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23 May 2024

High-zinc rice and randomized nutrition training among women farmers: A panel data analysis of adoption in Bangladesh

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Abstract

This paper aims to examine the effect of nutrition training on the adoption of high-zinc rice among female farmers with young children in Bangladesh. The authors first conducted a randomized control trial by providing female farmers with micronutrient training in randomly selected villages in May-June 2017, followed by a phone-based survey on high-zinc rice seeds among farmer trainees and counterparts in control villages. We conducted a three-visit panel survey in 2018–2020 to measure the effect of nutrition training on high-zinc rice adoption. We found that the adoption of high-zinc rice in the Aman or rainy season during July-August declined from 59% in 2018 to 8% in 2020 among treated farmers and from 13% to 2% among control farmers. The regression analysis indicated that nutrition training had a significant but diminishing effect on the adoption of high-zinc rice. Unavailability of seeds and low yields were cited as the major reasons for not using high-zinc rice, while lack of knowledge about high-zinc rice was the dominant reason among the control farmers. The results have shown that continuous training, public messaging, and improving seed systems are required to sustain zinc rice adoption. The trainings should tackle the nutritional advantages of biofortified crops to ensure knowledge retention and farm practices and management techniques to achieve optimal production.

Keywords: Biofortification, Zinc-enhanced rice, Adoption, Bangladesh
JEL codes: I12, O33, Q16

[1] Version accepted for publication. Published by Oxford Academic. Published in Q Open, 5(1), 2025, qoaf001. https://doi.org/10.1093/qopen/qoaf001.

1. Introduction

Current trends in micronutrient malnutrition particularly threaten the health of children and pregnant women. Indeed, malnutrition is the most significant risk factor for global morbidity and mortality linked to half of worldwide deaths in children (Khan and Ali 2023). A key micronutrient requirement for the adequate growth of children is zinc (Hassanein et al. 2019). Zinc is an essential micronutrient for growth especially for children, thus, deficiencies have been heavily linked to stunting (Monfared et al. 2023). Moreover, zinc deficiency has critical ramifications with regards to child health especially in compromising the immune system causing infections (Rerksuppaphol and Rerksuppaphol, 2019), diarrhea (Abolurin et al. 2020), and respiratory-related complications (Shivalingaiah and Ramarai, 2019). Affecting more than 1 billion people, zinc deficiency is considered a major nutrition problem especially in Asia (Swamy et al. 2016).

Zinc deficiency has been prevalent in Bangladesh since most rural households consume a rice-based diet with food items that inhibit absorption of zinc into the body and few animal-source foods (Arsenault et al. 2010). According to Ahmed et al. (2012) and Rahman et al. (2016), stunting due to zinc deficiency affects 41% of children under 5 years old and Bangladesh leads the world in percentage of population at risk of zinc deficiency at 55% based on the report by the International Zinc Nutrition Consultative Group (IZiNCG 2004).

In response, high-zinc 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 its seeds are largely unavailable to farmers. Several factors determine farmers' adoption of agricultural technologies in developing countries. Some studies focus on farmers' socioeconomic conditions and farm characteristics (Doss 2006; Ainembabazi et al. 2016), while other studies examine 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, crop availability and performance, as well as information on nutritional benefits have been identified as crucial determinants of acceptance and adoption (Talsma et al. 2017). For example, De Brauw et al. (2018) contended that the lack of knowledge about the nutritional status of household members limited one's ability to recognize the true returns of adopting biofortified crops while Birol et al. (2015) found that whether farmers produce for profit or for household consumption significantly affects the adoption of biofortified crops.

This study examined the effect of nutrition training on the adoption of high-zinc rice varieties which are developed to complement current interventions that aim to alleviate zinc deficiencies in Bangladesh. The contribution of this paper to current literature is threefold. First, we conducted a randomized control trial of nutrition training among women farmers with young children in Bangladesh. Tibamanya et al. (2022) highlighted that randomized control trials are ideal in studies involving varietal improvement since it removes the possibility of reverse causality and unobserved heterogeneity during the sampling stage.

The treatment consisted of a group training where basic knowledge about the importance of micronutrients and different high-zinc rice varieties, as well as farm management practices were taught. Evidence from current literature on the effects of nutrition information on the adoption of biofortified crops remain scant and mixed. Caeiro and Vicente (2020), for instance, found that knowledge of nutrition significantly increases the cooking and planting of orange-fleshed sweet potato (OFSP) among treated female farmers in Mozambique. In contrast, de Brauw et al. (2018) showed only a marginal effect of nutritional training on OFSP adoption in Mozambique. To our knowledge, however, few studies have examined how nutrition knowledge affects adoption of biofortified crops by combining randomized nutrition training and multiple-visit panel surveys.

Second, we also investigated the long-term effects of nutrition training on adoption of zinc-enhanced rice. In contrast to the existing literature on the effects of nutrition training on the adoption of biofortified crops (see, for example, Caeiro and Vicente 2020; Gilligan et al. 2020), we conducted a three-visit panel survey in 2018–2020 which allowed us to also look at disadoption and readoption of high-zinc rice varieties.

Third, we observed that only a few studies examined the effect of providing seeds or planting materials on the adoption of biofortified crops (De Groote et al. 2016; Gilligan et al. 2020) and other improved rice varieties (Simtowe et al. 2019; Bannor et al. 2020). Thus, we contribute to the literature by providing rice farmers with high-zinc rice seed to overcome their constraint to adoption and then analyzing the effect on adoption over 3 years.

