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Performance Study of Modified Rice Parboiler

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Authors' contributions

This work was carried out in collaboration between all authors. Author AG from the National Cereals Research Institute (NCRI) Badeggi was the person that designed and fabricated the old rice parboiling system. He was involved in the redesign, fabrication, performance assessment and analysis of the modified version of the parboiling system. He fabricated, tested and compiled the final paper. Authors AK and FS from Japan international Corporation Agency (JICA) were involved in the testing of the old parboiling system and recommended modification to be done in order to improve the performance. After the fabrication of the new model of the parboiler, they actively took part in the testing and final appraisal of the work. All authors read and approved the final manuscript.

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ABSTRACT

A small-scale rice parboiling system, developed in the National Cereals Research Institute (NCRI), was modified by a combined team of engineers of NCRI, Japan International Cooperation Agency (JICA), DESFABENG Co. Ltd and the Federal Ministry of Agriculture and Natural Resources, Nigeria. The system has a capacity to parboil 1000kg of rice per batch of over 8hours process time. This process duration is a

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combination of 6hours soaking, 1 hour 45 minutes steaming and 30 minutes packing. The equipment is comprised of a boiler and steaming sections, which are interconnected by a network of pipes to allow hot water and steam to soak and steam the paddy. The original design of the system had problems of uneven steaming and over-steaming, which usually results in variations in the coloration of processed rice, thereby making it unattractive to buyers. Also, longer cooking durations with attendant loss in flavor of the rice were observed. In order to solve this problem, the parboiling system was modified by incorporating additional steaming pipes at half of the height of the original design to reduce the distance travelled by the steam to get to the top of the system. The modified model drastically reduced the steaming duration of paddy from 1 hour 45 minutes to 45 minutes, thereby eliminating the problems of variations in coloration and longer cooking duration.

Keywords: Modified; rice parboiler; develop; soaking and steaming.

1. INTRODUCTION

Rice parboiling is a hydrothermal process which entails heat treatment to gelatinize the starch in rice kernel resulting in irreversible swelling and fusion of starch granules [1]. During this process, the starch changes from crystalline form to amorphous one. As a result of this transformation, the orderly polyhedral structure of the compound starch granules changes into a coherent mass [2].

It has been reported that parboiling of paddy requires three steps: soaking, steaming and drying. In the soaking process, the void spaces in the hull and rice kernel are filled with water, hence the starch granules absorb water and swells which causes an increase in the volume of the paddy [3] while during steaming, the starch in the rice kernel is gelatinized as a result of exposure of the soaked paddy to steam heat. Subsequently, the paddy is dried and tempered to 13-14% moisture content to impart hardness into the grains in order to withstand the pressures during milling.

Rice was consumed occasionally on Sundays and festive periods before 1970 but has become a staple food in many households in Nigeria [4]. The country consumes about 5 million metric tons of rice annually, of which over 35% is imported [5]. In order to satisfy the domestic consumption rate, government embarked on implementation of several agricultural programmes to boost production. However, locally processed rice acceptability in the market is still below expectation because of inadequate processing methods adopted by milled rice producers. Inappropriate rice parboiling methods used by local processors has been identified as one of the causes of low quality milled rice produced in the country. In order to solve this problem, the engineering department of the National Cereals Research Institute, Badeggi designed and developed a rice par-boiler. After several years of usage, it became necessary to modify the steaming system because the old model had problem of long steaming time of over 1 hour 45 minutes for 500kg batch of rice which usually cause production of uneven parboiling and dark yellow coloured rice which is unacceptable by some consumers. A team of scientists and engineers from the NCRI, JICA, DESFABENG CO. LTD and FMARD modified the par-boiler and achieved a steaming period of about 45 minutes for the same quantity of rice with the production of amber yellow coloured rice preferred by consumers. Thus, this is a presentation of the wok that was carried out.

2. MATERIALS AND METHODS

2.1 Description of Parboiling System

The old model parboiling system (Plate 1) is made up of the boiler and soaking /steaming sections. The boiler is a cylindrical vessel constructed with 3mm thick mild steel sheet. It is raised above the ground level to a height of 75cm with angle irons and enveloped with double bricks walls to form the firing area. A pressure relief system is incorporated at the top as a safety device in addition to a drain valve and steaming level indicator.

The soaking and steaming unit is a 75cm high rectangular tank with cover made with 2mm thick galvanised sheet and raised 15cm above the ground level. It has removable false bottom made with angle iron and screen raised 15 cm above the ground to allow steam to circulate. A steam distribution system made from perforated rectangular pipes is incorporated bellow the false bottom to spread steam evenly throughout the tank. A drain valve at the bottom of the tank provides drainage for soak water and the condensate.

The boiler and soaking/ steaming units are interconnected with pipe network carrying valves to convey water and steam for soaking and steaming operations respectively.

