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Assessing Consumer Willingness to Pay for Zinc-Biofortified Rice – the Case of Colombia

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Assessing Consumer Willingness to Pay for Zinc-Biofortified Rice – the Case of Colombia

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Abstract

Hidden hunger, a form of undernourishment caused by micronutrient deficiencies, remains a critical global challenge affecting billions worldwide. Biofortification of staple crops, such as rice, offers a promising solution to address this problem. However, changes in the physical and culinary characteristics due to biofortification may hinder consumer acceptance and limit the benefits of this approach. This research explores consumer preferences and willingness to pay (WTP) for zinc-biofortified rice in Cartagena, Colombia. A non-hypothetical experimental auction, including 400 consumers in five different locations within Cartagena, was conducted to analyze the impact of information, socioeconomic factors, and consumer nutrition knowledge on WTP for zinc-biofortified rice. The results indicate that zinc-biofortified rice is priced as a premium-quality rice relative to other rice market alternatives, highlighting that the high zinc content did not affect the sensory characteristics of the rice. The information treatment about either the “Benefits of zinc-biofortified rice” or the “Problems of zinc deficiency” had a positive impact on the WTP for zinc-biofortified rice, which was reinforced by participants' nutrition knowledge. These findings provide valuable insights for policymakers and stakeholders aiming to address malnutrition effectively, as well as retail companies hoping to market biofortified staple crops to vulnerable populations.

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1 Introduction

Hidden hunger, or the deficiency of essential micronutrients, is a critical global problem affecting more than 2 billion people worldwide (FAO 2013). One of the micronutrients of concern is zinc, with approximately 17% of the world's population at risk for zinc deficiency due to dietary insufficiency (King et al. 2016). Pregnant women and children are the most vulnerable groups, particularly in developing countries (Berhe et al. 2019; Maqbool and Beshir 2019). Zinc deficiency can have a negative effect on growth and development, weakened immune response, increased risk of infections such as diarrhea and pneumonia, and increased occurrence of stunting (Bhowmik, Chiranjib, and Kumar 2010; Black et al. 2008; Brown et al. 2009; Gupta, Brazier, and Lowe 2020). In children, zinc deficiency can have long-term effects on their cognitive and physical development, thus affecting their quality of life as adults (Black 1998; Wieser et al. 2013).

In Colombia, micronutrient deficiencies, including iron, vitamin A, and zinc, are a significant concern, with alarming rates among pregnant women and children in rural populations. Approximately 25% of Colombia's population has inadequate zinc intake (Cediel et al. 2015). Zinc deficiency is more prevalent in the Atlantic region, which includes the city of Cartagena, with 41% of children aged 1 to 4 years being affected (Woods et al. 2020).

Several strategies currently exist to combat hidden hunger, including distributing dietary supplements, promoting dietary diversification, and food fortification (Kennedy, Nantel, and Shetty 2003). While each of these has successfully limited micronutrient malnutrition (Dary and Hurrell 2006), they each have their limitations, primarily when it comes to reaching low-income segments of the population living in remote areas. For instance, dietary supplements are considered a viable alternative in areas with market access but challenging to implement in remote regions (Ofori et al. 2022). Dietary diversification is a very effective way of preventing micronutrient deficiency, but it is difficult to pursue when there is limited knowledge about the nutritional value of food and when there are income limitations (Agedew, Abebe, and Ayelign 2022). Finally, the higher market prices and accessibility of fortified food hinder its potential to combat micronutrient deficiency in developing countries (Ofori et al. 2022).

The World Health Organization (WHO) defines fortification as the practice of deliberately increasing the content of one or more micronutrients (e.g., vitamins and minerals) in a food or condiment to improve the nutritional quality of the food supply and provide a public health benefit with minimal health risk (n.d.). Food fortification can be achieved in different ways, such as (1) adding fortificants during processing (also known as industrial fortification), (2) adding fortificants during meal preparation (also known as home fortification), and (3) improving the nutritional content of crops through breeding (biofortification). Biofortification is a process of increasing the bioavailability of micronutrient concentrations (e.g., vitamins and minerals) in a crop through agronomic practices or genetic selection (plant breeding and transgenic techniques) (Nestel et al. 2006). Biofortification has emerged as a promising, cost-effective, and sustainable solution for supplying micronutrient-rich staple crops to vulnerable populations (Hodge 2014; Birol et al. 2015; Bouis and Saltzman 2017).

In partnership with the Consultative Group on International Agricultural Research (CGIAR), the International Rice Research Institute (IRRI), and others, Harvest Plus has been in the process of researching, developing, and disseminating biofortified crops for over 20 years. Rice is conceived as an excellent vehicle for biofortification because of its importance as a staple for more than half of the world's population. While brown rice contains an average of 0.71 mg of zinc per 100 grams of cooked rice, most of it is in the bran layer and, therefore, lost (during milling) in the production of milled rice, the main form in which rice is consumed (Hotz and McClafferty

2007; HarvestPlus n.d.). Zinc-biofortified rice provides an option to increase the concentration of this micronutrient in milled rice by up to fifty percent of the estimated average daily requirement (Woods et al. 2020).

However, developing effective biofortified crops with high acceptability among consumers is a challenge, as changes in nutritional value may also imply changes in physical and culinary characteristics. An example of this is golden rice, a biofortified rice variety containing a higher concentration of beta-carotene, a precursor of vitamin A, which confers rice a yellowish color. The evaluation of rice quality can be determined by considering certain characteristics or attributes, categorized as physical (e.g. color, size and shape, uniformity, broken and chalk rates) or culinary (e.g., texture, aroma, stickiness). The perception of these characteristics can also depend on geographic location (Custodio et al. 2019). For example, Rai et al. (2019) found that most respondents in Nepal could not differentiate fortified rice from non-fortified rice, and the sensory qualities of fortified rice were acceptable, with a score of 3.9 out of 5. The study found that the acceptance of fortified rice was high in remote at-risk populations where rice is a daily staple food. Meerza et al. (2023) conducted an experimental auction in Bangladesh and found that information about the health benefits of zinc-biofortified rice significantly increases consumers' willingness to pay (WTP) for zinc-biofortified rice and has a negative impact on the WTP for the non-biofortified rice. Lastly, a sensory analysis in Colombia and Bolivia found that consumers in both countries perceive zinc-biofortified rice as equal in quality to the alternative rice varieties (Woods et al. 2020).

While rice biofortification has the potential to address micronutrient deficiencies, there is a need for further research and investment to develop effective and sustainable biofortification programs (Hotz and McClafferty 2007). Assessing consumers' perceptions and, ultimately, their

WTP for new products is crucial for the success of any enterprise, including the adoption of biofortified rice. It is expected that the commercialization of zinc-biofortified rice will entail extra costs, such as those associated with identity preservation or price incentives for farmers to speed up adoption, and therefore, it is important to assess whether consumers can bear part of the cost or whether public policies will be needed to make zinc-biofortified rice sustainable.

The main objective of this study is to determine consumers' WTP for zinc-biofortified rice in Cartagena, Colombia, through a non-hypothetical experimental auction. The driving research question is whether consumers will be willing to pay a premium for zinc-biofortified rice, given that it provides more nutritional value than conventional rice. The research design includes two rice product alternatives bought from the local markets that are representative of standard-quality and premium-quality rice varieties, as well as a zinc-biofortified rice variety developed and produced in Colombia. The design also includes an information treatment about either the "Benefits of zinc-biofortified rice" or the "Problems of zinc deficiency." The main hypotheses this study addresses are:

Hypothesis 1. With no information about the rice products auctioned and based solely on consumers' assessment of the raw and cooked rice samples, there should be no significant difference in the WTP for zinc-biofortified and premium-quality rice, and a lower WTP for standard-quality rice, driven only by their perceived quality.

Hypothesis 2. When consumers can identify via labels the different rice products, we hypothesize that there will still be no significant difference in the WTP for zinc-biofortified and premium-quality rice, and a lower WTP for standard-quality rice.

Hypothesis 3. When consumers receive information about the benefits of biofortified rice, or the problems caused by zinc deficiency, the WTP for zinc-biofortified rice should increase relative to the two rice alternatives, therefore pricing the zinc-biofortified rice variety at a premium.

Hypothesis 4. Finally, we hypothesize that, everything else equal, consumers with more knowledge about nutrition will have a higher WTP for zinc-biofortified rice after seeing the labels and receiving the information treatment.

As explained in the methodology section, we designed the experiment to be able to answer each of the hypotheses accordingly.