The remainder of the paper is organized as follows. Section 2 presents literature showing the factors affecting the adoption of biofortified crops. In Section 3, we discuss the experimental design and survey process. Section 4 presents descriptive statstics. Section 5 discusses the application and results of the binary probit and multinomial probit models of high-zinc rice adoption. Finally, Section 6 sums up the key results and concludes with some policy recommendations.

2. Literature

The main benefit of biofortified varieties is the enhancement of the biological and genetic traits of staple crops with dense sources of specific micronutrients (De Brauw et al. 2018). This would be especially helpful in rural households where diets are not as diversified and access to food supplements, healthier food, and other fortified foods is limited (Meier et al. 2020). While Suri (2011) says that adoption of modern varieties are largely based on heterogeneity, existing literature points to at least five major factors that influence the adoption of biofortified crops.

First, adoption would occur only if the farmers' expected monetary and nonmonetary benefits of adoption were greater than those of their present practices (Foster and Rosenzweig 1995; Jack 2011). Same with other agricultural technologies, farmers tend to adopt new technologies when there are clear productivity and income advantages (Ogutu 2018). For high-zinc rice varieties specifically, adoption is contingent on whether the yield was comparable with or higher than that of the conventional varieties (Sanjeeva Rao et al. 2020). Additionally, days to maturity was also found to be a significant factor to the adoption of modern varieties in general (Birol et al. 2015; Hossain et al. 2006).

Second, a good understanding of the nutritional benefits and the agronomic characteristics of biofortified crops is important for increasing adoption (Gilligan 2012). Research suggests that targeted nutrition training have significant impacts in the adoption of biofortified crops (Ogutu 2018; Okello et al. 2019). Caeiro and Vicente (2020) noted considerable improvement in nutrition knowledge and cooking and planting of orange-fleshed sweet potato (OFSP) among treated female farmers. In addition, Gilligan et al. (2020) showed that the probability of adopting OFSP on a parcel was positively associated with the mother's nutrition knowledge. In terms of agronomic performance, Sanjeeva Rao et al. (2020) and De Groote et al. (2016) emphasized that farmers' adoption of high-zinc rice was possible only when the yield was comparable with or higher than that of the existing popular cultivated rice varieties. Related to the results of the other studies, Birol et al. (2015) found that high-iron pearl millet farmers producing for household consumption and those with knowledge on nutrition have significantly higher valuation of biofortified crops compared to farmers who produce for profit.

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 their study, they showed that the probability of adoption of OFSP was highest on parcels with joint control, but where the woman took the lead in deciding which crops were grown. In contrast, they also showed that the probability of adopting OFSP was lowest on parcels exclusively controlled by men. Furthermore, Vaiknoras et al. (2019) found that households with an educated and experienced female decision maker for bean production disadopted iron-biofortified beans more slowly than other households.

Fourth, 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; Ward and Pede 2014). A recent study by Vaiknoras et al. (2019) showed that informal dissemination within social networks was a major driver of rapid adoption of iron-biofortified beans in Rwanda. In the same manner, Okello et al. (2019) emphasized that the level of adoption and diffusion of biofortified crops is affected by mother-to-mother support groups for nutrition aside from health talks focused on nutrition. McNiven and Gilligan (2012) and Caiero and Vicente (2020) also explored the impacts of farmers' social network on the adoption of biofortified crops. Adoption of modern varieties and technologies in Bangladesh are also shown to be affected by access to extension services and farmer organizations (Islam et al. 2024; Rahaman et al. 2024)

The fifth factor is the role of seed availability or distribution, but only a few studies examined how it affected adoption. Simtowe et al. (2019) found that the adoption rate for drought-tolerant maize varieties in Uganda could increase to 30% if seeds were widely available and accessible to the farming population. For the adoption of modern rice varieties, Bannor et al. (2020) found that seed availability increased the probability of adoption by 4% in Odisha, India. The importance of the availability of seed and planting material was also investigated in the context of the adoption of biofortified staple crops. For example, De Groote et al. (2016) showed that seed availability was a major determinant of the adoption of quality protein maize in Ethiopia and Kenya. In looking at the adoption of biofortified orange sweet potato (OSP) in Uganda, Gilligan et al. (2020) reported that one of the major reasons for disadoption by farmers was the lack of access to new planting material.

3. Experimental design

3.1. Survey design and nutrition training

Data for this study were obtained through a combination of phone and door-to-door survey in Bogra and Sirajganj districts of Rajshahi Division in northwestern Bangladesh. Rice is the major crop in Rajshahi Division where the livelihood of most of its population heavily relies on agriculture (Osmani and Hossain 2015). In Rajshahi Division, the average poverty rate is relatively high at 28.9%. Meanwhile, the average poverty rate is relatively low in Bogra District at 14.5% and moderate in Sirajganj District at 23.8% (Hossain and Hossen 2020). The high prevalence of underweight and stunted children in Rajshahi Division makes it representative of national trends appropriate for the purposes of this study. Overall, the prevalence of underweight and stunting of children under 5 years of age in Rajshahi resemble the national average (Global Data Lab 2019). In 2017, the percentage of underweight children was 24.9% in Sirajganj and 38.9% in Bogra as compared to the national average of 26.5%. Meanwhile, the percentage of stunted children were 31.2% in Sirjganj and 37.3% in Bogra, while the national average was 31.3%.

