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# CHANGES IN THE ZINC CONTENT OF SELECTED BANGLADESHI RICE VARIETIES THROUGH MODIFIED PARBOILING AND MILLING METHODS

**S.S. Dipti[1*], C. Hotz[2], K.A. Kabir[3], M. Bipul[4]**

[1]Grain Quality and Nutrition Division, Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh
[2]Nutridemics, 85 East Liberty Street, Unit 506, Toronto, ON, M6K 3R4, Canada
[3]Consultant, Uttara Sector-7, Dhaka 1230, Bangladesh
[4]GAIN-Bangladesh, North Gulshan-2, Dhaka-1212, Bangladesh

## ABSTRACT

Zinc deficiency is prevalent among women and children in Bangladesh, and methods to increase the zinc content of parboiled rice could contribute to its prevention. We quantified the effect of modified parboiling conditions on zinc content and of the degree of milling on zinc and phytate contents of Bangladeshi rice varieties. Parboiling studies varied the conditions used in the local commercial operations, including pre-steaming and soaking times, change of soaking water, and steaming pressure. Milling studies used 10 Bangladeshi varieties at 0% (brown), 2%, 4%, 6%, 8%, and 10% degree of milling. With ambient soaking water, shorter soaking time was observed with a higher zinc content in brown rice, but not in 10% milled rice, and changing soaking water did not modify zinc content in brown or 10% milled rice. Pre-steaming time and open- *vs.* closed-system steaming had no significant effect on brown or 10% milled rice zinc content. Reducing the degree of milling from 10% to 6% or 4% resulted in a mean increase in zinc content of 27% and 47%, respectively, and an increase in phytate content of 35% and 72%, respectively. Zinc content in milled rice did not appear to be significantly affected by the parboiling conditions tested. While lower degree of milling resulted in higher zinc content, it is uncertain whether the higher phytate content would fully negate this increase by decreasing the bioavailable fraction of zinc. Human studies of zinc bioavailability from Bangladeshi rice at different degrees of milling are warranted.

**Keywords:** Degree of milling, parboiling, phytate, rice

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[*] Corresponding author e-mail: sharifadipti@gmail.com

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## INTRODUCTION

In Bangladesh, zinc deficiency is highly prevalent, affecting 45% of preschool children and 57% of non-pregnant, non-lactating women (ICDDRB et al., 2013). However, large-scale programs to prevent zinc deficiency are not currently being implemented. Rice provides 70% of *per capita* caloric intakes (FAO, 2009) in Bangladesh and hence is the most important staple food. Modifications to the zinc content of rice could provide a useful opportunity to deliver larger amounts of dietary zinc to the population.

Most rice in Bangladesh is parboiled and milled, and these post-harvest processes present potential opportunities to increase the zinc content of rice. Parboiling is the process by which rice paddy is hydrated and the starch then gelatinized by hydrothermal treatment, achieved by soaking and steaming. It has long been known that parboiling substantially increases milled rice thiamin content (Hinton, 1948), and the retention of thiamin in milled parboiled rice was shown to be maximized by optimizing the parboiling conditions (Subba and Bhattacharya, 1966). Some information also suggests that modernized methods of commercial parboiling (e.g., hot soaking, pressure steaming) may not only reduce processing time and improve the quality of the parboiled rice product, but also increase the content of some nutrients, including minerals (Ituen and Ukpakha, 2011 and Mazumder et al., 1960). The impact of these parboiling methods on zinc content of rice has not been studied systematically.

The ‘degree of milling’ of rice, expressed as the percent by weight of the milling fractions removed, is approximately 8-10% for commercially milled rice. Some studies have quantified the retention of zinc in rice at different degrees of milling, but the results are quite variable, ranging from as low as 55% (Pedersen and Eggum,1983) to >90% (Doesthale et al., 1979) for well milled rice. The potential to increase rice zinc content by using lower degrees of milling has not been quantified for rice varieties commonly consumed in Bangladesh.

The objective of this study was to determine the potential impact of modified parboiling conditions and degree of milling on the zinc content of rice using selected Bangladeshi rice varieties.

