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Are Rice Markets in Bangladesh Efficiently Pricing Rice Based on Quality? An Empirical Assessment

A thesis submitted in partial fulfillment
of the requirements for the degree of
Masters in Agricultural Economics and Agri-Business

by

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Abstract

Rice is an important staple for more than half of the world's population and is the main staple in Bangladesh, accounting for 65 percent to 70 percent of the daily calorie intake. The importance of rice consumption and the high level of food insecurity in Bangladesh highlights the importance of having markets that efficiently price rice according to consumer preferences. This study aims to assess how effectively rice prices in Bangladesh are reflective of rice quality. More specifically, we estimate how the rice market is currently pricing selected rice quality attributes, such as broken percentage, chalk percentage, kernel size and shape, color, homogeneity, and parboiling, using a pure hedonic price model. Rice samples were collected from different vendors in 10 retail markets across Dhaka, Bangladesh, and processed to objectively assess the attribute levels. The findings reveal that the shape, homogeneity, chalk percentage, and color of rice impact rice prices significantly, which can be understood as a sign that the market is efficiently pricing rice based on quality. The broken rate has a statistically significant but marginal impact on price only at high rates above 24.9 percent, which highlights that potential presence of inefficiencies. Correcting the potential problem evidenced by the lack of association between price and broken rate could lead to improvements in food security that are more environmentally sustainable.

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I am incredibly grateful to my parents for their love, prayers, care, and sacrifices for educating and preparing me for the future. I am wholeheartedly thankful to my husband, Dr. Sajib Roy, for his love, understanding, prayers, and continuing support throughout my degree here. Lastly, I am grateful to my sisters and friends for their advice, support, and encouragement.

Dedication

This thesis is dedicated to my parents, Mr. Ranjit Kumar Saha and Mrs. Aloka Saha, who taught me to perform all of my life tasks and set me free to face the world, to the best of my ability and without complaint; and my husband, Dr. Sajib Roy for being my support and believing in me.

Table of Contents

1 Introduction 1

2 Methodology.. 5

2.1 Pure Hedonic Price Model 5

2.2 Data 6

2.3 Measurement of physical attributes of rice 8

2.4 Piecewise Analysis... 11

3 Results and Discussion 12

3.1 Physical characteristics of rice 12

3.2 Results of the Pure Hedonic Price Model 17

3.3 Marginal price effects... 20

4 Conclusion... 23

5 References 26

6 Appendix 30

List of Figures

Figure 1. Location of the 10 selected markets in Dhaka, and poverty headcount ratio of the respective neighborhoods.......... 7

Figure 2. Statistical difference in rice price across markets (Dunn's test. Different letters mean statistical difference at the 5% level).......... 15

Figure 3. Statistical difference in broken percentage across markets (Dunn's test. Different letters mean statistical difference at the 5% level).......... 15

Figure 4. Scattered plot of original and fitted values of broken percentage, and threshold of broken rate indicating a change in slope.......... 26

Figure 5. Marginal price effect of selected rice quality attributes for Model 1 and Model 2.......... 26

List of Tables

Table 1. Descriptive statistics of the retail price of rice and selected rice quality attributes for 300 observation. 13

Table 2. Mean value of retail price and selected rice quality attributes by markets..................... 14

Table 3. Results from the piecewise regression analysis for broken percentage. 16

Table 4. Results of Pure Hedonic Price Model.. 22

1 Introduction

Rice is an important cash crop for millions of farmers worldwide and an important staple food for more than half of the world's population. Rice is the primary source of income for more than 200 million households across the developing world (Food and Agriculture Org., 2005), and over two billion people in Asia alone obtain 80 percent of their daily calories from rice (Chaudhari et al., 2018).

Bangladesh is the third largest rice producer globally after China and India, producing 36.3 million metric tons (MMT) in 2020/2021 (USDA, 2021). The rice industry in Bangladesh represents 70 percent of its agricultural gross domestic product, and is the primary income source for over 48 percent of the rural population (Sayeed and Yunus, 2018). On the demand side, despite a marginal decrease since 2000 (Yunus, Rashid, and Chowdhury, 2019), Bangladeshis consume the most rice per-capita worldwide with an average of 181.3 kg a year in 2020-2021 (Rosegrant et al., 2020). Rice contributes more than 63 percent and 71 percent of urban and rural consumers' caloric consumption, respectively (Minten, Murshid, and Reardon, 2013).

As a result of economic reform, including liberalization of commodity markets, Bangladesh has made significant progress in improving the wellbeing of its population in the last two decades. For instance, poverty and extreme poverty decreased from 49 percent in 2000 to 13 percent in 2016 (World Bank, 2019), undernourishment decreased from 21 percent in 2000 to 15 percent in 2017, and stunting among children decreased from 51 percent in 2000 to 36 percent in 2014 (Roser and Ritchie, 2019). Despite this progress, still 30.5 percent of the population suffered from moderate food insecurity and 10 percent from extreme food insecurity in 2017, while 33 percent children were classified as underweight in 2014 (Roser and Ritchie, 2019). The crucial role of rice as a livelihood for most rural households and a staple food across the country highlights the importance of understanding of how the rice market in Bangladesh functions as a way to help improve its efficiency. Assessing the relationship between rice prices and quality is also important given the lack of enforcement of rice quality standards in Bangladesh (Custodio et al., 2019), which makes transactions more costly as consumers must spend more time gauging the quality of the products, and could lead to consumer welfare losses if sellers charge a higher price than that granted by the quality of the rice they offer. In the context of this study, an efficient market is one that prices rice according to the quality standards of the rice products. For instance, if broken rice is seen as an inferior product, then rice products with high broken rice content should be priced at a discount and viceversa. If rice with varying content of broken rice is priced similarly, then that can be understood as an inefficiency.

Rice quality can be assessed using different classifications (Cuevas et al., 2016). Rice quality attributes can be classified into intrinsic attributes associated with the characteristics of rice kernels per se, such as color, cleanliness, shape and size, presence of broken and chalk kernels, texture, and aroma, and extrinsic attributes associated with the presentation of the product, such as packaging, labeling and branding. Attributes can also be classified into search, experience, and credence. Search attributes are available for product evaluation prior to purchasing, such as price, appearance, and brand. Experience attributes can be evaluated upon product experience that occurs after purchase or use of the product, such as taste, texture, ease of cooking, and swelling capacity. Credence attributes are those that consumers cannot evaluate or verify themselves, but rather rely on third-party assessments (organically produced, fair trade, etc.).