Plate 1. Old model parboiling system

2.2 The Modified System

Modification was only made on the steaming section. As shown in Plate 2, a second set of steam distribution pipes was incorporated half way the height of the soaking /steaming tank such that they are alternately fixed to the ones installed at the bottom of the tank in order for steam to be distributed evenly. Also, another removable false bottom is placed on the steam distribution pipes to prevent rice from getting into the perforations of the pipes.

Plate 2. Modified system

2.3 Experimental Procedure

18,000 Kg of rice, Faro 52 were obtained from NCRI rice store and divided into two (2) portions of 9,000kg each. Each of the portions was heat treated in three batches of 1000kg per batch in the modified and the old systems.

The 1,000kg samples were cleaned with both Pneumatic cleaner and wet cleaning systems and soaked with hot water from the boiler under the same condition of temperature, 70ºC and duration of 8 hours as an acceptable and recommended standard [4]. The samples were steamed until more than 98% of the paddy hulls cracked. This was done in batches in each of the parboiling systems in three replications. The time taken for each sample to be steamed was noted. They were shed dried on clean concrete platform in kernel layer at an average temperature of 28ºC for 24 hours and tempered further for 12 hours. The samples were milled with NCRI model rice mill developed at the National Cereals Research Institute in collaboration with the DESFABENG CO. Ltd., and the following analyses were carried out:

2.3.1 Total milling yield

This is the total quantity of rice that was milled. Each of the milled samples was weighed and expressed as percentage relative to the quantity of dried rice before milling:

$$\text{Percent total milling yield: } \frac{\text{Mass of Milled rice}}{\text{Mass of dried rice before milling}} \times 100 \quad (1)$$

2.3.2 Head rice yield and Percent broken grains

The head rice yield is the ratio of the quantity of whole milled rice (retaining more than ¾ of the total whole grain) to the total quantity of the milled rice while the Percent broken grains is the ratio of the quantity of the broken grains to the total quantity of milled rice.

The total milled rice is separated into whole and broken grains in two passes with a sieve SH1-400-0807 having 2.8mm holes diameter [6]. This sieve allows passage of less than ¾ broken grains. The whole and broken grains were weighed with precision balance BC 340. The percent head rice and broken grains were computed as follows:

$$\text{a) Head rice yield} = \frac{\text{Mass of whole grain}}{\text{Total mass of milled rice}} \times 100\% \quad (2)$$

$$\text{b) Percent broken grains} = \frac{\text{Mass of broken grains}}{\text{Total mass of milled rice}} \times 100\% \quad (3)$$

2.3.3 Colour

The colour of the rice samples were evaluated by placing 1g of rice on the Hunter lab colorimeter. The colour difference meter in the equipment was used to read the colours of the samples.

2.3.4 Swelling capacity

Three hundred and fifty millilitres (350ml) of water was heated to 100^0C in a 650 ml capacity graduated cylinder. Twenty five grams (25 g) of sample was lowered into the cylinder and covered. It was cooked on rectangular hot plate, HPS-460 for intervals of 10mins, 20mins, 30mins and 40mins. The decrease in volume, which is the amount of water absorbed indicates the swelling capacity of the rice samples [7].

2.3.5 Pastiness

The pastiness of the rice samples was determined with the Brabender Visco/Amilogragh equipment [8]. Each of the milled samples was ground to flour and the moisture content determined using the rapid oven dried method. Two grams (2 g) of the rice flour sample was weighed into aluminium dish and heated in oven at 135ºC for 1hour. The dish was then transferred into a desecrator and allowed to cool to room temperature overnight before weighing and the moisture content determined:

$$\text{M.C \% (wet basis)} = \frac{\text{Initial weight of sample} - \text{Weight of dried sample}}{\text{Initial weight of sample}} \times 100\% \quad (4)$$

The equivalent dry weight of the sample using 8% paste level and 450g paste concentration was determined [9].

$$\text{Dry Weight} = \frac{0.08 \times 450}{1 - \text{Moisture of Sample (wet basis)}} \quad (5)$$

The corresponding dry weight (ranging from 37.1g – 38.48g) was dispersed in 450ml of water for 1.5 mins and transferred into the amylograph bowl. The solution was heated from 30ºC to 95ºC at 1.5ºC/min for 30mins. The peak viscosity on heating from 50ºC to 95ºC was recorded in brabender units (BU). Breakdown viscosity, setback viscosity and consistency of the samples were calculated according to the method adopted by [7]:

a) Breakdown viscosity= Peak viscosity- Final viscosity on cooking at 95ºC
b) Setback viscosity = Viscosity when cooled to 50ºC – Peak viscosity
c) Consistency = Viscosity when cooled to 50ºC – Final cooking viscosity at 95ºC.