2 Material & Methods

2.1 Study Areas, Participants, and Recruitment

The study was conducted in Cartagena, a port city situated in Colombia's Caribbean coast with a predominantly urban population of more than one million inhabitants and a tropical savanna climate. According to the National Administrative Department of Statistics (DANE), the 2022 rates of poverty and extreme poverty were 36.6% and 13.8% for Colombia and 43.6% and 12.7% for Cartagena, respectively.

Our local partners were the Public National Training Service (SENA) and the Del Dique Foundation, both of which have experience and strong linkages throughout the community, particularly among low-income segments. With the objective of building a sample that is representative of the population in terms of socioeconomic status, we selected five different locations within Cartagena for this study: the Ternera Campus of SENA, the main campus of the University of San Buenaventura, and three community centers in the neighborhoods of Olaya, La Candelaria, and Los Alpes. SENA was chosen as the location to implement this study due to its suitability for recruiting subjects from low to middle socioeconomic status with a minimum of primary education and practical facilities. The other locations were selected following the recommendations from community leaders.

The study's target population was adults with purchasing power within their household with the socioeconomic strata distribution matching the makeup of the Cartagena population. We followed a convenience sampling approach guided by our local partners and included SENA students and employees, and participants from the neighborhoods of Olaya, La Candelaria, and Los Alpes. Most SENA students are adults from low-income households seeking training or a technical degree. Moreover, SENA employs many adults from our target population, which were also invited to participate. Community leaders from the neighborhoods of Olaya, La Candelaria, and Los Alpes recruited people randomly from their communities and invited them to participate.

A total of 40 non-hypothetical experimental auctions were conducted in May of 2023. Each experimental auction consisted of an average of 10 participants for a total of 400 participants. Each session lasted between 45 and 60 minutes. Each participant gave written consent at the beginning of each auction. Participants received 20,000 COP (approximately $5.00) as compensation for their participation.

The research team in each experimental auction section consisted of at least 17 people: a kitchen leader in charge of applying the cooking protocol (the same person oversaw all the sections), a rotating team of three kitchen assistants in charge of preparing and serving the cooked rice samples, three moderators in charge of running the experimental auctions, and ten enumerators in charge of applying the socioeconomic questionnaire. The team consisted of students from SENA's gastronomy and business programs, as well as researchers from the International Center for Tropical Agriculture (CIAT) and the University of Arkansas.

2.2 Products and Standardized Cooking Procedure

The experiment included three different milled rice products: (1) zinc-biofortified rice, (2) a standard-quality alternative, and (3) a premium-quality alternative. The reason for having two alternatives is twofold: first, to be able to assess zinc-biofortified rice relative to standard-quality rice, which we assumed is the most popular quality consumed by low-income households, and second, to assess if zinc-biofortified rice could also compete in the high-quality market segment. Also, since we could not perfectly control for all other quality attributes (e.g., broken and chalk percentage, amylose content, etc.), having two alternative rice products allows us to infer and disaggregate the impact of rice quality and biofortification.

The zinc-biofortified rice was produced by farmers in the northern region of Colombia under contract with CIAT and custom-milled by a local mill. The two rice alternatives were purchased in the market to simulate as closely as possible the qualities available to consumers. While sellers are not required to state the quality of the rice on the label, there is a precise market segmentation between premium quality and other lower rice qualities. Most premium rice labels highlight that they contain less than 10 percent broken rice. A recent study by Phillips et al. (2024) finds that Colombian consumers discount broken rice in a non-linear way, and find an inflection point in WTP at a 10% broken rate.

Milled rice in Colombia is classified into five grades (grade 1 has the highest quality and grade 5 has the lowest quality) based on broken rice, chalky rice, damaged rice kernels, red rice kernels, and other foreign materials (ICONTEC 2007). We conducted a quality analysis of the three rice products at the Rice Quality Lab of CIAT and found that based on broken and chalky rice, the zinc-biofortified and the premium-quality alternative both qualify as grade 1 (highest quality), and the standard-quality alternative qualifies as grade 3.

All rice varieties were prepared, cooked, and served in the same manner. For each trial session, 1 kg of each rice variety was added to 2 L of water and 20 g of salt, boiled at a temperature of 90–95˚C for 25 min, and cooked for 20 min (a total time of 45 min). Three separate rice cookers were used to standardize the preparation of each sample and avoid any cross-contamination. The rice was cooked fresh for each experimental auction (Figure A.1).

All rice samples were measured out in 30 g portions using predetermined plastic measuring spoons of 1/8 oz into paper cups and placed on a serving tray. One of each of the three varieties to be sampled was then organized in random order with pre-assigned letter labels (A, B, C) before being served to the participant. Samples were served at a temperature of around 40–50˚C. In addition, participants were provided with a 4 oz cup of water to rinse their palate before and between tasting different samples.

In addition to the cooked rice, participants received raw (uncooked) bagged samples of the three rice products to help them with the assessment.

2.3 Willingness to Pay Elicitation Method

We used a non-hypothetical experimental auction (EA) to elicit consumers' WTP for the three rice products. Auctions are defined as a market institution for determining prices and assigning goods. Auctions have a set of rules that determine, according to the bids presented by the participating bidders, who the winner of the auctioned good is and the price to be paid (McAfee and McMillan 1987). EAs attempt to simulate a real market situation in which the consumer makes the decision to buy and makes the purchase, thus offering participants real products and allowing for the exchange of real money. In this way, the participant may incur actual costs if a bid deviates from true WTP, which incentivizes the participant to reveal their true WTP (Lusk and Hudson 2004). Hence, EAs provide more accurate WTP values than hypothetical elicitation methods.

A random n^{th} price auction was used as an elicitation method to determine the WTP for the three milled rice products. In the random n^{th} price auction, even off-margin bidders are motivated to bid their true value because it is likely that their bid is close to the market clearing price (Canavari et al. 2019). The disadvantage of this method is that it can logistically have a higher cost since the number of units sold in each auction increases proportionally with *n*, and one cannot predict how many units of the good will be needed or sold in the auction.

Each EA section consisted of the following steps:

Introduction and Training Session

1. Participants received an oral explanation of the goal of the research and the method used, including details about the random n^{th} price auction mechanism. They were informed they would be compensated for their time at the end of the experimental auction. A cheap-talk script was read to control the potential effect of the compensation fee on participants' WTP.
2. To facilitate the learning process, three different candy bars were auctioned, following the same procedure used for the rice auctions. The random n^{th} price auction mechanism was used to find the winner of the auction (Figure A.2). Participants were encouraged to ask questions during the training session to clarify any doubts. The winners kept the candy that had been chosen as the binding product, while losers had to return the three candy bars.

EA Round 1: No Information

3. Participants were presented with three bags of unlabeled raw rice, three bowls of unlabeled cooked rice (products were only identified as A, B, or C), and a glass of water (Figure A.3). Participants were requested to examine the three rice products, both raw and cooked, which entailed trying the rice to ascertain the quality (e.g., taste, aroma, texture, appearance). Following standard sensory procedures, participants were asked to drink water between samples. Once all participants finished inspecting each product, they indicated their WTP for each product (COP per 500g) by recording their bids on a bidding card. The research team collected the bidding cards prior to starting Round 2.

EA Round 2: No Information, Label Provided

4. The rice products were identified with a label (standard, premium, or zinc-biofortified) (Figure A.3). Participants were given some time to assess the rice products again, if needed, and then requested to state their WTP for each product (COP per 500g) by recording their bids on a bidding card. The research team collected the bidding cards prior to starting Round 3.

EA Round 3: Information and Label Provided

5. The labels remained on the table to be referenced in Round 3. Participants were told orally, in Spanish, an information treatment. Half of the EA sections received an information script about the "Benefits of zinc-biofortified rice", and the other half about the "Problems of zinc deficiency." A translated version of both information scripts is provided below.