## MATERIALS AND METHODS

### Collection of Samples

We conducted studies using Bangladeshi rice varieties to quantify the effect of reduced degree of milling and of modified parboiling processes on rice zinc content. The conditions tested for parboiling and pre-treatment of rice were simulated to reflect the range of conditions used in local small- and large-scale rice mills and that could potentially be optimized without the need for additional equipment. All studies were conducted in the Grain Quality & Nutrition Laboratories at the Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh.

## Parboiling studies

For these studies, open (non-pressurized) and closed (pressurized) steaming systems were used after soaking. The open-steam method Autoclave was used at 100°C temperature but no pressure, and the pressure steam was obtained by placing the soaked paddy in a pressurized autoclave (Pressure 1kg $cm^{-2}$) with a water vessel to produce steam.

Soaking raw rice paddy in ambient temperature water without pre-steaming, following by open steaming represents conditions commonly used in traditional and semi-automatic rice mills, where batches of paddy are soaked in large tanks using tube well water to achieve adequate hydration, indicated when paddy husks begin to split, typically after 24-72 hours. During this time, soaking water may be changed every 12 hours to avoid microbial growth and fermentation. Soaked paddy is transferred to open tubular vessels, and steam is applied through a perforated pipe inserted in the center. Pre-steaming paddy prior to soaking has accelerates the time to achieve adequate hydration by raising the temperature of the paddy and soaking water. Pre-steaming followed by soaking and open-system steaming is used in small and large commercial mills using manual and semi-automatic operations. Pre-steaming followed by soaking and closed-system steaming is used in the larger commercial automatic mills. In this case, all steps are performed in a closed (pressurized) tubular tank with steam injectors. Our processing methods were designed to replicate these processes, as described below.

The parboiling studies were conducted in two sets. One set using ambient soaking water conditions and the open-steaming system, which considered soaking time and the intermittent changing of soaking water as variables. The second set used pre-steaming followed by soaking and either open- or closed-system steaming, where pre-steaming time and soaking time were considered as variables. All studies used paddy of a common rice variety, BRRI dhan29, derived from one homogenized batch.

## Pre-steaming

Pre-steaming was determined by steaming paddy for two or five minutes in an autoclave at 100 C, 0 g $cm^{-2}$, with a vessel of distilled water placed inside as a source of steam. After two and five minutes pre-steaming water was added. The temperature of the soaking water increased to 37°C followed by 38°C but eventually water temperature became 30°C.

## Soaking

Paddy samples (1 kg) were immersed in 2.5 litre distilled, deionized water (Barnstead Fistreem III Glass Still, Model A56220-857, Fistreem International Ltd., UK, and Barnstead E-Pure Ultrapure Water Purification Systems, Model: D4642-33, Thermo Fisher Scientific, USA). For the first studies, paddy was soaked in ambient temperature water (~25 C) for up to 48 hours, with samples drawn at 0, 12, 24, 36 and 48 hours. In a subset of samples, excess water was decanted at 12 hour intervals starting at 12 hours and replaced with fresh water. For the second studies, paddy was pre-steamed prior to soaking in distilled deionized water for 12 hours, with samples drawn at 0, 3, 6, 9 and 12 hours.

## Steaming

Open steam parboiling was replicated by putting the soaked paddy samples in a mesh bag and autoclaving (JSAC-40, JS Research Inc, South Korea) at 100 C, 0 kg $cm^{-2}$ for 30 minutes. A vessel of distilled water served as a source of steam. The closed steam parboiling system was replicated similarly but using the autoclave under pressure (10 minutes, reaching 121 C, 1 g $cm^{-2}$). Parboiled paddy samples were left to cool and then laid out on individual polyethylene sheets; these were partially dried in the laboratory under a fan and drying was completed under the sun until a moisture content of 13-14% was reached. Dried samples were dehusked and milled to 10% degree of milling following procedures described below.

## Milling studies

Ten rice varieties were selected to represent popular varieties produced in the two main growing seasons, Boro (irrigated) and Aman (rainfed). Ten rice varieties name are presented in table 1. Nine of the selected varieties were developed and released by BRRI and one is of Indian origin but popular in Bangladesh. For these studies, one standard soaking and parboiling method was used. Ambient temperature soaking water (25 C for 24 hours) followed by parboiling with the open steaming system described above was used.