The Department of Agricultural Extension, HarvestPlus[1] Bangladesh, and a partner non-government organization (NGO) were enlisted to help in the sampling due to their vast experience in working with women involved in rice farming within the Rajshahi Division.

[1] HarvestPlus is a program of the International Food Policy Research Institute (IFPRI) addressing hidden hunger by breeding vitamins and minerals to food crops.

Figure 1 summarizes the timeline of all data collection activities in this study. We first selected a random subset of 20 villages to be included in the study.[2] The village-level randomization was stratified at the *upazilla*-level. Upazillas are sub-districts consisting of 100 to 150 villages. The 20 selected villages were spread across eight upazillas. the sample selection for this study started by randomly dividing the 20 sample villages into treatment and control groups. The list of women farmers with at least one child of age 5 or below were obtained by visiting local government officials in each village. From the obtained lists, 20 women farmers were selected from each village.

[Insert Figure 1 here]

HarvestPlus and the partner NGO conducted the training before Aman season planting in the last week of May 2017. As stated earlier, the randomization was done at the village-level rather than the individual-level due to logistical considerations. Aside from practicality, this approach also helps prevent contamination problems because if there are farmers from both treatment and control groups in a single village, there would be risk of farmers from the treatment group sharing their acquired knowledge from the training to farmers in the control group. Also, control and treatment villages are generally far from each other as can be seen in Figure 2. There are two instances where treatment and control villages are near each other with less than 5 kilometers of distance between the two villages, but given social and cultural norms, women do not generally travel far away from their households.

[Insert Figure 2 here]

The micronutrient training discusses two main components of micronutrient information. First, information about nutrition such as its components, such as carbohydrate, protein, vitamins and minerals, and fat, and examples of food items containing the various

[2] The design of the clustered randomized control trial (RCT) was constrained by the budget and field conditions. Through power calculation, the number of villages were calibrated with an assumed response rate of 80% (400 valid responses), a balanced trial, and intraclass correlation coefficient of 0.3. The minimum detectable change was 28% in the bidding participation.

components. The second component included information on the effects and requirements of zinc on human nutrition especially for preventing diseases and health risks associated with zinc deficiency. Meanwhile, the second component involved different zinc rice varieties and the management practices required to cultivate zinc rice such as practices on planting and input use.

Aside from micronutrient training, information on the zinc varieties (i.e., BRRI dhan72 and BRRI dhan74) were also provided as well as the management practices required to cultivate zinc rice such as practices on planting and input use. A piece of information highlighted during the training is that the zinc rice varieties are inbred zinc varieties, which means that the succeeding farmers can harvest and use these seed sources for the next generation. This also means that the zinc properties are transferable over generations. This is important in the context of rice farmers in Rajshahi Division since they normally use homegrown planting materials of rice varieties for three reasons (see, for example, Singh and Kumar 2014; Iqbal and Toufique 2016). First, rice seed markets are not well-developed and hence good-quality seeds are not easily available in the market. This is more so for high-zinc rice because these varieties are relatively new and seed production and marketing are still low, although increasing over time. Second, the rice seed replacement rate is relatively low in Bangladesh, only about 30%. Farmers usually preserve rice seeds and use their own seeds in the next season. Third, farmers lack cash and use their own seeds. The use of homegrown planting materials of rice is common in Bangladesh and driven by the lack of seed supply in the market, farmers' behavior in using their own seeds, and lack of money to buy seeds.

3.2. Bidding process

After the training, the first phone survey was facilitated in June 2017 after we conducted a randomized control trial of nutrition training in the 20 randomly selected villages in May-June 2017 (Figure 2). We evenly split the sample villages for treatment and control villages in

Bogra and Sirajganj districts. During the phone survey in June to July 2017, we attempted to call a total of 400 women farmers of which 200 are treated farmers and 200 are control farmers. Among the total of 400 women farmers, 72 were not available during the phone calls, thus, we have reached a total of 328 women farmers with young children from 20 villages in Rajshahi Division, including those who participated in the training in the treatment villages and their counterparts in the control villages (Table 1). We asked women farmers if they were interested in participating in the bidding on high-zinc rice and then asked them how much they wanted to bid.

Of the 328 women farmers, approximately 53% were in the treatment villages and participated in the nutrition training and the remaining 47% were part of the control group and were not offered nutrition training (Table 1). As mentioned previously, since the treatment and control villages were generally situated at a distance from one another, there is lower probability that the training information were disseminated from the treatment to control villages.

[Insert Table 1 here]

The bidding process involved a two-stage process of eliciting the willingness to pay of the respondents for the high-zinc rice variety called BRRI Dhan72. In the first stage, the enumerator called the female respondent via mobile phone and asked if she was interested in participating in a bidding to buy a 2.5 kg packet of BRRI Dhan72 seeds on the condition that the seeds will be delivered to her house without any transportation or delivery costs. In the second stage, if the participant agreed to bid, the enumerator would ask her to state the price she was willing to pay for the seed bag. If the stated price exceeds the sale price of TK125 for a 2.5 seed bag of BRRI Dhan72, the respondent will get to buy it and will be delivered to her house. If the bid is lower than the sale price, then the respondent will not get the rice seeds.