Globally, consumer preferences for rice is heterogenous, and therefore the value attached to specific attributes varies geographically and by the socio-cultural context in which rice consumption is embedded. There is growing evidence, primarily from Asia and Africa, that indicates consumers are increasingly aware of rice quality, even among low-income households (Cuevas et al., 2016; Diagne, Demont, and Ndour, 2017; Calingacion et al., 2014; Rutsaert, Demont, and Verbeke, 2013; Demont et al., 2012; Tomlins et al., 2007; Tomlins et al., 2005). For example, consumers in Bangladesh and the eastern side of India consider slenderness, whiteness, medium size, good taste, and aromatic rice as premium-quality rice, and as such rice with those attributes commands a premium (Custodio et al., 2016). Good taste, slenderness, and whiteness were consistently mentioned in the top three most important rice characteristics preferred by urban households in Dhaka, and by most households across cities and socio-economic classes (Custodio et al., 2016). Parboiled rice (both double-boiled[1] and single-boiled[2]) is popular across Bangladesh. Previous research indicate that increases in income among households in Dhaka leads to an increase in the demand for high-quality rice, rather than higher per-capita consumption. Preference for long to extra-long kernels similarly increases with socio-economic status, particularly among urban consumers (Custodio et al., 2016).

Mottaleb and Mishra (2017) find that short and bold grain rice are considered fine quality rice in the southern parts of India (e.g., Tamil Nadu, Kerela) and Sri Lanka. On the other hand, consumers in the northern and western part of India and Pakistan prefers slender, long-grain rice (Giraud, 2013). Calingacion et al. (2014) report that medium size slender rice dominates in Bangladesh and Indonesia, long-grain rice is the most poular in the rest of southeast Asia, and

[1] Double-boiled rice refers to a modified parboiling process in which the paddy rice is (1) stemed, (2) boiled, (3) stemed a second time, and (4) dried.

[2] Single-boiled rice refers to the traditional steps in the parboiling process, in which paddy rice is (1) boiled, 92) stemed, and (3) dried.

short and bold rice is strongly preferred in northeast Asia. In the Philippines and Bangladesh, broken rice is perceived as a low quality product, and therefore the market price of rice decreases as the percentage of broken rice kernels increases (Cuevas et al., 2016, Mottaleb and Mishra, 2017). Households in Malaysia mostly prefer white long-grain aromatic rice, while in Indonesia, consumers prefer rice varieties that are long, slender in shape and with a white belly (Mottaleb and Mishra, 2017).

Regarding experience attributes, Bairagi et al. (2017) find that rice that cooks firm and dry is widely preferred by South Asian consumers because combining these two attributes characterizes parboiled rice, which is traditionally consumed in many regions in Bangladesh. Good taste is consistently mentioned in the top three most essential rice characteristics preferred by households in urban Bangladesh (Custodio et al., 2016). Rice consumers from southeast Asia (Thailand, Philippines, Vietnam, Cambodia) mostly prefer rice with a sticky texture (low amylose content) and fragrance (Custodio et al., 2019), while consumers in the northern and western part of India and Pakistan prefer nonsticky and aromatic rice (Giraud, 2013). Preference for rice across South and Southeast Asia is influenced by the respondents' education, family size, income, rice consumption, and rice expenditure share (Bairagi et al., 2017).

While there is ample research on consumer preferences for rice attributes, only few studies have looked into the economic valuation of rice quality attributes. In most markets the price differences between rice samples of different quality classes indicate that grain quality attributes contribute in some part to rice price itself (Cuevas et al., 2016). Determining the implicit contribution of various grain quality attributes to the market price of varying rice samples can be done through hedonic pricing analysis. Despite the importance of rice in Bangladesh, the literature is limited as to the impact of rice quality attributes on rice prices in Bangladesh.

Understanding the relationship between market prices and rice quality can provide valuable insights into whether the market differentiates rice qualities and price them accordingly, and point to potential areas for market imporvements, for instance, via the adoption of rice quality standards and labelling regulations. Furthermore, the assessment of the market pricing efficiency concerning rice quality attributes could help build food policies and marketing strategies catered to the specific preferences of consumers, which can potentially lead to improvements in consumer welfare and food security.

Results of this study have both economic and environmental implications. For instance, if markets are found not to discount broken rice, this could mean that more broken rice could be allocated for human consumption instead of being funneled off for animal feed or energy use, which has implications for environmental sustainability (Shew et al., 2019). Likewise, if the supply chain can increase the percentage of broken rice sold to consumers, this could lead to higher prices for broken rice and ultimately higher producer welfare.

The objective of this study is to assess how broken rice, chalk rice, color, shape and size, homogeneity, and processing (parboiling) affect rice prices in urban Dhaka. More specifically, the study aims at understanding whether rice markets are pricing rice efficiently based on quality attributes, which has implications for food security as well as for the economic and environmental sustainability of rice across Bangledesh.

2 Methodology

2.1 Pure Hedonic Price Model

Hedonic pricing assumes that a product is a basket of attributes associated with values contributing to its price. Pure Hedonic pricing regressions are based on Lancaster's "characteristics theory of value," which interprets that any good can be described in terms of its attributes or characteristics (Lancaster, 1971). In this scenario, the price consumers are willing to pay for rice is the function of physical characteristics of rice, such as:

$$P_i = \alpha X_i + \varepsilon_i \qquad (i)$$

where P_i represents the price paid by consumer i, X_i is a vector of rice quality attributes, and $\boldsymbol{\varepsilon_i}$ is the error term. The rice quality attributes considered in this study are (1) broken percentage, (2) chalk percentage, (3) color, (4) shape, represented by the length to width ratio (LWR), (5) homogeneity, and processing represented by two variables, namely (6) single-boiled rice, and (7) double-boiled rice (non-boiled rice is the reference). The model was estimated with and without market fixed effects to account for differences across the markets surveyed. Our econometric equation is as follows:

$$Price_i = \beta_0 + \beta_1\, Broken\ percentage_i + \beta_2\, Chalk\ percentage_i + \beta_3\, Color_i + \beta_4\, LWR_i + \beta_5\, Homogeneity_i + \beta_6\, Double-boil_i + \beta_7\, Single-boil_i + \sum_{j=1}^{9} \beta_j\, Market_{ij} + \varepsilon_i \qquad (ii)$$

2.2 Data

The data used in this study consists of 300 rice samples collected from ten different retail rice markets in urban Dhaka, Bangladesh, in September 2020. To capture potential price and quality heterogeneity due to differences in household socioeconomic status (e.g., income levels), the markets were selected from different neighborhoods of Dhaka, which were in turn chosen based on the average poverty headcount ratio of each respective neighborhood as estimated by the World Bank (2021). The markets in Dhanmondi, Gulshan, and Mohammadpur Town Hall are located in high-income neighborhoods, as reflected by their low poverty headcount ratio of 1.3, 3.3, and 4 percent, respectively. Farmgate/Tejgaon, Mirpur, and Agargaon Taltola are middle-income markets, with a poverty headcount ratio of 6.7, 6.6, and 7.6 percent, respectively. Finally, the Thathari Bazar/Old Dhaka, Jatrabari, Adabor, and Khilgaon markets are classified as low-income markets and located in neighborhoods with a poverty headcount ratio above 10 percent (Figure 1). There are many different rice types sold in Dhaka, including premium fragrant rice such as domestic chinigura and kalijira rice and imported jasmine and basmati rice. Aromatic rice usually sells at a premium because of its exquisite fragrance; however, since fragrance is not one of the attributes measured in this study, we intentionally focused on long- and medium-grain rice, the most popular rice types sold in Bangladesh. We collected rice samples from a minimum of five different vendors from each market and recorded their retail market price, origin (domestic or imported), and whether the rice is parboiled and, if so, whether single or double parboiled.

