EFFECT OF STEAMING ON PHYSICAL AND THERMAL PROPERTIES OF PARBOILED RICE

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ABSTRACT
Physical and thermal properties of four improved parboiled rice varieties (FARO 61, FARO 60, FARO 52 and FARO 44) and a local parboiled rice variety (Bisalayi) from Nigeria were investigated for effects of variety and steaming conditions. Translucency improved significantly (P<0.05) with parboiling and was different depending on variety; however, no effect of steaming time was found. The improved rice varieties showed better hardness and were less discolored than the local variety. FARO 61 was found to have the highest hardness with values of 79.36–158.17 N corresponding to steaming for 0–20 min, respectively, while the local variety (Bisalayi) has the least hardness of 59.45–113.65 N for the respective steaming times. For all the rice varieties studied, no residual gelatinization enthalpy was observed at the different steaming times which show that steaming completely gelatinized the rice starch during parboiling process.

Keywords: Rice paddy; Parboiling; Steaming; Translucency; Hardness; Lightness; Gelatinization

1. INTRODUCTION
Parboiling is a pre-milling hydrothermal (hydration and heat) treatment of paddy (rough rice) which brings about substantial physical and chemical alterations in rice. The main purpose of this process is to pre-gelatinize the starch granules, transforming the crystalline structure of the starch into an amorphous one. Starch gelatinization, imparts additional hardness to the rice grains and allows them to withstand harsher milling (Rao & Juliano, 1970; Bhattacharya, 1985; Islam et al, 2002a). It is reported that parboiled rice also has better organoleptic properties, retains more nutrients and cooks better than non-parboiled rice (Rao & Juliano, 1970; Sareepuang et al., 2008; Lamberts et al., 2008). In generally, parboiling process consists of three stages namely: soaking of paddy to saturation moisture content (SMC), steam heat treatment of the soaked paddy to partially gelatinize the rice starch, thereby eliminating white portions and cementing crack
developed in rice during harvesting and/or threshing and finally drying the steamed product to moisture content adequate for milling.

Chalkiness or white portion is an undesirable quality of parboiled rice. Parboiling brings about modifications in rice during which vitamins and minerals are transferred from the aleurone and germ into the starchy endosperm. These transformations are accompanied by reduction in white portion, and give milled rice more translucent appearance (Juliano and Bechtel, 1985). A common problem with parboiling, especially by employing high temperature and pressure and longer processing time, is darkening of the grain (Bhattacharya, 1995). Also, steaming operation, which bring about the gelatinization of starch, requires a lot of energy to produce steam for the process, it is therefore necessary to establish optimum processing conditions required to obtain better qualities of the finished product while saving energy and time. Marshall et al. (1993) studied the relationship between percentage of gelatinization and head yield (the primary parameter used to quantify rice milling quality given by the ratio of weight of rice grains that are three-quarters intact to the total weight of milled parboiled rice) of parboiled rice (Cooper and Siebenmorgen, 2005). They reported that maximum head rice yield could be achieved when the rice starch is 40% gelatinized during parboiling of paddy and that extensive parboiling or extensive starch gelatinization is not required to obtain maximum head rice yields.

Among many varieties of rice found, FARO 61, FARO 60, FARO 52 and FARO 44 are the most common improved varieties while Bisalayi is a popular local varieties produced and consumed in the Nigeria. Since most of the parboiled rice come from local producers, the processes (steaming) time vary among producers. Such variation may result in quality differences in the end product and possible over utilization of energy during steaming operation. The objective of this work was therefore to:

1) Study the effect of steaming time on physical properties (translucency, hardness, lightness, and colour intensity) of parboiled rice varieties
2) Evaluate the effect of steaming time on thermal properties (degree of gelatinization) of parboiled rice varieties
3) Determine the optimum steaming condition required to obtain optimum quality of parboiled rice.

2. MATERIALS AND METHODS

2.1 Samples
Samples of five improved rice paddy varieties (FARO 44, FARO 52, FARO 60, FARO 61) used in this study were harvested in December, 2012 by the Breeding Unit of Rice Research Program, National Cereal Research Institute (NCRI) Badeggi Niger State, Nigeria and one local variety (Bisalayi) also harvested in the same period was obtained from Crop Improvement Unit of Kano State Agriculture and Rural Development Agency (KNARDA). They were packed in nylon jute bags and transported in February, 2013 to Bioresource Engineering Department, McGill University, Montreal, Canada and stored at room temperature. Prior to experiments, the unparboiled paddy samples were taken out, thoroughly cleaned and flawed grains removed. The moisture contents of the samples were determined by the fixed air-oven method drying at 120°C for 24 h in duplicates and found to be 0.0713 ± 0.0023 g/g d.b.

