

Assessment of Postharvest Handling and Quality Control Practices of Rice in North Central Nigeria: A Case Study of Lafia, Nasarawa State

Marcus Olaniyi Ogunbiyi*

Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki 305-8572, Japan

Demand for rice in Nigeria has been increasing in recent years, and it has now become a food security and cash commodity crop. Rice features regularly on the daily menus of almost all Nigerians, and currently consumption is estimated at about 5 million tonnes annually. Although the country produces over 2 million tonnes of rice each year, representing about half of its rice requirement, research reports indicate that the rice is of poorer quality and grade than imported rice owing to the presence of broken and damaged grains, stones, and other impurities. This has led to low consumer demand for domestic rice. The poor competitive status of the local product in the domestic and international markets is thus discouraging and hampering the development of the rice industry in Nigeria.

This study carried out an assessment of the paddy rice processing and quality control methods used in Nigeria. Milled rice samples from selected target areas were analyzed for specific physical and cooking qualities, including head rice yield; ratio of broken, cracked, and damaged grain; foreign matter; whiteness; hardness; cooking time; grain elongation and swelling ratios; and water uptake. The results, which were compared with those obtained from two foreign milled rice samples, showed significantly greater percentages of broken, and damaged grains in rice milled in Nigeria (*Lafia 1*, *Lafia 2*, and *Assakio*) than in those produced and milled in other countries (referred to here as *Thailand* and *Japan*) ($p < 0.05$). Head rice yield was significantly lower in domestic rice than in foreign rice ($p < 0.05$). Notably, no foreign matter was found in the *Thailand* and *Japan* samples. Mean cooking time for *Japan* (non-parboiled rice) was about 16 min and between 15 and 23 min for the other (all parboiled) rice. There were no significant differences in grain elongation among the samples, but the swelling ratio was better in the domestic rice samples *Lafia 1* and *Lafia 2* than in the *Thailand* and *Japan* samples. The water uptake value in *Thailand* (2.07) was significantly greater than that in the domestic rice (1.54 to 1.81) ($p < 0.05$). It is therefore concluded that the methods of postharvest handling in Nigeria produced rice with poor physical quality and average cooking quality, even though the swelling ratio, one of the most important influences on consumer choice, was better in Nigerian rice. There is an urgent need for the Nigerian Government and other stakeholders in the rice value chain to invest in infrastructure, machinery, methodologies, and policies that will improve paddy rice processing capacity and processes and bring about the much-needed improvement in the quality of Nigerian domestic rice.

Key words: Rice, postharvest handling, grain quality, parboiled rice, Nigeria.

Introduction

Nigeria is undoubtedly one of the world's largest oil-exporting countries, but its economy still depends largely on agriculture, with the sector employing over 70% of the country's working population (Liverpool *et*

al., 2009). In 2010, the agricultural sector accounted for 40.89% of the nation's Gross Domestic Product (GDP) (National Bureau of Statistics, 2011). Although agriculture remains the bedrock of the Nigerian economy, the potential of the sector is yet to be fully realized. Food production and self-sufficiency are still

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* Corresponding author: Agro Processing and Marketing Department, Federal Ministry of Agriculture and Rural Development, PMB 135, Garki, Abuja, Nigeria.

Tel: 234-805-616-7230, E-mail: niyiogunbiyi2004@yahoo.com

a problem, despite the availability of a vast area of fertile and cultivable land (over 79 million hectares), most of which is traversed by rivers useful for irrigation (Federal Ministry of Agriculture, 2006). There still exists a large gap between food production and demand, resulting in massive importation of food products, especially rice, which is one of the major staples consumed by the Nigerian populace.

Rice is one of the oldest and most important cereal crops in the world and has become one of the most widely consumed staples for about half of the world's population (Harksworth, 1985). It is generally considered a major food crop in developing countries and an important source of nutrients in many parts of the world. (Hossain *et al.*, 2009, Parnsakhorn and Noomhorm, 2008, Danbaba *et al.*, 2011). In Nigeria, rice is the fourth major cereal crop and is the sixth major crop in cultivable areas, after sorghum, millet, cowpea, cassava, and yam (USAID, 2009). It is the only crop that is grown nationwide and in all agro-ecological zones, from the Sahel to the coastal swamps (Singh *et al.*, 1997). It is a food security and cash commodity crop and features regularly on the daily menus of most people. Rice commands a great market both locally and internationally; hence, promotion of rice production and processing would go a long way toward bridging the food-availability gap and improving the lives of the rural farmers who produce over 90% of the country's domestic rice.