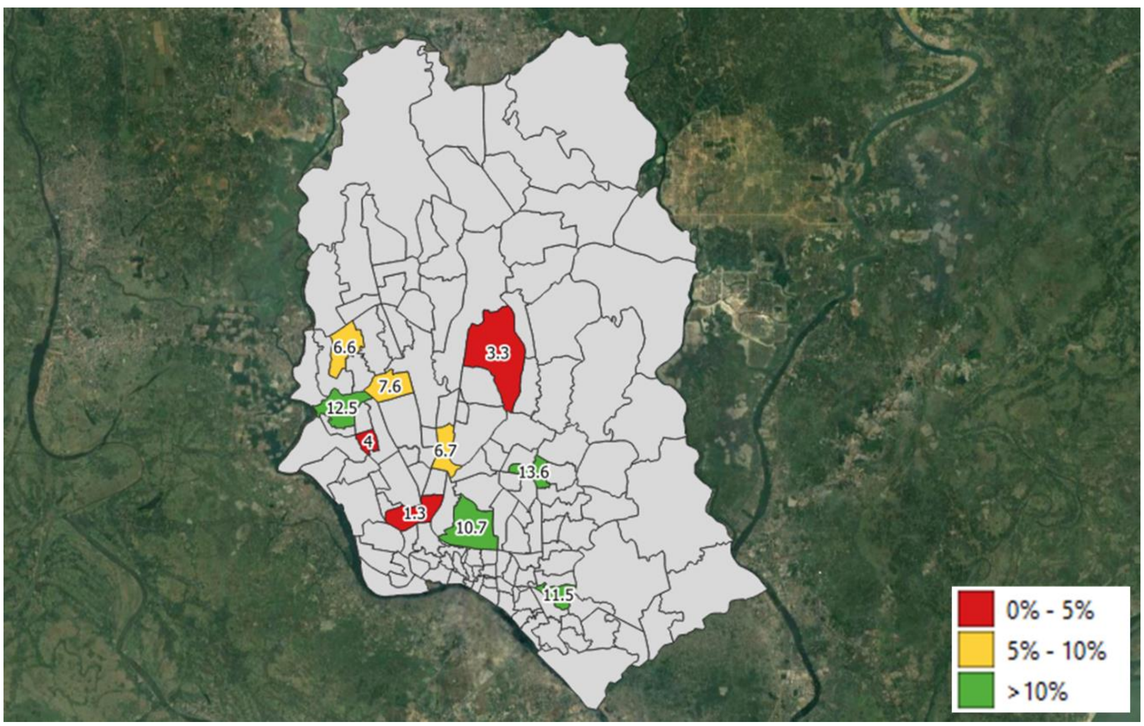

Figure 1. Location of the 10 selected markets in Dhaka, and poverty headcount ratio of the respective neighborhoods.

Measurement of physical attributes of rice

The rice samples were shipped to the U.S., where they went through physical analysis at the the University of Arkansas. The rice samples were processed to ascertain their quality based on the amount of broken and chalk rice, color, length, width, and homogeneity (e.g., long-grain, medium-grain, short-grain, mixed grains). The Vibe QM3 Rice Analyzer was used and calibrated to the Bangladeshi standard for milled rice (Appendix) developed by the Bangladesh Standards and Testing Institution (1981). The Vibe QM3 is an easy-to-use analysis and inspection instrument and shows absolute, accurate, and reproducible results for measuring, counting and classifying grain size, shape, and color. The Vibe QM3 rice analyzer is efficient, taking less than 30 seconds to analyze a 25-gram sample, and accurate, with a 0.5% accuracy of broken kernel detection and < 50 micron accuracy for kernel size and shape (length, width, area, and length to width ratio). Because of its very high resolution (3,000 color pixels per kernel), the Vibe QM3 rice analyzer can recognize any abnormal color and damage kernels such as chalky, black spot, yellow and red kernel for heat damage, and green kernels. The average size of the samples processed for this study was 750 grains of rice.

Milled rice is composed of head rice, defined by the Bangladeshi rice standard as a kernel whose length is at least 8/10 of the average length of the corresponding whole kernel, and broken rice, defined as a kernel whose length is less than 8/10 of the average length of the corresponding whole kernel (Bangladesh Standards and Testing Institution, 1981). The amount of broken rice in the sample is represented by the broken percentage, defined as:

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Where 9 $ü is the weight of broken rice in sample i.

There are two methods to estimate the amount of chalk rice: (1) the chalk percentage, defined as the weight of rice kernels with half or more of their area opaque and chalky relative to the weight of the sample, and (2) the chalk impact, defined as the kernel area across a sample that is opaque or chalk relative to the total kernel area in the sample. Chalk percentage is the measure used in the U.S. (USDA Grain Inspection Handbook), and is the measure used in this study. However, the Bangladesh standard does not specify how to measure chalkiness. The variable *Chalk percentage* is defined as:

$$Chalk\ percentage_i = \frac{WC_i}{Weight\ of\ Working\ Sample\ i} * 100 \qquad (iv)$$

where WC_i is the Weight of Chalk rice in sample i.

Color is measured in the CIELAB color space, a three-dimensional device independent “standard observer” color space model which includes all perceivable colors. CIELAB is made up of three channels: L*, which ranges from 0 to 100 and represents the lightness value of the color, where 0 and 100 indicate black and diffused white; a*, negative or positive values of which represent green or red respectively; and b*, representing blue as negative and yellow as positive value. The variable Color is estimated as:

$$Color_i = \sqrt{L_i^2 + a_i^2 + b_i^2} \qquad (v)$$

The higher the value of Color, the whiter the rice sample. Rice color is affected by many factors, including the genetic composition of rice varieties (Shinada et al., 2015), growing field conditions such as nighttime air temperature (Lanning and Siebenmorgen, 2013), aging of rice (Zhou et al., 2002), and processing variables such as degree of milling (Billiris et al., 2012; Yadav and Jindal, 2001) and parboiling (Lamberts et al., 2006).

