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Abstract

Lack of understanding of the need for micronutrients among farmers is a major constraint on the adoption of biofortified crops. To examine the issue, we conducted a micro-nutrition training among female farmers with young children in randomly selected villages of Bangladesh in May–June 2017. One week after the training, we conducted a phone-based bidding on high-zinc rice seeds among trainees and their counterparts in control villages. If the bidding price was higher than a pre-fixed price, the bidders were asked to buy a 2.5-kilogram bag at the pre-fixed price. More than 70% of the treated female farmers participated in the bidding process and only 23% were from the control group. Female farmers who self-proclaim to be actively involved in decision-making bid a higher price than other female farmers. To measure the long-term impact of the training, we conducted follow-up surveys in 2018, 2019, and 2020 and found that the adoption of high-zinc rice in Aman season declined from 59% in 2018 to 7.5% in 2020 among treated farmers and from 12.9% to 1.9% among control farmers. The regression analysis indicates that nutrition training has a long-term but diminishing impact on the adoption of high-zinc rice. Among treatment farmers, unavailability of seeds and low yields were cited as major reasons for not using high-zinc rice, while lack of knowledge about high-zinc rice was a dominant reason among control farmers.

Keywords: high-zinc rice, technology adoption, gender, decision-making biofortification

JEL codes: I12, O33, Q16

1. Introduction

Zinc is one of the key micronutrients required for children's adequate growth. Children who are zinc-deficient experience growth stunting and face high risk of infections including diarrhea and pneumonia (Brown et al. 2009). In Bangladesh, zinc deficiency is prevalent as stunting affects 41% of children aged under 5 years (Rahman et al. 2016). Bangladeshi rural households consume mainly a rice-based diet with few animal-source foods (Arsenault et al. 2010), leading to zinc-deficient diets. In response, zinc-enhanced rice varieties have been developed to provide up to 60% of daily zinc needs. Yet the diffusion of high-zinc rice has been limited as seeds are largely unavailable to farmers.

Several factors determine farmers' adoption of agricultural technologies in developing countries. A number of studies have focused on famers' socioeconomic conditions and farm characteristics (Feder and Umali, 1993; Doss, 2006; Foster and Rosenzweig 1995; Ainembabazi et al. 2016), while other studies have examined farmers' permanent adoption of a new technology based on their constraints and decisions (Dimara and Skuras 2003; Shiferaw et al. 2008; Shiferaw et al. 2015). In the case of biofortified crops, the lack of understanding of the need for micronutrients has been identified as a major constraint on adoption. For example, de Brauw et al. (2018) contend that the lack of knowledge in the nutritional status of household members limits one's ability to recognize the true returns of adopting biofortified crops.

This study addresses the challenge by conducting a randomized control trial of micronutrient training among female farmers with young children. We conducted training in randomly selected villages. In control villages, we identified female farmers with young children who did not receive training. In May–June 2017, we conducted a mobile phone–based auction among 328 women farmers with young children—including those who participated in the training in the treatment villages and their counterparts in the control villages—to obtain their willingness to pay (WTP) for zinc-enhanced rice seeds. Our results indicate that more than 70% of the trained female farmers participated in the bidding process, and only 23% were from the control group. Almost all who obtained the zinc-enhanced rice seeds from the bidding process planted the seeds in Aman season in 2017–2018. In follow-up surveys during 2018–2020, we asked if they had adopted zinc-enhanced rice. The results indicated that the adoption rate declined from 59% in 2018 to 7.5% in 2020 among treated farmers and from 12.9% to 1.9% among control farmers. To understand the reasons for the declined adoption rates and provide policy implications for promoting zinc-enhanced rice and biofortified crops in general, we performed a regression analysis of the adoption.

In the next section, we present some background literature followed by the methodology, data, and estimation models. We then discuss determinants of bidding participation and price for a high-zinc rice variety called BRRI Dhan72, before making concluding remarks.

2. Background

2.1. Zinc Deficiency and Biofortification of Rice in Bangladesh

Micronutrient malnutrition is widely regarded as a leading cause of child morbidity and mortality in developing countries (Black et al. 2008). Zinc deficiency, in particular, has become a major nutrition problem affecting more than 1 billion people, specifically children and pregnant women in Asia (Swamy et al. 2016). Bangladesh is an excellent case for studying the impact of micronutrient training on the adoption of high-zinc rice for several reasons. First, Bangladesh has a high prevalence of stunting in children under 5 years of age at 41%, which is an obvious effect of a zinc-deficient diet. Indeed, the International Zinc Association reported that Bangladesh ranks number one in percentage of population at risk for zinc deficiency at 54.8%. Second, zinc deficiency in Bangladesh exists more in communities that are consuming restricted meat-based diets and an increased amount of vegetables containing more phytates (Akhtar 2013). Third, zinc deficiency in Bangladesh is compounded by the fact that a third of its soils are highly zinc-deficient, affecting mainly the growth of rice, which is the dominant food in the country.

A complementary approach to addressing zinc deficiency in Bangladesh is biofortification of rice. The rice biofortification program aims to enrich biological and genetic food products with vital nutrients, vitamins, and proteins (Sharma et al. 2017). Developed conventionally to be a dense source of zinc nutrients, zinc-enhanced rice matures earlier, is high-yielding, and disease- and pest-resistant. In 2013, BRRI released the world's first zinc-enhanced rice variety called BRRI Dhan62. Between 2013 and 2016, BRRI and HarvestPlus released four open pollinated zinc-rice varieties that also included BRRI Dhan64, BRRI Dhan72, and BRRI Dhan74. High-zinc rice varieties were introduced in Bangladesh rural areas where many children are zinc-deficient.

2.2. Adoption of Biofortified Crops by Farmers

The key conceptual relationship between biofortified crops and the nutrition status of the poor can be analyzed in the biofortication impact framework by Qaim et al. (2007). In this framework, the improvement in nutritional status and the achievement of significant health advantages and economic benefits depend on whether biofortified crops are widely grown and consumed by the poor. There are three important pathways through which introducing biofortified crops can change the nutrition and health status of people in developing countries: local dietary patterns, technology efficacy, and technology coverage.