4. Descriptive statistics

4.1. Adoption of high-zinc rice in 2018–2020

In follow-up surveys during 2018–2020, we asked all the farmers if they had adopted the high-zinc rice seeds, irrespective of whether the farmers ended up purchasing the rice seeds from the bidding or not. After the first phone survey in 2017, we repeated the survey 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. Note that the 2017 bidding on rice seeds was conducted before the planting season for the 2018 Aman season. In the following year, a phone survey was conducted for the Aman season of 2019, asking about their adoption of high-zinc rice. The phone survey was repeated in 2020, asking for detailed information regarding the cultivation of high-zinc rice, the reasons for adoption and disadoption, and seed sources.

Figure 3 shows that about 59% of the treated farmers cultivated the high-zinc rice variety in 2018, whereas only 13% of the control farmers did so. The adoption rate decreased significantly to 19% and 8% among treatment and control farmers, respectively, in the Aman season of 2019. The adoption rate declined further to 8% and 2% in 2020. Thus, the adoption rate declined quickly for the two groups, but the adoption rate among the treatment farmers was higher than that of the control group in all 3 years.

[Insert Figure 3 here]

These observations follow the findings of existing literature. First, the micronutrient training seems to have a positive impact on short-term zinc rice adoption given the relatively higher adoption rate of treatment farmers similar to the results of previous studies (Gilligan 2012; Ogutu 2018; Okello et al. 2019). However, similar to the study of Gilligan et al. (2020), farmers have disadopted in the next seasons, possibly due to the lack of seed systems for high-zinc rice in the country. While farmers in Bangladesh generally use their own seeds, this is only applicable for a few seasons given the reduction in grain quality that results from this practice. Other possible factors in the declining adoption of high-zinc rice are lower yields, lack of information on biofortified crops especially for control farmers, and lack of experience and expertise in the appropriate farming practices for the said crop.

4.2 Reasons for non-adoption of high-zinc rice

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 2). Earlier research demonstrated that seed access constraints and underdeveloped seed delivery systems limited the adoption of new varieties despite their nutritional benefits (see, for example, Shiferaw et al. 2015). This large difference between treated and control farmers could also be explained by the difference in knowledge about the benefits of biofortified crops given the treated farmers have undergone nutrition training and may seek out zinc rice varieties more in the market compared to the control farmers. Another possible reason for non-adoption was the lower yield of high-zinc rice varieties compared with non-zinc rice varieties. To be specific, about 23% of the treated farmers and 18% among the control farmers cited the lower yield for not adopting high-zinc rice varieties. This corroborates our calculation of the difference in yield of zinc and non-zinc rice at the village level, where average yields are 4.80 t/ha and 5.06 t/ha, respectively. The average yield at the village level is also lower than yield from the experimenters' plot. For example, breeders at the Bangladesh Rice Research Institute reported that high-zinc rice variety BRRI dhan72 had an average yield of 5.7 t/ha, while the first zinc rice varieties yielded 4.5 t/ha (HarvestPlus, 2015). Meanwhile, other reasons for non-adoption include experience of flooding, lack of free seeds, and less cultivable rice land.

[Insert Table 2 here]

As expected, many control farmers (65%) cited the lack of knowledge about the high-zinc rice variety as a key reason for non-adoption. About 6% of the treated farmers also mentioned the same reason for non-adoption. In relation to this finding, Suri (2011) emphasized the heterogeneity of households in returns from adopting agricultural technologies. In the context of biofortified crops, Gilligan (2012) argued 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 individuals to recognize the true returns of adopting a biofortified crop.

5. Empirical model and results

5.1. Estimation model and variables

We estimated adoption models to examine the effects of micronutrient training on the adoption of high-zinc rice. The dependent variable, $Y_{i,t}$, is the adoption of high-zinc rice by farmer *i* in year *t* = 2018, 2019, and 2020:

$$Pr\left(Y_{i,t} = 1|Training\right) = \Phi\left(\beta_0 + \beta_1 Training_i + \beta_2 Xh_{i,t}\right) \quad (1)$$

where Φ is the cumulative normal distribution function. The dependent variable adoption takes the value of 1 if a farmer adopts high-zinc rice in a given year and 0 otherwise. $Training_i$ is the treatment assignment for women who were randomly selected to participate in the micronutrient training; *Xh* is a vector of other factors such as a dummy variable indicating whether women self-proclaimed to be actively involved in decision-making, rice yield difference at the village level in 2018, rice area harvested, number of children less than 5 years old within the household, age and education attainment of the respondent, a dummy variable for female adults in the household, and a location dummy.

Table 3 presents the definition of the variables used in the high-zinc rice adoption regression and their descriptive statistics. The key explanatory variable in our adoption model is the nutrition training dummy. This independent variable is essentially nutrition information based on the treatment assignment. Because the treatment villages were selected randomly, we can treat the training variable as an exogenous variable, which is not correlated with unobserved factors. Another major factor considered was women's involvement in decision-making in the use of income, largely similar to the idea of women's empowerment in agriculture as used in Malapit and Quisumbing (2015) and Malapit et al. (2015). In measuring women's involvement in decision-making, we inquired about their level of involvement in deciding how to utilize the income generated from rice farming. The study used three categories of women's involvement in decision-making: (1) no input or input into few decisions (0–25%), (2) input into some decisions (26–50%), and (3) input into most or all decisions (above 50%). The study also used a dummy variable to represent women who self-reported active involvement in decision-making as a proxy for intrahousehold bargaining power.

