ESTIMATING DEMAND VIA EXPERIMENTS IN THE AGRICULTURAL-NUTRITION SPACE

By

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ABSTRACT

Micronutrient malnutrition affects two billion individuals worldwide, especially developing countries' rural populations where the majority of food intake is from staple crops. The adoption and consumption of biofortified crops, which are staple food crops conventionally bred to have higher levels of micronutrients and minerals, is one agricultural-nutrition intervention being implemented to increase micronutrient intake. In this dissertation, I utilize experimental auctions to estimate consumer and farmer demand, measured via willingness-to-pay (WTP), for two biofortified staple food crops, rice and beans. I assess how information, farmer aspirations, and the difference in the experimental quantity used versus respondents' intended purchase quantity impact demand estimates. Findings can be used by implementers, extension agents, and agro-dealers regarding how best to increase demand for biofortified crops.

Chapter one examines the effects of nutrition information on rural Bangladeshi consumers' WTP for two ways to increase zinc intake through rice. I assess zinc intake via low-milling and biofortification of rice with increased zinc content, which is also low-milled to retain maximum zinc content. Results indicate that with information, consumers are willing to pay a premium for zinc biofortified rice compared to non-biofortified rice, when milled at the same level. However, results confirm Bangladeshi consumers' strong preference for high-milled rice, as they discounted low-milled rice even after receiving information on the nutritional benefits of biofortified or low-milled rice. Therefore, given current consumer preferences, other micronutrient intake interventions, beyond biofortification, should be explored.

In chapter two, I examine the role of farmer aspirations on WTP for biofortified bean seed, whose health benefits are considered a medium-term investment. Specifically, I assess if farmers classified as being high aspiring have a higher WTP for biofortified bean and if they

respond differently, as evidenced by their WTP, to nutrition and cooking quality information shared about the various bean seed types, via three rounds of bidding. I find that compared to the non-biofortified benchmark seed type, farmers are willing to pay a premium for biofortified bean seed when information is shared. Therefore, biofortified bean seed should be labeled, and nutrition and consumption information should accompany the seeds to elicit maximum demand. So, for initial roll-out, this study recommends targeting farmers that have achieved above a primary school education, that farm larger total land area across all crops, have greater assets, participate in farmer field days, are part of a savings group, and are members of a religious group as these characteristics distinguish high aspiring farmers.

Chapter three investigates if, and to what degree, varying bid quantity in WTP elicitation impacts per-unit WTP via a non-hypothetical field experiment using rural Zimbabwean farmers. I compare the status-quo approach of small, pre-fixed experimental quantities for bid elicitation versus an innovative approach where the experimental quantity is matched to each respondent's intended purchase quantity (IPQ). Farmers were randomly assigned to either a fixed quantity group (FQG) where they bid for 2kgs of seed or a variable quantity group (VQG) where their experimental quantity was matched to their IPQ. I find that the per-unit WTP is significantly biased upward when bids were elicited using a fixed quantity compared to farmers' IPQ. This bias was significantly higher for novel (biofortified bean) seeds. I find evidence that this bias in WTP is due to respondents' IPQ being above the fixed experimental quantity used. These results point to the need for researchers to critically consider the experimental quantity when designing input-based producer WTP studies. The estimated high WTP based on a small experimental bid quantity can have major implications for companies launching new products and estimating effective demand for agricultural inputs as well as governments setting input subsidy prices.

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CHAPTER 1. RURAL BANGLADESHI CONSUMERS' (UN)WILLINGNESS TO PAY FOR LOW-MILLED RICE: IMPLICATIONS FOR ZINC BIOFORTIFICATION

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1. Introduction

Micronutrient malnutrition, also known as 'hidden hunger', is one of the most prevalent forms of malnutrition, estimated to affect two billion individuals worldwide prior to the COVID-19 pandemic (FAO et al., 2015). Hidden hunger disproportionally affects developing countries' rural populations as a majority of food intake is from staple crops. Zinc deficiency, a main form of hidden hunger, is a severe public health problem in Bangladesh with 30% of the population at risk of inadequate zinc intake (Wessells et al., 2012). Zinc is essential for proper physical and cognitive development in children and adults. Additionally, zinc is crucial for immune system development and resiliency, which decreases susceptibility to infections such as diarrhea and pneumonia, a leading cause of child mortality in the developing world (Black et al., 2013), and to viral diseases such as COVID-19 (Wessels et al., 2020). In Bangladesh, 57% of women-of-childbearing-age (WOCBA) and 45% of preschool-age children are zinc deficient (IPHN, 2014; Rahman et al., 2016).

Increased zinc intake can readily be attained by improved dietary quality that meets both caloric and nutritional requirements. However, much of the world cannot access or afford a diet of micronutrient-rich foods like fruits, vegetables, and animal-source foods. Pre-COVID-19 estimates suggest that 3 billion people could not afford a healthy diet (FAO et al., 2020). Even when these foods are available, they are often allocated to men or adolescent boys in the household (Herrador et al., 2015), even though WOCBA and children under five have higher biological micronutrient needs (Black et al., 2013). To date, the majority of interventions used to address hidden hunger have been food fortification (during the processing stage) and supplementation, though with limited success in rural areas (Narayan et al., 2019).