Unlike modern rice seed varieties that provide immediate visible benefits to farmers, biofortifed crops have hidden benefits that are difficult to observe (Yamano et al. 2018). The literature suggests at least four major factors that influence the adoption of biofortified rice and other crops. First, in the broader agricultural technology adoption literature, Foster and Rosenzweig (1995) and Jack (2011) suggest that smallholder adoption will only occur if the farmers' expected monetary and nonmonetary benefits of adoption are greater than those of their present practices. In the case of high-zinc rice varieties, Sanjeeva Rao et al. (2020) point adoption of farmers in situations where the yield of high-zinc rice is comparable or higher than the conventional rice varieties. The authors also emphasized that biofortified rice varieties should possess greater than or equal to 35 mg/kg of zinc without yield penalty and desired cooking quality before their release and adoption.

Second, a good understanding of the nutritional benefits and the agronomic characteristics of biofortified crops is important for increasing adoption (Gilligan 2012). de Groote et al. (2016) explained that the knowledge of nutrition benefits will increase biofortified crops adoption in settings where farmers have a good understanding of the crops' agronomic performance. Caeiro and Vicente (2020), who conducted a randomized evaluation of related training on orange-fleshed sweet potato (OFSP), found considerable increases in knowledge of nutrition and the cooking and planting of OFSP among treated female farmers in Mozambique. In addition, Gilligan et al. (2020) showed that the probability of adopting OFSP on a parcel is positively associated with the mother's nutrition knowledge.

Third, adoption of biofortified crops has focused on the role of gender dimensions of intrahousehold bargaining power and decision-making. An example is Gilligan et al. (2020) who used patterns of ownership and control of land and other assets by married men and women in constructing a measure of bargaining power by gender. In the study, they showed that the probability of adoption of OFSP is highest on parcels with joint control, but where the woman takes the lead in deciding which crops are grown. In contrast, they also showed that the probability of adopting OFSP is lowest on parcels exclusively controlled by the man among households that planted at least some OFSP. Furthermore, Vaiknoras et al. (2019) found that households whose main decision-maker for bean production is a woman with some formal education and more years of experience growing beans dis-adopt iron-biofortified beans more slowly than other households.

The fourth factor is that farmers learn about new technologies through their social networks and by experimenting with them (Foster and Rosenzweig 1995; Conley and Udry 2010; Krishnan and Patnam 2014). In accordance with this perspective, Caeiro and Vicente (2020) found evidence of adoption of OFSP for production in the short- and medium-run through social networks between treated individuals and peer farmers. Likewise, McNiven and Gilligan (2012) showed that information networks within communities play a substantial role in first providing access to OFSP planting material and later in supporting sustained OFSP adoption by households outside the project. More recently, Vaiknoras et al. (2019) showed that informal dissemination within social networks and access to extension are also major drivers of rapid adoption of iron-biofortified beans in Rwanda.

As the above discussion suggests, the literature extensively covers the impact of nutritional information on biofortified crops. To our knowledge, however, the lack of understanding of the need for micronutrients as a major constraint on adoption of high-zinc rice varieties has not been adequately examined. Therefore, our study fills a potential gap in the existing literature by examining how nutrition training can influence the adoption of high-zinc rice varieties over time using panel data.

3. Methodology, Data, and Descriptive Analysis

3.1. Experimental Design and Auction

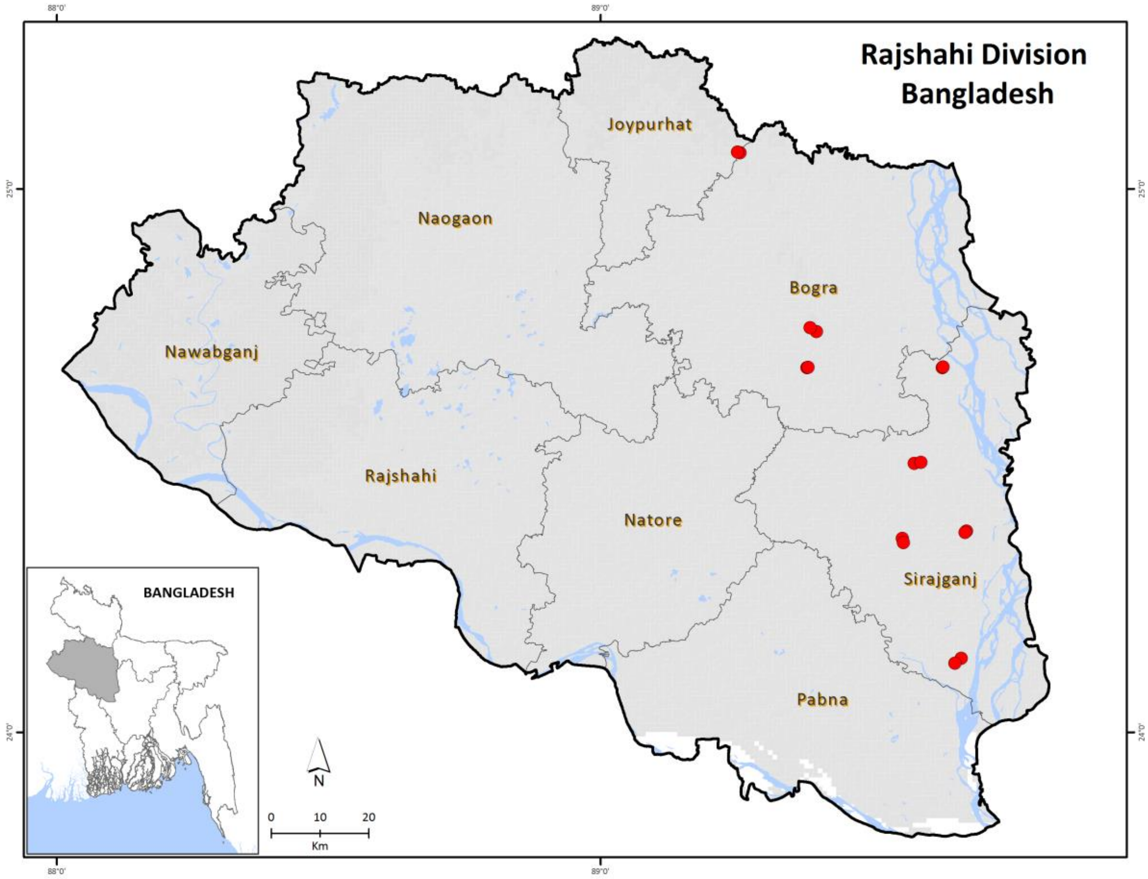
We have drawn our sample of women including mothers from villages in the Bogra and Sirajganj districts of the Rajshahi division. This area is suitable for the study because of the high prevalence of underweight and stunting of children below 5 years of age. In general, the rates of underweight and stunting of children under 5 years of age in Rajshahi are comparable to national estimates. In 2012, 34.7% and 34% of children below 5 years of age in Bangladesh and in the Rajshahi division, respectively, were underweight (World Food Programme 2012). Among all children aged under 5 in Bangladesh in 2012, 41.3% were stunted,[1] while the rate of stunting among children aged under 5 in the Rajshahi division was 41% (World Food Programme 2012). In addition, HarvestPlus and a partner nongovernment organization have been working with women who are involved in rice farming in this area. HarvestPlus identified the villages in which they have distributed BRRI Dhan72 but it was still largely unavailable to rice farmers after its release in 2015 for the Aman planting season. A random subset of 16 villages was selected for inclusion in the study. Figure 1 shows a map of the study area and the villages included, most of which are in Sirajganj. In 2012, more than 38% and 45% of children under 5 years of age in Sirajganj were underweight and stunted, respectively (World Food Programme 2012).

