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# Fortification of zinc in a parboiled low amylose rice: Effects of milling and cooking

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**Abstract:**

**BACKGROUND:** Rice is a staple diet for many people, but its micronutrient content is low. The process of parboiling induces several desirable changes in rice; it improves the retention of available micronutrients, and in the case of low-amylose varieties, it eases the cooking requirement. During parboiling of brown rice, if soaking is conducted in micronutrient rich solutions, it affects fortification. The present study is aimed to examine the suitability of zinc fortification by brown rice parboiling process in low-amylose rice.

**RESULTS:** Application of the method of zinc fortification by brown rice parboiling process increased the zinc content in unmilled rice. Milling caused reduction in zinc content indicating a high concentration of zinc at the outer layer. Both milled and unmilled rice could retain more than 87% of zinc upon cooking. Changes in color values in uncooked rice, due to zinc fortification, were non-significant at $p \leq 0.05$. Rehydration of zinc-fortified rice at 60°C for 25 min yielded hardness values similar to that of its cooked form.

**CONCLUSION:** The method of zinc fortification by brown rice parboiling is a pragmatic way to produce Zn-fortified parboiled rice to combat Zn deficiency with a reduced cooking requirement from a low-amylose variety.

**Keywords**: Brown rice; Zinc-fortification; Ready-to-eat; Texture; Pasting properties

Another version of **Abstract:**

**BACKGROUND:** Effectiveness of Zn fortification in a low amylose rice using brown rice parboiling method was investigated. During parboiling, before steaming step, brown rice was soaked in aqueous solutions of Zn at five different concentrations (100-500 mg/L) to obtain products having five levels of fortification.

**RESULTS:** Fortification elevated the Zn content in unpolished product up to 0.40 g/kg, corresponding to a zinc concentration of 500 mg/L in the soaking solution. Open cooking for 9 – 10 min yielded product hardness value from 150 to 180 g, which could be obtained by rehydrating at 60°C for 25 min. Reduction in Zn content was observed due to cooking as well as on milling. Milled forms of both fortified and unfortified rice had higher peak viscosity than the unmilled forms. The Zn fortified uncooked parboiled rice showed a V-type diffraction pattern with the peak between 12.82 and 19.67°. The changes in the color (L*, a* and b* values) of fortified products were non-significant at $p \leq 0.05$ due to fortification.

**CONCLUSION:** As zinc content in the fortified low-amylose parboiled rice was high even after polishing as compared to its unfortified form. The approach is a pragmatic way to obtain Zn-fortified ready-to-eat rice or rice with reduced cooking time to combat Zn deficiency among people.

**Keywords**: Brown rice; Zinc-fortification; Ready-to-eat; Texture; Pasting properties

## 1. **Introduction**

Deficiency of micronutrients (essential trace elements and vitamins) is considered as a silent epidemic and is a matter of global concern.[1] It is accounted for deaths of many under-privileged children, particularly in the developing countries.[2] Among the micronutrients zinc comes next to iron in terms of human nutritional requirement[3] and its deficiency is categorized as critical.[4] Zinc deficiency affects the immune system, causes a person susceptible to various infections, and restricts the growth in infants, and restricts various other outcomes in adults and affects women after childbirth.[5]

From the perspective of nourishment of human being, food of animal origin is considered as a zinc rich food. The average zinc intake in omnivorous is reported to be higher as compared to vegetarians.[6] In developing countries, Zn is derived mainly through food grains such as cereals and legumes.[7] Yet zinc intake is not adequate and zinc deficiency is widespread in developing countries.[8] In South Asia alone approximately 95% of the population are affected by zinc deficiency[9] and is accounted for about 0.4 million deaths occurring every year. [9]

Various strategies are put into place to alleviate Zn deficiency in low-income population. These include supplementation, fortification of staple foods and beverages,[10-12] modification in diet plan, and bio-fortification of staple food crops.[13] However, the methods of supplementation, dietary modification and bio-fortification are time-consuming and cost-ineffective methods.[13]

Cereals like wheat, rice, maize are used as staple foods, but unfortunately are not good source of micronutrients.[14] Hence, cereals are fortified with micronutrients and used as an effective vehicle for micronutrient supplementation. For the cereals which are milled as flour for consumption, a successful method of Zn fortification is reported.[9,15] However, rice is mostly consumed in whole grain form after cooking of parboiled or un-parboiled rice, and the above method is not suitable for such whole rice grains.