## Dehusking and milling

Outer husks were removed from dried paddy using a Satake Testing Husker (Model THU-35B, Satake Corporation, Hiroshima, Japan) with rubber rollers coated with polyvinyl chloride compound to avoid mineral contamination. The dehusked brown rice was milled using a Grainman tester mill (Model 60-220-50-DT, Grain Machinery Manufacturing Corporation, Miami, FL, USA). Six different degrees of milling were tested: 0%, 2%, 4%, 6%, 8%, and 10%, where 10% represents well-milled, polished rice, and the lower levels represent under milled rice. The degree of milling was calculated as the percent of outer milling fraction removed by weight using equation (1):

*% milling degree = 100 – [weight of milled rice (grams) / weight of brown rice (grams)] × 100*

For each rice variety, the milling time in seconds needed to achieve each degree of milling was calibrated using 100 grains, in triplicate, and the milling time was then applied to samples. Each sample was milled in 2 × 100 g lots and pooled.

Table 1. Bangladeshi rice varieties used in studies of degree of milling on zinc and phytate content

| Variety name | Season | District of origin | Description |
|---|---|---|---|
| BRRI dhan28 | Boro | Barisal | One of most highly produced varieties |
| BRRI dhan29 | | Gazipur | One of most highly produced varieties |
| BRRI dhan47 | | Satkhira | Popular rice variety, salt tolerant |
| BRRI dhan49 | | Rangpur | New variety to replace BR11 with better grain quality |
| BRRI dhan55 | | Gazipur | New variety |
| BRRI Hybrid3 | | Gazipur | One of most highly produced hybrid varieties |
| BR11 | Aman | Rajshahi | One of most highly produced varieties |
| BR16 | | Gazipur | Popular rice variety, low glycemic index |
| BRRI dhan52 | | Gazipur | New variety |
| Swarna | | Kushtia | Indian variety, popular among rice millers |

### Analysis of zinc and phytate content

Primary analysis for these samples was performed using atomic absorption spectrophotometry (AAS; Shimadzu Model AA-6800, Shimadzu Corporation, Tokyo, Japan). Samples were digested following an established method (IRRIASL, 2010). Briefly, 300-400 mg of oven-dried sample was weighed into 50 ml Erlenmeyer flasks, to which were added 12 ml each of 1:10 (v:v) 69-72% $HClO_4$ and 65% $HNO_3$. Duplicate samples were digested on a hotplate to completion (>7 hours), dissolved and made up to 25 ml using 1% $HNO_3$, and transferred to polypropylene tubes for AAS analysis. Blanks and quality control samples were subjected to the same digestion procedure. A certified standard reference material (SRM1568a, rice flour, National Institute of Standards and Technology, Gaithersburg, MD, USA) and pooled internal control sample of rice grains were included in each run. Intra-run and inter-run CVs were calculated for the standard reference material. In addition, a subset of samples was submitted to a reference laboratory (Waite Analytical Services, Adelaide, Australia) for duplicate analysis by ICP-OES (Wheal et al., 2011). Phytate content was determined using Dionex liquid chromatography at the School of Biological Sciences, Flinders University, Adelaide, Australia. Phytate was extracted using 1.25% $H_2SO_4$ and 200 mmol /l NaOH in deonized water was used as an eluant (Kim et al., 2007).

### Data analysis

For the degree of milling studies, data on zinc content (µg $g^{-1}$) are presented on a dry weight basis as the mean ± SD of Boro and Aman rice varieties and all varieties combined. For the parboiling studies, data shown are the mean ± SD of duplicate analysis of the same sample. Differences in zinc content by degree of milling were determined by ANOVA with Tukey’s post-hoc analysis. For samples that were not pre-steamed, the effect of soaking time and changing of soaking water on the zinc content of 0% and 10% milled samples were determined independently by ANOVA. For samples that were pre-steamed, the independent effects of pre-steaming time and soaking time on zinc content of 0% and 10% milled rice were similarly determined for the open and closed parboiling systems.

## RESULTS AND DISCUSSION

### Zinc content at different soaking times, with and without changing water

Longer soaking time resulted in an 11% decrease in zinc content in the brown rice samples between 0 and 48 hours ($P < 0.05$) but no significant effect was observed in the 10% milled rice samples. The zinc content of parboiled brown and milled BRRI dhan29 rice produced by different soaking times and with or without changing soaking water are presented in Table 2. There was no significant effect of changing water on the zinc content of rice in either brown or 10% milled rice samples.

