, national and international levels to provide

economic policy advice based on rigorous economics. Jeff worked as an economist and group leader at CSIRO from 2001 to 2016 where he provided research and advise to the Murray Darling Basin Authority, natural resource management boards and state departments for water, agriculture and natural resource management in South Australia, Victoria, and Western Australia and in Bangladesh, Indonesia, China and Laos.

Funding
No funding for this research.

Availability of data and materials
Data and materials will be available upon request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Yes, we are giving our consent for publication of this article in this journal.

Competing interests
Not applicable.

Received: 27 October 2021 Accepted: 4 February 2022
Published online: 07 May 2022

References
1. Abate GT, Francesconi GN, Getnet K. Impact of agricultural cooperatives on smallholders' technical efficiency: evidence from Ethiopia. 2013.
2. Abdul-Rahaman A, Abdulai A. Do farmer groups impact on farm yield and efficiency of smallholder farmers? Evidence from rice farmers in northern Ghana. Food Policy. 2018;81:95–105.
3. Abdulai A, Huffman W. The adoption and impact of soil and water conservation technology: an endogenous switching regression application. Land Econ. 2014;90(1):26–43.
4. Adesina AA, Djato KK. Relative efficiency of women as farm managers: profit function analysis in Côte d'Ivoire. Agric Econ. 1997;16(1):47–53.
5. Adewuyi S. Resource-use productivity of rural farmers in KWARA–state, Nigeria. Asset. 2012;1(1):123–31.
6. Ahmed AU, Ahmad K, Chou V, Hernandez R, Menon P, Naeem F, Naher F, Quabili W, Sraboni E, Yu B. The status of food security in the Feed the Future Zone and other regions of Bangladesh: Results from the 2011–2012 Bangladesh Integrated Household Survey. Project report submitted to the US Agency for International Development. International Food Policy Research Institute, Dhaka. 2013.
7. Ainembabazi JH, van Asten P, Vanlauwe B, Ouma E, Blomme G, Birachi EA, Nguezet PMD, Mignouna DB, Manyong VM. Improving the speed of adoption of agricultural technologies and farm performance through farmer groups: evidence from the Great Lakes region of Africa. Agric Econ. 2017;48(2):241–59.
8. Ainsworth EA. Rice production in a changing climate: a meta-analysis of responses to elevated carbon dioxide and elevated ozone concentration. Glob Change Biol. 2008;14(7):1642–50.
9. Angrist JD, Pischke J-S. Mostly harmless econometrics: an empiricist's companion. Princeton University Press; 2008.
10. Anwar MR, O'Leary G, McNeil D, Hossain H, Nelson R. Climate change impact on rainfed wheat in south-eastern Australia. Field Crop Res. 2007;104(1–3):139–47.
11. Baffes J, Gautam M. Is growth in Bangladesh's rice production sustainable?, The World Bank. 1996.
12. BBS. Yearbook of Agricultural Statistics-2015, Bangladesh Bureau of Statistics, Dhaka, Bangladesh. 2016.
13. Becker SO, Ichino A. Estimation of average treatment effects based on propensity scores. Stand Genomic Sci. 2002;2(4):358–77.
14. Bell AR, Bryan E, Ringler C, Ahmed A. Rice productivity in Bangladesh: what are the benefits of irrigation? Land Use Policy. 2015;48:1–12.
15. Bertrand M, Duflo E, Mullainathan S. How much should we trust differences-in-differences estimates? Quart J Econ. 2004;119(1):249–75.
16. Bhagowalia P, Headey D, Kadiyala S. Agriculture, income, and nutrition linkages in India insights from a nationally representative survey. International Food Policy Research Institute, Discussion Paper 01195. 2012.
17. Bhattarai M, Sakthivadivel R, Hussain I. Irrigation impacts on income inequality and poverty alleviation: policy issues and options for improved management of irrigation systems, IWMI, 2001.