First, we randomly divided the 16 sample villages into treatment and control groups. This village-level randomization was stratified by upazilla, which are administrative units consisting of 100–150 villages. The 16 sample villages are spread across eight upazillas. We then visited a local government official in all villages to generate a list of women farmers. From this list, we selected 25 women at random in each of the 10 treatment villages to participate in micronutrient training. Allocation to treatments was randomized at the village level rather than at the participant level due to logistical considerations. HarvestPlus and its partner organization conducted the training jointly during the last week of May 2017, right before the Aman season planting. Our comparison group consisted of 25 randomly selected women farmers in the 10 control villages.

During the micronutrient training, the facilitators discussed with treatment women two important components of micronutrient information. First, they gave information on the need for zinc in human body, to help them develop an understanding of the importance of micronutrients especially for preventing various diseases and health risks due to zinc deficiency. Second, the trainers talked about nutrition and its components, the different zinc-rice varieties, and management practices such as how to plant the field or how much fertilizer to use.

[1] The percentage of children under 5 years of age whose height-for-age z-score of < -2 SD below the median of the international reference population based on World Health Organization standard. Height-for-age is a cumulative measure of nutritional status and reflects the effects of chronic undernutrition on linear growth (O'Donnell et al. 2007).

Figure 1: Survey Areas in Rajshahi Division, Bangladesh



One week after the micronutrient training, we conducted a mobile phone–based auction among women farmers to elicit their WTP for seeds of a high-zinc rice variety called BRRI Dhan72. Specifically, we made phone calls to 200 treatment and 200 control women farmers in 11–21 June 2017. Women's WTP was elicited for seeds in two stages. In the first stage, an enumerator called a female respondent via mobile phone and asked whether she was interested to buy a 2.5-kilogram packet of seed of BRRI Dhan72 if we deliver the seeds to her house without charging for the transport cost. In the second stage, after the participant agreed to bid, the enumerator would ask her to state the price she was willing to pay for a 2.5-kilogram rice seed. If her stated price exceeded the sale price set by the study prior to the phone survey, the female respondent would get to buy at the sale price and the seed packet would be delivered to her house. If the participant's bid price was lower than the sale price, she would not get the rice seed.

During the June 2017 mobile phone survey, we collected data on women's involvement in making decisions on the use of income generated from rice production, individual and household characteristics, and understanding of the importance of micronutrients. These data were used to describe the characteristics of the sample female farmers and to examine the factors determining their participation in the bidding and WTP for seeds.

3.2. Bidding Results

Table 1 presents sample women respondents in the Rajhsahi division. During the phone bidding survey, a total of 328 women farmers with young children were reached from 16 villages because there are women farmers who did not answer phone calls. Among the total women respondents, 52.7% and 47.3% were treatment and control farmers, respectively. Of the 221 interviewed women farmers in Sirajganj, 56.6% were treated women farmers while 43.4% were from the control group. In Bogra, 107 women farmers were interviewed, of which 44.9% and 55.1%, respectively, consisted of treated and control women farmers.

Table 1: Sample Women Respondents in Rajshahi Division, Bangladesh

	Villages	Women Interviewed	Proportion of Women	
			Control	Treatment
	Number	Number	%	%
Bogra	6	107	55.1	44.9
Sirajganj	10	221	43.4	56.6
All	16	328	47.3	52.7

Source: Authors' calculation based on the mobile phone survey in 2017.

The bidding participation depended on the timing of the call (Appendix Figure 1). Bidding participation was 60% in the morning when the calls were made before 8 a.m., but quickly decreased afterward below 30% until noon. In most of the afternoon, bidding participation by women was above 50%, except at 1 p.m. and 4 p.m. when their husbands were taking their lunch and rest. The participation rate was mostly higher in the late evening. During the phone calls, the enumerators observed that some women could only be contacted when their husbands were at home.

Meanwhile, Table 2 shows the information on bidding participation and price for BRRI Dhan72. More than 70% of the treated farmers participated in the bidding process and only 23% from the control group. This is consistent with other studies that emphasized the important role of nutrition information in the acceptance of biofortified crops (Banerji et al. 2016; de Groote et al. 2014). For the bidding price, the overall average price of a 2.5-kilogram seed bag of BRRI Dhan72 was Tk108.1 (about $1.3). The price for the treatment group was Tk109.8, which is higher than Tk102.1 for the control group.

