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Effect of improved parboiling methods on the physical and cooked grain characteristics of rice varieties in Benin

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Abstract: The efficiency of traditional, intermediate and improved parboilers was compared through their effects on certain physical and cooking quality traits. Two varieties (NERICA 4 and Gambiaka) commonly cultivated and consumed in Benin were used. Results showed that the traditional parboiler had the highest level of heat-damaged grains (90%) with the improved equipment having the least (17%). The improved and intermediate parboiling technology produced grains of comparable hardness (4 kg and 6 kg, respectively, for Gambiaka and NERICA 4) while the traditional method resulted in a sample with the least hardness for both Gambiaka (4 kg) and NERICA 4 (3 kg). The improved method and the intermediate technology using wooden sticks at the bottom of the vessel had higher water uptake (2.97 ml/grain) and grain swelling ratios (5.41) as compared to the traditional and intermediate methods using a container with a perforated bottom.

Keywords: Rice, quality, parboiling methods, Benin

Introduction

Rice is parboiled in Benin mainly for domestic consumption and to a limited extent for sale. Parboiling is carried out mostly by women in their homes. These women are not aware of the simplicity and technicalities of parboiling (Diop *et al*., 1997), and heat the paddy in a vessel, either after wetting with water or soaking for a few hours. In some cases, paddy is boiled with excess water and then steamed (Behrens and Heinemann, 2007). When paddy is appropriately parboiled, the required hardness is imparted to the grain. Parboiling results in higher milling recovery, more translucent kernels and increased swelling when cooked to the desired softness (Ali and Ojha, 1976); consumers in most African countries favor these rice grain quality traits (Sakurai *et al*., 2006). Recently, Houssou and Amonsou (2004) developed an improved rice parboiler for use in Benin that gives a better quality product. In collaboration with the Institut national de la recherche agricole du Benin (INRAB), the Africa Rice Center developed a farmer-to-farmer video on parboiling based on the improved parboiler. The main component of this video was the improved parboiling equipment which is essentially a vat that is placed on top of a larger aluminum pot. The improved rice parboiling process can be summarized in five steps: washing, soaking in hot water, re-washing, steaming and drying.

Shows of the video were organized across 80 villages of central Benin to enable women processors to have easy access to the information and to learn how to operate the improved parboiler and its principle of steaming the paddy. Unfortunately, most of the women involved in rice parboiling in central Benin where the new equipment was tested could not afford this improved parboiler, but some instead adapted the learned principle of steaming the paddy to their local system by developing more affordable intermediate equipment for parboiling (Zossou *et al*., 2009). In follow-up research after video screening, the two most frequently encountered local innovations in rice parboiling were: (1) the use of a pan with a perforated base to steam the paddy and (2) the use of wooden sticks which were covered with a jute sack on which the paddy was then placed for parboiling.

The absence of foreign matter (impurities) is an important criterion of choice for a given milled rice product (Tomlins *et al*., 2005). Many previous studies (Ali and Ojha, 1976; Houssou, 2005; Manful *et al*., 2008) have shown that changes in the physical and cooking properties such as increasing the percentage of head rice through increasing rice grain hardness, translucency, swelling and elongation ratio, and reducing stickiness can be achieved by appropriate parboiling methods. The above grain quality traits increase consumer acceptability of rice (Correa *et al*., 2006). The objective of this study is therefore to compare the efficiency of traditional, intermediate (local innovations made by women rice parboilers)

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and improved parboilers using two varieties: a locally produced rice variety (Gambiaka) and a new high yielding variety (NERICA 4) developed by the Africa Rice Center.

Materials and Methods

Rice varieties

Two rice varieties: NERICA 4, an improved high yielding upland variety developed by the Africa Rice Center (AfricaRice) and released in Benin and Gambiaka, a commonly grown local variety, were chosen for this study.

Equipment

The parboiling equipment (methods) used were: (1) Traditional equipment (Figure 1): this consisted of one pot or a big barrel in which paddy is soaked, pre-heated and steamed; (2) Intermediate technology equipment (local adaptation): Two types of intermediate technology were used in this study. The first consisted of a pot with wooden sticks at the bottom, which are covered with a jute sac. The second consisted of a pot with a perforated container placed on top of it (Figure 2); (3) Improved equipment (Figure 3): this consisted of a paddy-holding vat and a moulded aluminium pot. The paddy-holding vat is perforated at the bottom and tightly fits on top of the aluminium pot which contains water.