18. Bilu, HR November 6, 2019, 'Binadhan-17: a new paddy variety with multiple benefits. The Business Standard, https://www.tbsnews.net/economy/agriculture/binadhan-17-new-paddy-variety-multiple-benefits-22053.
19. BRRI Brief description of BRRI varieties, Bangladesh Rice Research Institute, Bangladesh.
20. Burch D, Lawrence G, Green G, Ichijo K, Nonaka I, Pimentel M, Carneiro M. World Development Report 2008: agriculture for development (No. E14 231). Washington, DC: The World Bank; 2007.
21. Chen C, Wang E, Yu Q, Zhang Y. Quantifying the effects of climate trends in the past 43 years (1961–2003) on crop growth and water demand in the North China Plain. Clim Change. 2010;100(3–4):559–78.
22. Craig BJ, Pardey PG, Roseboom J. International productivity patterns: accounting for input quality, infrastructure, and research. Am J Agr Econ. 1997;79(4):1064–76.
23. De Janvry A, Sadoulet E. World poverty and the role of agricultural technology: direct and indirect effects. J Dev Stud. 2002;38(4):1–26.
24. deGraft-Johnson M, Suzuki A, Sakurai T, Otsuka K. On the transferability of the Asian rice green revolution to rainfed areas in sub-Saharan Africa: an assessment of technology intervention in Northern Ghana. Agric Econ. 2014;45(5):555–70.
25. Dehejia RH, Wahba S. Propensity score-matching methods for nonexperimental causal studies. Rev Econ Stat. 2002;84(1):151–61.
26. Dillon A. The effect of irrigation on poverty reduction, asset accumulation, and informal insurance: evidence from Northern Mali. World Dev. 2011;39(12):2165–75.
27. Dorosh P. Foodgrain Production and Imports: towards Self-sufficiency in Rice?. Out of the Shadow of Famine. 2000.
28. Emran S, Shilpi F. Agricultural productivity, hired labor, wages, and poverty: evidence from Bangladesh. World Dev. 2018;109:470–82.
29. Evenson RE, Gollin D. Assessing the impact of the Green Revolution, 1960 to 2000. Science. 2003;300(5620):758–62.
30. Faltermeier L, Abdulai A. The impact of water conservation and intensification technologies: empirical evidence for rice farmers in Ghana. Agric Econ. 2009;40(3):365–79.
31. FAO April 2018, Rice Market Monitor, Food and Agriculture Organization of the United Nations, Volume xxi, Issue no. 1. http://www.fao.org/3/I9243EN/i9243en.pdf.
32. Gertler PJ, Martinez S, Premand P, Rawlings LB, Vermeersch CM. Impact evaluation in practice, The World Bank, 2016.
33. Gillespie S, Harris J, Kadiyala S. The agriculture-nutrition disconnect in India: What do we know?. 2012.
34. Gilligan DO, Hoddinott J. Is there persistence in the impact of emergency food aid? Evidence on consumption, food security, and assets in rural Ethiopia. Am J Agr Econ. 2007;89(2):225–42.
35. Gödecke T, Stein AJ, Qaim M. The global burden of chronic and hidden hunger: trends and determinants. Glob Food Sec. 2018;17:21–9.
36. Haddad L, Kennedy E, Sullivan J. Choice of indicators for food security and nutrition monitoring. Food Policy. 1994;19(3):329–43.
37. Haddad L. The global nutrition report 2017. Washington, DC: IFPRI; 2017.
38. Hawkes C, Ruel MT. Understanding the links between agriculture and health, International Food Policy Research Institute Washington, DC, 2006.
39. Hazel PBR. The Asian Green Revolution. Proven Success in Agricultural Development, International Food Policy Research Institute, Washington DC, 2010; pp. 67–97.
40. Headey D, Chiu A, Kadiyala S. Agriculture's role in the Indian enigma: help or hindrance to the crisis of undernutrition? Food Secur. 2012;4(1):87–102.
41. Headey DD. Developmental drivers of nutritional change: a cross-country analysis. World Dev. 2013;42:76–88.
42. Headey DD, Hoddinott J. Agriculture, nutrition and the green revolution in Bangladesh. Agric Syst. 2016;149:122–31.