3.3. Understanding the Importance of Micronutrient Training

Aside from bidding participation and price, Table 3 gives information on the farmers' understanding of the importance of micronutrients. As a whole, the proportion of treatment farmers who understood the effect of zinc deficiency in the human body is significantly higher than the control group. Approximately 76% of treatment farmers understood that adolescents become stunted with zinc deficiency, which increases the risk of diabetes. In addition, about 70% of the treatment group understood that zinc deficiency increases disease risks and delays cure from diarrhea and asthma.

Most treatment farmers also have knowledge on the effects of zinc deficiency in terms of causing inattentiveness to learning and work, and affecting weight loss.

Table 2: Bidding Participation and Price for BRRI Dhan72

	All	Control	Treatment	*p*-Value of Difference
	(A)	(B)	(C)	(D)
Bidding				
Participation (%)	48.5	23.2	71.1***	0.000
	(50.1)	(42.4)	(42.4	
[No. of observations]	[328]	[155]	(173]	
Bidding price (Tk/2.5 kilogram)	108.1	102.1	109.8	0.410
	(49.2)	(33.3)	(52.9)	
[No. of observations with price information]	[159]	[36]	[123]	

Source: Authors' calculation based on the mobile phone survey in 2017.

Table 3: Understanding the Importance of Micronutrients

	All	Control	Treatment	p-Value of Difference
	(A)	(B)	(C)	(D)
Understanding of the importance of micronutrients (%)				
Adolescents become stunted	52.1	25.2	76.3***	0.000
	(50.0)	(43.5)	(42.6)	
Increases diabetes risks	50.9	22.6	76.3***	0.000
	(50.1)	(41.9)	(42.6)	
Increases disease risks	46.0	19.4	69.9***	0.000
	(49.9)	(39.6)	(46.0)	
Delays cure from diarrhea and asthma	47.0	21.3	69.9***	0.000
	(50.0)	(41.1)	(46.0)	
Causes inattentiveness to learning and work	26.8	14.2	38.2***	0.000
	(44.4)	(35.0)	(48.7)	
Causes weight loss	25.6	15.5	34.7***	0.000
	(43.7)	(36.3)	(47.7)	
[No. of observations]	[328]	[155]	[173]	

Notes: Numbers in parentheses are standard deviations, and numbers in square brackets are observation numbers. *** denotes statistical significance at the 1% level. The exchange rate in June 2017 was $1 = Tk80.6.
Source: *Authors' calculation based on the mobile phone survey in 2017.*

The aforementioned pattern supports the literature on gender-based specialization in managing child diets, and intrahousehold gender dynamics about crop choice decisions and children's nutritional status. For example, the Behrman (2011) qualitative interviews about orange sweet potato in Uganda found that women take the lead in deciding what food is prepared and consumed within the household most especially for children. Evidence from Uganda also suggests that women play an important role in the decision to adopt orange-fleshed sweet potato OSP, but that this decision is often made jointly with their husbands. Under the collective model of the household, which allows for the possibility of disagreement between household members, Gilligan et al. (2020) noted that the resolution may depend on the relative bargaining power of individuals within the household (Manser and Brown 1980; McElroy and Horney 1981). Consistent with this expectation, we found in Table 4 that women who have greater involvement in making decisions on the use of income generated from rice production participated more in the bidding for BRRI Dhan72 and bid a higher price than other women farmers. To be specific, about 63% of women farmers who self-proclaimed to be actively involved in decision-making have participated in the bidding with an average bidding price of Tk119.5.

Table 4: Bidding Participation and Price by Extent of Involvement in Decision on the Use of Income from Rice Production

		Extent of Involvement in Decision on Income Use		
	All	No Involvement	Some Involvement	Large Involvement
	(A)	(B)	(C)	(D)
Bidding				
Participation (%)	48.5	32.1	47.0**	63.4***
	50.1	47.0	50.1	48.4
[No. of observations]	328	78	151	101
Bidding price	108.1	97.8	101.2	119.5
(Tk/2.5 kilogram)	49.2	47.4	35.1	60.1
[No. of observations with price information]	159	25	71	64

Notes: *** and ** indicate significance at the 1% and 5% levels, respectively. Numbers in parentheses are standard deviations, and numbers in square brackets are observation numbers. The exchange rate in June 2017 was $1 = Tk80.6.
Source: *Authors' calculation based on the mobile phone survey in 2017.*

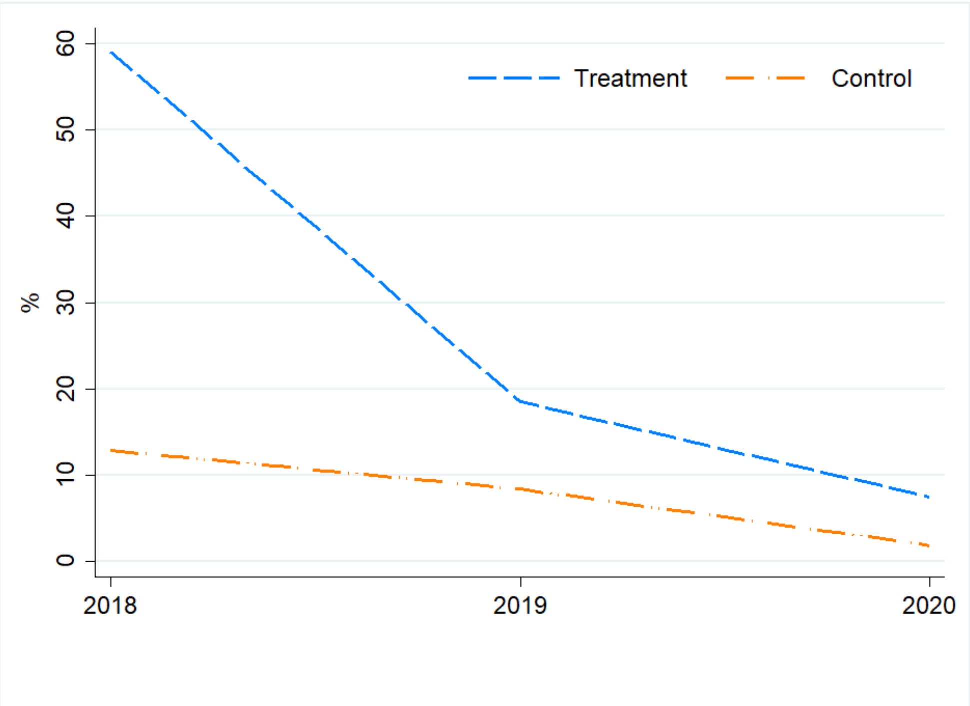
Overall, the results suggest that the micronutrient training made a difference on both the participation level in the bidding process for the high-zinc rice variety and the understanding of the importance of micronutrients. But the micronutrient training did not influence the bidding price, as shown in Table 2, and the extent of women's involvement in decision-making as reported in Table 4. However, one must bear in mind that the resulting bidding prices were obtained only from those who participated in the bidding. That is, there are women farmers who did not answer phone calls and who did not participate in the bidding. Other factors, such as education and wealth of women farmers, may also have influenced the bidding prices. Thus, we need to examine the determinants of bidding prices by conducting a more detailed analysis of whether the results in Table 2 hold true after controlling for observable factors and possible selection bias.