   Benefits of zinc-biofortified rice

   Rice is a high-calorie food and a good source of energy. However, its protein, fat, and fiber content are relatively low, and it contains low amounts of vitamins and minerals. Due to the high consumption of white rice, it is necessary to increase the content of essential minerals such as zinc in this food. Rice (A, B, or C depending on the randomization of the auction) is a biofortified rice with zinc that would help reduce the high rates of zinc deficiency in the population compared to standard rice. For example, in an adult woman this would contribute 24% of the daily zinc requirements, while standard rice contributes 16%, that is, a 50% increase in zinc intake. Zinc is an essential mineral for the proper functioning of the body at different stages of life, such as pregnancy, lactation, early childhood, school age and adolescence. It is very *important to strengthen the immune system and help muscle growth and development. In the child population, it has positive long-term effects on physical, neurological, and behavioral development. Biofortified rice with zinc is a product that has not been genetically modified.*

Problems of zinc deficiency

Rice is a high-calorie food and a good source of energy. However, its protein, fat, and fiber content are relatively low, and it contains low amounts of vitamins and minerals. Rice (A, B, or C depending on the randomization of the auction) is a biofortified rice with more zinc content than standard rice. Zinc is an essential mineral for the proper functioning of the body at different stages of life, and its deficiency can have very serious consequences in periods of life that require a greater nutritional intake, such as pregnancy, lactation, early childhood, school age, and adolescence. Zinc deficiency is associated with a weak immune system, more frequent infections, and delays in growth and development in children. Children who suffer from zinc deficiency can have long-term negative effects on their physical, neurological, and behavioral development. In Colombia, the situation regarding zinc is worrying. Recent surveys indicate a high prevalence of zinc deficiency, especially in children under 4 years of age, where it occurs in 1 in 3 children. This is particularly evident in low-income rural populations. The Atlantic region is the most affected by this nutritional problem in the country; it is where the highest prevalence of zinc deficiency occurs in the child population at 41%. Biofortified rice with zinc is a product that has not been genetically modified.

6. After receiving the new information, participants were once again allowed to inspect each product. Then, they indicated their WTP for each product (COP per 500g) by recording their bids on a bidding card. The bidding cards were collected by the research team.

Determination of Auction Winners

7. The research team, with the assistance of participants, selected the winning round, product, and n^{th} price. Participants who offered the n^{th} price or above for the binding rice product and round won the auction, were required to pay the n^{th} price, and received ½ kilo of the winning product. Every participant received 20,000 COP for their participation. Participants were thanked for their participation and dismissed.

2.4 Participant Questionnaires (Surveys)

After the third EA round, a survey was conducted that included the following categories: a sociodemographic questionnaire, Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access, Household Food Insecurity Access Scale (HFIAS) Generic Questions, and a Consumer Nutrition Knowledge Questionnaire. The sociodemographic questionnaire asked participants about their gender, age, education, household income, social class, and rice consumption habits. HDDS and HFIAS were developed by the Academy for Educational Development as part of the FANTA project. Household food access, defined as the ability to acquire enough food that meets the nutritional needs of all household members in terms of quality and quantity during a specific period, was measured through the HDDS questionnaire (Swindale and Bilinsky 2006). HDDS has been well received and utilized in numerous papers, including a research paper by Mekonnen et al. (2020), which found that HDDS is a robust predictor of a household's mean probability of nutrient adequacy in Ethiopia. Additionally, the HFIAS questionnaire consists of nine questions that have proven effective in distinguishing between food-insecure and food-secure households across various cultural contexts (Coates, Swindale, and Bilinsky 2007; Gebreyesus et al. 2015; Salarkia et al. 2011; Knueppel, Demment, and Kaiser 2010). Both HDDS and HFIAS serve critical roles in assessing household food access and insecurity, offering insights into prevalence rates and changes over time. The Consumer Nutrition Knowledge questions were modified from the original Melesse and van den Berg paper (2021) to fit the Cartagena population better.

The survey was written and designed in Spanish. The survey was recorded using tablets, and one enumerator was assigned to each participant to help if needed. The enumerator read each question to the participant to ensure a full understanding of each question. An English translation of each questionnaire can be found in Appendix B.

2.5 Statistical Methods

An ordinary least-squares model (OLS) with clustered standard errors by individual was used for the analysis. Each of the 400 participants provided a total of nine prices, one for each of the three rice products in each of the three EA rounds, resulting in 3,600 price observations. The clustering method used was proposed by MacKinnon and White (1985) and allowed us to estimate heteroskedasticity-robust standard errors with the HC1 correction while accounting for clustering. It involves a small-sample correction by adjusting the degrees of freedom based on the number of regressors in the model. This adjustment helps improve the accuracy of the estimator, especially when the sample size is relatively small. All analyses were performed using R Statistical Software (v4.2.2; R Core Team 2022).

We studied consumer WTP for zinc-biofortified rice compared to standard and premium alternatives following the introduction of labels and information using the following generic specification:

$$WTP_i = \beta_0 + \beta_1 Premium_i + \beta_2 Standard_i + \beta_3 Round2_i + \beta_4 Round3_i + \beta_5 Premium_i * Round2_i + \beta_6 Premium_i * Round3_i + \beta_7 Standard_i * Round2_i + \beta_8 Standard_i * Round3_i + X_i\theta + \varepsilon_i \quad (1)$$

Where $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7, \beta_8$, and θ are parameters to be estimated, and ε_i is the error term. Tables 1 and 2 define the variables of interest, including the vector of sociodemographic variables X_i.

From equation (1) we defined the following three models to assess all the relevant hypotheses posed in the introduction:

- Model 1: set the vector of sociodemographic variables X_i equal to zero in equation (1),
- Model 2: identical to equation (1),
- Model 3: equation (1) plus an interaction term between rice variety, consumer nutrition knowledge, and round.

Table 1. Definition of the dependent and independent variables associated with the three rice products and the experimental auction rounds.

Variable	Description
Willingness to pay	
WTP_i	the price of the rice the consumer is WTP in experimental auction, measured in a monetary value (COP/500g) for the i[th] participant
Rice Variety	
$Premium_i$	dummy variable; 1 if the rice is the premium alternative; 0 otherwise
$Standard_i$	dummy variable; 1 if the rice is the standard alternative; 0 otherwise
Round	
$Round2_i$	dummy variable; 1 if the WTP price is from Round 2; 0 otherwise
$Round3_i$	dummy variable; 1 if the WTP price is from Round 3; 0 otherwise

Table 2. Set of sociodemographic variables included in vector X_i.

Variable	Description	Mean (St. Dev.)
Demographic Features		
Female	dummy variable; 1 if female; 0 otherwise	0.7625 (0.426)
Age	dummy variable; 1 if above 40 years old; 0 if below 40 years old	0.4375 (0.496)
Household Size	continuous variable; total number of family members in household	4.07 (1.706)
No. of Children	continuous variable; number of children (below 10 years of age) currently living in the household	0.55 (0.498)
Education Level		
High Education	dummy variable; 1 if the participant has completed a technical education or higher; 0 otherwise	0.6225 (0.485)
Income Level		
Middle Income	dummy variable; 1 if the participant has an income between 1,400,001 COP and 2,800,000 COP; 0 otherwise	0.1825 (0.386)
High Income	dummy variable; 1 if the participant has an income more than 2,800,001 COP; 0 otherwise	0.19 (0.392)
Prefer not to respond	dummy variable; 1 if the participant did not respond to income; 0 otherwise	0.1325 (0.339)
Social Class		
Low Social Class	dummy variable; 1 if the participant has a low social class (levels one and two); 0 otherwise	0.79 (0.407)
Dietary Questionnaires		
Household Dietary Diversity Score (HDDS)	a continuous variable that measures the respondent's food diversity (0 to 12, with 12 being the most dietary diverse)	8.505 (1.921)
Household Food Insecurity Access Scale (HFIAS)	a continuous variable that measures the respondent's level of food insecurity (0 to 27, with 27 being high food insecurity)	6.07 (6.052)
Consumer Nutrition Knowledge	a continuous variable that measures the respondent's level of knowledge about nutrition (0 to 38, with 38 being 100% correct)	22.15 (5.239)

3 Results and Discussion

3.1 Descriptive Statistics

Table 3 outlines the socioeconomic characteristics of the sample (400 participants) and the comparable population. Most of the participants were female (76.25%) compared to 51.92% in the population of Cartagena. The larger share of females in the sample was expected, given that women are primarily in charge of food purchases, a pre-requisite for participation in the survey. There were significant differences in the age ($p<0.10$) and education composition ($p<0.01$) of the sample relative to the population, with participants being older and more educated than their population counterpart. Colombia employs a social strata system to categorize neighborhoods based on socioeconomic factors. This system assigns each area a stratum number from 1 to 6, with 1 being the lowest and 6 the highest socioeconomic category. The strata system affects utility prices (such as water, electricity, and gas), with higher-income neighborhoods (strata 5 or 6) having higher utility bills (DANE 2021). The strata distribution in the sample was statistically the same as the population according to a Pearson chi-squared test. The average household size in the sample was 4.07 people.

Over half (56.5%) of the participants spend more than 40% of their income on food (Table 4). Regarding rice consumption habits, the results indicate that taste is the most important quality attribute for over half of the participants, followed by texture (37% of the participants consider it the most important quality attribute) and appearance. Rice is mostly purchased in supermarkets (71.50%), followed by neighborhood stores (24.25%). Most participants (41.50%) report a household rice consumption between 2-4 kg/week, and 18.25% report consuming over 6 kg/week. Finally, most participants report washing the rice before cooking, and a strong preference for domestic rather than imported rice.