2.2 Parboiling procedure
Based on the result obtained from hydration experiment on optimum soaking time (to reach moisture content of approx. 40% d.b.) for different rices during soaking at 60°C, 180-g batches in duplicated of paddies were soaked at 60°C for 6 h for FARO 60, 7 h (for Bisalayi, FARO 44 and FARO 52) and 8 h FARO 61. At the end of the soaking period, samples were steamed in an autoclave (Consolidated still and
sterilizer) at 100°C for 5, 10, 15 and 20 min. The average moisture content after steaming was between 42 – 45 % dry basis. Samples were dried at room temperature (20 -25°C) to a moisture content range of 13 – 16 % (d.b.).

Parboiled paddy samples were de-husked using an electric compact rice husker (TR 200, Kett Electric Laboratory, Tokyo) and polished using a test polisher (Pearlest, Kett Electric Laboratory, Tokyo).

2.3 Kernel translucency
Grain translucency was determined by adopting the method of Marshall et al. (1993) with slight modification as follows: 200 well-milled whole kernel grains were selected at random from each variety at each steaming time. Translucency was assessed subjectively from the randomly selected kernels by accepting only those grains that were completely translucent. Grains were placed on black table surface illuminated from above by a fluorescent lights. Completely translucent kernels were separated from those with white portion. Percentage of translucency was determined as follows:

2.4 Hardness
About 25 grains of rough rice were randomly selected from each sample. Hardness of 25 unfissured whole brown rice kernels was measure using a compression method (Instron 4502, Canton MA, USA). The average bio-yield point value (Mohsienin, 1980) of the 25 measurements was expressed as the hardness in newtons (N). Brown rice kernels were put on the base plate and the bio-yield point value measured in flat position (Islam et al., 2001). A 500 N load cell, a probe of 3.84 mm diameter and 5 mm/min compression rate were used. The probe was set to travel a distance of 2.25mm into the sample.

2.5 Lightness value
A spectrophotometer (CM – 3500d, Minolta Co., Ltd., Japan) was used to measure the lightness and saturation of the colour intensity value of the whole kernel milled rice utilizing the L*a*b* uniform colour space procedure. The value of L* expresses the lightness value, a* and b* represent red/green and yellowness/blue coordinates, respectively of the L*, a* and b* colour space system. The instrument was calibrated with a standard white plate having L*, a* and b* values of 98.80, -0.22 and -0.39, respectively and zero calibration cylinder (CIE L* = 0.09, average reflectance = 0.01%) Each measurement was replicated seven times and the average value was considered.

2.6 Determination of thermal properties of rice varieties
The thermal (gelatinization) properties were determined with a Differential Scanning Calorimeter (DSC Q100, TA instruments, Wilmington, DE USA). Heat flow and temperature calibrations of the DSC were performed using pure indium with heat of fusion and a melting temperature of 28.41 J/g and 156.66°C respectively. The instrument was coupled with refrigerated cooling system. Nitrogen was used as a purge gas at a flow rate of 50 ml/min. Raw and parboiled rice were de-husked using an electric compact rice de-husker (TR 200, Kett Electric Laboratory, Tokyo) and polished using a test polisher (Pearlest, Kett Electric Laboratory, Tokyo). Rice flour was then prepared by grinding samples of the polished rice using a coffee grinder (SUMEET Multi Grind, India) and passed through 0.075 mm sieve (Fisher brand test sieve, Fisher scientific co., USA).

An empty aluminum pan (40 µl) was tarred on a balance and a mass of 3 ± 0.01mg flour was carefully measured into the center of the pan. Considering the moisture content of each sample, appropriate volume of distilled water was added to the pan by micropipette to achieve a water/flour ratio of 2:1. This ratio accounts for more than 60% moisture, corresponding to the moisture content required for rice
gelatinization and to obtain a single endotherm during DSC experiment (Billiaderis et al., 1986). The pans were hermetically sealed with TA sample crimping device. The sealed samples were stored at room temperature for one hour to stabilize before thermal scanning. The pans were placed in the sample cells of the DSC while an empty pan was sealed and placed in the reference cell of the DSC.