3.4. Cultivation of Zinc-Enhanced Rice in 2018–2020

The main focus of this study is to measure the long-term impact of the micronutrient training. To achieve this objective, the survey was repeated for 3 years, in 2018, 2019, and 2020. In the follow-up door-to-door survey of 2018, respondents were asked about their cultivation of high-zinc rice varieties in the Aman season of 2018, as well as detailed information on rice, production, adoption, and seed sources. In the phone-based survey for the Aman of 2019, respondents were asked about their adoption of high-zinc rice. In the Aman season of 2020, the phone survey collected detailed information regarding the cultivation of high-zinc rice, reasons for adoption and dis-adoption, and seed sources.

Figure 2 shows that about 59% of the treated farmers cultivated the high-zinc rice variety in 2018 and 13% among control farmers. The adoption rate decreased significantly from about 19% to 8% in the Aman season of 2019 and 2020, respectively, among treated farmers. Likewise, among control farmers, the adoption rate declined from 8% in 2019 to 2% in 2020. Therefore, it seems that adoption of high-zinc rice variety in the study area has been limited. As de Brauw et al. (2018) pointed out, biofortified crops face many constraints on adoption. These include lack of information on how to grow biofortified crops or their potential yields, and weak national seed systems that may lead to a lag in the uptake even if information on the benefits of the crops is available.

Figure 2: Adoption of Zinc-Enhanced Rice in 2018–2020



Source: Authors' calculation based on the panel surveys.

In terms of reasons for not adopting the high-zinc rice variety in 2020, about 47% of the treated farmers and 15% of the control farmers mentioned the unavailability of seeds in the market (Table 5). Earlier research demonstrates that seed access constraints and underdeveloped seed delivery systems limit the adoption of new varieties despite their nutritional benefits (see, for example, Shiferaw et al. 2015). Another major reason for the non-adoption is the lower yield of high-zinc rice varieties compared with non-zinc rice varieties. To be specific, about 23% of treated farmers and 18% among control farmers cited the lower yield for not adopting high-zinc rice varieties. Other reasons for non-adoption include experience of flooding, lack of free seeds, and less cultivable rice land.

As expected, many control farmers (65%) cited the lack of knowledge about the high-zinc rice variety as a key reason for not adopting this biofortified crop. About 6% of the treated farmers also mentioned the same reason for non-adoption. In relation to this finding, other authors emphasized the heterogeneity of households in returns of adopting biofortified crops with respect to the nutritional status of their members. For example, Gilligan (2012) argues that individuals may be less knowledgeable about the nutritional status of their household members than they are about the comparative advantage in growing certain crops. Except if individuals seek medical attention for a severe nutritional deficiency, Gilligan (2012) pointed out that most of them are unaware of their micronutrient status, and this in turn limits the ability of the individual to recognize the true returns of adopting a biofortified crop.

Table 5: Reasons for Non-Adoption of High-Zinc Rice in 2020

	Aman Season	
Reasons	Treatment	Control
	%	%
Lack of knowledge on zinc-rice variety	5.6	64.5
Seeds not available in the market	46.9	15.1
Yield of zinc-rice variety is not good	23.1	17.8
Due to flooding	6.3	
Did not get free seed	4.4	
Less cultivable rice land	3.1	
Taste is not good	1.9	0.7
Low price of product	1.9	
Others	6.9	2.0
(No. of non-users)	(160)	(152)

Source: Authors' calculation based on the panel surveys.

4. Estimation Models

4.1. Conceptual Discussion of Adoption and Dis-adoption

A major factor that can affect the decision of farmers to grow high-zinc rice varieties is their agro-economic performance relative to other varieties. For example, Sanjeeva Rao et al. (2020) emphasized that farmers' adoption of high-zinc rice is possible only when the yield is comparable to or higher than the existing, popular cultivated rice varieties. If growing high-zinc rice in one season provides comparable or higher yields, then farmers are more likely to cultivate the variety again in the next growing season. A good understanding of the nutritional benefits of high-zinc rice will also influence the farmers' decision to adopt. An example is Gilligan et al. (2020) who found that the probability of adopting OFSP on a parcel increases with the mother's nutrition knowledge. In this study, therefore, we examine how yield gain and knowledge of nutrition benefits can affect the adoption of high-zinc rice varieties over time by using panel data.

Intrahousehold bargaining power and decision-making will also influence adoption of biofortified crops. Gilligan et al. (2020) have demonstrated this adoption mechanism in the context of OFSP adoption in Uganda. They showed higher probability of adoption of OFSP on parcels where the woman takes the lead in deciding which crops are grown.