Table 3. Demographic characteristics of the sample and population.

Variable	Sample (%, n = 400)	Population (%) †
*Gender****		
Female	76.25	51.92
Male	23.50	48.08
Other	0.25	
*Age**		
30 or younger	33.00	50.76
31-40	23.25	15.20
41-50	18.00	11.75
51 or older	25.75	22.29
*Education Level****		
Primary or less	5.50	30.80
Secondary	32.25	35.00
Technical	23.00	13.60
Technological	14.75	3.70
University or higher	24.50	16.20
Household Income		
Less than 700,000 COP	19.50	
Between 700,001 COP - 1,400,000 COP	30.00	
Between 1,400,001 COP - 2,100,000 COP	13.75	
Between 2,100,001 COP - 2,800,000 COP	4.50	
Between 2,800,001 COP - 3,500,000 COP	5.25	
More than 3,500,001 COP	13.75	
Prefer not to respond	13.25	
Socioeconomic Strata		
1	54.00	43.45
2	25.00	32.69
3	14.75	17.41
4	5.50	2.59
5	0.75	2.68
6	0.00	1.18
Household Size (mean)	4.07	

Notes: Significance codes: *= 10%, **=5%, ***=1%.

†. Sources: Cartagena Como Vamos (2022) for gender and age distributions. DANE (2021) for education level distributions. Cartagena Como Vamos (2023) for socioeconomic strata distribution.

Table 4. Rice Consumption Habits (%, n=400).

Variable	Share
Which aspect of rice quality is most important to you when purchasing rice?	
Taste	50.50
Texture	37.00
Appearance	11.50
Other	1.00
What proportion of your income do you spend on food?	
Less than 20%	4.25
20% - 40%	39.25
41% - 60%	36.50
61% - 80%	16.50
More than 80%	3.50
In what kind of business do you usually buy rice? (only one answer)	
Supermarkets	71.50
Neighborhood Stores	24.25
Shopping Center	3.25
Other	1.00
How much rice does your household consume per week?	
Less than 2 kilograms	13.00
2 - 4 kilograms	41.50
4 - 6 kilograms	27.25
More than 6 kilograms	18.25
Do you have a habit of cleaning and washing rice before cooking it?	
Yes	77.50
No	22.50
If you had to choose, do you prefer domestic or imported rice?	
Domestic	73.25
Imported	7.00
Indifferent	19.75

3.2 Regression Results

In analyzing the factors influencing consumers' WTP across different products, several key initial findings emerged from the study which are shown in Table 5. The analysis indicates that consumers were consistently (across the three auction rounds) willing to pay a premium for zinc-biofortified rice relative to standard-quality rice and were willing to pay a premium for zinc-biofortified rice relative to premium-quality rice only after the information treatment (Round 3).

Initially, the research aimed to discern whether WTP differed solely based on consumers' preferences without additional information. Results from Round 1, and the accompanying box and whisker plot (Figure 1), revealed that the standard rice alternative exhibited a significantly lower WTP of 391.72 COP/500g and premium rice exhibited no significant difference in WTP relative to zinc-biofortified rice. These findings support hypothesis 1 in that quality attributes drive the WTP for rice when no labeling or information about the rice products is available.

To assess the impact of labeling on WTP, we analyzed the differences in WTP between Round 1 and Round 2. The WTP for both zinc-biofortified and premium rice increased significantly ($p<0.01$) from Round 1 to Round 2, but the difference in WTP between both products was not statistically significant in Round 2. Notably, there was no significant change in the WTP for standard rice between Round 1 and Round 2. The changes in WTP for each product between Rounds 1 and 2 partially supported hypothesis 2 in that the rice quality attributes seem to continue dominating consumers' WTP, but the labeling did not significantly decrease the WTP for standard rice.

We can assess the impact of information by comparing the results of Round 2 and Round 3. The results show a significant ($p<0.01$) increase in the WTP for zinc-biofortified rice of 9.10%, but no significant changes in the WTP for premium and standard rice as a result of the information treatment. It should also be noted that the WTP for the three rice products are significantly ($p<0.01$) different from each other in Round 3, which confirms hypothesis 3. Lastly, the study examined whether the type of information about zinc influenced WTP, comparing Round 3A and Round 3B. The results revealed no significant difference in WTP between the different information scripts for any rice product, indicating that negative information was just as effective as positive information, which aligns with previous findings in the literature (Birol et al. 2015).

Table 5. Differences in WTP between rounds or information treatments.

Product	Round 1: no labeling and no information	Round 2: labeling and no information	% change in WTP
Biofortified	2,473.65 COP/500g [a]	2,669.58 COP/500g [a]	7.92% ***
Premium	2,474.32 COP/500g [a]	2,679.70 COP/500g [a]	8.30% ***
Standard	2,081.93 COP/500g [b]	2,003.30 COP/500g [b]	-3.78%
	Round 2: labeling and no information	**Round 3: labeling and information**	**% change in WTP**
Biofortified	2,669.57 COP/500g	2,912.40 COP/500g [a]	9.10% ***
Premium	2,679.70 COP/500g	2,600.77 COP/500g [b]	-2.95%
Standard	2,003.30 COP/500g	2,024.75 COP/500g [c]	1.07%
	Round 3A: labeling and information about the "Benefits of zinc-biofortified rice"	**Round 3B: labeling and information about "Problems of zinc deficiency"**	**% change in WTP**
Biofortified	2,969.95 COP/500g	2,856.55 COP/500g	-3.82%
Premium	2,634.57 COP/500g	2,567.98 COP/500g	-2.53%
Standard	2,028.43 COP/500g	2,021.18 COP/500g	-0.36%

Notes: For each round, different letters represent significant differences at the 1% level.
Significance codes: *= 10%, **=5%, ***=1%

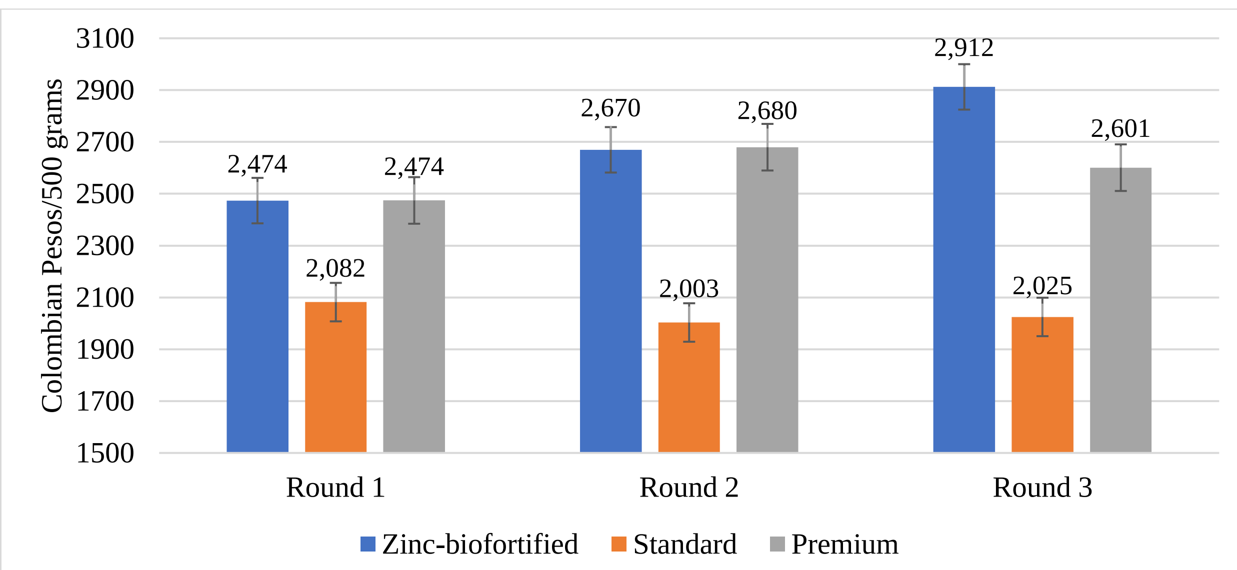

Figure 1: Average willingness to pay (WTP) for each of the three rice products in each experimental auction round.

Table 6 shows the regression results for the three regression models defined in section 2.5. The results from Model 1 (no socioeconomic covariates) replicate the findings discussed above. Model 2 shows that, everything else equal, gender ($p<0.01$), high income ($p<0.01$), dietary diversity ($p<0.01$), household size ($p<0.05$), and high education ($p<0.05$) were significantly and positively impacting WTP for rice. It should be noted that a large model (Model 4) including interaction terms for consumer knowledge score, HDDS score, and HFIAS score was also performed (Appendix C), in which the HDDS score was no longer significant and specific round interactions with knowledge became significant.