[Insert Table 3 here]

After the initial year, the subsequent use of high-zinc rice depended on its performance in 2018. For instance, if the yield of high-zinc rice was lower than that of other rice varieties, farmers may have decided to disadopt the variety despite its nutritional benefit. On the other hand, if the variety performed well with comparable or higher yield in addition to the nutritional benefit, adopter farmers may have decided to replant the variety and even expand the area for cultivating it. Even non-adopters in the first year may decide to adopt the variety after seeing its performance in the adopters' fields. Thus, we measured the performance of high-zinc variety BRRI dhan72 at the village level. We developed a variable that was constructed as $dif_{yield} = Zinc_{yield_{2018}} - Nonzinc_{yield_{2018}}$. In our follow-up door-to-door survey in 2018, we were able to ask the sample farmers about their rice yield during the Aman season of that year. The survey in 2018 was done door-to-door to allow us to gather information on the bidding for high-zinc rice seed, adoption, rice area and production, reasons for adoption and disadoption, and other data that could not be easily obtained through phone surveys. All the other surveys were done by phone because these focused only on the adoption of high-zinc rice seed. Note that all villages have at least some adoption of high-zinc rice varieties and hence this could be constructed for all the villages. Accordingly, we calculated the average yield of high-zinc rice and non-zinc rice in each village in 2018, along with the yield difference. We included this variable in Equation (1) and estimated the models for the subsequent years, 2019 and 2020.

To identify characteristics of farmers who belong to a specific group, we estimated the multinomial probit model (MNP):

$$Pr(G_i = j) = \frac{exp(Training_i \gamma_j + X_i \gamma_j + X_h \gamma_j)}{\sum_{j=0,\dots,4} exp(Training_i \gamma_j + X_i \gamma_j + X_h \gamma_j)} \quad j = 0, \dots, 4 \tag{2}$$

where G_i is an indicator variable denoting the adoption of individual farmer i in household h with respect to jth group. In this study, the dependent variable is a categorical variable defined on the four groups. The categorical variable takes value 1 ($G_i = 1$) for farmers in the "Never Adopted group," that is, farmers who did not cultivate the high-zinc rice in 2018, 2019, and 2020. It takes value 2 ($G_i = 2$) for farmers in the "2018 Users Only group," that is, farmers who cultivated high-zinc rice in 2018 only. It takes value 3 ($G_i = 3$) for farmers in the "Continuous Users group," that is, farmers who cultivated high-zinc rice in 2018 and continued to use it for at least one more year. Finally, it takes value 4 ($G_i = 4$) for the "Late-Entry group" of farmers who did not adopt in 2018 but adopted in 2019 or 2020.

5.2. Empirical results

Our empirical analysis starts with an analysis of the balancing test. To do this, we conducted a *t*-test of mean values of the main household characteristics (Table 4) and estimated a probit regression using micronutrient training as the dependent variable and the household characteristics as exogenous variables (Table 5). Both *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 the exposure of the treatment group to micronutrient training.

[Insert Table 4 here]

Around 27% to 35% of women farmers in the sample have self-proclaimed that they participated in decision-making regarding the use of income from rice production (Table 7). The average age of the respondents is 31 years old while their average years of schooling is 6 years. Among the respondents, 36% and 41% of households have children under 5 years of age and around 14% to 17% of farmers reported that they were still preparing for planting during the phone bidding survey in the 2017 Aman season.

[Insert Table 5 here]

Once we have confirmed that all of the main household characteristics are balanced, we estimated the adoption model separately for 2018, 2019, and 2020 which is reported in Table 6. The positive and significant effect of the nutrition training appeared to hold throughout these three survey periods, indicating that the training exerted a persistent effect on the adoption of the high-zinc rice variety which is similar to the findings of studies such as that of Ogutu et al. (2020), Caeiro and Vicente (2020), and Okello et al. (2019) that training and extension efforts on biofortified crops drive its adoption positively. These findings also relate to the significance of some household characteristics. Regarding household characteristics, the estimated coefficient of the women's involvement in decision-making was positive and significant for the 2018 adoption model[3]. The adoption of the high-zinc rice variety in 2018 also increased in households with a larger number of children less than 5 years old.[4] The findings on women's decision making and number of young children in the household relate to the findings of Gilligan et al. (2020) that households with female decision makers are more inclined to adopt biofortified crops either due to less prioritization on income or more awareness of nutritional needs.

The estimated coefficient of the yield difference at the village level was significantly negative for the 2019 adoption model. This suggested that adopter farmers may have decided to disadopt the high-zinc rice variety depending on whether the variety performed well, in addition to its nutritional benefit. Our results are in line with the findings of Sanjeeva Rao et al. (2020) and Ogutu (2018) where even if farmers are interested in the nutritional benefits of biofortified crops, their adoption would still be heavily anchored on whether they can maintain at least similar levels of productivity. Adoption is also less likely in households with larger landholdings, which is consistent with Gilligan et al. (2020) in the context of adoption of biofortified orange sweet potato in Uganda. Households with larger landholdings often have higher income status and therefore can afford to buy more nutritious food and have more diversified diets. Also, households with more landholdings are usually market oriented. They are not only producing for home consumption but also sell their surplus on the market. Therefore, these households will be willing to grow other varieties highly demanded on the market, and the high-zinc varieties may not necessarily be their top choices.