The size of rice is measured by the length and width of the kernels (in millimeters). The length of rice in sample i is the average length across all kernels j in sample i:

$$Length_i = \sum_{j=1}^{n} length_{ij} \quad \text{(vi)}$$

The Bangladesh rice standard distinguishes four rice classes based on average kernel length: extra long grain (≥ 7.00 mm), long grain (6.0 mm. - 6.99 mm.), medium grain (5.0 mm. - 5.99 mm), and short grain (< 5.0 mm) (see Appendix).

Likewise, the width of rice in sample i is the average width across all kernels j in sample i:

$$Width_i = \sum_{j=1}^{n} Width_{ij} \quad \text{(vii)}$$

Finally, the shape of rice is measured by the length to width ratio (variable LWR) as follows:

$$LWR_i = Length_i / Width_i \quad \text{(viii)}$$

Based on the LWR, the Bangladesh rice standard distinguishes four rice classes: Slender (> 3.0), medium (2.4 - 3.0), bold/coarse (2.0 - 3.39), and round (< 2.0) (see Appendix).

Rice homogeneity refers to whether the rice sample can be considered of one type (e.g., long-grain or medium-grain rice), or a mixed of different types. We calibrated the Vibe QM3 Rice Analyzer following USDA's definition of milled rice classes (USDA Grain Inspection Handbook). According to this definition, milled rice can be classified as long grain if it contains no more than 10.0 percent of whole or broken kernels of medium or short grain rice. The same 10 percent mixed threshold applies for the definition of medium- and short-grain milled rice. The variable homogeneity was specified a a binary variable equal to 1 if the sample was mixed, and zero if it was classified as either long-, medium-, or short-grain rice.

Finally, we created two binary variables to identify whether the samples were of single- and double-boiled rice. In Bangladesh, single-boiled rice is produced following the traditional three-step process of (1) soaking, (2) steaming, and (3) drying paddy rice, while double-boiled rice is steamed twice (once before and once after soaking) and, hence, follows a four-step approach (Zaman, 2001).

Vendors identified all the rice samples collected for this study as domestic rice, which is expected considering that Bangladesh was 97.2 percent rice self-sufficient in the last five years (USDA, 2021). The lack of variability in the origin of rice (domestic versus imported) refrains us from assessing the impact of rice origin.

2.4 Piecewise Analysis

It is important to know if an independent variable affects the dependent variable differently over certain ranges. For instance, it may be that prices are not very sensitive to the broken rate under a threshold, say 15 percent, but at higher broken rates, the visual quality becomes more evident, and therefore, prices decrease at a different, higher rate. This is particularly important for the broken and chalk percentages, which can be altered by production and processing practices to match the market demand.

The steps involved in a piecewise analysis include (1) a preliminary visual assessment of the independent variable to identify a priori values for the slope and threshold point, and (2) the estimation of the regression using those a priori values to assess whether there is a statistically significant difference in the relationship between the independent and dependent variable. The piecewise analysis was performed using the NL command in Stata®.

3 Results and Discussion

3.1 Physical characteristics of rice

Table 1 shows the descriptive statistics of the retail price and the selected rice quality attributes for all samples. The average retail price was 63.84 BDT/Kg (0.764 US$/kg), with samples ranging from 44 to 100 BDT/kg (0.526 to 1.197 US$/kg). Of the total 300 rice samples analyzed, 209 were double-boiled, 45 single-boiled, and 46 non-boiled rice.

The broken rate ranged from 0.43% to 46.15%, with an average of 5.35%. The average broken rate is considered low by international trade standards, given that rice with 5% or less broken is typically classified as high-quality rice. To give some context of the high quality of the rice samples in our study, according to the USDA rice standard, U.S. No.1 grade rice must have 4 percent broken or less (Pitchford, J. B., and Handbook, U. G. I. (1995). Based on the Bangladeshi standard for milled rice (Appendix), a 5% broken rate corresponds to high-quality rice (Grade I) for both non-parboiled and parboiled rice (Bangladesh Standards and Testing Institution, 1981). The low average broken rate is explained in part by the fact that 84.7% of the samples are parboiled rice, which is known to reduce the amount of broken rice (Bruce and Atungulu, 2018).

The chalk rate ranged from 0% to 89.56%, with an average of 12.56%. The very large variability is partially explain by the fact that our samples include parboiled rice, which has a very low chalk rate as the parboiling process decreases chalkiness (Meresa et al., 2020). The average chalk rate of the samples corresponds to a U.S. No. 5 or No. 6 grade according to the USDA rice standard (Pitchford, J. B., and Handbook, U. G. I. (1995), while according to the Bangladeshi standard for milled rice (Appendix), a 13% chalk rate corresponds to sub-standard rice (Bangladesh Standards and Testing Institution, 1981).

Color ranged from 56.86 to 79.61, with an average of 68.76. Regarding rice size and shape, the average length, width, and LWR were 5.07 mm, 1.98 mm, and 2.62, respectively, which according to the Bangladeshi standard for milled rice (Appendix) corresponds to medium grain rice. The assessment of each sample by size and shape revealed that 95 samples correspond to medium grain, 16 to short grain, and 189 samples are considered mixes of different types.

shows the average price and value for each quality variable across the ten different markets, ranked by average price in descending order. The results from the Kruskal-Wallis test show that differences in prices and broken rate across markets are statistically significant ($p < 0.01$ and $p < 0.10$, respectively), while differences across markets for all other quality attributes considered are statistically the same.

Table 1. Descriptive statistics of the retail price of rice and selected rice quality attributes for 300 observation.

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Price (BDT/Kg)	63.84	11.32	44.00	100.00
Broken rate (%)	5.35	7.07	0.43	46.15
Chalk rate (%)	12.56	22.13	0.00	89.56
Color	68.76	5.27	56.86	79.61
Length (mm)	5.07	0.55	3.75	6.20
Width (mm)	1.98	0.29	1.56	2.63
LWR	2.62	0.51	1.59	3.90

Looking at the price difference across markets in more detail, we see that the average rice price is the highest in the high-income markets of Dhanmondi (market 1), Gulshan (2), and Mohammadpur (3) (**Error! Reference source not found.**), while the low-income markets of Thathari Bazar/Old Dhaka (7), Jatrabari (8), Adabor (9), and Khilgaon (10), have the lowest prices and no significant difference among them.

The statistical analysis for the average broken percentage across markets () reveals that the quality of the rice samples varies significantly across markets, and that the rice purchased in Mohammadpur (3) have the lowest, and that from Jatrabari (8) have the highest, broken percentage.