For the samples pre-steamed for 2 minutes and 5 minutes, the soaking water temperature initially rose to 37 C and 38 C, respectively, and then decreased to 30 C in both sets of samples. There was a trend towards decreasing zinc content with increasing soaking time for the brown and 10% milled rice samples at either pre-steaming time, but this was only significant for the samples that were subsequently parboiled with closed system steaming ($P<0.05$) but not with open steaming (Table 3). The zinc content of parboiled BRRI dhan29 rice with different pre-steaming and soaking times, followed by open- or closed-system steaming are presented in Table 3. The longer pre-steaming time of 5 minutes compared to 2 minutes did not have a significant effect on zinc content of brown or 10% milled rice in either the open or closed steam systems.

When data were pooled for samples across all soaking and pre-steaming times, there was no overall significant difference between the open and closed steam parboiling methods on the zinc content of brown rice (23.1 ± 0.9 vs 22.6 ± 0.8, respectively; $P > 0.05$, n=20) or 10% milled rice (11.7 ± 0.6 vs 11.9 ± 1.5, respectively; $P > 0.05$, n=20).

### Zinc and phytate contents of brown and milled rice by degree of milling

The zinc and phytate contents of brown and milled rice by degree of milling are presented in table 4. A step-wise decrease in zinc content was observed with increasing degree of milling for boro and aman parboiled rice varieties alike. Figure 1 shows with all rice varieties combined, zinc content of milled rice was significantly lower than in brown rice starting at 4% degree of milling; the retention of zinc was reduced to approximately three-quarters at 4% degree of milling, two-thirds at 6%, and about half at 10% degree of milling.

Table 2. Zinc content of parboiled brown and milled BRRI dhan29 rice produced by different soaking times and with or without changing soaking water.

| Rice type | Treatment | Soaking time (hours)[a] | | | | | Soaking time | Water change |
|---|---|---|---|---|---|---|---|---|
| | | 0 | *12* | *24* | 36 | 48 | *P*[b] | *P*[c] |
| | | *Zinc, µg/g*[d] | | | | | | |
| Brown rice | No water change | 24.7<br>1.6 | ± 23.7<br>0.7 | ± 24.0<br>1.6 | ± 22.8<br>0.5 | ± 22.1<br>0.9 | ± | |
| | Water changed[e] | - | - | 23.7<br>2.2 | ± 23.6<br>0.2 | ± 22.0<br>0.1 | ±* | ns |
| 10% polished | No water change | 14.0<br>1.5 | ± 12.7<br>0.3 | ± 12.3<br>0.1 | ± 12.0<br>1.1 | ± 11.3<br>1.1 | ± | |
| | Water changed[e] | - | - | 13.8<br>0.1 | ± 13.7<br>1.1 | ± 12.8<br>1.3 | ±ns | ns |

[a] Rice paddy was soaked in distilled, deionized water at ambient temperature (25 C). All samples were open parboiled in an autoclave (30 minutes, 100 C, 0 g/cm$^2$).

[b] A statistically significant effect of soaking time was tested for by ANOVA:*, *P* <0.05; ns = non-significant.

[c] A statistically significant effect of changing water was tested for by ANOVA with all soaking times combined (*P* <0.05); ns = non-significant.

[d] Zinc content was determined by AAS and is expressed on a dry weight basis. Data are presented as the mean ± SD of duplicate analysis of the same sample.

[e] Soaking water was changed after the 12, 24, and 36 hour time points.

Phytate content was significantly reduced with higher degrees of milling. The greatest reduction in phytate retention (i.e. 39%) occurred between 0% and 2% degree of milling, whereas the reduction in zinc retention was more incremental, with a similar percentage reduction at increasing levels of degree of milling (Figure 1). The phytate: zinc molar ratio, a predictor of zinc bioavailability, tended to decrease with increasing degree of milling. However, this apparent reduction was only statistically significant between brown rice (0% degree of milling) and all other milled forms; the phytate:zinc molar ratio was not significantly different between any degree of milling from 2% to 10% (Table 4).