In this paper we assess rural Bangladeshi consumers' willingness-to-pay (WTP) for two alternative low-cost rice products intended to improve zinc intake: (1) zinc biofortified low-milled rice and (2) non-biofortified low-milled rice. We measure the impact of varying amounts of information for these two products on 576 consumers' WTP by conducting economic experiments using the Becker-DeGroot-Marschak (BDM) mechanism.

Bangladeshi consumers prefer eating high-milled rice produced from paddy that is first parboiled. These processes—parboiling and high milling—produce rice with reduced zinc content (see section 2.2). Low milling protects rice grain zinc content from being removed. Biofortification further enhances the zinc content of rice,[1] but to maintain the majority of zinc content after undergoing parboiling, it also requires low milling. In our experiments, we provided study participants information about the nutritional benefits of low-milling and zinc biofortification. By evaluating the two nutritious low-milled products—zinc biofortified and non-biofortified rice—relative to high-milled rice, we are able to evaluate the viability (or lack thereof) of low-milled rice and zinc biofortified rice's consumer demand as a way to increase zinc intake. Results of our experiments confirm rural Bangladeshi consumers' strong preference for high-milled rice. Relative to high-milled rice, consumers discounted the two more nutritious low-milled rice products by 10%, even after receiving information on low milling benefits. Among the two discounted low-milled products (biofortified and non-biofortified), consumers

[1] Biofortified zinc rice has 75% more zinc than non-biofortified rice varieties at the same milling level (Andersson, 2017).

were WTP a 4.6% premium for zinc biofortified rice compared to non-biofortified rice after receiving zinc biofortified rice nutrition benefits information. However, this premium is still not sufficient to compensate for the steep discount consumers placed on low-milled rice. Since low milling is necessary to preserve the nutritional value of zinc biofortified rice, the results of this study indicate that increasing zinc intake through consumption of low-milled rice will require focused and strategic investments by the government and others to change consumer perceptions of and preferences for low-milled rice.

This paper makes several important empirical contributions to the literature. First, we measure consumer demand for a zinc biofortified crop and its invisible zinc trait. While numerous studies have explored the acceptance of and WTP for biofortified foods, most have been for visible traits, namely vitamin A biofortification which results in a change of color (Chowdhury et al., 2011; De Groote et al., 2011; Oparinde et al., 2016A). Fewer studies have elicited consumer WTP for invisible crop traits (credence goods), and primarily examined iron biofortified crops (Oparinde et al., 2016B; Banerji et al. 2016). An exception is Valera et al.'s (2019) study, which estimated WTP for zinc rice seed, but from producers' perspective as a production input rather than a consumption good. To our knowledge, no study has evaluated consumer WTP for the zinc trait in any crop and the majority of work on rice in Bangladesh has focused more on producer decision-making (Spielman et al., 2017; Ortega et al., 2019; Bashar et al., 2019), relative to consumer preferences. This paper contributes to filling this gap and pushes forward consumer-focused research on an important food crop in Bangladesh.

Another contribution of this study is the focus on WTP for processing techniques where the main objective is to improve nutritional content. A variety of WTP studies regarding food processing have been conducted; however, the focus is often on consumer interest in processing that preserves food attributes (Olsen et al., 2010), or enhances food safety (Ortega et al., 2011). One exception to this is a recent study by Chowdhury et al. (2021) that implemented a WTP experiment for fortified rice in Bangladesh. Additional research has been done on WTP for value-added products. Specific to rice, the Africa Rice Center has researched consumer demand for improved processing techniques (such as parboiling, milling, and grading), but the focus has been to increase the local rice quality and raise its competitiveness against imported rice (Demont and Ndour, 2015).

This paper is organized as follows: Section 2 provides a background on zinc biofortified rice and rice processing practices in Bangladesh, Section 3 describes the study's conceptual framework, and Section 4 shares data and sample descriptive statistics. Estimation strategies, empirical models used, and analysis results are described in Section 5. Section 6 concludes and discusses this study's policy implications.

2. Background

2.1 Rice in Bangladesh and Zinc Biofortified Rice

Rice (*Oryza sativa* L.) is the staple food crop in Bangladesh contributing 62% of daily calories (BBS, 2017). It is consumed at least twice daily. An important agricultural crop, the majority of rice (~96%) is sourced domestically (FAO, 2019) as it covers 75% of all cropped land in the country (BBS, 2017).

Biofortification, the breeding of staple food crops to improve nutritional content, is now considered a proven and scalable strategy to address hidden hunger.[2] Biofortified crops are bred to have the same agronomic and consumption attributes as the most popular varieties in a given agro-ecological zone (Bouis and Saltzman, 2017). For a discussion of yield and input costs of

[2] Biofortification can be through conventional and transgenic breeding methods. For zinc rice in Bangladesh, conventional breeding methods were used.

biofortified zinc rice, see Appendix A.1. In a global prioritization index for biofortified crop development and delivery, Bangladesh ranked first for zinc biofortified rice suitability based on the country's production and consumption of rice in addition to their zinc deficiency status (Herrington et al., 2019). Zinc biofortified rice was introduced in Bangladesh in 2013 and delivers 75% more zinc content than common rice varieties (28 µg/g and 16 µg/g, respectively), at the same milling level (Andersson, 2017).[3] Zinc rice can provide up to 60% of daily zinc needs when processed and cooked using typical Bangladeshi consumption patterns (Andersson, 2017).