Social networks also influence adoption decisions based on two channels (Vaiknoras et al. 2019). The first channel is by increasing the likelihood that a household is aware of the variety, while the second channel is through the reduction of adoption costs by making planting material more easily accessible. In line with this mechanism, Vaiknoras et al. (2019) showed that informal dissemination within social networks and access to extension are also major drivers of rapid adoption of iron-biofortified beans in Rwanda. Caeiro and Vicente (2020) also found evidence of adoption of OFSP for production in the short- and medium-run through social networks between treated individuals and peer farmers. Likewise, McNiven and Gilligan (2012) showed that information networks within communities play a substantial role in first providing access to OFSP planting material and later in supporting sustained OFSP adoption by households outside the project.

Meanwhile, several factors also affect dis-adoption of biofortified crops. These include lack of information about how to grow biofortified crops or their potential yields (Almekinders and Hardon 2006), seed access constraints and underdeveloped seed delivery systems (Shiferaw et al. 2008), preference on varietal attributes (Stevens and Winter-Nelson 2008; De Groote et al. 2011; Adekambi et al. 2020), and household heterogeneity in expected returns in terms of productivity, access to markets, and nutritional status of household members (Suri 2011; Gilligan 2012). In our analysis, female farmers with young children that were identified in control villages allowed us to verify whether the lack of nutrition information constrains the adoption of high-zinc rice varieties. Even in the presence of nutrition information on the crop, farmers would be deterred to adopt high-zinc rice varieties if seeds are unavailable to market due to weak national seed systems. Thus, the adoption of the variety will be limited in situations where farmers are constrained by the unavailability of seeds.

4.2. Estimation Model

To examine the impacts of the micronutrient training on the adoption of zinc-enhanced rice, we estimate adoption models. The dependent variable, *Y*, is the adoption of zinc-rice of farmer *i* in season *s* of the year 2018.

$$\Pr(Y_{is2018} = 1) = \Phi(\beta_1 Training_i + \beta_2 Decision_i + \beta_3 X_i + \beta_4 X_h) \quad (1)$$

where Φ is the cumulative normal distribution function. The dependent variable, B_{ij}, takes the value of 1 if a woman in household j participates in bidding, and zero otherwise; $Training_i$ is the treatment assignment for women who were randomly selected to participate in the micronutrient training; $Decision_i$ is a dummy variable indicating whether women self-proclaimed to be actively involved in decision-making; X_i includes bidding timing parameters such as bidding date, bidding time in hour, and a dummy variable for bidding during weekdays; and X_h is a vector of other factors such as whether a household has children under 5 years of age, age and education of women, dummy variable for female adults in the household, and location dummy.

Because the treatment villages were selected randomly, we can treat the training variable as an exogenous variable, which is not correlated with unobserved factors.

After the initial year, the subsequent use of zinc-enhanced rice depends on its performance in 2018. For instance, if the yield of zinc-enhanced rice is lower than other rice varieties, farmers may decide to dis-adopt the variety despite its nutritional benefit. On the other hand, if the variety performs well, with comparable or higher yields in addition to the nutritional benefit, adopter farmers may decide to re-plant the variety and even expand the area for cultivating the variety. Even non-adopters in the first year may decide to adopt the variety after seeing its performance on the adopters' fields. Thus, we measure the performance of zinc-enhanced variety (BRRI Dhan72) at the village level. We develop a variable which is constructed as $\mathrm{dif}_{\mathrm{yield}} = Zinc_{yield_{2018}} - Nonzinc_{yield_{2018}}$. We include this variable in Equation 1 and estimate the models for the subsequent years, in 2019 and 2020.

4.3. Variables

The phone bidding survey in June 2017 contains a set of questions related to bidding participation and bidding prices, which we use as the key dependent variables of interest in this study. Female respondents from both treatment and control groups were also asked about their knowledge of six potential effects of zinc deficiency in human body: adolescents become stunted, increases diabetes risks, increases disease risks, delays cure from diarrhea and asthma, causes inattentiveness to learning and work, and causes weight loss. We employ these as crude measures of farmers' understanding on the importance of micronutrients. Appendix Table 1 presents a definition of variables.

The key independent variable in our regressions is a micronutrient training dummy, essentially a nutrition information based on the treatment assignment, which has been similarly used by a similar (e.g., Banerji et al. 2016. Another major explanatory variable measures women's involvement in decision-making in the use of income, largely similar with the idea of women's empowerment in agriculture (see, for example, Malapit and Quisumbing 2015; Malapit et al. 2015). We employ a dummy variable in this case if a woman self-proclaimed that she is actively involved in decision-making as a proxy for intrahousehold bargaining power. In the bidding participation model, we include the bidding dates from 11 June to 21 June 2017, the hour of the day starting from 7:00 a.m. until 11:00 p.m., and a dummy for weekday. We also include a dummy for Sirajganj district. Moreover, household characteristics such as dummies for children below 5 years of age and a female adult in the household, as well as age and education of women are included, consistent with Sraboni et al. (2014), and Gilligan et al. (2020).

5. Discussion

5.1. Econometric Results

We begin our empirical investigation with an analysis of balancing test (Appendix Table 2). To do this, we conducted *t*-test of mean values of the main household characteristics and estimated a probit regression of micronutrient training on these exogenous variables. Both the *t*-test and probit estimation results show that treatment and control farmers do not differ significantly on any of the main household characteristics. This means that the random assignment of women farmers to the treatment and control groups ensures that those in either group are similar in all other respects, except in that treatment women were exposed to the micronutrient training. Around 26% to 34% of women farmers in the sample have self-proclaimed that they participated in decision-making regarding the use of income from rice production (Table 6). Having a female adult in the household is fairly widespread. On average, the age of women is 31 years old while their schooling is 6 years. Around 35% to 41% of households have children under 5 years of age.

Table 6: Mean Values of Women's and Household Characteristics by Treatment Status

Variables	Control	Treatment	*p*-Value of Difference
Involved in decision-making	0.265	0.347	0.108
Children aged 1 to 5 years	0.413	0.358	0.412
Age of member	30.4	31.7	0.114
Education level	6.5	5.8	0.310
Female adult	0.819	0.879	0.134

Source: *Authors' calculation based on the panel surveys.*

Once we have determined that all of the main household characteristics are balanced, we examine the impacts of micronutrient training on bidding participation and bidding price as reported in Table 7. Most importantly, the micronutrient training dummy displays a significant positive impact on bidding participation. The estimated coefficient of the micronutrient training indicates that the probability of bidding increases by 46.9%. This result is supportive of evidence that nutrition information matters for introducing new biofortified crops (see, for example, Chowdhury et al. 2011; Naico and Lusk 2010).