Since a good part of total rice produced is consumed as parboiled rice (in India 60% is converted to parboiled form), hence, researchers are investigating parboiled rice as the vehicle for micronutrients by effecting fortification during parboiling. Rerkasem *et al.*[12] reported the paddy parboiling method of Zn fortification using $ZnSO_4$ and ZnO. His method of zinc fortification involves steeping of paddy in zinc enriched solution for duration to complete soaking requirement, followed by steaming and drying. Rerkasem *et al.*[12] recommended both $ZnSO_4$ and ZnO as good sources of zinc for rice fortification with negligible effects on the organoleptic properties. As a whole fortification of zinc during parboiling is reported as a cost-effective approach for delivering this micronutrient to a large population.[12]

Over the years the parboiling methods are evolving in order to address the issues of quality and production time. Among various methods, CFTRI method involved soaking of the paddy in hot water (about 70°C) for about 3 h and water is re-circulated to prevent temperature difference between the top and bottom and drained, steamed and dried.[16]

Parboiling of brown rice has been investigated by few researchers as an alternative to the method of paddy parboiling for production of parboiled rice. It has several advantages over the methods of paddy parboiling when the processing steps are followed in a controlled manner. It facilitates quick water uptake during the soaking step due to the removal of the husk which in turn reduces the processing time as well as discoloration.[17-19]

Reduction in cooking time is one favorable change in rice characteristics induced by parboiling in case of certain paddy varieties. For example, when a low amylose variety of paddy named *chokuwa,* available in Assam, India, is parboiled the cooking requirement gets reduced. It becomes so easy to cook that traditionally the product is consumed after hydrating in water at room temperature or warm water.[20-21] Hence, traditionally the product is viewed as a ready-to-eat form of rice which requires marginal cooking or no-cooking. Mahanta and Dutta[20] reported its parboiling process by the conventional paddy parboiling method. With a modification, Wahengbam and Hazarika[21] reported preparing parboiled brown rice from *chokuwa* paddy by the brown rice parboiling method and presented the process conditions. Extending the study, the brown rice parboiling method for *chokuwa* variety is modified to effect zinc fortification and produce a ready to eat form of zinc fortified rice. Such a Zn-fortified parboiled brown rice will have a wider reach to include the low-income group. Also, it will be an option as aid-material to the people affected by disaster and natural calamities when the cooking of food is difficult.

We present here the development of Zn fortified quick-cooking rice employing the brown rice parboiling method, and findings of the investigation on consequence of the Zn-fortification and processing on the physico-chemical properties of the rice.

## 2. Materials and methods

### *2.1 Materials*

The low amylose paddy variety of Assam, India, *chokuwa* was collected from the nearby local farm and equilibrated for a few days. Brown rice was obtained by dehusking the *chokuwa* paddy in a laboratory sheller (RTE-07, A-GRAIN, India). Brown rice was then stored in the refrigerated condition in airtight containers for 3 days until it was used for processing.

### *2.2 Production of Zn-fortified parboiled brown rice*

The *chokuwa* brown rice (100 g) was washed and rinsed with distilled deionised water once and then drained the excess water. Five different concentrations of Zn solution (using $ZnSO_4.H_2O$, Sigma-Aldrich, USA, as the Zn source) were used for fortification (Table 1). Zinc fortification was carried out during the soaking step (60°C for 90 min), with brown rice to Zn solution ratio of 1:2 (w/v). Later, the excess solution was drained, and sample was steamed at 1 atm (guage pressure) for 10 min in a vertical autoclave followed by tray drying at 40°C till it reached to about 12% moisture content.[21] The unfortified parboiled brown rice (designated as ZnR-0) was produced following the similar processing condition except the addition of Zn. The product thus obtained was milled for 30 s and 60 s to yield milled or polished rice by using a rice polisher (RTE-08, A-GRAIN, India). All experiments were repeated thrice.