Eight zinc rice varieties have been developed through partnership between CGIAR's HarvestPlus Program, the International Rice Research Institute (IRRI), the Bangladesh Rice Research Institute (BRRI), and the Bangabandhu Sheikh Mujibur Rahman Agricultural University and have been delivered throughout almost the entire country (Bashar et al., 2019). To date, much effort around zinc biofortified rice has focused on farm side production. However, as plant breeding of new varieties and delivery of currently released zinc biofortified varieties expand, the focus has shifted to understanding consumer demand and market-based approaches to reach the non-farm zinc deficient population. Production can enter the market in one of two ways –as marketable surplus or as a differentiated product grown specifically for sale to capture a price premium. This study's results will shed light on whether a price premium for biofortified rice exists which can serve as a demand-pull strategy for producers to cultivate more land under biofortified rice.

While not examined in this paper, a likely additional cost passed to the consumer, beyond the production point, is certification and/or quality checks of the zinc credence good in

[3] See Appendix A.2 for a discussion of zinc content in other commonly consumed foods in Bangladesh.

biofortified zinc rice and its differentiation throughout the value chain (Banerji et al., 2016; Gabriel and Menrad, 2017). This certification can come via a third-party company or government which would test rice for claim of biofortification (e.g., PAS 233:2021 by BSI (2021)). Further, these testing results must be communicated to final consumers through signaling like product labeling. The costs of these requirements are currently unknown but should be evaluated in light of this study's WTP findings.

2.2 Typical Processing Techniques and Nutrition Retention

Processing impacts the degree of zinc retention in rice grain. Rice is harvested as paddy which consists of a husk layer covering the caryopsis (brown rice). Typically, the husk is removed to produce brown rice. The brown rice is milled at various levels (degrees) to remove outer layers of the caryopsis and eventually the aleurone layer to produce white rice (Muthayya et al., 2014; IRRI, 2019). In Bangladesh and other regions of South Asia and West Africa, paddy rice undergoes an additional step of parboiling before being milled. Parboiling involves soaking and steaming paddy rice, at different temperatures, which can reduce the number of broken grains that occur during milling. Parboiled rice is also preferred in Bangladesh due to its longevity (less spoilage), digestibility, and reduced stickiness (Jaim and Hossain, 2012). While zinc is contained in the endosperm of the grain and, therefore, is mostly protected during milling, this is not the case if paddy rice is first parboiled (Taleon et al., 2022). During parboiling, zinc moves from the endosperm towards the kernel bran, making it more vulnerable to removal during milling (Taleon et al., 2020).

While less-milled rice is often consumed in rural areas due to its lower costs, high-milled (white) rice is the most popular rice in urban areas (Custodio et al., 2016) and even those eating less-milled rice prefer to eat white rice (GAIN, 2016). In a recent study conducted in

Bangladesh, zinc concentration was measured for parboiled rice at the low-milling level of 8% (to remove most of the pericarp and germ), and the highest milling level of 16% which produces white rice. The analysis showed that the low-milled grain had up to 77% more zinc than the highly milled grain and when combining the zinc content increase through biofortification and low-milling, biofortified low milled rice had up to 156% higher zinc content than non-biofortified high-milled rice (Taleon et al., 2022). In addition to zinc loss, other vitamin and micronutrients are also lost during a high degree of milling (Muthayya et al., 2014).

The traditional rice milling methods in Bangladesh, the *dheki* hand method or the Engelberg machine mills grain to approximately the 7.5% level. However, automatic rice mills are increasing in number throughout the country and traditional mills are disappearing as it becomes less expensive to send grain to automatic rice mills (Reardon et al., 2014). The automatic rice facilities mill upwards of 16% and double-polish the grain, which while increasing the rice grade and price premium (Khan and Murshid, 2018) produces rice with reduced nutritional content.

3. Methodology

3.1 Experimental Design and Conceptual Framework

This study's experiment is designed to assess consumers' WTP for rice grain with increased zinc content and to assess whether the WTP for this nutrition trait differs by the two approaches of increasing zinc content—low-milling processing techniques versus biofortification plus low-milling.[4] This study tests these differences with and without information on zinc nutritional benefits associated with biofortification and low-milling. Two rice varieties representing non-biofortified (NB) rice (BRRI dhan28) and biofortified (B) rice (BRRI dhan42)

[4] The 'biofortification plus low milling' approach is henceforth referred simply as 'biofortification' for brevity.

are used in this study.[5] To retain nutritional value, the biofortified rice is milled at 7.5%, which represents low-milling (LM) level. Though adding a zinc biofortified rice milled at 15% seems like a natural addition to the experiment, we did not present this grain option to consumers due to the chemical reaction that occurs during parboiling; milling at 15% removes much of the added genetic zinc content bred into the grain. The non-biofortified rice is milled at two levels – 7.5% (LM) and the more popular 15% (high-milling level, HM). Thus, the experiment includes three rice grain types, consisting of two different rice varieties and two levels of milling—non-biofortified BRRI dhan28 at high-milled level (NBHM), non-biofortified BRRI dhan28 at low-milled level (NBLM), and biofortified BRRI dhan42 at low-milled level (BLM). The experiment follows a between-subject design and consists of three groups—Treatment group 1 (TG1) that received information on zinc biofortified rice, Treatment group 2 (TG2) that received milling nutrition information, and a control group that received no information.