[Insert Table 6 here]

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[3] We re-estimated the adoption probit equations for a subsample including only respondents stating that they (females) are involved in farm decision making. We found that nutrition training still had a positive and significant effect on the adoption of high-zinc rice across all years. We also found that the marginal effects of nutrition training on high-zinc rice adoption is higher in 2018 for the subsample (0.485 compared to 0.437) while results for 2019 and 2020 are almost identical.

[4] We also re-estimated the adoption probit equations for the treated subsample. Once again, we found that a higher number of children less than 5 years old in the household had a positive and significant effect on the adoption of high-zinc rice in 2018.

The multinomial probit model uses the previously mentioned adoption groups G_i. Table 7 summarizes the number of respondents included in each adoption group and their disaggregation based on whether they are a part of the control or treatment group. The Never Adopted group is the largest group when considering all observations. The group is also considerably larger for control farmers which is understandable since they were not provided with nutrition training. Among adopters of high-zinc rice, majority of the farmers only used it during the first cropping season after the bidding and disadopted after. An interesting finding is that there are a number of farmers in the control group that were in the Late-Entry group, possibly due to the eventual sharing of information either between farmers or from extension workers in the three-year coverage of the survey.

[Insert Table 7 here]

Finally, the results from the MNP model (Table 8) indicated that nutrition training matters in the adoption of high-zinc rice for both Adopters in 2018 and Continuous users groups, similar to earlier findings. We also found that the villages with higher zinc-rice yield were more likely to be in the Adopters in 2018 group. In contrast to this, the villages with lower zinc-rice yield were more likely to be in the Late-entry group. Since the yield differences were aggregated at the village level, then those who adopted early were able to gain significant yield advantages over non-zinc rice and that farmers opted to adopt later when observing higher yields from non-zinc rice varieties. The results of the MNP on household characteristics validate our earlier findings using the probit model. Farmers with relatively large landholding were more likely to be in the Never-adopted group but less likely to be in the Adopters in 2018 group which means that those with relatively large landholding prefer non-zinc rice varieties possibly due to the combination of productivity and income outcomes and market preferences while those with smaller landholding who may be practicing sustenance farming are more enticed by the nutritional benefits of high-zinc rice. Furthermore, households with a large number of children less than 5 years old tended to adopt high-zinc rice and belong to the Adopters in 2018 and Continuous users groups supporting the assertion that the perceived nutritional benefit of high-zinc rice for children drive adoption.

[Insert Table 8 here]

6. Conclusions and policy implications

A key constraint to the adoption of biofortified crops is farmers' limited understanding of the need for micronutrients. Bangladesh has prioritized the development and release of high-zinc rice varieties in hopes to address zinc deficiency specifically for children and pregnant women. In this study, we employed primary data from a randomized experiment to investigate the importance of micronutrients among mothers. More importantly, we examined the effect of the training on high-zinc rice adoption through a 3-year panel survey conducted in 2018, 2019, and 2020. Overall, the results indicated that nutrition training had a significant but diminishing effect on the adoption of high-zinc rice.

Our findings also have relevance for policy implications. Indeed, the introduction of high-zinc rice varieties in Bangladesh has allowed the government to address zinc deficiency among many children. Nutrition training has been found to be significant in the adoption of high-zinc rice. This implies that there is a need to expand the reach of training and extension efforts to encourage more farmers to adopt high-zinc rice. The results of the probit model also show that while still positive and significant, the marginal effects of nutrition training on high-zinc rice adoption has diminished over time. Several research have found that edutainment television programs have significant effects on farming practices, and thus, may be used as an innovative way of knowledge extension to farmers (Areal et al. 2020; Clarkson et al. 2018). These programs were found to influence farming practices by providing examples that they can identify with (Areal et al. 2020) and featuring farmers that viewers will find motivational and trustworthy (Clarkson et al. 2018). This innovation can be utilized to allow the retention of farmers' knowledge regarding the nutritional benefits of high-zinc rice varieties.

Aside from the short-term effect of nutritional training on farmer adoption of high-zinc rice, there were also other factors leading to diminishing adoption such as observed yield and seed access. From the results, it was seen that farmers who observe lower yields for high-zinc rice compared to other varieties are more likely to disadopt in the future. Areas for improvement could be highlighting farm practices and management techniques during trainings to ensure optimal yields for high-zinc rice varieties, as well as continuous effort in developing high-zinc varieties with higher yield potential. Farmers also mentioned the lack of access to seeds as a reason of non-adoption. This could be mitigated by improving seed systems either by increasing the capacity of pertinent government agencies to do so or nurturing private seed sector engagement by capacitating and supporting private seed nurseries. Both options would provide farmers with higher and more consistent access to high-zinc rice varieties compared to their current practices.

Although the main results indicated that nutrition training had a diminishing effect on the adoption of high-zinc rice, we also observed that farmers did not adopt again once they disadopted. This can be attributed to the fact that the nutritional benefits of high-zinc rice are visible only when this biofortified crop is consumed by children in the households. Therefore, the findings in this article suggest that the government needs to support farmers' adoption of high-zinc rice varieties on a regular basis and assist them in achieving high yields.

While the study has several strengths such as the use of a randomized control trial experiment to evaluate the effect of nutrition training on adoption of high-zinc rice, it also has important limitations. First, the adoption used in the study is based on the number of households using the biofortified crop and not the area allocated for it. However, the results may be comparable given that there are small differences in total land area between the farmers.