To answer hypothesis 4, Model 3 includes the vector of socioeconomic variables plus the interaction between product, round, and knowledge. The results showed that a 1-point increase in knowledge score significantly ($p<0.05$) increases the WTP for zinc-biofortified rice in Round 3 by 27.54 COP, thus supporting hypothesis 4. These findings suggest that having prior knowledge about nutrition reinforces the positive impact of information on the WTP for zinc-biofortified rice. Additionally, the WTP for standard rice in Round 3 decreases significantly ($p<0.10$) by 29.02 COP for each 1-point increase in the participant's nutrition knowledge score. It is also worth noting that the WTP for premium rice in Round 3 decreases ($p<0.11$) by 29.76 COP per 1-point increase in the nutrition knowledge score. These results for standard and premium rice confirm the findings from Meerza et al. (2023), which indicated that a negative spillover may occur as more knowledge is obtained by consumers.

An additional model (Model 5) was conducted to test whether the impact of information on WTP for zinc-biofortified rice varies across socioeconomic strata and education levels (Appendix D). The results from Model 5 show that the impact of information on WTP for zinc-biofortified rice is statistically the same across the socioeconomic strata and education levels of participants, which has important marketing implications.

Table 6. Model Results – WTP (COP/500g) with clustering by participant ID.

Variable	Model 1 Coefficient (St. Dev) ^	Model 2 Coefficient (St. Dev) ^	Model 3 Coefficient (St. Dev) ^
Intercept	2473.650 (38.360) ***	1913.564 (121.899) ***	1902.203 (191.530) ***
Standard	-391.725 (53.626) ***	-391.725 (53.118) ***	-91.784 (227.689)
Premium	0.675 (60.043)	0.675 (59.239)	28.265 (251.238)
Round 2	195.925 (58.023) ***	195.925 (56.303) ***	-144.336 (245.376)
Round 3	438.750 (64.043) ***	438.750 (62.439) ***	-171.288 (277.833)
Standard x Round 2	-274.550 (78.203) ***	-274.550 (77.045) ***	133.993 (338.192)
Standard x Round 3	-495.925 (83.954) ***	-495.925 (82.791) ***	146.828 (365.611)
Premium x Round 2	9.450 (87.270)	9.450 (85.720)	269.431 (370.905)
Premium x Round 3	-312.300 (91.005) ***	-312.300 (89.554) ***	346.977 (394.249)
Gender (Female)		157.280 (32.547) ***	157.280 (32.426) ***
Age (40 years or older)		-3.460 (30.145)	-3.460 (30.012)
Household Size		31.857 (13.981) **	31.857 (13.987) **
Children under 10		3.528 (28.043)	3.528 (27.925)
High Education		72.485 (28.631) **	72.485 (28.669) **
Middle Income		-3.422 (35.154)	-3.422 (35.143)
High Income		246.831 (58.494) ***	246.831 (58.335) ***
Income – No Response		23.897 (47.154)	23.897 (47.140)
Low Social Class		-39.358 (49.367)	-39.358 (49.203)
Nutrition Knowledge Score		2.597 (2.970)	3.110 (7.563)
HDDS Score		20.919 (7.642) ***	20.919 (7.646) ***
HFIAS Score		1.839 (2.799)	1.839 (2.796)
Round 2 x Knowledge Score			15.362 (11.284)
Round 3 x Knowledge Score			27.541 (12.797) **
Standard x Knowledge Score			-13.541 (10.457)
Standard x Round 2 x Knowledge Score			-18.444 (15.641)
Standard x Round 3 x Knowledge Score			-29.018 (16.998) *
Premium x Knowledge Score			-1.246 (11.679)
Premium x Round 2 x Knowledge Score			-11.737 (17.248)
Premium x Round 3 x Knowledge Score			-29.764 (18.398)
R^2	0.114	0.140	0.146
Adjusted R^2	0.112	0.135	0.139
No. of observations	3600	3600	3600
No. of clusters	400	400	400

^Notes: Significance codes: *= 10%, **=5%, ***=1%

4 Conclusions and Policy Implications

Hidden hunger, characterized by the deficiency of essential micronutrients, presents a critical global challenge impacting over two billion individuals worldwide (FAO 2013). Of particular concern is the shortfall of zinc, affecting approximately 17% of the global population due to inadequate dietary intake (King et al. 2016). Vulnerable groups, notably pregnant women and children in developing nations, face adverse consequences such as compromised growth, weakened immune response, and increased susceptibility to infections (Bhowmik, Chiranjib, and Kumar 2010; Black et al. 2008; Brown et al. 2009; Gupta, Brazier, and Lowe 2020). In Colombia, micronutrient deficiencies, including zinc, iron, and vitamin A, are prevalent concerns, especially among pregnant women and children in rural areas. To combat this issue, various strategies have been implemented, including the distribution of dietary supplements, dietary diversification promotion, and food fortification (Kennedy, Nantel, and Shetty 2003). Among these, biofortification has emerged as a promising approach, aiming to enhance the nutritional content of staple crops (Hodge 2014; Birol et al. 2015).

The primary aim of this study was to investigate consumers' WTP for zinc-biofortified rice in Cartagena, Colombia. By employing a non-hypothetical experimental auction, we sought to assess whether consumers were willing to pay a premium for zinc-biofortified rice compared to standard and premium-quality rice alternatives. Additionally, we aimed to examine the impact of labeling and information on WTP and explore the influence of consumer nutrition knowledge on purchasing decisions. Through this investigation, we attempted to provide insights into the potential market acceptance and sustainability of biofortified crops as a viable solution to address micronutrient deficiencies in vulnerable populations.

Results indicate that socioeconomic factors such as gender, income, education, dietary diversity, and household size significantly and positively impacted WTP, underscoring the importance of considering these variables when designing interventions aimed at promoting zinc-biofortified rice. The descriptive analysis revealed that a considerable proportion of participants (56.5%) allocated more than 40% of their income to food expenses, highlighting the importance of understanding consumer behavior in the context of food affordability.

Consumers consistently were willing to pay a premium for zinc-biofortified rice relative to standard-quality rice, with this preference being further reinforced once labeling and additional information about either "Benefits of zinc-biofortified rice" or the "Problems of zinc deficiency" was introduced. These results supported hypotheses 1 and 2, highlighting the absence of any underlying quality issues with the zinc-biofortified rice variety used in this study, and the importance of rice quality on WTP. Moreover, this signified that, even without information, there were no discounts on taste for the zinc-biofortified variety compared to the alternatives, which has been an ongoing concern for biofortified staple crops. This finding aligns with those reported in many other studies and synthesized by Birol et al. (2015), and suggests that the intrinsic quality of the zinc-biofortified variety used in this study is appealing to Colombian consumers. Therefore, the breeding of zinc-biofortified rice must strive to maintain a high-quality standard to ensure a high WTP because Colombian consumers are aware of, and willing to pay a premium for, quality rice. Additionally, the high WTP for zinc-biofortified rice found in this study underscores the potential role of consumers in supporting the higher costs of production of zinc-biofortified rice. Furthermore, the interaction between rice product, round, and knowledge revealed important insights into the role of consumer nutrition knowledge in shaping WTP. While an increase in the participant's nutrition knowledge score positively influenced WTP for zinc-biofortified rice, it led to a decrease in WTP for standard and premium rice varieties, indicating a negative spillover effect as consumers gained more information, confirming the findings from Meerza et al. (2023).

Effective information dissemination and marketing strategies play a crucial role in enhancing consumer awareness and understanding of zinc-biofortified rice attributes. The results from Model 5 showed that the impact of information on the WTP for zinc-biofortified rice did not vary across socioeconomic strata or education level; therefore, a broad marketing campaign across all consumers would be most appropriate for the zinc-biofortified rice in the Cartagena markets. Additionally, a broad marketing campaign could be a more cost-effective option compared to differing marketing strategies for different groups of consumers; therefore, this result has a significant impact for the potential costs association with future marketing campaigns. Clear communication of the nutritional benefits and quality of biofortified rice could influence consumer perceptions and preferences, thereby driving adoption rates. Policymakers should prioritize investments in education and outreach programs that promote consumer knowledge and awareness of zinc-biofortified rice, especially considering the identified knowledge gaps regarding micronutrient deficiencies in other global regions such as Tanzania (Kilasy et al. 2024). Additionally, partnerships with food manufacturers and retailers could help facilitate the integration of biofortified rice into the market, further enhancing its accessibility to consumers.