The WTP experiments elicit information regarding respondents' WTP for the aforementioned rice grain types. We utilize the Becker-DeGroot-Marschak (BDM) (Becker, DeGroot, and Marschak 1964) method, an incentive-compatible single response procedure used in experimental economics to measure consumer WTP. In the BDM mechanism, a respondent submits a bid for a good being auctioned, 1 kilogram of each rice grain type in this study. The respondent does not bid against others as in a traditional auction, but against a random market price drawn from a distribution established *ex-ante*. If the respondent's bid is greater than the market price drawn, then s/he pays the randomly drawn price and receives the good. Alternatively, if the respondent's bid is less than the market price, no transaction occurs.

[5] BRRI dhan28 is the most popular non-biofortified rice grain in Bangladesh for the study season so it serves as the experiment's benchmark grain. BRRI dhan42 was selected as the biofortified rice used as it most closely resembles the grain characteristics of BRRI dhan28 (Tiongco and Hossain, 2015).

The respondent's true WTP for a unit of the good being auctioned is defined as the price that induces a utility indifference between winning and not winning the good. Rational behavior under the BDM mechanism is for the respondent to place a bid equal to their WTP (Lusk and Shogren, 2007). In the case of individuals bidding on multiple goods, as in our case, one of the bids is selected at random to be the binding bid such that only one good's bid is compared against a market price for that particular good. The difference in bids between BDM experiments with and without information reveals the premium, or discount, due to the different rice grain attributes as perceived by the consumer.

The BDM elicitation method varies between either endowing respondents with a good and having them bid to upgrade that good, known as "endow and upgrade", or asking participants to offer full bids for a particular good (Lusk and Shogren, 2007). We use the full bidding method as we are interested in capturing total WTP for each product. At the start of the study, each participant received a participation fee of 500 Bangladesh taka (BDT), the equivalent of US $6.04.[6] As we included participation fees, there is a possibility of inflated WTP bids, though literature suggests mixed effects of significance (Corrigan and Rousu, 2006; Banerji et al., 2017).

Prior to the experiment, enumerators explained the BDM procedure one-on-one to respondents. To ensure understanding, a practice round was conducted with common crackers. Respondents were allowed to ask questions on the experimental procedure. Following this, if the respondent was randomly assigned to either of the treatment arms, they listened to a respective one-minute informational clip on zinc nutritional enhancement via zinc biofortified rice (TG1) or via decreased milling practices (TG2). Those not randomly assigned to TG1 or TG2, served as

[6] The exchange rate during the experiment was 82.73 BDT to 1 USD. The participation fee is approximately equal to a daily wage for the study locations plus the average price for one kilogram of rice.

the control group. To mimic market settings, in all groups, one kilogram of the three uncooked rice grains (NBHM, NBLM, and BLM) were placed in randomized order before the respondents in equal sized clear containers without labels but with different colored lids: red, orange, and green. The invisible zinc attribute cannot be detected in the BLM rice, but low-milled rice is easily identifiable by its brown color compared to high-milled rice which is white. In TG1, both the audio clip and the enumerator identified the BLM rice from the NBLM and NBHM rice. Similarly, in TG2, the audio clip and the enumerator identified the two low-milled rice grains. Consumers could touch and smell grains during the experiment.

In TG1 and TG2, after listening to the audio clip, respondents submitted bids for each rice type but told only one bid would be binding. In the control group, no audio clips/information was provided, so respondents submitted bids after completing the practice round. The randomly selected market price distribution, uniform between 28-50 BDT/rice kg, was based on local market prices. Respondents were not informed of this price range, simply that prices were based on current prices from their local market. Respondent bids were not censored. To select the binding bid, participants drew one of three colored die (red, orange, or green) from an opaque bag which corresponded to each of the three rice products' lid colors. Next, the participant drew one "coin" from another opaque bag of market prices. The enumerator compared the respondent's bid to the market price drawn and transactions were carried out according to BDM rules. After completing the experiment, respondents completed a questionnaire.