The refrigerated cooling system was turned on and the flour samples were heated from 20°C to 100°C at a heating rate of 10°C/min. The onset (\(T_o\)), peak (\(T_p\)) and conclusion (\(T_c\)) temperatures of gelatinization and the residual gelatinization enthalpy (\(\Delta H\)) were determined with the Universal Analysis Version 1.2 software supplied by the DSC Company. The residual gelatinization enthalpy was measured in J/g of dry solid weight as the area under Heat flow against temperature.

2.7 Statistical analysis
The data of the effect of dependent variables (steaming time and variety) on the dependent variables (percentage of translucency, hardness, lightness, gelatinization temperature and gelatinization enthalpy) were statistically analyzed using SAS software (version 9.2), and where there was significant effect, means were separated using the Duncan’s multiple range test (\(P<0.05\)).

3 RESULTS AND DISCUSSION
3.1 Translucency
The presence of white portions or chalkiness in grain is an important quality indicator in rice. Chalkiness causes softness in grains and has other unwanted effects. Chalkiness can be determined by visualizing a grain with the naked eyes or by the use of transmitted light (Bhattacharya, 2011). One major importance of parboiling is its effectiveness in eliminating white core in rice grains, thereby improving the translucency. Typical change in translucency during parboiling of selected paddy rice is shown in Figure 1 for FARO 61 variety. Adequate soaking enables water to reach the center of rice grains and facilitates the elimination of white portions when enough heat from steam is applied to paddy.

Translucency varied from 23.67 – 93.00, 27.67 – 91.00, 19.67 – 74.67, 28.00 – 92.67 and 22.33 – 82.33 for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively, 0 – 20 mins steaming. Steaming show significant influence (\(p<0.05\)) on percentage of translucency for all the varieties studied between untreated sample and 5 min of treatment. Percentage change in translucency of parboiled rice is shown in Figure 2. There was no observable difference in percentage translucency during steaming from 5 – 20 for paddy, except for FARO 44. Furthermore, FARO 60 and FARO 44 show lower translucency compared to other varies of rice. Marshall et al., (1993) reported values of 78 % and 88 % for Lemont and Tebonnet rice varieties which coincide with the values obtained for FARO 60 and FARO 44. Chalkiness or white portion in rice is as a result of poorly developed which gives an opaque appearance in rice (Bhattacharya, 2011). Steaming resulted in gelatinization of rice starch, thereby converting the opaque crystalline starch in rice into a clear amorphous structure. The low values of percentage translucency obtained for FARO 60 and FARO 44 could be due to high degree of poorly formed starch components (amylose and amylopectin) in FARO 60 and FARO 44 than the rest of rice varieties studied (Bhattacharya, 2011).
Parboiling process greatly improves milling quality of paddy rice by imparting hardness to the grains so making them resistant to breakage during milling. This reduces breakage losses and increases yield during milling and is of economic advantage to rice producers and millers. Biswas and Juliano (1988) and Islam et al. (2000) reported that hardness of rice increases during parboiling, especially, due to heat treatment. In this study, hardness of rice was found to increase with steaming duration and ranged from 59.45 – 113.65, 79.39 – 158.17, 77.24 – 136.70, 73.59 – 136.65, and 73.14 – 126.20 for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively. Steaming show substantial influence (p<0.05) on hardness for all the varieties studied. FARO 61 was found to have the highest hardness with initial value of 79.36 N which increased to 143.39, 147.05, 155.93 and 158.17 N with increase in steaming time from 5, 10, 15 and 20 min, respectively. Similarly, the local variety (Bisalayi) was found to have the lowest hardness value.
compared to the improved varieties. Differences in values of initial hardness of the selected varieties of paddy could be due to different levels of cracks or fissures imparted on paddy during harvesting and threshing. Thus during parboiling, the starchy endosperm melts and re-unites to seal all cracks, thereby, imparting hardness to rice. Figure 3 shows the percentage increase in hardness during steaming of paddy. Initial increase in hardness during 10 min of steaming was more pronounced in FARO 60 and FARO 52 as compared to other varieties. This could be as a result of rapid fusion between the gelatinized starch and protein bodies in FARO 60 and FARO 52.