Table 2. Mean value of retail price and selected rice quality attributes by markets

Variable	**Markets**										
	3	**2**	**1**	**4**	**5**	**6**	**9**	**8**	**10**	**7**	**P-Value^**
Price (BDT/Kg)	72.77	69.3	68.3	65.43	64.36	63.66	60.77	59.47	57.5	56.87	0.000***
Broken rate (%)	3.75	4.53	5.42	4.02	6.25	5.95	4.06	8.11	6.03	5.35	0.096*
Chalk rate (%)	12.35	14.37	10.78	13.29	12.66	12.31	14.11	13.17	12.11	10.42	0.848
Color	69.67	69.23	68.8	68.95	68.9	67.39	68.89	69.35	68.2	68.21	0.825
Length (mm)	5.04	5.07	5.06	5.06	4.98	5.04	5.1	5.07	5.13	5.15	0.979
Width (mm)	1.92	1.93	1.93	1.99	1.97	1.97	1.96	2.05	1.99	2.06	0.217
LWR	2.7	2.71	2.7	2.61	2.59	2.61	2.64	2.53	2.61	2.53	0.867

*. Market variables 1 through 10 correspond to the following neighborhoods (1) Dhanmondi (high income), (2) Gulshan (high income), (3) Mohammadpur (high income), (4) Farmgate/Tejgaon (middle income), (5) Mirpur (middle income), (6) Agargaon Taltola (middle income), (7) Thathari Bazar/Old Dhaka (low income), (8) Jatrabari (low income), (9) Adabor (low income), and (10) Khilgaon (low income).

^. Kruskal-Wallis test. ***, **, * represent 1%, 5%, and 10% significance level.

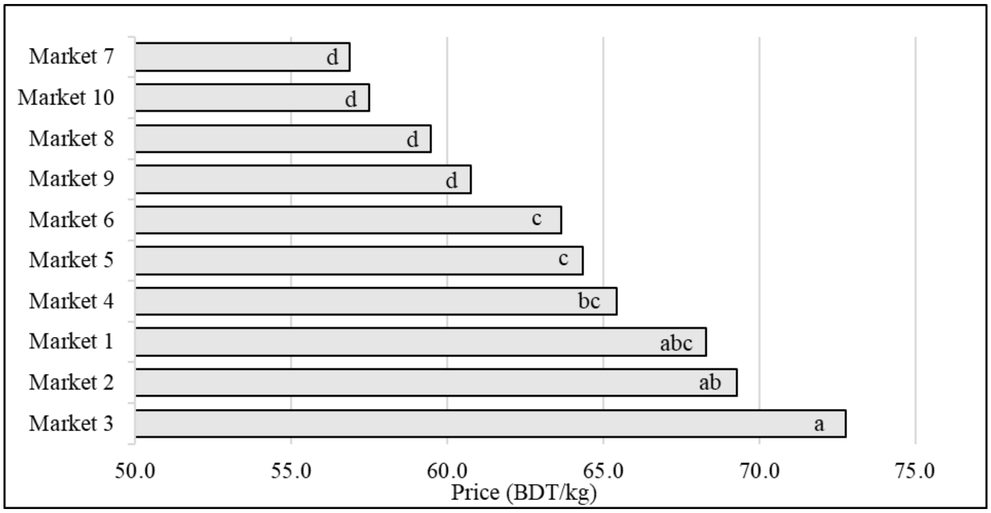

Figure 2. Statistical difference in rice price across markets[*].

*. Dunn's test. Different letters mean statistical difference at the 5% level. Market variables 1 through 10 correspond to the following neighborhoods (1) Dhanmondi (high income), (2) Gulshan (high income), (3) Mohammadpur (high income), (4) Farmgate/Tejgaon (middle income), (5) Mirpur (middle income), (6) Agargaon Taltola (middle income), (7) Thathari Bazar/Old Dhaka (low income), (8) Jatrabari (low income), (9) Adabor (low income), and (10) Khilgaon (low income).

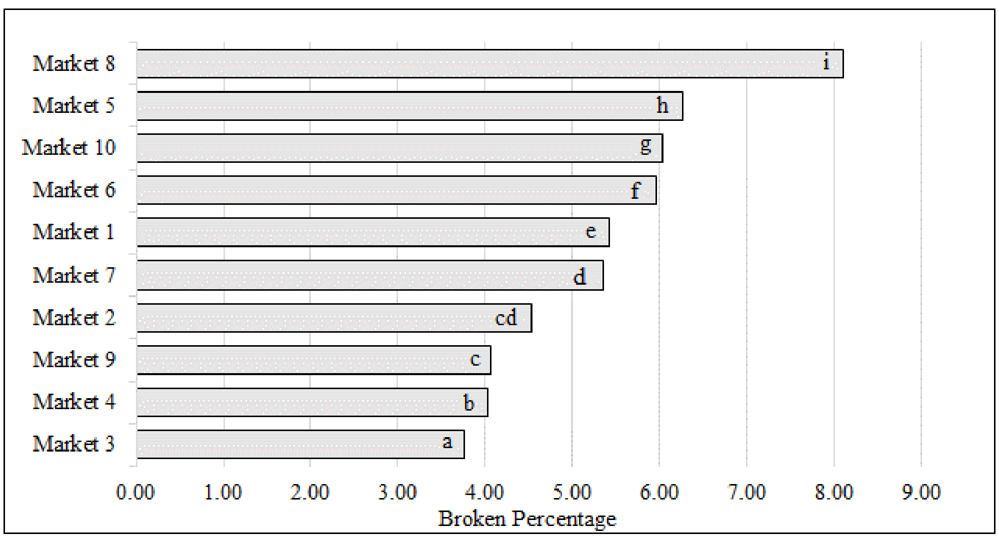

Figure 3. Statistical difference in broken percentage across markets

*. *. Dunn's test. Different letters mean statistical difference at the 5% level. Market variables 1 through 10 correspond to the following neighborhoods (1) Dhanmondi (high income), (2) Gulshan (high income), (3) Mohammadpur (high income), (4) Farmgate/Tejgaon (middle income), (5) Mirpur (middle income), (6) Agargaon Taltola (middle income), (7) Thathari Bazar/Old Dhaka (low income), (8) Jatrabari (low income), (9) Adabor (low income), and (10) Khilgaon (low income).

shows the results for the piecewise analysis for broken rice and highlights the existence of two distinctive segments: a first segment from 0 to 24.94 broken percentage with a slope of -0.404 ($p < 0.05$) (which means that the rice price decreases by BDT 0.404/kg for every percentage increase in the broken percentage), and a second segment of the curve with a steeper slope that is not significantly different from zero ($P>0.10$). below shows the distribution of the original and fitted values and the threshold broken percentage at which the slope changes significantly. Base on this analysis, the disaggregation of the variable broken percentage into two variables is warranted. Thus, the broken percentage variable is split into the following two variables:

- Broken percentage 1: includes the observations with a broken perentage less than or equal to 24.94 percent, and zero otherwise
- Broken percentage 2: includes the observations with a broken percentage greater than 24.94 percent, and zero otherwise

Given that the variables Broken percentage 1 and Broken percentage 2 include zero values, then these are included in nominal (rather than logarithmic) terms in the regression.