Table 3. Zinc content of parboiled BRRI dhan29 rice with different pre-steaming and soaking times, followed by open- or closed-system steaming.

| | | Soaking time (hours) [a] | | | | | Soaking time | Pre-steaming time |
|---|---|---|---|---|---|---|---|---|
| Rice type | Pre-steaming time (minutes) | 0 | 3 | 6 | 9 | 12 | *P* [b] | *P* [c] |
| | | *Zinc, µg/g* [d] | | | | | | |
| Open steaming | | | | | | | | |
| Brown rice | 2 | 24.0 ± 0.6 | 23.8 ± 1.1 | 23.8 ± 1.1 | 21.5 ± 0.1 | 21.4 ± 0.1 | | |
| | 5 | 23.9 ± 0.1 | 23.6 ± 1.3 | 23.1 ± 1.3 | 23.1 ± 0.1 | 23.1 ± 0.1 | ns | ns |
| 10% polished | 2 | 11.9 ± 1.3 | 11.8 ± 1.4 | 11.7 ± 1.5 | 11.5 ± 1.3 | 11.3 ± 0.1 | | |
| | 5 | 12.7 ± 0.9 | 12.2 ± 1.1 | 12.1 ± 2.5 | 11.4 ± 0.8 | 10.7 ± 1.2 | ns | ns |
| Closed steaming | | | | | | | | |
| Brown rice | 2 | 24.0 ± 0.8 | 23.1 ± 0.2 | 22.8 ± 0.1 | 21.8 ± 0.1 | 21.6 ± 0.3 | | |
| | 5 | 23.3 ± 0.6 | 23.1 ± 0.4 | 22.7 ± 0.1 | 22.3 ± 1.7 | 21.4 ± 0.6 | * | ns |
| 10% polished | 2 | 15.6 ± 1.5 | 12.7 ± 0.5 | 11.3 ± 2.2 | 11.1 ± 0.2 | 10.7 ± 0.8 | | |
| | 5 | 12.8 ± 0.7 | 12.5 ± 1.3 | 11.0 ± 1.1 | 11.0 ± 0.8 | 10.5 ± 0.8 | * | ns |

[a] Rice paddy was soaked in distilled, deionized water at ambient temperature (25 C). All samples were open parboiled in an autoclave (30 minutes, 100 C, 0 g/cm$^2$).

[b] A statistically significant effect of soaking time was tested for by ANOVA:*, *P* <0.05; ns = non-significant.

[c] A statistically significant effect of changing water was tested for by ANOVA with all soaking times combined (*P* <0.05); ns = non-significant.

[d] Zinc content was determined by AAS and is expressed on a dry weight basis. Data are presented as the mean ± SD of duplicate analysis of the same sample.

[e] Soaking water was changed after the 12, 24, and 36 hour time points.

The rice flour SRM was analyzed for zinc content 6 times with each run, over 6 days, for 36 measurements. The zinc content was 19.9 ± 0.3 µg g$^{-1}$, just within the upper certified range of 19.4 ± 0.5 µg g$^{-1}$. Reproducibility was very high, with an inter-run CV of 1.6% and a mean intra-run CV of 1.5%. The correlation coefficient for zinc content in a subset of n=60 samples analyzed in the reference laboratory was r=0.96 ($P < 0.001$).

Table 4. Zinc and phytate contents of brown and milled rice by degree of milling (mean ± SD)

| Degree of milling [a] | 0% | 2% | 4% | 6% | 8% | 10% | *P* [b] |
|---|---|---|---|---|---|---|---|
| *Zinc, µg/g dry weight* [c] | | | | | | | |
| *Boro* rice varieties (n=6) | 19.3 ± 1.8 $^{1}$ | 16.9 ± 1.0 $^{2}$ | 14.8 ± 0.8 $^{3}$ | 12.7 ± 0.6 $^{4}$ | 11.2 ± 0.4 $^{4,5}$ | 10.5 ± 0.9 $^{5}$ | ** |
| *Aman* rice varieties (n=4) | 17.2 ± 3.9 $^{1}$ | 14.2 ± 2.9 $^{1,2}$ | 13.1 ± 3.7 $^{1,2}$ | 11.5 ± 4.0 $^{1,2}$ | 9.4 ± 4.6 $^{1,2}$ | 8.3 ± 4.1 $^{2}$ | * |
| All varieties (n=10) | 18.5 ± 2.8 $^{1}$ | 15.8 ± 2.3 $^{1,2}$ | 14.1 ± 2.4 $^{2,3}$ | 12.2 ± 2.4 $^{3,4}$ | 10.5 ± 2.8 $^{4}$ | 9.6 ± 2.7 $^{4}$ | ** |
| Phytate, mg/g dry weight | 9.23 ± 1.66 $^{1}$ | 5.65 ± 0.93 $^{2}$ | 4.33 ± 0.65 $^{2,3}$ | 3.45 ± 0.98 $^{3,4}$ | 2.94 ± 1.15 $^{3,4}$ | 2.55 ± 0.75 $^{4}$ | ** |
| Phytate:zinc molar ratio [d] | 49.9 ± 8.2 $^{1}$ | 35.8 ± 6.3 $^{2}$ | 31.0 ± 5.2 $^{2}$ | 28.1 ± 5.7 $^{2}$ | 28.2 ± 8.9 $^{2}$ | 26.6 ± 4.1 $^{2}$ | ** |