Second, seed access variables were not collected during the surveys. We advise future research to include variables such as sources and prices of seeds and other inputs, as well as alternative seed sources. Third, we have also highly focused on households and cases where females were the decision-makers and the training attendees. Recent studies such as the one of Gilligan et al. (2020) show that the inclusion of both genders and the diversification of trainings (i.e providing nutrition training to men and agricultural production training to women) improve long-term adoption of nutrition-related agricultural products and technologies so this should be explored in future research. Lastly, due to the COVID-19 pandemic, our follow-up surveys in 2019 and 2020 were done through phone calls and focused only on high-zinc rice adoption and some important variables were not re-collected such as yield, income, and information on the retention of nutrition knowledge due to time and resource constraints.

Data availability statement

The data used in this study are available on reasonable request to the corresponding author.

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Table 1. Sample women respondents in Rajshahi Division, Bangladesh
Source: Authors' calculations based on the initial phone-based survey in 2017.

District	Villages	Women interviewed	Proportion of women	
			Control	Treatment
	Number	Number	%	%
Bogra	10	107	55.1	44.9
Sirajganj	10	221	43.4	56.6
All	20	328	47.3	52.7

Table 2. Reasons for non-adoption of high-zinc rice in 2020
Source: Authors' calculations based on the last phone-based survey in 2020.

	Aman season	
Reasons	Treatment	Control
	%	%
Lack of knowledge on high-zinc rice variety	5.6	64.5
Seeds not available in the market	46.9	15.1
Yield of high-zinc rice variety is not good	23.1	17.8
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)

Table 3. Description of variables in the regression and descriptive statistics
Source: Authors' calculation based on panel surveys.

Variable	Description	Mean (A)	S.D. (B)
Dependent variable			
High-zinc rice adoption	Dummy variable for high zinc rice adoption	18.60	38.9
Independent variables			
Micronutrient training	Dummy variable for participation in nutrition training	0.527	0.5
Involved in decision-making	Dummy variable for women's involvement in the decision to use income from rice production	0.308	0.462
Yield difference in 2018	Difference in yield of zinc and non-zinc rice at the village level	-0.706	1.135
Rice area (ha)	Rice area	0.119	0.049
No. of children <5 years old	Number of children less than 5 years old	0.4	0.6
Age of household member	Age of the respondent	31.1	7.2
Education level	Years of successfully completed school year	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	0.5
Number of observations	Households that participated in phone bidding experiment	328	

Table 4. Mean values of characteristics of women and households by treatment status
Source: Authors' calculation based on the phone-based survey in 2017.

Variables	Control	Treatment	*p*-value of difference
Involved in decision-making	0.265	0.347	0.108
No. of 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
Farmers still preparing for planting	0.168	0.139	0.467

Table 5. Probit regression results of micronutrient training participation
Source: Authors' calculation based on the mobile phone survey in 2017.

Variables	Coefficient
Involved in decision-making (= 1)	0.230
	(0.142)
No. of children aged 1 to 5 years	-0.004
	(0.977)
Age of member	0.008
	(0.457)
Education level	-0.008
	(0.567)
Female adult (=1)	0.266
	(0.200)
Farmers still preparing for planting (=1)	-0.204
	(0.302)
Sirajganj district (=1)	0.190
	(0.231)
Constant	-0.534
	(0.206)
Number of observations	328

Notes: Number in parentheses are *p*-values.

Table 6. High-zinc rice adoption over time (probit marginal effects)
Source: Authors' calculation based on panel surveys.

Variables	2018 (A)	2019 (B)	2020 (C)
Micronutrient 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 (hectares)	-0.064**	0.013	-0.003
	(0.03)	(0.02)	(0.01)
No. of children aged 1 to 5 years	0.155***	0.024	-0.003
	(0.06)	(0.03)	(0.02)
Age of household 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.

Table 7. Categorization of respondents based on adoption behavior
Source: Authors' calculation based on panel surveys.

User group	Control	Treatment	Total
Never Adopted	122 (78.71)	61 (35.26)	183 (55.79)
2018 Users Only	18 (11.61)	79 (45.66)	97 (29.57)
Continuous Users	2 (1.29)	23 (13.29)	25 (7.62)
Late-Entry	13 (8.39)	10 (5.78)	23 (7.01)
Number of observations	155	173	328

Notes: Number in parentheses denote percentage of the group to observation totals.

Table 8. High-zinc rice adoption over time (multinomial probit marginal effects)
Source: Authors' calculation based on panel surveys.

	Never-adopted (A)	Adopters in 2018 (B)	Continuous user (C)	Late-entry in 2019 or 2020 (D)
Micronutrient training (=1)	-0.353***	0.278***	0.109***	-0.034
	(-8.26)	(5.85)	(2.77)	(-1.32)
Involved in decision-making (=1)	-0.088*	0.058	0.019	0.011
	(-1.70)	(1.23)	(0.63)	(0.36
Yield difference in 2018	-0.040	0.107***	-0.019	-0.047*
	(-0.98)	(2.66)	(-0.57)	(-1.80)
Area (ha)	0.052**	-0.053**	0.004	-0.002
	(2.14)	(-2.18)	(0.21)	(-0.16)
No. of children <5 years old	-0.123***	0.088**	0.040*	-0.004
	(-2.67)	(2.13)	(1.70)	(-0.14)
Age of household member	0.003	-0.002	-0.004	0.002
	(0.89)	(-0.59)	(-1.50)	(1.20)
Education (years)	0.006	-0.002	-0.007	0.003
	(0.92)	(-0.22)	(-1.56)	(1.41)
Female adult (=1)	0.036	-0.080	0.061	-0.017
	(0.50)	(-1.13)	(1.05)	(-0.44)
Sirajganj District (=1)	-0.099	-0.037	0.050	0.086
	(-1.08)	(-0.41)	(0.62)	(1.45)
Number of observations			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.