Table 3. Results from the piecewise regression analysis for broken percentage.

Price	Coefficient	Std. Error	P>t
Intercept 1	66.083	0.951	0.000***
Slope 1	-0.404	0.165	0.015***
Intercept 2	24.940	38.977	0.523
Slope 2	-0.619	0.573	0.281
Observations	300		
R-squared	0.084		

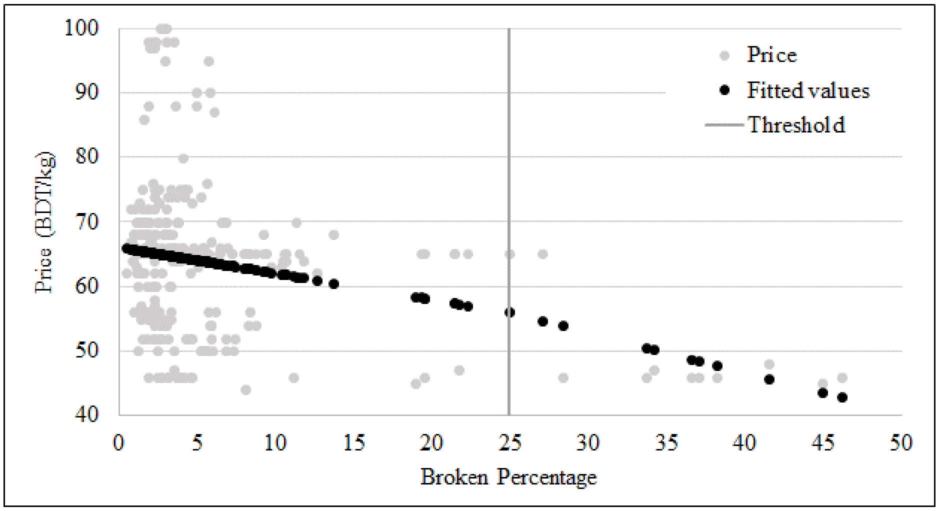

Figure 4: Scattered plot of original and fitted values of broken percentage, and threshold of broken percentage indicating a change in slope.

The same approach was used to ascertain whether there was a difference in the relationship between rice price and chalk percentage, and the results show that the Chalk percentage can be treated as a single variable with the same relationship to price over the range observed in the samples.

3.2 Results of the Pure Hedonic Price Model

As a result of the descriptive analysis conducted and shown above, two hedonic price models were estimated, namey, Model 1 with no market fixed effects, and Model 2 with market fixed effects[1]. Both models include the following set of rice quality covariates: Broken percentage 1, Broken percentage 2, Chalk percentage, LWR, Color, Homogeneity, Double-boil, Single-boil.

[1] Market variables 1 through 10 correspond to the following neighborhoods (1) Dhanmondi (high income), (2) Gulshan (high income), (3) Mohammadpur (high income), (4) Farmgate/Tejgaon (middle income), (5) Mirpur [1] (middle income), (6) Agargaon Taltola (middle income), (7) Thathari Bazar/Old Dhaka (low income), (8) Jatrabari (low income), (9) Adabor (low income), and (10) Khilgaon (low income).

Both models were found to have no problems of heteroscedasticity and collinearity according to the Breusch-Pagan and variance inflation factor tests, respectively.

The dependent variable price, and the independent continuous variables LWR and Color are expressed in logarithm. Because of the presence of zero values, the variables Broken percentage 1, broken percentage 2, and Chalk percentage are expressed in nominal terms. Homogeneity is a binary variable equal to 1 if the rice is a mixed of different types (long, medium, or short grain), and zero if it is not mixed. Finally, double-boil and single-boil are also binary variables equal to 1 if the rice is double or single boiled, respectively, and zero otherwise.

shows the results for the two hedonic price models. Model 1 presents the best fit (highest F value) among the two models, which suggests that consumers value the selected rice quality attributes similarly regardless of market fixed effects. The magnitude and significance of the coefficients of the selected quality variables is similar between Model 1 and 2, which is a sign of the robustness of the findings.

The results suggest that broken percentage at a rate below 24.9 percent (variable *Broken percentage 1*) has no impact on rice prices, whereas at rates above 24.9 percent (variable *Broken percentage 2*) modestly but significantly ($p<0.05$) decreases the price of rice. To illustrate, the results from Model 1 and Model 2 (coefficient of -0.0025 and -0.0020 for *Broken percentage 2*, respectively) suggest that a 1-percent increase in the broken percentage above 24.9 reduces the price of rice by 0.25 percent and 0.20 percent, respectively. The negative relationship between broken percentage and rice prices was expected as a high broken rate is commonly associated with lower-quality rice as found by Afsar et al. (2012) for Bangladesh and more generally in studies conducted in Asia (Custodio et al., 2019). The findings of this study suggest that the impact of broken rice differs depending on its level, and if prices truly reflect consumer preferences, that consumers are indifferent about the amount of broken rice up to a rate of 25 percent.

Chalk rice (*Chalk percentage*) has a small but significant ($p<0.01$) impact on rice price in both models. The results from Model 1 and Model 2 (coefficient of -0.0016 and -0.0015 for Chalk percentage, respectively) suggest that a 1-point increase in the chalk percentage reduces the price of rice by 0.16 percent and 0.15 percent, respectively. These significant but marginal impacts reveal that consumers in Bangladesh are largely indifferent to the presence of chalk rice, which may be influenced by the fact that most of the rice consumed in Bangladesh is parboiled, which changes the color of rice from white to more yellow and changes the visual aspect of chalk rice. Custodio et al (2016) report that a 1-percent increase in overall chalkiness reduces rice price by 0.10 in Bangladesh, a modest impact simiar to the one found in this study.

Color has a positive and significant ($p<0.05$) impact on price in both models. Since color is specified in a log form (variable *Log_color*), the coefficients can be interpreted as elasticities. Thus, the results suggest that a 1-percent increase in Color (whiteness) results in a 0.412 percent and 0.319 percent increase in the price of rice in Model 1 and Model 2, respectively. The positive relationship between color and price is supported by the previous findings by Custodio et al. (2016), which show that consumers consistently rank whiteness as a valuable rice quality attribute. Nevertheless, it is interesting to note that most rice consumed in Bangladesh is parboiled, which is less white than non-parboiled rice, and despite our objective measurement, whiteness is a subjective attribute in the eyes of consumers.

The shape of rice (variable Log_LWR) has a significant ($p<0.001$) and positive impact on rice price, increasing it by 0.224 percent and 0.230 percent for every 1-percent increase in LWR under the assumptions of Model 1 and Model 2, respectively. This finding aligns with previous results reported by Custodio et al. (2016), which suggest that Bangladeshi consumers value slenderness greatly.