[a] Degree of milling is expressed as the % polish (outer layers of whole rice grain including bran and germ portions) by weight determined as: 1- [weight of polish/weight of brown rice grain] × 100, in 100 grains.

[b] One-way ANOVA; *P<0.05, **P<0.001

[c] Zinc content was expressed on a dry weight basis as the mean ± SD across varieties. Unlike superscripts indicate means that are significantly different from each other (Tukey's post-hoc, $P < 0.05$).

[d] The phytate zinc molar ratio was calculated as: (mg phytate/660) / (mg zinc/65.4), where 660 is the molecular weight of phytate and 65.4 is the molecular weight of zinc.

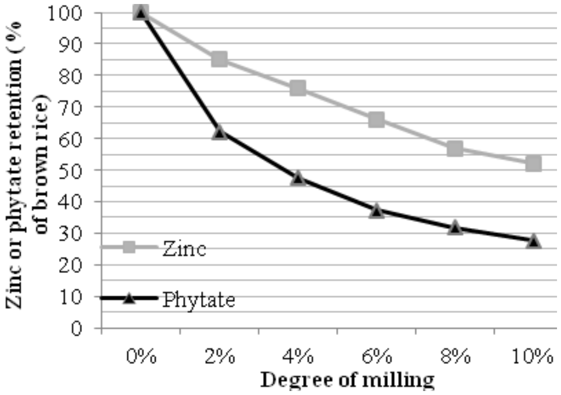

Figure 1. Zinc and phytate retention of rice by degree of milling, as the percent of content in brown rice. Retention of zinc at each degree of milling was determined from the mean of ten rice varieties. Phytate content was analyzed in a subset of samples only with the following sample sizes by degree of milling: 0%, n=9; 6%, n=2; 8%, n=7; 10%, n=9. There were no samples analyzed for phytate content at 4% or 6% degree of milling.

These systematic studies provide quantitative measurements of the magnitude of increase in zinc content that may occur with use of lower degrees of milling of Bangladeshi rice varieties. They also determined that several variables in parboiling conditions have minimal to no effect on rice zinc retention. Longer soaking time was associated with a small significant decrease in zinc retention, but only in brown rice when soaked at ambient temperatures, and in 10% milled or brown rice when pre-steamed followed by closed steam parboiling. Changing the ambient soaking water at 12 hour intervals did not significantly affect rice zinc content. These results fill information gaps with regard to the potential to maximize retention of zinc in parboiled, milled rice products in Bangladesh.

Higher degrees of milling had a linear decreasing effect on the zinc content of parboiled rice, where at the highest level tested (i.e. 10%) zinc content was reduced by half. While some previous studies had observed a negligible (Doesthale et al., 1979) or relatively modest decline (Liang et al., 2008) in zinc content of rice with 10-12% degree of milling, the magnitude of decrease observed in this study of 10 Bangladeshi rice varieties is consistent with the range observed in other studies. A 10-12% degree of milling resulted in retention of zinc of 73% (Villareal et al., 1991) and 55% (Pedersen and Eggum, 1983) compared to brown rice. The reasons for this variability across studies may be attributed to differences in the localization of zinc in the different fractions of the grain as a result of either genetic or environmental variation. In the present study, zinc retention ranged from 35 to 69%, suggesting that a substantial portion of zinc is located in the outer layers in these Bangladeshi varieties.