The optimum grain hardness was achieved at 20 min of steaming for Bisalayi and FARO 44 while for FARO 61, FARO 60 and FARO 52 it was attained at 15 min. The varietal difference in hardness of rice grains could be due to the difference in the structural arrangement of starch granules among rice varieties in addition to varying extent of bonding between gelatinized starch and ruptured protein bodies. The extent of adhesion between gelatinized starch granules and ruptured protein bodies during steaming among different varieties can affect the hardness of rice due to parboiling (Bhattacharya, 2011). Kernel hardness is a very important attribute especially during milling and storage of rice. Harder grains are less susceptible to insect attack and to the development of moulds.

![Graph showing percentage change in hardness of rice due to parboiling](image)

**Figure 3: Percentage change in hardness of rice due to parboiling**

### 3.3 Lightness value

Discolouration of rice as a result of parboiling is another important quality indicator that affects market value and consumer acceptability of the product. The lightness value of selected varieties of rice significantly decreased (P<0.05) with steaming time. Figure 4 shows the effect of steaming on the lightness value at different times. The lightness value decreased as the steaming time increases with values of 78.34 – 58.98 N, 71.27 – 58.67 N, 73.85 – 59.06 N, 70.21 – 57.00 N and 69.75 – 58.67 N for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 respectively, corresponding to 0 – 20 min of steaming. Steaming time significantly (P < 0.05) affected lightness value of Bisalayi (local variety) more than the FARO varieties. This clearly shows that prolonged steaming period during parboiling of rough rice adversely affects lightness and colour quality of rice. Bhattacharya & Rao (1966) and Islam et al. (2002) reported that severe parboiling, such as extended steaming time greatly affect the colour of parboiled rice. The varietal difference in colour change observed in this work could be due to a more rapid nonenzymatic browning of
the Maillard reaction in the Bisalayi than in the FARO varieties. Mir and John Don Bosco (2013) reported that difference in genetic makeup could also result in varietal difference in colour of parboiled rice.

![Figure 4: Percentage change in lightness value of rice due to parboiling](image)

### 3.4 Degree of gelatinization

One of the major advantages of parboiling is to improve the hardness of rice and thus reduce kernel breakage during milling operation. Steaming operation, which produces parboiled rice, requires a lot of energy to produce steam for the process. Gelatinization temperatures and enthalpy of selected unparboiled rice varieties from Nigeria are shown in Table 1. For Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, gelatinization temperature ranged from 72.78 – 83.78°C, 73.90 – 82.55°C, 73.16 – 80.98°C, 64.24 – 77.70°C, and 64.37 – 75.26°C, respectively while gelatinization enthalpies for the respective varieties are 5.76, 3.62, 3.15, 1.55 and 2.35 J/g. Rice varieties from West Africa have been found to exhibit low gelatinization enthalpies (Traore et al., 2011; Odenigbo et al., 2013). Raw samples of Bisalayi, FARO 61 and FARO 60 have peak gelatinization temperature in the range reported in the literature (Normand and Marshall, 1989; Miah et al., 2002). However, FARO 52 and FARO 44 have lower values compared to other varieties used in this work. The enthalpy range of the selected varieties of rice used in this study was also found to be lower than those reported by previous authors (Normand and Marshall, 1989; Miah et al., 2002; Islam et al., 2002b).

During steaming of different varieties of paddies at 100°C for 5 – 20 min, it was observed that there was no residual enthalpy of gelatinization of the parboiled samples at the different steaming times. This could be due to low gelatinization enthalpies (1.55 – 5.76 J/g) of the raw parboiled rices used in this study. Marshall et al. (1993) and Islam et al. (2002b) studied the gelatinization properties of rice with respect to different parboiling conditions. They observed a decrease in gelatinization enthalpy with severity of parboiling and related it to the degree of starch gelatinization during heat processing. Marshall et al. (1993) proposed that during parboiling, rice starch only requires 40% gelatinization for maximum head rice yield to be obtained. Figure 5 shows a typical thermogram at different parboiling periods of selected rice varieties from Nigeria.