43. Headey DD, Hoddinott J. Agriculture, nutrition and the green revolution in Bangladesh. Agric Syst. 2016;100(149):122–31.
44. Heckman J, Ichimura H, Smith J, Todd P. Characterizing selection bias using experimental data, National bureau of economic research. 1998.
45. Hossain M, Quasem M, Akash MM, Jabber M. Differential impact of modern rice technology: the Bangladesh case. Dhaka: Bangladesh Institute of Development Studies; 1990.
46. Hussain I, Perera L. Improving agricultural productivity for poverty alleviation through integrated service provision with public-private sector partnerships: examples and Issues, IWMI. 2004.
47. Irz X, Lin L, Thirtle C, Wiggins S. Agricultural productivity growth and poverty alleviation. Dev Policy Rev. 2001;19(4):449–66.
48. Islam MA. Impact of improvedrice varieties adoption on farmers' well-being (Livelihood) in rural Bangladesh. Bangladesh J Agric Econ. 2018; 38(1–2).
49. Kabir M, Salam M, Chowdhury A, Rahman N, Iftekharuddaula K, Rahman M, Rashid M, Dipti S, Islam A, Latif M. Rice vision for Bangladesh: 2050 and beyond. Bangladesh Rice J. 2015;19(2):1–18.
50. Khan AR. The economy of Bangladesh: a quarter century of development. Springer; 2015.
51. Khoury CK, Bjorkman AD, Dempewolf H, Ramirez-Villegas J, Guarino L, Jarvis A, Rieseberg LH, Struik PC. Increasing homogeneity in global food supplies and the implications for food security. Proc Natl Acad Sci. 2014;111(11):4001–6.
52. Liu L, Zhu Y, Tang L, Cao W, Wang E. Impacts of climate changes, soil nutrients, variety types and management practices on rice yield in East China: a case study in the Taihu region. Field Crop Res. 2013;149:40–8.
53. Loayza NV, Raddatz C. The composition of growth matters for poverty alleviation. J Dev Econ. 2010;93(1):137–51.
54. Mahbub A, Hossain M, Janaich A. Hyrid rice adoption in Bangladesh. A socioeconomic assessment of farmers experience: research Monograph, Series no. 18', Social Sciences Division, 2001; p. 38.
55. Mendola M. Agricultural technology adoption and poverty reduction: a propensity-score matching analysis for rural Bangladesh. Food Policy. 2007;32(3):372–93.
56. Meyer BD. Natural and quasi-experiments in economics. J Business Econ Stat. 1995;13(2):151–61.
57. Mohammad A, Mosharaff H. Environment and agriculture in a developing economy-problems and prospects for Bangladesh, Edward Elgar Publishing Ltd. 2001.
58. Nguezet PMD, Diagne A, Okoruwa VO, Ojehomon V. Impact of improved rice technology (NERICA varieties) on income and poverty among rice farming households in Nigeria: a local average treatment effect (LATE) approach. Q J Int Agric. 2011;50:267–91.
59. Nguyen MC, Winters P. The impact of migration on food consumption patterns: the case of Vietnam. Food Policy. 2011;36(1):71–87.
60. Nhamo N, Rodenburg J, Zenna N, Makombe G, Luzi-Kihupi A. Narrowing the rice yield gap in East and Southern Africa: using and adapting existing technologies. Agric Syst. 2014;131:45–55.
61. Nin A, Arndt C, Preckel PV. Is agricultural productivity in developing countries really shrinking? New evidence using a modified nonparametric approach. J Dev Econ. 2003;71(2):395–415.
62. O'Donnell CJ. Measuring and decomposing agricultural productivity and profitability change. Aust J Agric Resour Econ. 2010;54(4):527–60.
63. Oni OA, Nkonya EM, Pender JL, Phillip D, Kato E. Analyzing drivers of food crop productivity in Nigeria. J Rural Econ Dev. 2009;18:36–45.
64. Peng S, Cassman KG, Virmani S, Sheehy J, Khush G. Yield potential trends of tropical rice since the release of IR8 and the challenge of increasing rice yield potential. Crop Sci. 1999;39(6):1552–9.