Parboiled rice sampleswere coded ZnR1 to ZnR5in Table 1,and a suffix was addedfor milling time (0 = unmilled, 30 = 30 s milling and 60 = 60 s milling).

*2.3 Determination of Zn content*

Two milliliters of 69% $HNO_3$ was added to the labelled tubes each containing about 0.1 g of rice powder. The tubes were then vortexed for a few seconds, and were left overnight at room temperature to soak. Another 2 ml of 30% $H_2O_2$ was added andwaited to outgas for 15 min in a Class II safety cabinet.[22] The tubes were placed into the carrousel for the microwave digestor(CEM Mars 6, 1800W) and digestion programme (3 stageprocesses) were operated which lasted for a total of 65 min. Then, volumes were made up to the final weights (~30 g) with deionised water and precise masses were recorded. The zinc content was analyzed in triplicates by inductively coupled plasma-optical emission spectrometry (ICP-OES, Agilent Technologies 5100, USA).

*2.4 Effect of Zn concentration in soaking solution on its uptake*

The percent (%) uptake of Zn in the Zn-fortified parboiled rice was determined by following the method of Kam *et al.*[23]

*2.5 Effect of cooking and milling on Zinc content*

To make *komal chawal* edible, rehydration ratio of approximately 1.6-1.7, the time of rehydration at 40$^{o}$C was more than 30 min such that the cooking time was 9-10 min in boiling water.[21] To have an estimate of the loss of fortificant upon rehydration in boiling water, preliminary cooking trials were carried out and assessed for Zn retention. Ten g of rice in 70 ml of heated water, maintained at 100°C, was examined. The required cooking time for raw rice was 18 min, and for parboiled rice it was between 9 and 10 min. The cooked rice was freeze-dried (Christ-Alpha 1-4 LD, Germany) and powdered using a ball mill (PM 100, Retsch, UK).The percent retention after cooking was calculated by following the method of Kam *et al.*[23]

*2.6 Changes in color of uncooked raw, unfortified and Zn-fortified rice*

Color values in terms of lightness (L*), yellowness (b*) and redness (a*) were determined in the powder form of uncooked raw, unfortified and Zn-fortified parboiled rice by using a colorimeter (UltraScan VIS, Hunter Lab, USA). The total color difference ($\Delta E$) and chroma (C*) values are derived from L*a*b* values. Five samples were examined each time.

*2.7 Textural properties of cooked and rehydrated rice*

Textural analysis was carried out after the rice was cooked and rehydrated as previously described.[21] Textural properties of cooked and rehydrated (at 60°C for 10 – 25 min) parboiled rice samples were determined by using a texture measuring instrument (TA-HD Plus,Stable Micro Systems, UK). The two-cycle compression test was used by following the procedure of

Dutta and Mahanta.[20] The optimum rehydration condition to obtain a ready-to-eat form of Zn-fortified rice was determined by comparing the textural properties of cooked rice.

*2.8 X-ray diffraction patterns of rice flour*

The X-ray diffractograms of raw and Zn-fortified parboiled rice flours were obtained using a X-ray diffractometer (Bruker Axs, Germany). The spectra were scanned over a diffraction angle ($2\theta$) of 10–40° at a step size of 0.05° with a target Cu K$\alpha$ value of 1.5 A° ($\lambda$) at an operating scan speed of 1°/s. The software (OriginPro 8.5) was used to calculate the peak center, and full width half maximum (FWHM). The interplanar distance 'd' from Bragg law ($d=n\lambda/2\mathrm{Sin}\theta$), and size of crystallites ($\gamma$) using Sherrer's formula ($\gamma = K\lambda/\beta\mathrm{Cos}\theta$) were calculated, where K = constant (0.91), $\beta$ = (FWHM $\times \pi/180$), and $\theta$ = angle of incidence. The mean percent (%) crystallinity was determined by using equation 1.[24]

$$\%\ \text{Crystallinity} = \left( {Area\ under\ peak} \middle/ {Total\ area} \right) \times 100 \qquad (1)$$

*2.9 Pasting properties of rice flour*

The pasting properties of flour suspensions (12% w/w; 28 g total weight) were recorded using a Rapid Visco Analyzer (RVA Starchmaster 2, Australia) by following the method of Klein *et al.*[25] The pasting parameters, namely peak viscosity (PV), hot paste viscosity (HPV), cold paste viscosity (CPV), breakdown (BD=PV-HPV), and total setback (SBt=CPV-PV) were recorded.