The commercialization of biofortified rice entails various costs, including those associated with identity preservation throughout the supply chain. While this study did not delve into a comprehensive analysis of such costs, it is crucial for policymakers to anticipate and address them effectively. Failure to account for these costs could undermine the viability and sustainability of biofortified rice production and distribution. Therefore, future policy interventions may need to incorporate mechanisms such as production subsidies to incentivize zinc-biofortified rice production while ensuring its affordability for consumers. With that said, the high WTP for zinc-biofortified found in this study implies that the market could accommodate some of those costs via price premiums.

In conclusion, this study contributes to the growing body of literature on consumer preferences and behaviors regarding biofortified crops, particularly in the context of addressing hidden hunger. By uncovering the drivers of WTP for zinc-biofortified rice and the impact of information and socioeconomic factors, this research offers valuable insights for policymakers, researchers, and stakeholders seeking to promote the adoption of biofortified staple crops as a sustainable solution to malnutrition.

5 References

Agedew, Eskezyiaw, Zeweter Abebe, and Abebe Ayelign. "Exploring barriers to diversified dietary feeding habits among adolescents in the agrarian community, North West Ethiopia." *Frontiers in Nutrition* 9 (2022): 955391.

Birol, Ekin, J. V. Meenakshi, Adewale Oparinde, Salomon Perez, and Keith Tomlins. "Developing country consumers' acceptance of biofortified foods: a synthesis." *Food Security* 7 (2015): 555-568.

Berhe, Kidanemaryam, Abadi Kidanemariam, Gebrehiwot Gebremariam, and Alem Gebremariam. "Prevalence and associated factors of adolescent undernutrition in Ethiopia: a systematic review and meta-analysis." *BMC nutrition* 5 (2019): 1-13.

Bhowmik, Debjit, K. Chiranjib, and S. Kumar. "A potential medicinal importance of zinc in human health and chronic." *Int J Pharm 1*, no. 1 (2010): 05-11.

Black, Maureen M. "Zinc deficiency and child development." *The American journal of clinical nutrition* 68, no. 2 (1998): 464S-469S.

Black, Robert E., Lindsay H. Allen, Zulfiqar A. Bhutta, Laura E. Caulfield, Mercedes De Onis, Majid Ezzati, Colin Mathers, and Juan Rivera. "Maternal and child undernutrition: global and regional exposures and health consequences." *The lancet 371*, no. 9608 (2008): 243-260.

Bouis, Howarth E., and Amy Saltzman. "Improving nutrition through biofortification: a review of evidence from HarvestPlus, 2003 through 2016." *Global food security* 12 (2017): 49-58.

Brown, Kenneth H., Janet M. Peerson, Shawn K. Baker, and Sonja Y. Hess. "Preventive zinc supplementation among infants, preschoolers, and older prepubertal children." *Food and nutrition bulletin* 30, no. 1_suppl1 (2009): S12-S40.

Canavari, Maurizio, Andreas C. Drichoutis, Jayson L. Lusk, and Rodolfo M. Nayga Jr. "How to run an experimental auction: A review of recent advances." *European Review of Agricultural Economics* 46, no. 5 (2019): 862-922.

Cartagena Como Vamos. "Informe de Calidad de Vida 2022 Cartagena." (2022).

Cartagena Como Vamos. Power BI Tool. (2023).

Cediel, Gustavo, Manuel Olivares, Alex Brito, Héctor Cori, and Daniel López de Romaña. "Zinc deficiency in Latin America and the Caribbean." *Food and nutrition bulletin* 36, no. 2_suppl (2015): S129-S138.

Coates, Jennifer, Anne Swindale, and Paula Bilinsky. "Household Food Insecurity Access Scale (HFIAS) for Measurement of Household Food Access: Indicator Guide (v. 3)." *Washington, D.C.: Food and Nutrition Technical Assistance Project, Academy for Educational Development* (2007).

Custodio, Marie Claire, Rosa Paula Cuevas, Jhoanne Ynion, Alice G. Laborte, Maria Lourdes Velasco, and Matty Demont. "Rice quality: How is it defined by consumers, industry, food scientists, and geneticists?." *Trends in food science & technology* 92 (2019): 122-137.

DANE. "Gran Encuesta Integrada de Hogares – GEIH – 2021." (2021).

DANE. "Gran Encuesta Integrada de Hogares – GEIH – 2021 - 2022." (2021-2022).

DANE. "Metodología de estratificación socioeconómica urbana para servicios públicos domiciliarios." (2021).

Dary, Omar, and Richard Hurrell. "Guidelines on food fortification with micronutrients." *World Health Organization, Food and Agricultural Organization of the United Nations: Geneva, Switzerland* 2006 (2006): 1-376.

FAO. "The State of Food and Agriculture (SOFA) 2013." (2013).

Gebreyesus, Seifu Hagos, Torleif Lunde, Damen H. Mariam, Tasew Woldehanna, and Bernt Lindtjørn. "Is the adapted Household Food Insecurity Access Scale (HFIAS) developed internationally to measure food insecurity valid in urban and rural households of Ethiopia?." *BMC nutrition* 1 (2015): 1-10.

Gupta, Swarnim, A. K. M. Brazier, and N. M. Lowe. "Zinc deficiency in low-and middle-income countries: prevalence and approaches for mitigation." *Journal of Human Nutrition and Dietetics* 33, no. 5 (2020): 624-643.

HarvestPlus. "ZINC-ENRICHED RICE: Improving food and the food system with a naturally nutritious harvest." (n.d.).

Hodge, J. "Food fortification: a "techno-fix" or a sustainable solution to fight hidden hunger. The Future of Global Relations." *The future of global relations* (2014): 1-68.

Hotz, Christine, and Bonnie McClafferty. "From harvest to health: challenges for developing biofortified staple foods and determining their impact on micronutrient status." *Food and Nutrition Bulletin* 28, no. 2_suppl2 (2007): S271-S279.

ICONTEC. "Norma Técnica Colombiana (No. 671; ARROZ ELABORADO (BLANCO) PARA CONSUMO)." *Instituto Colombiano de Normas Técnicas y Certificación*. (2007).

Jannasch, Annegret, and Ya-Jane Wang. "Development of a limited-water soaking method on the fortification of rice with calcium and iron by parboiling." *Journal of cereal science* 94 (2020): 103014.

Kennedy, Gina, Guy Nantel, and Prakash Shetty. "The scourge of" hidden hunger": global dimensions of micronutrient deficiencies." *Food Nutrition and Agriculture* 32 (2003): 8-16.

Kilasy, Pius, Brandon R. McFadden, Kelly A. Davidson, and Leah H. Palm-Forster. "Knowledge gaps about micronutrient deficiencies in Tanzania and the effect of information interventions." *Global Food Security* 40 (2024): 100745.

King, Janet C., Kenneth H. Brown, Rosalind S. Gibson, Nancy F. Krebs, Nicola M. Lowe, Jonathan H. Siekmann, and Daniel J. Raiten. "Biomarkers of Nutrition for Development (BOND)—zinc review." *The Journal of nutrition* 146, no. 4 (2016): 858S-885S.

Knueppel, Danielle, Montague Demment, and Lucia Kaiser. "Validation of the household food insecurity access scale in rural Tanzania." *Public health nutrition* 13, no. 3 (2010): 360-367.

Lusk, Jayson L., and Darren Hudson. "Willingness-to-pay estimates and their relevance to agribusiness decision making." *Applied Economic Perspectives and Policy* 26, no. 2 (2004): 152-169.

MacKinnon, James G., and Halbert White. "Some heteroskedasticity-consistent covariance matrix estimators with improved finite sample properties." *Journal of econometrics* 29, no. 3 (1985): 305-325.

Maqbool, Muhammad Amir, and AbduRahman Beshir. "Zinc biofortification of maize (Zea mays L.): Status and challenges." *Plant breeding* 138, no. 1 (2019): 1-28.

McAfee, R. Preston, and John McMillan. "Auctions and bidding." *Journal of economic literature* 25, no. 2 (1987): 699-738.

Meerza, Syed Imran Ali, Khondoker Mottaleb, Alwin Dsouza, Md Shajedur Rahaman, and Md Abdur Rouf Sarkar. "Consumers' valuation of a biofortified crop: Evidence from a laboratory experiment." *Agricultural Economics* 54, no. 5 (2023): 697-708.

Mekonnen, Daniel A., Elise F. Talsma, Laura Trijsburg, Vincent Linderhof, Thom Achterbosch, Aafke Nijhuis, Ruerd Ruben, and Inge D. Brouwer. "Can household dietary diversity inform about nutrient adequacy? Lessons from a food systems analysis in Ethiopia." *Food security* 12 (2020): 1367-1383.