Figure 1. Traditional equipment (a) Paddy directly placed in water in the pot (b) General shape of the traditional parboiler

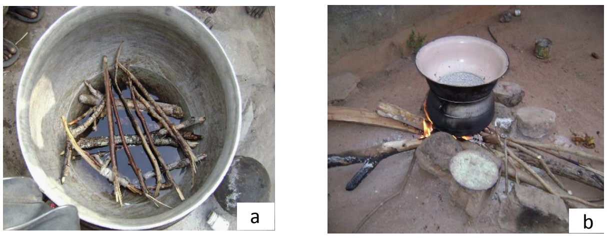

Figure 2. Intermediate equipment (a) Wooden sticks at the bottom of the pot (b) General shape of the intermediate parboiler

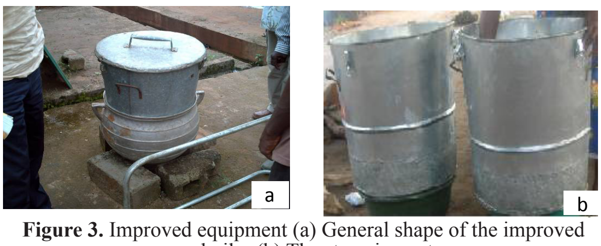

Figure 3. Improved equipment (a) General shape of the improved parboiler (b) The steaming vat

Parboiling methods

Each of the two varieties, Gambiaka and NERICA 4, was parboiled using each of the three different methods.

Traditional method

Rice paddy was soaked for 14 hours in cold water (at ambient temperature = ~ 27.8 ºC) without pre-cleaning and washing. After draining, small batches of 10 kg at a time were steamed. About 5 liters of water was placed in the pot, the drained paddy put on top and heated for 45 min. After steaming, the paddy was spread in the sun on tarpaulins for 1 hour and the drying continued in the shade for up to three days.

Intermediate technology (using container with perforated bottom)

Paddy, which had been pre-cleaned and washed, was soaked in water and heated for up to 30 min to a temperature of about 60°C before being removed from the heat and the paddy left in the hot water for 14 h to cool to ambient temperature and drained. The drained paddy was placed in a pan with a perforated bottom, which was placed on top of a pot. The lower pot contained about 5 liters of water over which the paddy was steamed in 25 kg batches for up to 25 min. After steaming, the paddy was then spread on tarpaulins in the sun for 45 min and the drying continued in shade for up to three days.

Intermediate technology (wooden sticks at bottom of pot)

Paddy, which had been pre-cleaned and washed, was soaked in water and heated for up to 30 min to a temperature of about 60°C before being left in the hot water for 12 h to cool to ambient temperature and drained. The drained paddy was placed on a jute sack covering sticks at the bottom of a pot and steamed for up to 30 min over 5 liters of water. The paddy was sun-dried for 1 h on a tarpaulin and for up to three more days in the shade.

Improved rice parboiling method

Paddy that had been thoroughly pre-cleaned and washed was soaked in water and heated for about 30 min to a temperature of about 60°C before being left in the hot water for 12 h to cool to ambient temperature. The paddy was then removed from the water, washed with clean water and drained in a basket. The drained paddy was then put in the parboiling vat previously placed on top of a pot containing about 10 liters of water. The water in this pot did not touch the bottom of the vat so that the rice was steamed for up to 20 min but not cooked. Steaming was halted when most of the husks on top of the paddy were split open. The paddy was then dried in the sun on tarpaulins for 1 h and in the shade for up to three days.

Milling

The samples were dehusked in a THU-34A Satake Testing Rice Husker (Satake, Japan). The brown rice obtained was whitened in a BS08A Satake single pass Friction Rice Pearler (Satake, Japan) with the degree of whiteness set between 'Low' and 'Medium' on the equipment.

Physical quality

Grain dimensions

For each rice variety and processing method, 10 whole grains were randomly selected from the milled rice, and the length, width and thickness determined using a micrometer screw gauge. This measurement and all others relating to physical quality were carried out in triplicate.

Level of impurities

A 20 g sample of milled rice was weighed. The head rice and broken grains were removed. Foreign matter such as dead insects, pieces of wood, dust, stones and unshelled paddy were then weighed. % Impurities = weight of impurities x 100/20 g

Head rice ratio

From a 20 g sample of cleaned milled rice, the head rice was manually separated and weighed. Milled rice grains with a length greater than three-quarters that of complete grains were classed as head rice, the remainder considered as broken grains. Head rice ratio = Weight of head rice (g) / 20

Grain hardness

Grain hardness was measured using a Kiya grain hardness tester (Fujihara Seisakusho LDT, Japan). For each rice sample, 10 grains were tested. The handle was initially turned to the left to make room to place a grain on the sample table. The handle was then turned to the right until a cracking sound was heard. At this time, the black pointer returns to the zero point and the "mother pointer" (red) remains. The reading of the "mother pointer" (kg) indicates the hardness of the grain.