The degree of milling of commercial rice is typically 8-10% (Kennedy et al., 2002) or more. Using 10% degree of milling as the baseline for current practice, reducing milling to 6% or 4% could result in a 27% or 47% increase in rice zinc content, respectively. While brown rice has the highest zinc content, promoting brown rice consumption may not be considered optimal. Brown rice has an earthy flavor, tougher texture, and longer cooking time than well-milled rice, and hence it may be more difficult to influence consumers to choose brown rice. In contrast, undermilled rice has been found to have greater acceptance among consumers when tested under controlled study conditions (Roberts, 1979 and Billiris et al., 2012) and it may thus be more likely to influence consumers to choose undermilled rice than brown rice. More comprehensive consumer testing would be required to define an acceptable level of under milling.

## Zinc bioavailability

Another critical issue with regard to improving the adequacy of dietary zinc intakes is that of zinc bioavailability. While on average, zinc content could increase by 30-50% compared to well-milled rice, the amount of absorbable zinc may not be greater than in well-milled rice due to the higher phytate content. Reducing the degree of milling from a baseline of 10% results, on average, in a higher phytate content, but not in the phytate: zinc molar ratio, which is a strong predictor of zinc bioavailability in humans (Miller et al., 2007). This indicates that the benefit of a higher rice zinc content at lower degrees of milling may be somewhat minimized by having a lower bioavailability, but this may not be significant. To our knowledge, zinc bioavailablity from rice milled to different degrees has not been studied in humans. In a rat study, the amount of bioavailable zinc from rice was in the order of brown > undermilled > well milled (Hunt et al., 2002). However, adult rats may not be an appropriate model for human zinc absorption [19] as they are known to produce intestinal phytase. Zinc absorption from meals based on 95% extraction vs 80% extraction wheat was measured in human isotopic tracer studies (Rosado et al., 2009). Despite the higher zinc content of the 95% extraction wheat diet, the amount of zinc absorbed (1.6 mg day$^{-1}$) was similar to that from the 80% extraction wheat (1.5 mg day$^{-1}$), suggesting that the additional zinc content was not sufficient to compensate for the lower bioavailability.

It was previously demonstrated that modifications to the soaking and steaming conditions of parboiling altered the thiamin content in milled rice (Subba and Bhattacharya, 1966), increasing with longer soaking time and higher temperature. For example, the thiamin content of parboiled milled rice was 28% higher when soaked at 60C than when soaked at room temperature prior to steaming. Based on these studies, it was also suggested that an inward migration of soluble thiamin into the rice endosperm only occurred after steaming, and thus was likely associated with the gelatinization process (Subba and Bhattacharya, 1966). Hence steaming conditions might also modify the migration of nutrients from the outer layers towards the endosperm. We did not consistently observe similar effects of soaking time or pre-steaming time on zinc content of rice (Table 2 and 3). The differences in migration of zinc under parboiling conditions could be related to its solubility. For example while thiamin in rice may be readily soluble in water, zinc may be bound to proteins (Schjoerring et al., 2009) that could limit its migration in the grain.

The effects of pre-steaming time and closed vs open steaming on zinc content were also not important and, as a result, specific recommendations for modifying procedures for the purpose of increasing rice zinc content are not justified.

Increasing the content of bioavailable forms of zinc could provide a useful opportunity to deliver larger amounts of dietary zinc to the Bangladeshi population, which has been shown to have higher rates of deficiency than for other nutrients (ICDDR, B et al., 2013). Studies to consider all possibilities to achieve this in the context of local rice processing systems are important as zinc deficiency is directly associated with increased risk of morbidity and mortality in children due to diarrhea, pneumonia, and malaria (Black et al., 2008). It is also a major risk factor for childhood growth stunting, which is associated with increased risk of death from infectious diseases (Black et al., 2008), impaired cognitive function, lower attained education, and reduced earning potential (Victora et al., 2008).

## CONCLUSION

In conclusion, of the post-harvest processing modifications tested here, reducing the degree of milling would have the greatest impact on the zinc content of Bangladeshi rice. Determining the relative bioavailability of zinc at different degrees of milling in human isotopic tracer studies would provide critical information to assess the biological efficacy of this strategy.

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