The results further suggest that women's involvement in decision-making is positively and highly significant in explaining bidding participation. The probability of bidding for BRRI Dhan72 was higher by 24.7 percentage points for those women who have greater involvement in the decision-making. This finding is consistent with past studies showing that women's bargaining power affects the adoption of new agricultural technologies (Fisher and Carr 2015). Another important finding shown in

Table 7 is the positive and significant effect on bidding participation for households with children below 5 years of age.

The results from the probit model further indicate that the timing of the bidding survey matters for participation. The later the call was made during the day, the higher the probability for the women participants to bid for the seeds. Likewise, the probability of participating in the bidding increases when the phone survey was conducted during a weekday. The effect of the bidding date on participation is not significant. As the planting season progressed during the survey period, farmers who refused to participate in the phone survey had completed rice planting. Thus, those farmers who were still preparing for planting tended to participate in the phone survey. As for other characteristics, bidding participation is higher for households with female adult members, but the estimated coefficient is not significant as well as for age, education, and location of female members.

Table 7: Determinants of Bidding Participation and Bidding Price for BRRI Dhan 72

Variables	Bidding	Bidding Price
Micronutrient training (= 1)	0.469***	14.395*
	(0.06)	(8.27)
Involved in decision-making (= 1)	0.247***	20.053**
	(0.07)	(8.79)
Bidding day and time		
Bidding date	0.020	
	(0.01)	
Bidding time (hour)	0.027***	
	(0.01)	
Bidding weekday	0.161*	
	(0.08)	
Household Characteristics		
Children aged 1 to 5 years	0.232***	-4.792
	(0.07)	(6.07)
Age of member	-0.004	0.007
	(0.01)	(0.55)
Education level	-0.017	0.070
	(0.01)	(1.10)
Female adult (=1)	0.131	0.775
	(0.10)	(12.00)
Sirajganj district (=1)	0.046	32.549***
	(0.09)	(8.01)
Constant	-3.100***	51.084*
	(0.82)	(27.28)
Number of observations	328	154

BRRI = Bangladesh Rice Research Institute.
Notes: ***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Numbers in parentheses are standard errors.
Source: Authors' calculation based on the panel surveys.

After controlling for the bidding participation by including the correction term in the third column of Table 7, the results indicate that the micronutrient training increases the bidding price for BRRI Dhan72 by Tk41 for a 2.5-kilogram bag. Because the average bidding price is about Tk108, this indicates a 13.0% increase in the bidding price. Because of their understanding of the importance of micronutrients, women farmers may have realized the benefits of BRRI Dhan72. Similar with the bidding participation probability, the women's involvement in decision-making dummy has a positive and significant impact on the bidding price. It means that women farmers are not only eager to participate in the bidding because they are involved in decision-making, but they are also willing to pay a higher price. Unlike with the participation probability, the Sirajganj district dummy has positive and significant impact on the bidding price. Even if the women's bidding participation in this location is not significant, they were willing to pay a higher price.

Finally, Table 8 reports the results from the adoption model separately for 2018, 2019, and 2020. The positive and significant effect of the nutrition training appears to hold throughout these three survey periods, indicating that the training exerts a long-term impact on adoption of the high-zinc rice variety. The estimated coefficient of the yield difference at the village level is significantly positive and negative for the 2018 and 2019 adoption models, respectively. This suggests that adopter farmers may decide to re-plant or dis-adopt the zinc-enhanced rice variety depending on whether the variety performs well, in addition to its nutritional benefit. Regarding the household characteristics, the estimated coefficient of the women's involvement in decision-making is positive and significant for the 2018 adoption model, suggesting that the probability of adopting the high-zinc rice variety increases with women farmers' say in decision-making in the household. Additionally, the adoption of the high-zinc rice variety in 2018 also increases for households with children below 5 years of age. Adoption of high-zinc rice is less likely in households with larger land holdings, which is consistent with the findings of Gilligan et al. (2020) in the context of adoption of the biofortified orange sweet potato in Uganda.

5.2. Policy Implications

A key constraint on the adoption of biofortified crops is the limited understanding of the need for micronutrients among farmers. In Bangladesh, high-zinc rice varieties have been developed and released to address the problem of zinc deficiency, particularly among children and pregnant women. In this study, we employed data from the randomized experiment to build an understanding on the importance of micronutrients among mothers. We also used a phone-based bidding auction to obtain women farmers' revealed preference for buying seeds of high-zinc rice. More importantly, we examined the long-term impact of the training on high-zinc rice adoption through a three-year panel survey conducted in 2018, 2019, and 2020. Overall, the results indicate that nutrition training has a long-term but diminishing impact on the adoption of high-zinc rice.

Several important policy implications can be drawn from our results. First, the adoption of high-zinc rice in the study area is limited among treatment farmers due to unavailability of seeds and low yields, while lack of knowledge about high-zinc rice was a dominant reason among control farmers. Therefore, policymakers need to have a clearer understanding of these constraints in order to gain better insights into policy design and action plan for enhancing the adoption and diffusion of high-zinc rice.

Second, policies that strengthen national seed system could avoid a lag in the uptake of high-zinc rice, especially if information on the benefits of this biofortified crop is available.

Third, farmers need to be educated on the potential yields of high-zinc rice, how to grow this biofortified crop and its benefits through extension activities by the government.

Fourth and finally, providing micronutrient training among mothers appears to be crucial for disseminating high-zinc rice. An important practical policy implication of this result is that agricultural interventions that put emphasis on education for nutrition and engagement with female farmers in the dissemination of high-zinc rice could be the best strategy to influence the decision of farmers to adopt and consume this biofortified crop. In relation to this, any policy design or incentive that aims to increase the intrahousehold bargaining power of women with a nutritional campaign about high-zinc rice could lead to both increase in household well-being and successful adoption and consumption of high-zinc rice.