Miah et al. (2002) reported that the residual enthalpy of starch after hot soaking of paddy dropped from 6.03 to 0.86 J/g after 120 mins, amounting to 86% gelatinized starch in rice. Normand and Marshall, (1993) showed that the enthalpy of Lemont rice variety decreased from 14.6 – 2.2 J/g during conventional parboiling of rough rice in a pressure cooker for 8 min at 121°C. The result obtained by the authors show that approximately 85.6% of the rice were gelatinized during steaming.

Thus the degree of gelatinization during parboiling of selected varieties of rice from Nigeria could not be estimated in this work. Steaming, therefore, completely gelatinized the rice starch during processing.
Table 1: Gelatinization properties of non-parboiled paddy rice varieties from Nigeria.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Bisalayi</th>
<th>FARO 61</th>
<th>FARO 60</th>
<th>FARO 52</th>
<th>FARO 44</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;o&lt;/sub&gt;, °C</td>
<td>72.78±0.38&lt;sup&gt;a&lt;/sup&gt;</td>
<td>73.90±0.18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>73.16±0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>64.24±0.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>64.37±0.82&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;p&lt;/sub&gt;, °C</td>
<td>76.61±0.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77.03±0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>76.07±0.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>68.79±0.28&lt;sup&gt;b&lt;/sup&gt;</td>
<td>69.31±1.43&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>T&lt;sub&gt;c&lt;/sub&gt;, °C</td>
<td>83.78±1.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>82.55±0.85&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80.98±0.08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77.70±1.10&lt;sup&gt;b&lt;/sup&gt;</td>
<td>75.26±0.47&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>∆H, J/g</td>
<td>5.76±1.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.62±0.65&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.15±0.37&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.55±0.74&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.35±0.08&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
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Means with the same superscript along the lines are not significantly different at P < 0.05
T<sub>o</sub>, T<sub>p</sub>, and T<sub>c</sub> are onset, peak and conclusion gelatinization temperatures, respectively; ∆H is the gelatinization enthalpy.

![Figure 5: Thermogram of raw and parboiled Bisalayi rice flour (soaked at 60°C, steamed at 100°C for 5, 10, 15 and 20 min)](image)

4 CONCLUSION
The physical (translucency, hardness, lightness value) and thermal (gelatinization) properties during steaming of selected rice varieties from Nigeria were investigated. The findings from this study show that steaming time significantly affects physical and thermal properties of parboiled rice. Percentage translucency ranged from 23.67 – 93.00, 27.67 – 91.00, 19.67 – 74.67, 28.00 – 92.67 and 22.33 – 82.33 for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively, 0 – 20 mins steaming, with FARO 60 and FARO 44 having lower percentage of translucency than other varieties of rice at the end of 20 min of steaming. Steaming resulted in gelatinization of rice starch, thereby transforming the opaque crystalline starch in rice into an a clear amorphous structure. The low values of percentage translucency
obtained for FARO 60 and FARO 44 could be due to high degree of poorly formed starch components (amylose and amylopectin) in FARO 60 and FARO 44 than the rest of rice varieties.

The improved rice varieties used in this study show better hardness than the local variety which might be due to the difference in the structural arrangement of starch granules among rice varieties in addition to varying extent of bonding between gelatinized starch and ruptured protein bodies. Hardness of rice was found to increase with steaming duration and ranged from 59.45 – 113.65 N, 79.39 – 158.17 N, 77.24 – 136.70 N, 73.59 – 136.65 N, and 73.14 – 126.20 N for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44, respectively. The optimum grain hardness was achieved at 20 min of steaming for Bisalayi and FARO 44 while for FARO 61, FARO 60 and FARO 52 it was attained at 15 min.

Bisalayi (local variety) was found to be more discoloured more than the FARO (improved) varieties. Lightness value decreased with increase in steaming period with values of 78.34 – 58.98, 71.27 – 58.67, 73.85 – 59.06, 70.21 – 57.00 and 69.75 – 58.67 for Bisalayi, FARO 61, FARO 60, FARO 52 and FARO 44 respectively, corresponding to 0 – 20 min of steaming. The varietal difference in colour change observed as observed could be due to a more rapid nonenzymatic browning of the Maillard reaction in the Bisalayi than in the FARO varieties in addition to genetic make-up among cultivars.

Steaming completely gelatinized rice starch in samples, thus, there was no residual enthalpy of gelatinization after steaming of paddy.

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