Chalkiness

Two hundred whole grains were selected randomly and visually assessed for chalkiness. A score of 1 (less than 10% chalkiness), 5 (10 to 20% chalkiness) or 9 (over 20% chalkiness) was given to each sample according to the standard evaluation systems of the International Rice Research Institute (IRRI, 1996).

Whiteness and translucency

The whiteness and translucency of the milled rice were determined using a Satake milling meter (Satake Engineering Co. Ltd., MM-1B Japan). The Satake milling meter was calibrated using the "standard white and brown plates". The sample case was filled with grains and placed in the sample inlet port. The values of whiteness and translucency displayed on the screen were recorded. This measurement was triplicated.

Heat damaged grains

A Grainscope (TX-200, Kett Electric Laboratory, Japan) was used to identify heat-damaged milled grains. Fifty grams of milled rice were weighed in triplicate and observed using the Grainscope. A given grain was considered as "heat damaged" when at least 1/10 of its surface area was burnt. The heat damaged grains (HDG) were weighed and the percentage calculated as follows:

$$\%\ HDG = \frac{Weight\ (HDG)}{50} x100$$

Cracked grains

A Grainscope (TX-200, Kett Electric Laboratory, Japan) was used to identify cracked grains (CR). Fifty grams of milled rice were weighed in triplicate and observed using the Grainscope. A given grain was considered as "cracked" when it had even a small fissure on its surface. The cracked grains were weighed and the percentage calculated as follows:

$$\%\ CR = \frac{Weight\ (CR)}{50} x100$$

Cooking properties

Cooking time

Five grams of milled rice of each sample were weighed in triplicate and poured into 135 ml of vigorously boiling distilled water in a 400 ml beaker and covered with a watch glass. After 10 minutes of further boiling, 10 grains were taken out every minute with a perforated ladle. The grains were pressed between two petri dishes and were considered cooked when at least 9 out of the 10 grains no longer had opaque centers. The time was then recorded.

Swelling ratio

Eight grams of milled rice was put into a wire mesh cooking basket. The height of the raw rice in the cooking basket was measured using a vernier caliper (H1). The samples were then cooked according to the cooking times determined above. The cooking basket was subsequently removed and stood erect for 2 minutes for the water to drain off. The height of the cooked rice in the cooking basket was measured using a vernier caliper (H2). This determination was carried out in triplicate. Swelling ratio = H2/H1

Water uptake ratio

Eight grams of milled rice were weighed and put into a wire mesh cooking basket. The initial weight of the cooking basket plus raw rice (W1) was taken. The cooking basket was lowered into 160 ml boiling water in a 400-ml beaker with the regulator of the hot plate switched to "high". After 1 minute, the regulator was turned to "low" and the beaker was covered with a watch glass. The sample and the cooking basket were then removed just after the cooking times determined above were reached. The sample and the cooking basket were held erect for 2 min for the water to drain off. The final weight of the cooked rice and cooking basket (W2) was then measured. This determination was carried out in triplicate. The water uptake ratio was determined as follows: Water uptake ratio = (W2-W1)/8

Grain elongation ratio on cooking

The lengths of 10 milled grains were measured with a vernier caliper and put into a wire cylinder. The wire cylinder was placed into vigorously boiling distilled water in a 400-ml beaker. After 1 minute, the beaker was covered and the regulator of the hot plate set to "medium". Samples were cooked according to the cooking times determined above. The lengths of the 10 cooked grains were then measured. Elongation ratio was examined in triplicate and calculated as follows: Elongation ratio = Average length of cooked grains / Average length of raw grains

Gel consistency

This was determined according to the method of Cagampang *et al*. (1973). This measurement was triplicated.

Statistical data analysis

The data obtained were analyzed using analysis of variance (ANOVA) (SAS 9.2) at a 95% confidence level. The individual sensory attribute data were analyzed by one-way ANOVA to determine significant variation among the mean sensory scores.