3.2 Empirical Strategy

Regression analysis is used to examine the information treatment effect on consumers' WTP total and marginal bids. Since the experiment was between subjects, we estimate the treatment effect via Pooled Ordinary Least Squares (POLS) method.[7] Further, we had no zero bids and less than 1% of bids submitted were outside of the market price range (28-50 BDT) used. Following Canavari et al. (2019), as the share of bid observations outside of the market price range is trivial, resulting estimates between using Tobit versus OLS do not diverge. Therefore, for ease of interpretation, we use OLS for analysis and do not censor bid observations. Equation 1.1 is a parsimonious specification intended to estimate only the information treatments' effect in explaining WTP bid variation (i.e., coefficient β_3). We test the robustness of the treatment effect size by incorporating control variables ($\boldsymbol{X_i}$) in equation 1.2, and the interaction of the treatment with a subset of control variables (vector $\boldsymbol{Y_i}$) in equation 1.3. Our specification for the linear panel data model used is:

$$Total\ Bid_{ij}^{t} = \alpha + \beta_1 P_j + \beta_2 T^t + \beta_3 (P_j * T^t) + u_{it} \qquad \text{for } t=1, 2 \tag{1.1}$$

$$Total\ Bid_{ij}^{t} = \alpha + \beta_1 P_j + \beta_2 T^t + \beta_3 (P_j * T^t) + \boldsymbol{\eta X_i} + u_{it} \qquad \text{for } t=1, 2 \tag{1.2}$$

$$Total\ Bid_{ij}^{t} = \alpha + \beta_1 P_j + \beta_2 T^t + \beta_3 (P_j * T^t) + \boldsymbol{\eta X_i} + \boldsymbol{\gamma}(T^t * \boldsymbol{Y_i}) + u_{it} \quad \text{for } t=1, 2 \tag{1.3}$$

where Bid_{ij}^{t} is the WTP bid for consumer *i* for the rice product *j* under information treatment *t*. Each of these three equations are estimated separately for the two information treatments—t=1 represents information on zinc biofortified rice and t=2 represents information on low-milling. Variable T^t delineates individuals randomly assigned to treatment group *t* (=1, =2) and the control group (=0). P_j is an indicator of nutritionally enhanced rice product. In the case of the zinc biofortification treatment (t=1), we compare BLM (*Pj*=1) to the NBLM (*Pj*=0). For the information on low-milling (t=2), we compare NBLM (*Pj*=0) to the NBHM (*Pj*=2). The $\boldsymbol{X_i}$ represents a vector of respondent characteristics and experiment controls. $T^t\ \boldsymbol{x}\ \boldsymbol{Y_i}$, is a vector of

[7] As robustness checks, random effects and panel Tobit analysis were conducted and results hold.

interaction terms between the treatment variable and selected respondent characteristics based on *a priori* hypotheses and previous literature (De Groot et al., 2011; Diagne et al., 2017; Zossou et al., 2022; Chowdury et al., 2016; Valera et al., 2019). Finally, u_{it} is the idiosyncratic error term. Robust standard errors were clustered at the participant level for equations 1.1-1.3.

Next, we use regression analysis to examine WTP premiums/discounts by comparing (1) BLM versus NBLM rice (under treatment, t=1), and (2) NBLM versus NBHM rice (under t=2). The value of Equation 2, below, lies in identifying additional determinants of premiums/discounts of BLM and NBLM, beyond the information treatment itself, which can be used for nutritional awareness campaign targeting to maximize finite resources (time, money, etc.). Our OLS estimator for WTP premium/discount can be represented as:

$$MargBid_i^t = \alpha + \beta T^t + u_{it} \qquad \text{for } t\text{=1, 2} \qquad (2.1)$$

$$MargBid_i^t = \alpha + \beta T^t + \boldsymbol{\eta X_i} + u_{it} \qquad \text{for } t\text{=1, 2} \qquad (2.2)$$

$$MargBid_i^t = \alpha + \beta T^t + \boldsymbol{\eta X_i} + \boldsymbol{\gamma}(T^t * \boldsymbol{Y_i}) + u_{it} \qquad \text{for } t\text{=1, 2} \qquad (2.3)$$

where $MargBid_i$ is estimated as individual i's difference in WTP bids for a nutritionally enhanced product (either BLM rice in case of t=1 or NBLM rice in case of t=2) against its counterfactual (i.e., NBLM rice in case of t=1 or NBHM rice in case of t=2). If the resulting coefficient is positive, it represents a positive marginal WTP or premium for BLM compared to NBLM rice. If the resulting estimates coefficient is negative, it represents a negative marginal WTP or discount for BLM compared to NBLM rice. The same holds for NBHM versus NBLM rice. Like in equations 1.1-1.3, the $\boldsymbol{X_i}$ represents a vector of respondent characteristics and experiment controls and $T^t \boldsymbol{x} \boldsymbol{Y_i}$, is a vector of interaction terms between the treatment variable and select respondent characteristics. Finally, u_{it} is the idiosyncratic error term. In these models, coefficient β measures the effect of the information treatment on consumers' WTP premium (or discount) for the nutritionally enhanced trait (either zinc biofortification or low milled rice). Robust standard errors were clustered at the block level for equations 2.1-2.3.