Regarding the homogeneity of rice (*Homogeneity*), the results suggest that rice mixes have a positive (0.154 and 0.139 for Model 1 and 2, respectively) and significant (p<0.001 for both models) impact on rice prices relative to pure types (e.g., long grain, medium grain, and short grain). To our knowledge, this is the first study objectively assessing this attribute, but the results are counterintuitive since we expected that rice mixes would have an inferior appearance and be priced lower than more homogeneous-looking rice.

Finally, Model 2 shows that, all else equal, rice is priced significantly (p<0.001) lower in the four low-income markets of Thathari Bazar/Old Dhaka (variable Market 7), Jatrabari (variable Market 8), Adabor (variable Market 9), and Khilgaon (variable Market 10), than in Dhanmondi (Market 1).

3.3 Marginal price effects

To better understand the impact of the rice quality attributes on the price of rice in Bangladesh, we calculate their marginal effects using the estimates from Model 1 and Model 2 () and the distribution of the quality attributes (Table 1). We ascertain the effect of each quality attribute on rice price by estimating the rice price at the minimum and maximum attribute values observed in our study, keeping all other independent variables at their mean values. Thus, the marginal price effect shows how much the price of rice changes with changes in the quality variables in the model.

The shape of rice, represented by the LWR, has the largest impact on rice price over the range observed in this study (). Looking at Model 1, the price for rice with a low LWR of 1.59 is 10.6

percent lower than the average, while for slender rice high a LWR of 3.90 is 9.6 percent above the average market price. Homogeneity also has a significant (although counterintuitive) marginal effect, and attracts a 9.3 percent discount if it is a homogeneous sample and a 5.9 percent premium if it is mixed relative to the average market price. Changes in the chalk percentage over the range observed in this study affect rice price from an 11.3 percent discount for rice with a chalk percentage of 89.56 to a 2.0 price premium for rice with a chalk percentage of zero. Finally, a broken percentage above 24.94 (variable Broken percentage 2, which has a mean value of 1.31 percent, representing a broken percentage of 26.25) can change rice price from a discount of 10.9 percent for the highest broken rate observed in this study (46.15 percent) to 0.3 percent premium for rice with exactly 24.94 percent broken rate (*Broken percentage 2* = 0).

Table 4. Results of Pure Hedonic Price Model

Log_price	Mode 1			Model 2		
	Coefficient	Std. Error	P-Value	Coefficient	Std. Error	P-Value
Constant	2.136	0.726	0.004***	2.536	0.657	0.000***
Broken rate 1	0	0.002	0.96	0.003	0.003	0.278
Broken rate 2	-0.002	0.001	0.043**	-0.002	0.001	0.075*
Chalk rate	-0.002	0.001	0.009***	-0.001	0.001	0.008***
Log_color	0.412	0.177	0.021**	0.319	0.159	0.045**
Log_LWR	0.224	0.056	0.000***	0.23	0.042	0.000***
Homogeneity	0.154	0.019	0.000***	0.139	0.017	0.000***
Double-boil	-0.023	0.024	0.349	-0.025	0.021	0.241
Single-boil	-0.037	0.032	0.243	-0.029	0.028	0.3294
Market 2				0.014	0.033	0.7675
Market 3				0.054	0.037	0.143
Market 4				-0.028	0.035	0.423
Market 5				-0.045	0.032	0.165
Market 6				-0.062	0.03	0.037**
Market 7				-0.151	0.032	0.000***
Market 8				-0.117	0.038	0.002***
Market 9				-0.121	0.037	0.001***
Market 10				-0.15	0.035	0.000***
Observation	300			300		
F	34.18			21.81		
R^2	0.34			0.491		
Adj. R^2	0.3219			0.4603		

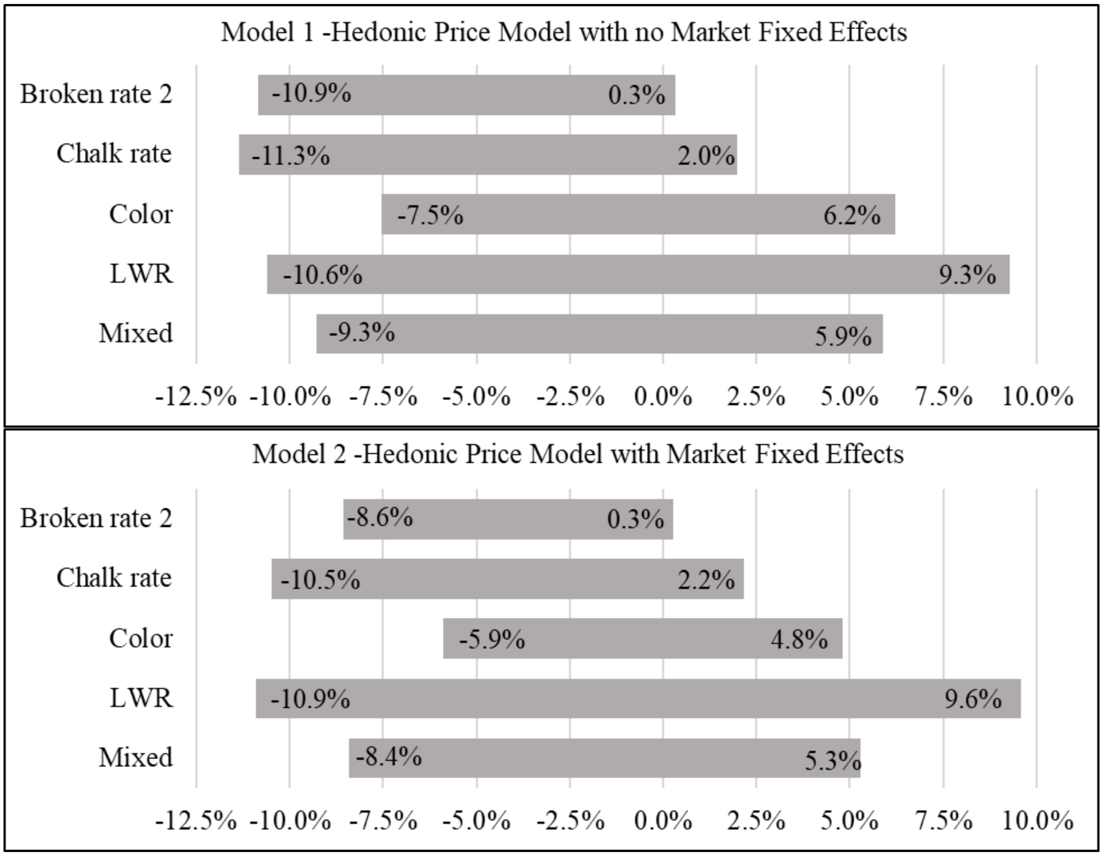

Figure 5: Marginal price effect of selected rice quality attributes for hedonic price Model 1 (no market fixed effects) and Model 2 (with market fixed effects).