*2.10 Percent head rice yield (% HRY) on milling*

The percent head rice yield (%HRY) of dehusked rice was calculated by following the method of Lohani *et al.*[26]

*2.11 Statistical analysis*

Three replications were performed for analytical determinations, except for texture profile analysis, in which it was replicated for nine times for every sample. One-way analysis of variance (ANOVA) was carried out for data analysis and applied the Duncan's mean comparison test at a probability of $p=0.05$ to determine differences among treatments using IBM SPSS Statistics 20.

## 3. Results and discussion

*3.1 Determination of total Zn content*

As compared to the unprocessed (Raw-0) and unfortified parboiled rice (ZnR-0) samples, the total Zn content in the uncooked Zn-fortified parboiled rice samples increased remarkably (Fig. 1). The Zn concentration in samples increased significantly ($p \leq 0.05$) with an increase in Zn fortification concentrations irrespective of soaking time (Fig. 1). The amount of Zn in the uncooked and unmilled fortified parboiled rice samples (ZnR1-0 to ZnR5-0) was between 0.12 and 0.40 g/kg rice, which was higher than that of the Raw-0 and ZnR0-0 samples. On subjecting to milling, the Zn concentration decreased, though it remained significantly higher in samples soaked in solutions with higher Zn concentration. High reduction was observed due to increasing the milling duration to 60 s (0.08 –0.28 g/kg) as compared to 30 s milled (0.10 – 0.36 g/kg) samples. However, these ranges were still higher than the milled Raw-60 and ZnR0-60 samples. It showed that even after polishing, Zn concentration remained higher in Zn-fortified rice samples. Thus, the brown rice parboiling method of polished rice could be obtained that had Zn concentration higher than that of unmilled (0 s) rice of 0.02 to 0.07 g/kg, as also indicated by Rerkasem *et al.*[12]

*3.2 Effect of Zn concentration in soaking solution on its uptake*

The total Zn content of unfortified rice grains observed in the present study corresponded to the values reported by the Indian Council of Medical Research (ICMR),[27] where the zinc content of cereals ranged from 0.01 to 0.02 mg/100 g. The Zn content in samples ZnR2-0, ZnR3-0, ZnR4-0 and ZnR5-0 as compared to ZnR1-0 were in the order of 1.60, 2.26, 2.73, and 3.20 times, respectively. The % Zn uptake in the uncooked Zn-fortified rice samples (ZnR1-0 −ZnR5-0) is shown in Fig. 2(a). The uptake of $Zn^{+2}$ ions from the solution might be due to the process of adsorption at aleurone layer followed by diffusion within the grain. The % uptake for 0 s (unmilled) Zn-fortified rice grains was between 39.62 and 61.83% (Fig. 2a), while the maximum was for ZnR1-0. In the case of 30 s and 60 s milled samples, the % uptake was between 33.0−49.5% and 28.53−40.61%, respectively. At lower Zn-fortification concentrations (i.e in ZnR1 to ZnR3), the uptake of Zn into the rice kernels per unit mass of Zn available in the solution was marginally higher compared to that of ZnR4 and ZnR5.