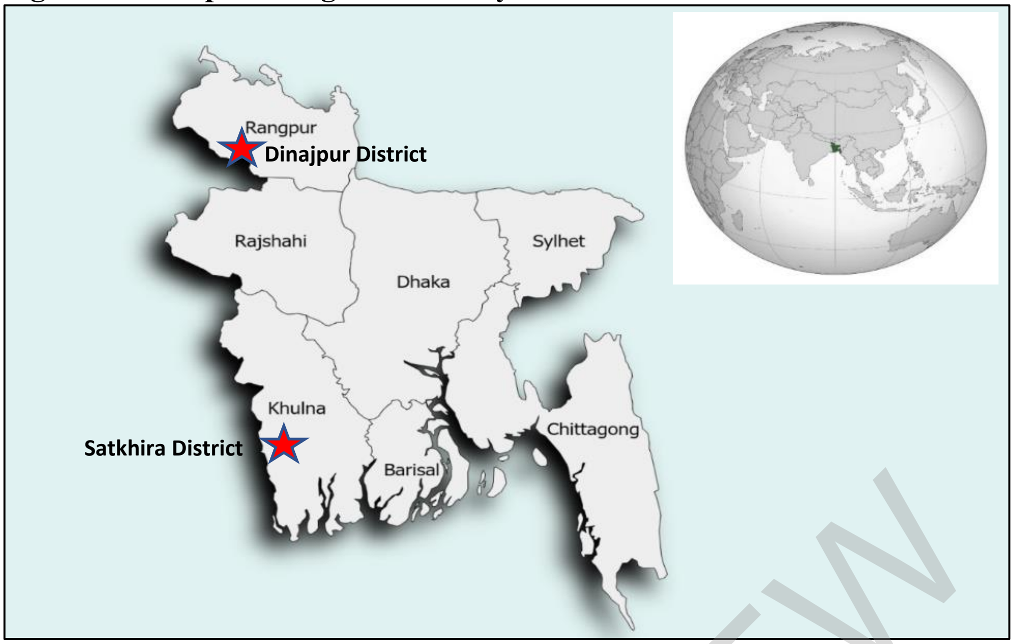
3.3 Data

Data was collected through collaboration with the CGIAR's HarvestPlus Program and BRRI. Ethical clearance was obtained prior to commencing field work.[8] Dinajpur and Satkhira districts were specifically selected as study locations representing a surplus rice producing region with many automatic rice mills and a net rice purchaser with few automatic rice mills, respectively. A total of 576 rice consumers, split evenly between Dinajpur district in the north and Satkhira district in the south, participated in the study.[9] Study participants represent rural households that purchase rice from the market. For a detailed description of sample selection process, see Appendix A.3.

[8] This study complies with Institutional Review Board (IRB) guidelines of the International Food Policy Research Institute (IFPRI) and the Memorandum of Understanding with the IFPRI Agriculture Policy Support Unit in Dhaka which allows the Ministry of Agriculture to approve research for local clearance; additional Bangladesh IRB approval was not required. This study's approval:IFRI IRB #00007490; BRRI Agreement #2018H8348.BRR.

[9] Within Dinajpur, data collection occurred in Parbatipur, Birganj, and Sadar upazilas and in Satkhira, Kaliganj, Kolaroa, and Satkhira Sadar upazilas.

Figure 1.1: Map of Bangladesh Study Locations



*Sources: mapsland.com, paintmaps.com

The study targeted the main household decision-maker for rice purchases. In our sample, respondents are 93% male and, on average, 42 years old (Table 1.1). Approximately half of the respondents' main income source is farming, and on average, they have five years of formal education. On average, the per-capita household consumption of rice is 150 kg per year. Respondents vary in the frequency of rice market purchases – 12% purchase rice on a daily basis while 34% of respondents purchase on a monthly basis, or less frequently. Additional sample statistics are in Table 1.1.

Table 1.1: Sample characteristics and balancing test

Variable	Sample Mean (Std Deviation) Control (N=192)	Treatment 1 (Biofortification) (N=192)	Treatment 2 (Low-milling) (N=192)	P-value of Group Mean Comparison
Male (%)	94.8 (22.3)	92.7 (26.1)	92.7 (26.1)	0.638
Household Head (%)	84.9 (35.9)	86.5 (34.3)	84.9 (35.9)	0.883
Age	41.2 (12.7)	41.9 (13.3)	41.4 (13.3)	0.853
Years of formal education	5.1 (4.8)	5.1 (4.7)	5.3 (4.8)	0.870
Main occupation: farming[1] (%)	52.6 (50)	51.6 (50.1)	52.6 (50)	0.973
Household size	4.8 (1.6)	4.7 (1.7)	4.8 (1.6)	0.934
No. of children under 5 y.o. in HH	0.4 (0.6)	0.4 (0.6)	0.4 (0.6)	0.585
No. of WOCBA[2] in HH	1.5 (0.8)	1.4 (0.7)	1.5 (0.8)	0.515
HH's per-capita yearly rice consumption (in 10kg)	15 (3.9)	15.3 (4.1)	15.2 (3.6)	0.747
HH purchases rice more than 1/week (%)	29.2 (45.6)	33.3 (47.3)	31.8 (46.7)	0.6750
HH purchases rice 1/week or 2/month (%)	37.5 (48.5)	30.7 (46.3)	35.4 (48.0)	0.3615
HH purchases rice 1/month or less often (%)	33.3 (47.3)	35.9 (48.1)	32.8 (47.1)	0.788
HH's per-capita monthly income (in BDT)	2120.7 (1642.1)	2053.9 (1484.5)	2070.1 (1590.8)	0.910
Zinc biofortified rice awareness (%)	8.3 (27.7)	9.9 (29.9)	13 (33.7)	0.311