65. Peng S, Tang Q, Zou Y. Current status and challenges of rice production in China. Plant Prod Sci. 2009;12(1):3–8.
66. Pingali PL. Green revolution: impacts, limits, and the path ahead. Proc Natl Acad Sci. 2012;109(31):12302–8.
67. Poulton C, Kydd J, Dorward A. Overcoming market constraints on pro-poor agricultural growth in Sub-Saharan Africa. Dev Policy Rev. 2006;24(3):243–77.
68. Rahman S. Six decades of agricultural land use change in Bangladesh: effects on crop diversity, productivity, food availability and the environment, 1948–2006. Singap J Trop Geogr. 2010;31(2):254–69.
69. Sadoulet E, de Janvry A. Agricultural trade liberalization and low income countries: a general equilibrium-multimarket approach. Am J Agr Econ. 1992;74(2):268–80.
70. Sayeed KA, Yunus MM. Rice prices and growth, and poverty reduction in Bangladesh. FAO: Rome, Italy. 2018.
71. Shew AM, Durand-Morat A, Putman B, Nalley LL, Ghosh A. Rice intensification in Bangladesh improves economic and environmental welfare. Environ Sci Policy. 2019.
72. Shideed KH, El Mourid M. Adoption and impact assessment of improved technologies in crop and livestock production systems in the WANA region. The development of integrated crop/livestock production in low rainfall areas of Mashreq and Maghreb Regions (Mashreq/Maghreb Project). ICARDA, Aleppo, Syria, 2015.
73. Shimono H. Earlier rice phenology as a result of climate change can increase the risk of cold damage during reproductive growth in northern Japan. Agr Ecosyst Environ. 2011;144(1):201–7.
74. Slavin JL, Lloyd B. Health benefits of fruits and vegetables. Adv Nutr. 2012;3(4):506–16.
75. Smith JA, Todd PE. Does matching overcome LaLonde's critique of nonexperimental estimators? J Econ. 2005;125(1–2):305–53.
76. Thirtle C, Lin L, Piesse J. The impact of research-led agricultural productivity growth on poverty reduction in Africa, Asia and Latin America. World Dev. 2003;31(12):1959–75.
77. Timmer P. Agriculture and pro-poor growth: an Asian perspective. Available at SSRN 1114155. 2015.
78. van Dorp M, Oenema S, Verdonk I. Agriculture-nutrition linkages: linking agriculture and food security to nutrition improvement, Wageningen UR Centre for Development Innovation. 2011.
79. van Rijsbergen B, Elbers W, Ruben R, Njuguna SN. The ambivalent impact of coffee certification on farmers' welfare: a matched panel approach for cooperatives in Central Kenya. World Dev. 2016;77:277–92.
80. Wailes EJ. Rice: Global trade, protectionist policies, and the impact of trade liberalization. Global agricultural trade and developing countries. 2015; p. 185.
81. Webb P. Impact pathways from agricultural research to improved nutrition and health: literature analysis and research priorities. Rome: Food and Agriculture Organization and Geneva: World Health Organization. 2013.
82. Winters P, De Janvry A, Sadoulet E, Stamoulis K. The role of agriculture in economic development: visible and invisible surplus transfers. J Dev Stud. 1998;34(5):71–97.
83. Wu H, Ding S, Pandey S, Tao D. Assessing the impact of agricultural technology adoption on farmers' well-being using propensity-score matching analysis in rural China. Asian Econ J. 2010;24(2):141–60.
84. Xiao G, Zhang Q, Yao Y, Zhao H, Wang R, Bai H, Zhang F. Impact of recent climatic change on the yield of winter wheat at low and high altitudes in semi-arid northwestern China. Agr Ecosyst Environ. 2008;127(1–2):37–42.
85. Yosef S, Jones AD, Chakraborty B, Gillespie S. Agriculture and nutrition in Bangladesh: mapping evidence to pathways. Food Nutr Bull. 2015;36(4):387–404.

Publisher's Note