Milling causes a reduction in available Zn in rice grain due to removal of outer layers as reflected by the lower estimated % uptake values. The percent loss of residual Zn concentration in the uncooked rice, when milled between 0 s and 30 s, 30 s and 60 s, and 0 s and 60 s, varied from 10.0 to 22.0%, 6.5 to 33.0%, and 27.0 to 42.0% corresponding to average losses of 15.6%, 19.6% and 32.4% respectively; the loss was marginally higher with an increase in milling duration. It also indicated that the outer portion (aleurone layer) of grain was more concentrated with zinc. Such a decrease in the rate of loss beyond the outer aleurone layer in subsequent milling possibly indicated that the migration of the fortificant was strongly bonded to the gelatinized or hydrolyzed carbohydrate molecules of the rice.

3.3 *Effect of cooking and milling on Zn content*

The Zn content in the cooked Zn-fortified rice was between 0.10 and 0.35 g/kg rice (Fig. 1). Cooking slightly reduced the Zn content of cooked rice as compared to uncooked counterparts. The reduction of Zn content from uncooked to cooked rice was between 0.003 and 0.040 g/kg rice. The percent loss after cooking was up to 42.4%, which was similar to an earlier report of Kimura and Itokawa.[28]

The percent retentions of Zn in the Zn-fortified cooked unmilled (0 s) rice samples were between 88 to 94% (Fig. 2(b)). The successive reduction of Zn retention was evident in 60 s milled samples. The percent loss of residual Zn in the milled cooked samples was between 10.0 to 18.6% for 0 – 30 s milled samples with an average of 14.4%. About 8.8 to 47.7% were the losses between 30 s and 60 s, and 25.8 to 57.0% losses between 0 s and 60 s of milling with an average value of 27.5% and 37.9%, respectively. These results indicated that the Zn ions possibly bonded with the hydrolyzed starch molecules of rice might got loosened during cooking; it might be the probable reason for higher % loss of residual Zn between 30 s and 60 s rice grains compared to that of 0 and 30 s of milled samples.

*3.4 Changes in color of uncooked raw, unfortified and zinc-fortified rice*

The changes in lightness (L*), redness (a*) and yellowness (b*) values of all the samples are given in Table 2. The lightness (L*) values of raw rice were higher than that for unfortified and Zn-fortified parboiled rice samples. The a* and b* values of raw sample was lesser than the parboiled rice (Table 2). The color values were marginally affected by the time of milling. No significant differences ($p \leq 0.05$) were observed in a* values of 60 s and 30 s milled Zn-fortified samples. The b* values of Zn-fortified unmilled rice (ZnR1-0–ZnR5-0) samples had less significant difference to that of unmilled raw rice (Raw-0). The yellowness (b*) values of unfortified parboiled rice (ZnR0) samples were higher than that of the raw sample; it might be contributed from the migration of bran pigments. However, b* values of Zn-fortified rice samples were slightly lower than the unfortified parboiled rice (ZnR0). This might be due to the interaction of zinc sulphate with rice starch and bran pigment. The changes in the color values (L*a*b*) of different Zn-fortified samples with an increase in Zn concentrations were non-significant. Similar observation was reported for Zn-fortified potato starch.[29] Considering 60 s milled raw rice (Raw-60) as the reference sample, the change in total color difference (ΔE) was determined. The ΔE values between the raw and parboiled rice samples (unfortified and fortified) were significantly different ($p \leq 0.05$). The chroma (C*) values of unfortified parboiled rice (ZnR0) samples was slightly higher than the raw and fortified samples. The overall inference was that no adverse color changes were observed due to Zn fortification.

*3.5 Textural properties of cooked and rehydrated rice samples*

The textural attributes of the cooked rice were compared with the warm-water soaked (at 60°C for 10 to 25 min) counterparts (Fig. 3). The mean hardness values of cooked rice were between 150 and 180 g (Fig. 3(a)). The mean hardness values of 10 min-soaked unmilled rice grains (477–2582 g) were more than milled (356-1790 g) counterparts. Similar pattern was obtained for 15 min soaked unmilled samples. Except for raw rice samples, the hardness value of 20 min rehydrated parboiled rice samples changed remarkably compared to 10 to 15 min soaked (rehydrated) samples. Except for a few cases, the hardness values of most of the 20 min soaked milled and unmilled rice samples were close to that of cooked rice. Thus, further rehydration was continued till 25 min; the hardness values of both 25 min unmilled and milled processed parboiled rice samples were nearly or less than or equal to that of cooked rice. There was a slight difference in the hardness values with increasing Zn fortification concentration and milling time. However, the exact trend was difficult to predict. Thus, hardness generally decreased with increasing milling time which was mostly observed for 10−15 min soaked samples.