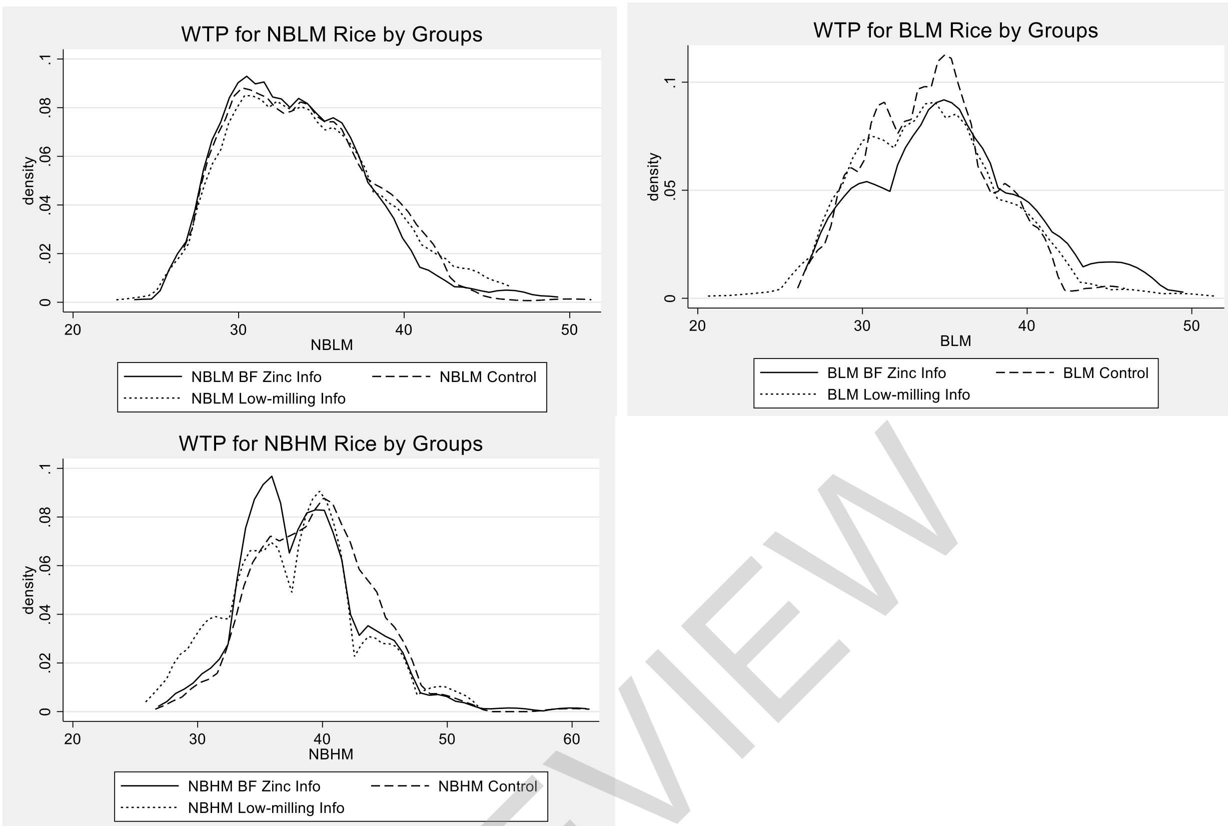
Source: author's data.
Note 1: Category includes self-employed farmers and farm laborers on another's farm.
Note 2: WOCBA: females ages 15–49, as defined by the WHO.

4. Results and Discussion

4.1 WTP for Nutritional Traits

The distribution of WTP bids by control and treatment groups is presented in Figure 1.2.

Figure 1.2: Kernel density for (1) NBLM Rice WTP, (2) BLM Rice WTP, and (3) NBHM Rice WTP



The mean bids for the three products suggest a strong preference for NBHM, which is currently the most preferred type of rice grain consumed. Under all three scenarios, consumers' WTP for 1 kg of NBHM is about 4–5 BDT more than the other two nutritionally enhanced rice grains (Table 1.2). In comparing WTP bids, we find consumers place a 14% premium ($p<0.01$) on NBHM rice compared to NBLM rice and a 13% premium ($p<0.01$) on NBHM rice when compared to BLM rice when no information is shared about milling's impact on nutrition. Further, when information is shared about the negative effect of milling on nutrition, the premium for the preferred NBHM grain declines to 9.9% (p-value<0.01) compared to the NBLM grain (translating to a treatment effect size for milling information of 4.1%) and to 9.4% ($p<0.01$) compared to BLM grain (translating to a treatment effect size for milling information of 3.8%).