Results

Tables 1 and 2 show the effect of parboiling method on, respectively, the physical and cooked rice characteristics of Gambiaka. Significant differences were found ($P<0.05$) in the level of heat-damaged grains obtained from different parboiling methods. The traditional method had the highest level of heat-damaged grains, with the improved method having the least. However, at the same levels of damage, no significant differences were found in the milling yield from the different parboiling methods although the improved method gave a slightly higher value of 76.8%. With regards to the cooked rice characteristics, no significant differences were found ($P<0.05$) in the level of impurities and grain elongation ratios of samples of Gambiaka prepared under different parboiling regimes. However, significant differences were observed in the grain swelling and water uptake ratios of the samples. The improved method and the intermediate technology with wooden sticks at the bottom of the vessel produced higher water uptake and grain swelling ratios than both the traditional method and the intermediate method using a container with a perforated bottom.

Table 1. Effect of different parboiling methods on physical characteristics of Gambiaka

Parboiling methods	Physical characteristics: % Heat-damaged grains	Grain hardness (kg)	% Cracked ratio	% Milling return	% Translucency
Improved method	0.17^{d}	5.76^{ab}	10.67^{c}	76.79^{a}	4.01^{a}
Intermediate technology (wooden sticks at bottom of pot)	0.67^{b}	6.74^{a}	12.00^{bc}	76.72^{a}	4.00^{a}
Intermediate technology (using container with perforated bottom)	0.30^{c}	5.62^{b}	13.67^{b}	76.42^{a}	4.21^{a}
Traditional method	0.90^{a}	5.02^{b}	27.00^{a}	76.16^{a}	3.00^{b}
LSD (0.05)	0.01	1.03	2.03	0.71	1.34

*Means with the same alphabet as superscript within columns are not significantly different at 5%.

Table 2. Effect of different parboiling methods on cooked rice characteristics of Gambiaka

Parboiling methods	Cooked rice characteristics: Water uptake ratio	Grain swelling ratio	% Impurities	Cooking time (min)	Elongation ratio
Improved method	2.34^{a}	4.07^{a}	0.11^{a}	21.07^{a}	1.27^{a}
Intermediate technology (wooden sticks at bottom of pot)	2.36^{a}	3.68^{b}	0.12^{a}	22.02^{a}	1.16^{a}
Intermediate technology (using container with perforated bottom)	2.15^{b}	3.62^{b}	0.11^{a}	21.71^{a}	1.16^{a}
Traditional method	2.02^{c}	3.10^{c}	0.12^{a}	18.53^{b}	1.23^{a}
LSD (0.05)	0.08	0.07	0.01	1.07	0.21

*Means with the same alphabet as superscript within columns are not significantly different at 5%.

The effects of variable parboiling methods on the physical and cooked-rice characteristics of NERICA

4 are presented in Tables 3 and 4. Just as with Gambiaka, no significant differences ($P<0.05$) were found in the milling yield of samples of NERICA 4 prepared under different parboiling regimes. However, NERICA 4 had higher milling yields (80.8% to 81.6%) compared to Gambiaka (76.1% to 76.8%). The trend with regards to heat-damaged grains was also similar, with the traditional method having the highest number and the improved method the least. No significant differences were found in the grain elongation ratios from samples under different parboiling methods. At $P<0.05$, significant differences were found in the grain swelling and water absorption ratios. The improved method produced grains with the highest water uptake and grain swelling ratios. Accordingly, this method produced grains with the highest degree of gelatinization (Manful *et al*., 2008) after parboiling. Samples from the traditional method had the lowest water uptake and grain swelling ratios. Table 5 shows the effect of variable parboiling methods on the chalkiness score of the Gambiaka and NERICA 4 samples. All the samples had a chalkiness score of 5 before parboiling and this was reduced for all to a score of 1 after parboiling.

Table 3. Effect of different parboiling methods on the physical characteristics of NERICA 4

Parboiling methods	Physical characteristics				
	% Heat-damaged grains	Grain hardness (kg)	% Cracked grains	% Milling return	% Translucency
Improved method	0.37^{d}	6.52^{a}	8.33^{c}	81.56^{a}	3.24^{b}
Intermediate technology (wooden sticks at bottom of pot)	0.67^{b}	6.30^{ab}	12.00^{b}	80.82^{a}	3.48^{ab}
Intermediate technology (using container with perforated bottom)	0.60^{c}	7.06^{a}	12.00^{b}	80.76^{a}	3.78^{b}
Traditional method	0.860^{a}	4.78^{b}	23.33^{a}	80.77^{a}	2.47^{c}
LSD (0.05)	0.01	1.55	3.07	1.36	0.30

*Means with the same alphabet as superscript within columns are not significantly different at 5%.