Texture is a complex-multi-dimensional characteristic. However, for deciding the palatability of cooked rice, the hardness and adhesiveness are the important properties of texture.[30] The adhesiveness property of texture is considered as the energy required to overcome the sticky forces. A significant difference ($p \leq 0.05$) was observed in most of the rice samples. The adhesiveness of cooked rice samples was between -2.86 and -0.53 g/s (Fig. 3(b)). Most of the adhesiveness values of 25 min soaked samples were close to that of cooked parboiled rice. The cohesiveness is a property of a food by which the food withstands well in the second deformation as compared to the first deformation. Thus, the values were like samples that were soaked for 20−25 min followed by cooking (Fig. 3(c)). The gumminess of the 10 to 15 min soaked samples was higher compared to 20−25 min soaked samples. It is derived from hardness and cohesiveness, and thus, more the hardness more was the gumminess (Fig. 3(d). The gumminess values of 25 min soaked Zn-fortified parboiled rice samples were between 30 and 60 g compared to cooked samples (40–50 g). Springiness is the elastic property of food, which measures how the food is returned to its original shape after the deformation. The springiness of the cooked and 20 − 25 min soaked unfortified and Zn-fortified parboiled rice was between 0.70 to 0.90 (Fig. 3(e)). No adverse changes were noticed due to the increasing order of Zn fortification concentrations on the cooked or rehydrated rice samples. The chewiness is the product of gumminess and springiness. It is the energy required to chew a solid food until it is ready for swallowing. The chewiness of both the cooked and rehydrated (25 min) rice samples was between 26 and 34 (Fig. 3(f)). The unmilled and 10 to 15 min soaked samples were chewier compared to milled counterparts (Fig. 3(e)). In conclusion, the required duration to convert the rehydrated parboiled into edible form (ready-to-eat) was decided based on the hardness value. The hardness appeared to be the most important characteristic of texture in deciding the palatability properties of cooked rice. The hardness values of 20–25 min soaked (at 60°C) and cooked rice grains were similar to that of cooked rice. Thus, the Zn-fortified parboiled rice, when soaked for 25 min at 60°C, could render into an edible texture. This condition might be considered as the ready-to-eat Zn-fortified rice grains.

### *3.6 X-ray diffraction patterns of rice flour*

The XRD pattern of raw and Zn-fortified parboiled rice flour is shown as the mean % crystallinity in Fig. 4. The peak center (2θ), FWHM (°C), inter planar distance (d, nm), and size of crystallites (λ, nm) are given in Table 3. The A-type crystallinity of raw rice flour was either markedly reduced or destroyed after processing. The A-type patterns with slight changes in the peak angle were observed in both milled and unmilled raw rice flour. The Zn-fortified parboiled rice showed the V-type pattern; a nearly similar pattern was reported by Prasert and Suwannaporn.[31] The result indicated that the hydrothermal process destroyed the crystalline structure of the starch granules and formation of amylose-lipid complexes occurred during gelatinization of starch, as indicated by the occurrence of the V-type pattern.[28] However, a peak center or angle of the 60 s milled Zn-fortified rice flour was slightly lesser than the unmilled counterparts. No such significant differences were observed in the processed rice samples due to an increase of Zn fortification concentrations. The FWHM were between 0.44 to 3.01°, and it depended on peak sharpness. The 'd' spacing of Zn-fortified unmilled parboiled rice samples were between 0.68 and 0.69nm, which was slightly higher than that of the milled counterparts. The mean percent crystallinity of raw rice was higher than the processed rice indicating a loss of the crystalline nature due to hydrothermal treatment; similar range of % crystallinity was reported by Shih *et al.*[32] The nearly same mean % crystallinity of the Zn-fortified rice at higher fortification concentrations indicated the weakening of the crystal lattice of starch due to penetration of Zn, that might had been structurally modified. The size of crystallites of Zn-fortified parboiled rice was between 7.76 and 14.75; it depended on the peak size.