Figure 1. Timeline of data gathering activities

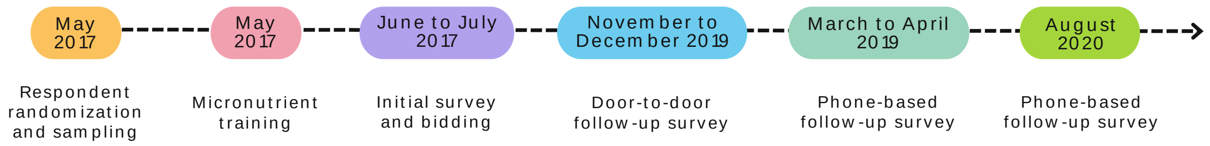

Figure 2. Survey Areas in Rajshahi Division, Bangladesh
Source: IRRI GIS.

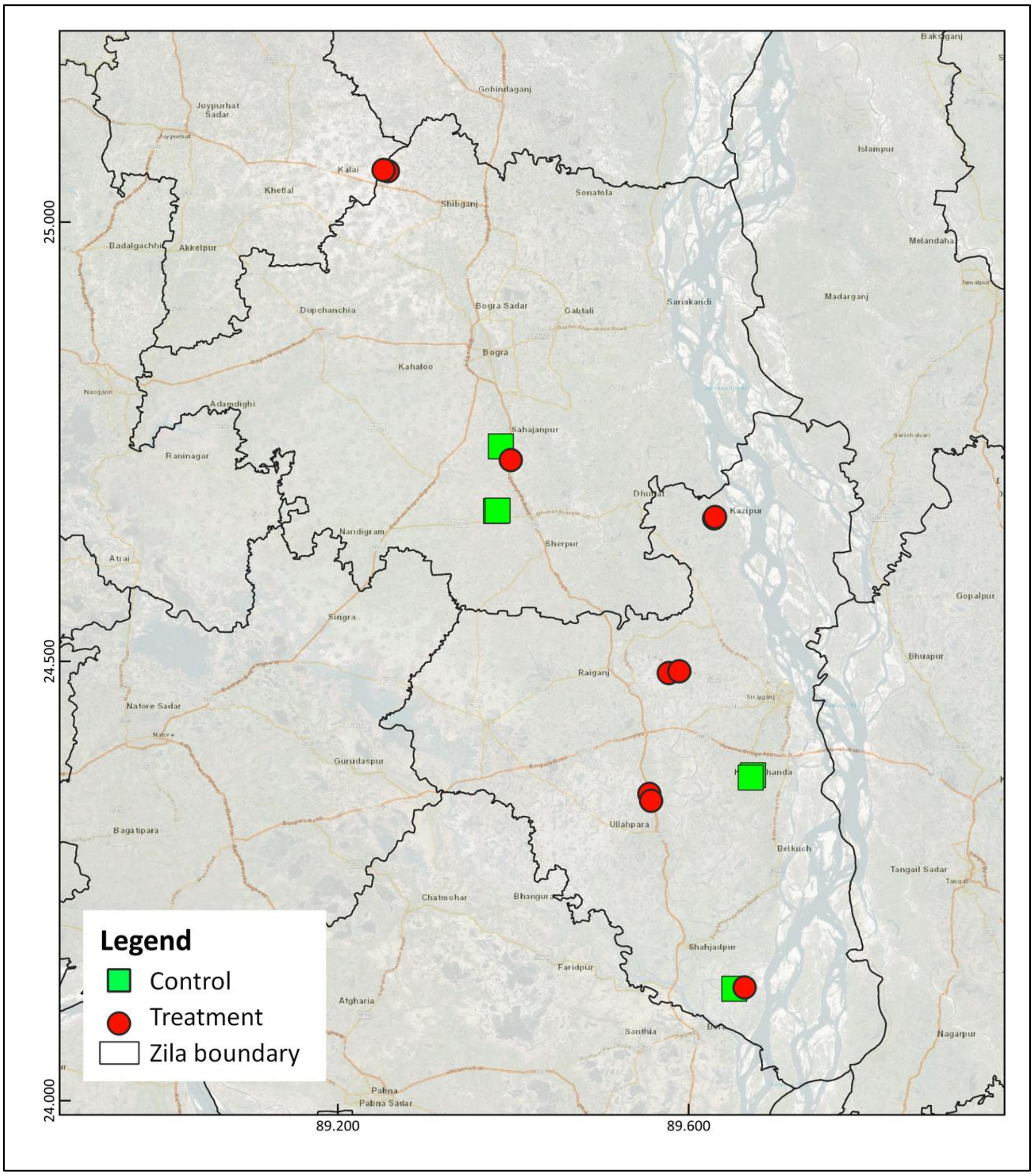

Figure 3. Adoption of high-zinc rice in 2018–2020
Source: Authors' calculation based on panel surveys.