Table 4. Effect of different parboiling methods on cooked rice characteristics of NERICA 4

Parboiling methods	Cooked rice characteristics				
	Water uptake ratio	Grain swelling ratio	% Impurities	Cooking time (min)	Elongation ratio
Improved method	2.97^{a}	5.41	0.11^{b}	21.25^{a}	1.30^{a}
Intermediate technology (wooden sticks at bottom of pot)	2.78^{ab}	4.38^{b}	0.12^{ab}	22.47^{a}	1.23^{a}
Intermediate technology (using container with perforated bottom)	2.65^{b}	4.36^{b}	0.13^{a}	21.69^{a}	1.23^{a}
Traditional method	2.49^{b}	4.24^{c}	0.12^{ab}	18.55^{b}	1.40^{a}
LSD (0.05)	0.30	0.07	0.01	1.70	0.26

*Means with the same alphabet as superscript within columns are not significantly different at 5%.

Table 5. Effect of parboiling on chalkiness scores of Gambiaka and NERICA 4

Variety	Before parboiling	After parboiling	
	Score	Methods	Score
Gambiaka	5	Improved	1
Gambiaka	5	ITUC	1
Gambiaka	5	ITUW	1
Gambiaka	5	Traditional	1
NERICA 4	5	Improved	1
NERICA 4	5	ITUC	1
NERICA 4	5	ITUW	1
NERICA 4	5	Traditional	1

Discussion

The quality of rice is determined by its physicochemical properties which are themselves influenced greatly by genotype and environmental factors such as location, cultural practices and postharvest management (Fitzgerald *et al*., 2009). Consumer preference for a particular rice grade depends on both intrinsic and acquired qualities (Pillaiyar, 1988). The most appropriate way of assessing the efficiency of rice parboilers is a comparison of the grain qualities of samples from the parboilers.

The physical quality of parboiled rice grains tends to decline with increased levels of heat-damaged grains. When the heat-damaged grains are removed from a sample of parboiled rice, the amount of available edible grains is reduced. The improved parboiler had the least amount of heat-damaged grains in this study. This was followed in turn by the intermediate technology using a container whose bottom is replaced by perforated metal, by the intermediate technology using wooden sticks at the bottom of the pot and then by the traditional method. A similar trend was observed with swelling and water uptake ratios of the grains. These findings are consistent with those of Diop *et al*. (1997) and Houssou and Amonsou (2004).

Grain appearance is largely determined by the translucency of the endoderm and this is inversely related to the amount of chalkiness. Though chalkiness partially or totally disappears upon parboiling and cooking, and as a result may have no direct effect on cooking and eating qualities, high levels of chalkiness downgrades the physical quality, reduces milling recovery and can determine whether a particular rice sample attracts a competitive price on the market (Gayin *et al*., 2009; Adu-Kwarten *et al*., 2003, Khush *et al*., 1979; Indudhara and Bhattacharya, 1982). Raw milled samples of NERICA 4 and Gambiaka had high chalkiness scores of 5. All the parboiling methods studied managed to reduce this chalkiness to a score of 1. This means that even the traditional method was good enough as a way of reducing chalkiness in uncooked rice grains (Table 5). Endoderm translucency is enhanced during parboiling mainly due to the pre-gelatinization of its starch (Kondo, 2006). According to Adu-Kwarten *et al*. (2003) this trait also greatly influences consumer preference for parboiled rice. Examination of the effect of parboiling on Gambiaka grain translucency from this study (Table 1) shows that the traditional method was significantly different ($P<0.05$) from the other methods, which were not significantly different from each other. A similar result was observed for NERICA 4 (Table 3).

Grain hardness is a very important trait, especially when it comes to storage of milled grains as harder grains are more resistant to insect attack and less susceptible to the development of moulds. The improved and intermediate technology parboiling methods produced grains of comparable hardness while the traditional method produced the sample with the least hardness for both Gambiaka and NERICA 4 (Tables 1 and 3). The ability of a rice variety to swell on cooking is an important quality trait for most consumers in developing countries, and again the improved parboiling method gave the best results. Both intermediate technologies had similar effects. In general, the traditional method appeared to be the least favorable method of parboiling.

Conclusion

The improved rice parboiler gave better results for both Gambiaka and NERICA 4 in terms of improving physical and cooking traits. Apart from a reduction in cooking time for the samples, the traditional method appears to be the least appropriate of the parboiling methods assessed in this study. The intermediate technologies, whether using wooden sticks at the bottom of the pot or using a container whose bottom is replaced by a perforated metal, produced comparable results. With regards to the reduction in the amount of heat-damaged grains and the swelling capacities of the grains, the improved parboiled technology and the intermediate technology method using a container whose bottom is replaced by a perforated metal were observed to be preferable to the intermediate technology with wooden sticks at the bottom of the pot.

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