*3.7 Pasting properties of rice flour*

The pasting properties of the 60 s milled and unmilled (0 s) raw, unfortified and Zn-fortified parboiled rice flour samples are shown in Fig. 5(a) and (b). As compared to parboiled samples, the raw sample had the maximum PV; it reflected the water binding capacity of ungelatinized starch granules that became gelatinized in the presence of moisture and heat to form a viscous paste. The milled rice form of raw, unfortified and most of the Zn-fortified parboiled rice had higher PV, HPV, BV, CPV and SBt. Similar findings were reported by Perdon *et al.,*[33] which might be due to the removal of bran layer. The setback viscosity of milled-fortified rice decreased with an increase in fortification concentration; this indicated the meagre tendency of the sample to undergo retrogradation. The change was opposite to the report of Sanni *et al.*[34] It might be due to different starch sources as these researchers used maize flour. Negligible BD and a near linear rise in viscosity of processed rice might be attributed to leaching of the short linear molecular chains which caused thickening phenomenon; it suggested the suitability for specific uses.

*3.8 Percent head rice yield (%HRY) on milling*

In order to examine the improvement in the degree of polishing or milling in the Zn-fortified parboiled brown rice developed from brown rice parboiling method, a comparison was made in the % HRY of raw and Zn-fortified parboiled rice. The % HRY of Zn-fortified parboiled rice, after polishing for 30 s and 60 s was between 81.77 and 88.58%, and 79.48 and 84.60%, respectively (Table 2). There was a reduction in % HRY with an increase of the milling time. The % HRY of

60 s milled Zn-fortified parboiled rice samples was about 1.9 to 7.8% higher as compared to Raw-60. On the other hand, the 30 s milled samples had higher HRY values (about 0.4% to 8.0%) compared to Raw-30. The degree of milling of raw rice was slightly higher than the parboiled rice which showed the higher extent of bran removal for raw rice at the same milling time.[35]

## 4. Conclusions

It was concluded that the brown rice parboiling method is a cost-effective method in developing the Zn-fortified ready-to-eat parboiled rice from a low-amylose rice variety called *chokuwa*. It increased a good amount of Zn in the uncooked and cooked-fortified parboiled rice. The production and consumption of such Zn-fortified ready-to-eat parboiled rice might prove to be a rapid and economical option to enhance the amount of Zn intake, especially in the rice based diet. Consumers might not visually differentiate between Zn-fortified and unfortified parboiled rice due to non-significant differences in their appearance. The rehydration condition for the ready-to-eat rice was recommended to be 60°C for 20 – 25 min based on the hardness values of the rehydrated rice which was like the cooked rice. Further research is required for quantifying the bio-accessible and bioavailable forms of Zn from such fortified rice in the human diet.

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**Legends of Figures:**

**Figure 1.** Zinc content in the uncooked and cooked raw, unfortified and Zn-fortified parboiled rice

**Figure 2.** The percent (a) uptake and (b) retention of Zinc in the Zn-fortified unmilled and milled parboiled rice

**Figure 3.** Comparison of textural properties, namely (a) hardness (b) adhesiveness, (c) cohesiveness, (d) gumminess, (e) springiness, and (f) chewiness of raw, unfortified and Zn-fortified rice of cooked and warm water rehydrated (60°C, 10–25 min) rice grains

**Figure 4**. X-ray diffraction patterns of unprocessed raw and zinc-fortified parboiled rice

**Figure 5**. Pasting properties of raw, unfortified and zinc-fortified parboiled rice flour (a) unmilled, and (b) 60 s milled rice flour

**Legends of tables:**

**Table 1.** Coding of samples

**Table 2.** Changes in color values and % head rice yield (%HRY) of raw, unfortified and Zn-fortified parboiled rice grains

**Table 3.** X-ray diffraction analysis of raw and zinc-fortified parboiled rice