3. RESULTS AND DISCUSSION

The results of the analysis carried out on the rice samples are shown on Table 1 and discussed as follows:

Table 1. Comparism of parboiling parameters of the old and new parboiling system

Performance parameters	Old parboiling systems				Improved parboiling system			
	1	2	3	Average	1	2	3	Average
Steaming duration (mins)	105	100	107	104	45	48	43	45.7
Total milling yield(%)	69.5	71.2	68.8	70.0	70.0	69.5	71.1	70.2
Head rice yield (%)	98.0	96.8	98.2	97.7	96.5	97.2	98.0	97.2
Broken grains (%)	1.7	2.9	1.6	2.1	2.3	2.4	1.5	2.1
Colour (ΔE)	9.5	9.3	8.8	9.2	5.5	5.1	4.9	5.1
Swelling capacity (ml)	176	182.5	189.2	182.6	165	156.9	168.0	163.3
Pastiness:								
Peak viscosity	18.2	19.0	19.5	18.9	10.2	19.6	17.0	18.6
Final viscosity at 95ºC	42.6	41.7	42.3	42.2	41.5	40.2	42.2	41.3
Viscosity on cooling to 50ºC	65.0	63.7	62.9	63.9	63.0	62.5	64.0	63.2
Breakdown viscosity	24.4	22.7	22.8	23.3	22.3	20.6	24.2	22.4
Setback viscosity	47.0	43.7	42.4	44.4	21.5	22.3	21.8	21,8
Consistency	22.4	22.0	20.6	21.7	21.5	23.3	22.8	22.5

3.1 Steaming Duration

The duration taken by the modified system to complete the steaming process was observed to be 45 mins which is about half of the duration (104 mins) taken by the old one. This is because the vertical distance covered by the movement of the steam was shortened by the introduction of the additional set of steam distribution pipes half way along the height of the steaming tank. This indicates that more time is saved in carrying out the parboiling operation for the modified system.

3.2 Total Milling Yield, Head Rice Yield and Percent Broken Grains

The values for total milling yield, head rice yield and broken grains were almost the same for the modified system and the old one. Total milling yield for the old system was observed to be 69.8%, and 70.2% for the modified version. Correspondingly, the head rice yields for both systems were appreciably high (98.0% for the old and 97.0% for the modified one). Percent broken grains were also low for the two systems as both systems recorded 2.1%.

3.3 Colour

The colour difference, ΔE5.1 of the rice steamed with the modified system was amber yellow which is less than those produced from the old one with colour difference, ΔE9.2 (deep

yellow). The amber yellow coloured rice produced with the improved system has been reported to be more accepted by consumers compared to the rice with dark yellow colour [10].

The dark coloured rice obtained with the old system was due to the longer duration taken for the steam to travel vertically from the bottom to the top of the steaming tank due to the incorporation of a single set of steam distribution pipe-network. This observation conforms with a report whereby the relatively high level of reducing sugars and amino acids in parboiled rice in addition to the combined effect of longer heat treatment duration were found to be responsible for parboiled rice discolouration [11,12,13]. Conversely, the distance (vertical height) the steam travelled to completely parboil the rice was shortened by half due to the incorporation of the second set of steam distribution pipe-network halfway along the height of the steaming tank. As a result, the steaming duration was shorter, hence producing the bright amber yellow coloured rice.

3.4 Swelling Capacity

The swelling capacity, 163.3 ml of the rice obtained with the improved parboiling system was slightly less than the old model (182.6ml). This shows that it takes shorter time to cook the rice produced with the improved system compared with those from the old one. This observation conforms to an investigation carried out by [14] where parboiled rice that was exposed to severe steaming for longer times took more time to cook.

3.5 Pastiness

Pastiness indices (peak viscosity, final viscosity on cooking at 95ºC, viscosity on cooling to 50ºC, breakdown viscosity, and consistency) of the sample were almost the same for both the improved and old systems except for setback viscosity where the value, 44.4 BU for the old system is higher than those obtained with the improved system (21.9 BU).

4. CONCLUSION

The conclusions arising from this study are summarised as follows:

i) The steaming duration during the parboiling process was highly affected by the modification that was carried out on the old system. The second set of steam distribution pipe that was incorporated to the steaming tank reduced by less than half the time taken for the steam to flow through the vertical height of the tank. A saving in time of about 60 mins was recorded with the improved system as it took only 45 mins to completely gelatinize the starch in the kernels while the old one used 104 mins.
ii) The total milling yield, head rice yield and percent broken grains were not significantly affected by the modification as both the old and modified systems recorded almost the same values.
iii) The colours of the rice parboiled with the two systems at the same conditions differed from one another. The colour difference, ΔE9.2 obtained from the rice parboiled with the old system which was dark yellow in colour compared with those obtained from the modified system having amber yellow colour.

iv) The swelling capacity represented by the water absorption rate of the rice samples were slightly affected by the modification made on the parboiling system. The rice produced with the modified system had less water absorption rate (163.3ml) compared with the old system which had 182.6ml. This indicates that the rice processed with the modified system will take comparatively less time to cook.
v) All the viscosity values: peak viscosity, final viscosity at 95ºC, viscosity on cooling at 50ºC, breakdown viscosity and consistency were almost similar. This shows that the rice obtained with the improved system still retained the desirable pastiness qualities required in parboiled rice.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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