Results also show that without information on the zinc biofortified variety, there is a small difference ($p<0.10$) in consumers' WTP bid for the two low-milled rice—BLM and the NBLM such that a 1.1% premium exists for BLM rice. However, when information is shared on increasing zinc intake via zinc biofortified rice, consumers were willing to pay a 5.8% price premium for BLM rice over NBLM rice (p-value<0.01). Information on zinc biofortified rice increased WTP for BLM rice by 4.6% over NBLM. After sharing the information on zinc biofortified rice, consumers still discounted BLM rice relative to NBHM rice, but the discount reduced from 13.2% in the control group to 7.8% in TG1 (Table 1.2).

Table 1.2: Willingness to Pay (WTP) for rice types (BDT/1kg) and traits

	Rice type	Statistic	Control Group* (N=192)	Treatment 1: Zinc Biofortified Information (N=192)	Treatment 2: Milling Nutrition Information (N=192)
Mean WTP	Non-biofortified,	Mean	$33.8^{a, \lambda}$	$33.5^{b, j}$	34.1^{c}
	low-milled variety (a)	SD	(4.1)	(4.2)	(4.4)
	Biofortified,	Mean	$34.2^{h, g, \lambda}$	$35.5^{b, d, f, h}$	$34.2^{d, e}$
	low-milled variety (b)	SD	(3.7)	(4.7)	(4.4)
	Non-biofortified,	Mean	$39.4^{a, g, i, \gamma}$	$38.5^{f, j, \gamma}$	$37.8^{c, e, i}$
	high-milled variety (c)	SD	(4.6)	(4.8)	(5.2)
WTP for traits	Nutrition (Zinc) via	BDT/1kg	0.4	1.9	
	biofortified genetic trait	SD	(2.9)	(4.1)	
	(b-a)	%	+1.1	+5.8	
	Nutrition (Zinc) via	BDT/1kg	-5.1	-3.0	
	biofortified genetic trait	SD	(3.0)	(4.8)	
	(b-c)	%	-13.2	-7.8	
	Nutrition via decreased	BDT/1kg	-5.5		-3.7
	milling (a-c)	SD	(3.1)		(4.8)
		%	-14.0		-9.9
	Nutrition via decreased	BDT/1kg	-5.1		-3.6
	milling (b-c)	SD	(3.0)		(4.3)
		%	-13.2		-9.4

Notes: (1) rice types in the control group were unknown (unlabeled) to respondents at bidding time. Zinc is an invisible seed trait so unless told, respondents could not differentiate the zinc biofortified variety, (2) numbers with matching English letters (a-j) denotes raw WTP bid differences significant at $p<0.01$, (3) numbers with matching Greek letters (λ, γ) denotes raw WTP bid differences significant at $p<0.10$, (4) SD=standard deviation.

Next, we examine the effect of the information treatment on consumers' WTP for the two nutritionally enhanced rice products. For biofortification information, we obtain the effect by keeping milling level constant and compare bids for control and TG1 groups for BLM and NBLM rice. We obtain the milling information effect by keeping the genetics constant and compare bids for the control and TG2 groups for NBLM and NBHM rice. Results for zinc biofortified low-milled rice are presented in Table 1.3 and for non-biofortified low-milled rice in Table 1.4. We find Bangladeshi consumers are WTP a significant premium for BLM rice after exposure to zinc biofortified rice information (TG1) when compared to NBLM rice. Analysis results match findings from mean WTP bids (Table 1.2) and show respondents are WTP a premium of 1.55 BDT for BLM rice compared to NBLM rice after receiving zinc biofortified rice information (represented by variable: received zinc biofortified info x BLM rice product), (Table 1.3). This estimated treatment effect is robust after controlling for consumer and experiment characteristics and interaction effects (columns 2 and 3, Table 1.3).

Further evaluating cross-effects of receiving zinc biofortified rice information and additional covariates, in column 3, we find positive WTP for each additional year of formal education attained by the respondent. This result outweighs the negative and significant impact on consumer WTP of respondents' formal education when no information is received (column 3).

Aside from information exposure cross-effects, respondents' bid increases with per-capita household monthly income and with each additional child in the household that is under five while bids decrease as respondents age (but only in column 3). Consistent with Hoffman (1993), those participating in morning sessions had a lower WTP for NBLM rice than those in afternoon sessions though counter to other studies findings (Demont and Ndour, 2015; Diagne et al., 2017).

Potentially, individuals do not feel rushed about their rice purchase in the morning knowing that if they do not "win" during the experiment, they still have time to purchase rice from the market while this may not be the case for afternoon session participants.

Turning now to the same models for NBLM versus NBHM rice (Table 1.4), we find that after receiving the information on low-milling nutritional benefits, Bangladeshi consumers' WTP for low-milled rice increased by BDT 1.78/kg. This estimated effect of the information treatment is statistically significant and robust across model specifications (Table 1.4).

Statistical differences in mean WTP bids between NBLM and NBHM rice without information, and mean WTP bids between NBHM rice with and without information, support findings in Table 1.2. Further evaluating cross-effects of receiving low-milling nutrition information and additional covariates, in column 3, we find negative WTP for NBHM rice as the respondent's household monthly per-capita income increases, which is counter to the effect of income when the respondent did not receive information. Aside from information exposure cross-effects, respondents' bid for NBHM rice decreases if they participated in the morning session.