4 Conclusion

The rice sector is a major contributor to the agricultural economy, and is the main staple food for nearly every household in Bangladesh. The dominance of rice in the agricultural production and consumption matrix heightens the importance of ensuring that markets work efficiently in the sense of pricing rice according to the quality offered so that consumers can choose the rice options that best fits their preferences and budgets, and the supply chain can properly source and generate the rice products to meet that demand. This study estimates the economic value of the selected intrinsic rice quality attributes deemed of importance in Bangladesh using a hedonic price model estimated based on 300 rice samples collected in Dhaka.

The results suggest that the broken percentage, chalk percentage, LWR, color, and homogeneity of rice all have a statistically significant impact on rice prices. The shape of rice, represented by the LWR, has the largest impact on rice price, followed by homogeneity. The chalk percentage has a modest impact, while the broken percentage is statistically significant only when rates go above 24.94 percent, and even then it has only a marginal impact on rice prices.

The fact that the broken rate has such a minor impact on rice prices highlights a potentially relevant market inefficiency, because broken rice traditionally carries a price discount vis-à-vis whole rice that in this case is not being transmitted to consumers. This scenario is problematic from a food security perspective in two possible ways. First, it may mean that the market is overpricing rice with high percentage of broken rice to the detriment of consumers that prefer that type of rice but are forced to pay a higher than fair price. Second, the striking difference between the (low) average broken percentage among the rice samples used in this study and the threshold broken percentage of 24.94 at which rice prices react to the broken percentage may mean a potential missing opportunity for selling more broken rice for human consumption.

Pricing rice accurately based on the broken percentage could improve food security by allowing consumers to either (1) afford to buy more rice with a given budget, or (2) improve the intake of other food items by buying the same amount of rice for less. Furthermore, it could lead to environmental benefits related to a higher efficiency in the production of rice food rations per hectare. For example, at Bangladesh’s average yield of 4.4 metric tons of paddy rice per hectare (USDA, 2021) and an average 55/70 (55 % whole rice, 70% milled rice) paddy rice quality, which is considered the standard for commercialization in the U.S., one hectare of rice generates

2,420 kilograms of whole rice and 660 kilograms of broken rice[1]. Using that paddy rice to produce milled rice with a 5-percent broken rate yields 2,547 kilogram of milled rice per hectare, or 14 rice rations per year at the average per-capita consumption of 181.3 kg per year observed in Bangladesh, and results in a surplus of 533 kilograms of broken rice. Producing milled rice with a 15-percent broken rate yields 2,847 kilograms of milled rice per hectare or 16 rice rations per year, and generates a surplus of 233 kilograms of broken rice. Finally, using the whole amount of broken and whole rice yields 3,080 kilograms of milled rice with a broken rate of 21.4 percent[2], sufficient to feed 17 people per year. In perspective, assuming that the surplus broken rice generated in the production of milled rice with 5-percent brokens is not consumed by humans but used for other purposes (e.g., feed or energy), then the numbers above suggest that it would take 11.4 million hectares to feed the entire Bangladeshi population (160 million people) with milled rice with 5-percent broken, and 9.4 million hectares with rice with 21.4 percent broken, a saving of 2 million hectares.

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[1] The amount of whole and broken rice produced by hectare in Bangladesh assuming an average rice yield and a quality equivalente to a 55/70 paddy rice is estimated as follows:
Whole rice = 4,400 kg paddy rice/ha * 0.55 = 2,420 kg/ha
Broken rice = 4,400 kg paddy rice/ha * (0.70-0.55) = 660 kg/ha

[2] The broken rate (by weight) is estimated as the weight of broken rice divided by the weight of milled rice. Thus, the broken rate for a 55/70 paddy rice equals 0.15/0.70 = 0.214.

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6 Appendix

Bangladesh Standard Specification for Grades on Milled Rice (First Revision, BDS 592 : 1981).

Table 1. Clasiffication of rice varieties based on size and shape, and definition of head and broken rice.

Size
Extra long grain: ≥ 7.00 mm.
Long grain: 6.0 mm. - 6.99 mm.
Medium grain: 5.0 mm. - 5.99 mm
Short grain: < 5.0 mm.
Shape (Length/Breadth)
Slender: > 3.0
Medium: 2.4 - 3.0
Bold (Coarse): 2.0 - 3.39
Round: < 2.0
Definition of head and broken rice
Head rice: ≥ 8/10 of grain length
Broken rice: ≥ 1/2 of grain length
Small broken rice: ≤ 1/2 of grain length

Table 2. White (non-parboiled) rice standard.

Item No.	Grading factor	Grading requirements			
		Grade-I	**Grade-II**	Grade-III	Grade-IV
1.	Moisture, percent by mass (max.)	14.0	14.0	14.0	14.0
2.	Head rice, percent (min.)	90.0	85.0	75.0	68.0
3.	Big brokens, percent (max.)	8.0	12.0	20.0	25.0
4.	Broken and small brokens, percent (max.)	2.0	3.0	5.0	7.0
5.	Damaged grain, percent (max.)	0.5	1.0	2.0	3.0
6.	Contrasting varieties, percent, (max.)	2.0	5.0	10.0	15.0
7.	Chalky/immatured grain percent, (max.)	1.0	2.0	3.0	4.0
8.	Paddy (grain per 1000 gm.)	1.0	2.0	3.0	4.0
9.	Foreign matters, percent, (max.)	0.2	0.3	0.5	1
10.	Degree of milling	Extra well milled	Well milled	Reasonably milled	Under milled

Notes: (1) Any rice not falling in any of the above grades shall be considered as sub-standard. (2) The grade requirements are expressed in percentage except for paddy seeds.
Source: Bangladesh Standards and Testing Institute, 1981.

Table 3. Parboiled rice standard

Item No.	Grading factor	Grading requirements			
		Grade-I	Grade-II	Grade-III	Grade-IV
1.	Moisture, percent by mass (max.)	14.0	14.0	14.0	14.0
2.	Head rice, percent (min.)	95.0	90.0	85.0	80.0
3.	Big brokens, percent (max.)	4.0	8.0	12.0	16.0
4.	Brokens and small brokens, percent (min.)	1.0	2.0	3.0	4.0
5.	Damaged grain, percent (max.)	0.5	1.0	2.0	3.0
6.	Contrasting varieties, percent (max.)	2.0	5.0	10.0	15.0
7.	Paddy (grain per 1000 gm.)	1.0	2.0	3.0	4.0
8.	Foreign matters, percent (max.)	0.3	0.4	0.5	1.0
9.	Degree of milling	Extra well milled	WELL MILLED	Reasonably well milled	Under milled

Notes: (1) Any rice not falling in any of the above grades shall be considered as sub-standard. (2) The grade requirements are expressed in percentage except for paddy seeds.
Source: Bangladesh Standards and Testing Institute, 1981.