Melesse, Mequanint B., and Marrit van den Berg. "Consumer nutrition knowledge and dietary behavior in urban Ethiopia: a comprehensive study." *Ecology of Food and Nutrition* 60, no. 2 (2021): 244-256.

Nestel, Penelope, Howarth E. Bouis, Jonnalagadda V. Meenakshi, and Wolfgang Pfeiffer. "Biofortification of staple food crops." *The Journal of nutrition* 136, no. 4 (2006): 1064-1067.

Ofori, Kelvin F., Sophia Antoniello, Marcia M. English, and Alberta NA Aryee. "Improving nutrition through biofortification–A systematic review." *Frontiers in Nutrition* 9 (2022): 1043655.

Phillips, Juliann, Alvaro Durand-Morat, Lawton L. Nalley, Eduardo Graterol, Michelle Bonatti, Katerine Loaiza de la Pava, Sergio Urioste, and Wei Yang. "Understanding demand for broken rice and its potential food security implications in Colombia." *Journal of Agriculture and Food Research* 15 (2024): 100884.

R Core Team. "R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria." v. 4.2.2. (2022).

Rai, Anjana, Macha Raja Maharjan, Helen A. Harris Fry, Parbati K. Chhetri, Purna Chandra Wasti, and Naomi M. Saville. "Consumption of rice, acceptability and sensory qualities of fortified rice amongst consumers of social safety net rice in Nepal." *Plos one* 14, no. 10 (2019): e0222903.

Salarkia, Nahid, Morteza Abdollahi, Maryam Amini, and M. Eslami Amirabadi. "Validation and use of the HFIAS questionnaire for measuring household food insecurity in Varamin-2009." *Iranian Journal of Endocrinology and Metabolism* 13, no. 4 (2011): 374-383.

Swindale, Anne, and Paula Bilinsky. "Household dietary diversity score (HDDS) for measurement of household food access: indicator guide." *Washington, DC: Food and Nutrition Technical Assistance Project, Academy for Educational Development* (2006).

World Health Organization. “Food Fortification.” (n.d.).

Wieser, Simon, Rafael Plessow, Klaus Eichler, Olivia Malek, Mario V Capanzana, Imelda Agdeppa, and Urs Bruegger. “Burden of micronutrient deficiencies by socio-economic strata in children aged 6 months to 5 years in the Philippines.” *BMC Public Health*, vol. 13 (2013): 1167.

Woods, Bo-Jane, Sonia Gallego-Castillo, Elise F. Talsma, and Daniel Álvarez. "The acceptance of zinc biofortified rice in Latin America: A consumer sensory study and grain quality characterization." *PLoS One* 15, no. 11 (2020): e0242202.

6 Appendix A

Photos from Experimental Auction

Figure A.1. Standardized preparation of rice samples, including cooking and serving.

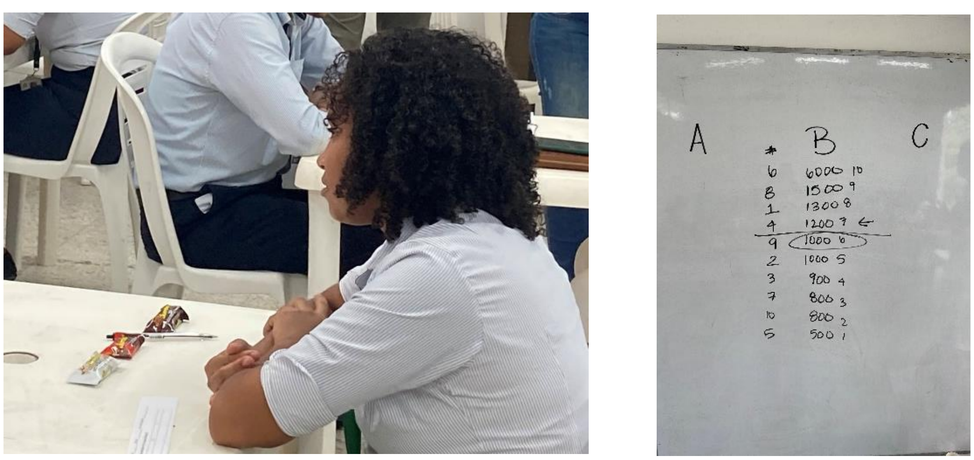

Figure A.2. Participant receiving instructions during the candy bar experimental auction training. Whiteboard used to explain the random nth price method to select the winners.

Figure A.3. Presentation of the auction products in each of the experimental auction rounds. In Round 1 there was no information given to participants about the three rice products. In Round 2 the rice products were labelled. Finally, in Round 3, the information treatment about the benefits of zinc-biofortified or the health risks of zinc deficiency was given orally.

Figure A.4. Enumerator conducting the socioeconomic questionnaire with one of the participants.

7 Appendix B

Socioeconomic Questionnaire

1. **Gender**
   ☐ **1.** Male ☐ **2.** Female

2. **Age**
   ☐ **1.** 30 years or younger ☐ **2.** 31-40 years ☐ **3.** 41-50 years ☐ **4.** 51 years or older

3. **How many people make up your household? ______**

4. **How many children younger than ten live in your household? ______**

4.1 How many less than one year old?
4.2 How many less than five years old?

5. **Level of education completed**
   ☐ **1.** Primary or less ☐ **2.** Secondary ☐ **3.** Technical ☐ **4.** Technologist ☐ **5.** University

6. **Total monthly household income**
   ☐ **1.** Less than C$ 700,000 ☐ **2.** C$ 700,001 – C$ 1,400,000
   ☐ **3.** C$ 1,400,000 – C$ 2,100,000 ☐ **4.** C$ 2,100,001 – C$ 2,800,000
   ☐ **5.** C$ 2,800,001 – C$ 3,500,000 ☐ **6.** More than C$ 3,500,001

7. **To which social class does your household belong?**
   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

8. **What proportion of your income do you spend on food?**
   ☐ **1.** Less than 20% ☐ **2.** 20% - 40% ☐ **3.** 41% - 60% ☐ **4.** 61% - 80%
   ☐ **5.** More than 80%

9. **In what kind of business do you usually buy rice? (only one answer)**
   ☐**1.** Supermarkets ☐ **2.** Neighborhood Stores ☐ **3.** Shopping Center ☐ **4.** Other:__________

10. **How much rice does your household consume per week?**
    ☐ **1.** Less than 2 kilos ☐ **2.** 2 - 4 kilos ☐ **3.** 4 – 6 kilos ☐ **4.** More than 6 kilos

11. Do you have a habit of cleaning and washing rice before cooking it?

☐ **1.** Yes ☐ **2.** No

12. If you answered "yes" on (10), for what reason do you do it? (you can select multiple answers)

☐ **1.** Because it reduces cooking time ☐ **2.** To remove damaged or foreign grains

☐ **3.** For tradition ☐ **4.** To remove impurities

☐ **5.** Because it improves the flavor of the rice ☐ **6.** Because it improves the flavor of rice

☐ **7.** Others Which one(s)? ___________________________

13. If you had to choose, do you prefer domestic or imported rice?

☐ **1.** Domestic ☐ **2.** Imported ☐ **3.** Indifferent

14. List the characteristics that are most important when selecting which rice to buy.

	1. Very important	**2.** Important	**3.** Something important	**4.** Unimportant	**5.** It's not important
A. Price	☐	☐	☐	☐	☐
B. Brand	☐	☐	☐	☐	☐
C. Uniform grain	☐	☐	☐	☐	☐
D. Whiteness	☐	☐	☐	☐	☐
E. Long, fine grain	☐	☐	☐	☐	☐
F. Cleaning	☐	☐	☐	☐	☐
G. Presence of broken rice	☐	☐	☐	☐	☐
H. Presence of opaque or chalky rice	☐	☐	☐	☐	☐
I. Fortified	☐	☐	☐	☐	☐
J. Taste	☐	☐	☐	☐	☐

Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access

I would like to ask you about the types of foods that you or anyone else in your household ate yesterday during the day and at night.

	Questions	**Value**
A	Any bread, rice, pasta, cookies, or any other foods made from cereals?	

B	Any potatoes, yams, manioc, cassava, or any other foods made from roots or tubers?	
C	Any vegetables?	
D	Any fruits?	
E	Any beef, pork, chicken, lamb, or other meats except fish?	
F	Any eggs?	
G	Any fresh or dried fish or shellfish?	
H	Any foods made from beans, peas, lentils, or nuts?	
I	Any milk, cheese, yogurt, or other milk products?	
J	Any foods made with oil, fat, or butter?	
K	Any sugar or honey?	
L	Any other foods, such as condiments, coffee, tea?	

Instructions: place a 1 if anyone in the household ate the food in question, place a 0 in the box if no one in the household ate the food in question.