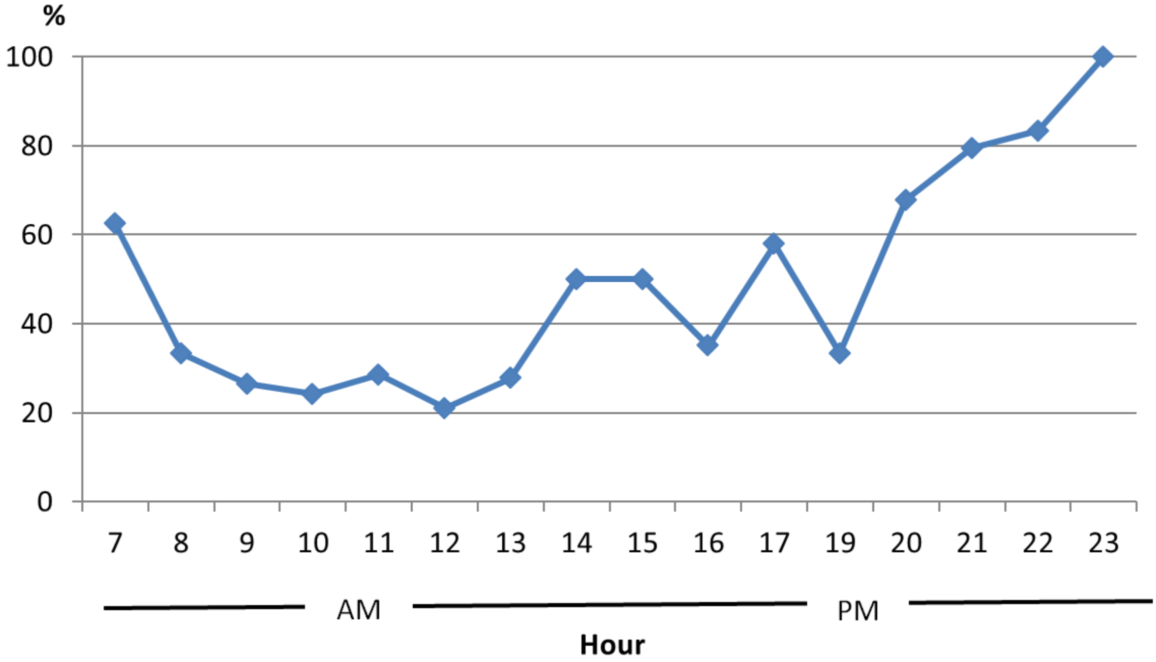
Table 8: High-Zinc Rice Adoption over Time (Probit: Marginal Effects)

Variables	2018 (A)	2019 (B)	2020 (C)
Micro-nutrient training (= 1)	0.437***	0.072*	0.058**
	(0.05)	(0.04)	(0.03)
Involved in decision-making (= 1)	0.126*	0.030	0.000
	(0.07)	(0.04)	(0.02)
Yield difference in 2018		-0.099**	-0.001
		(0.04)	(0.02)
Area (hectare)	-0.064**	0.013	-0.003
	(0.03)	(0.02)	(0.01)
Number of children aged 1 to 5 years	0.155***	0.024	-0.003
	(0.06)	(0.03)	(0.02)
Age of member	-0.007	0.000	-0.001
	(0.00)	(0.00)	(0.00)
Education level	-0.012	0.001	0.000
	(0.01)	(0.00)	(0.00)
Female adult (=1)	0.004	0.018	0.031
	(0.09)	(0.05)	(0.02)
Sirajganj district (=1)	0.2300	0.228**	-0.006
	(0.06)	(0.09)	(0.04)
Constant	-1.203	-2.488***	-2.178***
	(0.56)	(0.70)	(0.94)
Number of observations	328	328	328

Notes: Absolute values of *z*-statistics based on robust standard errors are in parentheses. ***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.
Source: Authors' calculation based on the panel surveys.

APPENDIXES

Appendix Figure 1: Bidding Participation for BRRI Dhan 72 by Hour



BRRI = Bangladesh Rice Research Institute.
Source: Authors' calculation based on the panel surveys.

Appendix Table 1: Descriptive Statistics

Variable	Description	Mean (A)	S.D. (B)
Dependent variables			
Bidding participation	Dummy variable for participating in a bidding for 2.5-kilogram BRRI Dhan72 seeds	0.485	0.501
Bidding price	Bidding price for 2.5-kilogram BRRI Dhan72 seed	108.1	49.2
Independent variables			
Micronutrient training	Dummy variable for participation in nutrition training	0.527	0.500
Involved in decision-making	Dummy variable for women's involvement in the decision on the use of income from rice production	0.308	0.462
Bidding date	Date for the phone bidding from 11 to 21 June	16.6	2.6
Bidding time (hour)	Hour of receiving in phone bidding experiment	15.1	5.0
Bidding weekday	Dummy variable for receiving in phone bidding experiment in weekdays	0.832	0.374
Household Characteristics			
Children aged 1 to 5 years	Number of children aged 1 to 5 years	0.4	0.6
Age of member	Age of the respondent	31.1	7.2
Education level	Years of successfully completed school years	6.1	5.8
Female adult (=1)	Dummy variable for wife in men-headed household	0.851	0.357
Sirajganj district	Dummy for respondents in Sirajganj district	0.527	0.500
Number of observations	Households participated in phone experiments	328	

BRRI = Bangladesh Rice Research Institute.
Note: The exchange rate was $1 = Tk80.6 in June 2017.
Source: Authors' calculation based on the panel surveys.

Appendix Table 2: Probit Regression Results of Micronutrient Training Participation

Variables	Coefficient
Involved in decision-making (= 1)	0.218
	(0.16)
Number of children aged 1 to 5 years	-0.010
	(0.13)
Age of member	0.009
	(0.01)
Education level	-0.007
	(0.01)
Female adult (=1)	0.238
	(0.21)
Sirajganj district (=1)	0.181
	(0.16)
Constant	-0.573
	(0.42)
Number of observations	328

Source: Authors' calculation based on the panel surveys.

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