Household Food Insecurity Access Scale (HFIAS)

Each of the questions in the following table is asked with a recall period of four weeks (30 days). The respondent is first asked an occurrence question – that is, whether the condition in the question happened at all in the past four weeks (yes or no). If the respondent answers "yes" to an occurrence question, a frequency-of-occurrence question is asked to determine whether the condition happened rarely (once or twice), sometimes (three to ten times) or often (more than ten times) in the past four weeks.

Example:
Occurrence. In the past four weeks, did you worry that your household would not have enough food?

0 = No (skip to Q2)
1 = Yes

Frequency. If (yes) for occurrence, how often did this happen?

1 = Rarely (once or twice in the past four weeks)
2 = Sometimes (three to ten times in the past four weeks)
3 = Often (more than ten times in the past four weeks)

	Occurrence Questions	Occurrence	Frequency
1	In the past four weeks, did you worry that your household would not have enough food?		
2	In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?		
3	In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources?		
4	In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?		
5	In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?		
6	In the past four weeks, did you or any household member have to eat fewer meals in a day because there was not enough food?		
7	In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to get food?		
8	In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?		
9	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?		

Modified Consumer Nutrition Knowledge Questionnaire

Total of 38 questions. Treat each correct and incorrect answer as 1 and 0, respectively. Index value varies from 0 to 38.

1. Health experts often give people advice about diets. Do you think health experts recommend that people should be eating more, the same amount, or less of these foods?

Food Item	More	Same	Less	Do not know
1.1. Vegetables				
1.2. Sugary foods				

1.3. Meat				
1.4. Starchy foods				
1.5. Fatty foods				
1.6. High fiber foods				
1.7. Fruit				
1.8. Salty foods				

2. Experts recommend consuming foods with more vitamins and minerals. Food companies add them through a process called fortification (i.e. fortified foods). Which of these foods has folic acid and iron mandatory added?

- ☐ Vegetable oil
- ☐ Powdered milk
- ☐ Table salt
- ☐ Wheat flour
- ☐ Do not know

3. In general, are these foods High or Low in carbohydrate?

Food Item	High	Low	Do not Know
3.1. Beef			
3.2. Pasta			
3.3. Cabbage			
3.4. Bread			
3.5. Rice			
3.6. Chicken			
3.7. Honey			

4. In general, are these foods High or Low in protein?

Food Item	High	Low	Do not Know
4.1. Chicken			
4.2. Peanut			
4.3. Beans			
4.4. Fruit			
4.5. Potato			
4.6. Egg			

5. Evaluate the following statements

	True	False	Do not Know
5.1. Table salt has a lot of vitamins and minerals.			

5.2. Eating more bread helps to increase protein in the diet.			
5.3. Proteins are the best and most efficient source of energy.			
5.4. Rice is a good source of proteins.			
5.5. Vitamins are a good source of energy.			
5.6. Cereal, bread and pasta are good sources of carbohydrates.			
5.7. Saturated fats are usually found in animal products like meat & dairy			
5.8. Sun light is an important source of vitamin C			

6. Which food group is our body's best source of energy?

☐ Meats

☐ Fats, oils and sweets

☐ Breads and cereals

☐ Milk and cheese

☐ Do not know

7. Bread, cereals, rice and pasta are a good source of

☐ Carbohydrates

☐ Vitamin C

☐ Proteins

☐ Vitamin D

☐ Do not know

8. Evaluate the following statements

	True	False	Do not Know
8.1. What one eats can affect the risk of getting a disease			
8.2. Milk is important for the development and strength of our bones			
8.3. A high intake of salt may increase blood pressure			

9. Obesity is major health problem or disease that is largely related to eating habit and lifestyle of people. Which one of the following would not be a likely cause of obesity?

☐ Overeating carbohydrates and fats

☐ Excess calories in the body

☐ Lack of physical activity

☐ Overeating of fruits and vegetables

☐ Do not know

10. Which of these serious health problems has/have been linked to obesity?

☐ Type 2 diabetes

☐ Heart disease

☐ High blood pressure

☐ Stroke

☐ All of the above

☐ Do not know

11. Risk of high blood pressure is most likely to be reduced by eating a diet with

☐ Less sugar

☐ More fiber

☐ More iron

☐ Less salt

☐ Do not know

8 Appendix C

Table C. 1. Model 4: willingness to pay for three rice products by round, including the vector of socioeconomic variables Xi, and all interaction terms.

Variable	Coefficient (St. Dev) ^
Intercept	1882.183 (258.989) ***
Standard	-291.180 (352.063)
Premium	146.099 (367.541)
Round 2	21.179 (401.384)
Round 3	152.738 (402.443)
Standard x Round 2	-101.581 (530.944)
Standard x Round 3	-239.457 (546.014)
Premium x Round 2	165.405 (562.953)
Premium x Round 3	29.101 (565.324)
Gender (Female)	157.280 (32.445) ***
Age (40 years or older)	-3.460 (30.053)
Household Size	31.857 (14.006) **
Children under 10	3.528 (27.979)
High Education	72.485 (28.660) **
Middle Income	-3.422 (35.158)
High Income	246.831 (58.353) ***
Income – No Response	23.897 (47.135)
Low Social Class	-39.358 (49.278)
Nutrition Knowledge Score	2.172 (7.772)
HDDS Score	27.386 (20.674)
HFIAS Score	-0.502 (6.788)
Round 2 x Knowledge Score	14.389 (11.573)
Round 3 x Knowledge Score	27.157 (12.923) **
Standard x Knowledge Score	-11.593 (10.700)
Standard x Round 2 x Knowledge Score	-18.090 (15.945)
Standard x Round 3 x Knowledge Score	-29.258 (17.181) *
Premium x Knowledge Score	0.219 (11.860)
Premium x Round 2 x Knowledge Score	-10.121 (17.430)
Premium x Round 3 x Knowledge Score	-29.223 (18.558)
Round 2 x HDDS Score	-12.071 (32.153)
Round 3 x HDDS Score	-30.844 (34.412)
Standard x HDDS Score	10.860 (30.259)
Standard x Round 2 x HDDS Score	22.069 (43.824)
Standard x Round 3 x HDDS Score	40.086 (46.348)
Premium x HDDS Score	-18.829 (30.829)
Premium x Round 2 x HDDS Score	2.818 (45.647)
Premium x Round 3 x HDDS Score	29.481 (47.321)
Round 2 x HFIAS Score	-6.804 (10.680)
Round 3 x HFIAS Score	-8.761 (10.984)
Standard x HFIAS Score	10.524 (10.040)
Standard x Round 2 x HFIAS Score	6.594 (14.664)

Standard x Round 3 x HFIAS Score	8.348 (15.259)
Premium x HFIAS Score	1.626 (10.280)
Premium x Round 2 x HFIAS Score	7.291 (15.202)
Premium x Round 3 x HFIAS Score	9.086 (15.700)
R^2	0.149
Adjusted R^2	0.139
No. of observations	3600
No. of clusters	400

Notes: Significance codes: *= 10%, **=5%, ***=1%

9 Appendix D

Table D. 1. Model 5: Willingness to pay for zinc-biofortified rice between rounds 2 and 3 as a function of selected socioeconomic variables and interactions.

Variable	Coefficient (St. Dev)
Intercept	2410.626 (238.218) ***
Round 3	71.526 (362.222)
Knowledge Score	20.206 (8.810) **
Low Social Class	-156.195 (126.882)
Low Education	-172.778 (88.301) *
Round 3 x Knowledge Score	10.240 (13.403)
Round 3 x Low Social Class	-72.047 (197.098)
Round 3 x Low Education	3.727 (131.645)
R^2	0.070
Adjusted R^2	0.062
No. of observations	800
No. of clusters	400

Significance codes: *= 10%, **=5%, ***=1%

10 Appendix E

IRB Approval

UNIVERSITY OF ARKANSAS

To:	Alvaro Durand-Morat
From:	Douglas J Adams, Chair IRB Expedited Review
Date:	04/05/2023
Action:	**Exemption Granted**
Action Date:	04/05/2023
Protocol #:	2302451174
Study Title:	Consumer willingness to pay for zinc biofortified rice in Colombia

The above-referenced protocol has been determined to be exempt.

If you wish to make any modifications in the approved protocol that may affect the level of risk to your participants, you must seek approval prior to implementing those changes. All modifications must provide sufficient detail to assess the impact of the change.

If you have any questions or need any assistance from the IRB, please contact the IRB Coordinator at 109 MLKG Building, 5-2208, or irb@uark.edu.

cc: Lawton L Nalley, Investigator
Sara Ann Oswalt, Investigator

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