Nigeria has a high potential for rice production in terms of land availability, human resources, and good climate, but rice production is not sufficient to meet consumption (Fig. 1, Ochigbo and Gbabo, 2004). The country is therefore a major importer of rice, mainly from Thailand, which enjoys a substantial part of the Nigerian market because of the high quality of its parboiled milled rice (Parnsakhorn and Noomhorm, 2008).

Because of the increasing contribution of rice to the per capital calorie consumption of Nigerians (this contribution is currently put at 9%; Erhabor and Ojogho, 2011), demand for rice has been increasing much faster than domestic production, and more than in any other African countries, since the mid-1970s (Bamidele *et al.*, 2010). Average yearly per capita consumption has grown substantially at 7.3% a year, from 3 kg in the 1960s to 15.8 kg in 1981–1990, to 22 kg in 2000, and, by 2007, to an estimated 27 kg (NFRA, 2010; Bamidele *et al.*, 2010). Currently, the average per capital con-

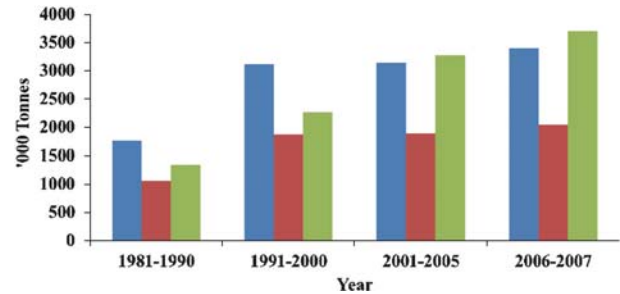


Fig. 1. Rice consumption and domestic production in Nigeria (Source: NFRA, 2010)

■ Paddy rice production ■ Milled rice production ■ Milled rice consumption

sumption of rice in Nigeria is over 32 kg a year. Average annual rice production is about 2.21 million tonnes of milled product, whereas national consumption is estimated at 5 million tonnes of milled rice leaving a shortfall of over 2.79 million tonnes that is bridged by importation (Wudiri and Fatoba, 1992; Ogundele and Akpokodje, 2004; NFRA, 2010; USAID, 2009).

Due to the importance of rice in the daily Nigerian meal and as a strategic commodity in the Nigerian economy, the Nigerian Government has actively interfered in the Nigerian rice economy over the past 30 years (Aliyu, 2004). Government intervention has occurred from two perspectives. First, the government embarked upon certain deliberate policies to increase local production of rice. One of these was the Presidential Initiative on Increased Rice Production, Processing and Export, which started in 2003. The program was the most specific and ambitious government program on rice. Its target was to attain the production of 6 million tonnes of milled rice from 10.3 million tonnes of paddy rice by 2005 and ensure that by year 2007, 3 million hectares, would have been put under rice cultivation to produce about 15 million tonnes of paddy rice or 9.0 million tonnes of milled rice. (FMINO, 2006; Ministry of Agriculture, 2006). These goals were not achieved, owing to the perennial problems and challenges of the production, postharvest, and other sub-sectors of the rice value chain.

Second, to encourage local rice production and to stimulate import substitution, the Nigerian Government at one time or the other ordered the banning of rice importation and subsequently imposed a 100% import duty, as well as 10% levy (for rice development) on imported rice. The 10% levy is solely for rice development. However, the taste for imported

Table 1. Grouping standards for milled rice by grain length and length-to-width ratio

Grain length			Grain configuration		
Type	Grain length (mm)	Scale	Description	Length/width ratio	Scale
Extra-long	≥ 7.51	1	Slender	≥ 3.1	1
Long	6.61–7.50	3	Medium	2.1–3.0	3
Medium	5.51–6.60	5	Bold	1.1–2.0	5
Short	≤ 5.50	7	Round	≤ 1.0	9

*Classification according to the International Rice Research Institute.

Source: The Food Agency (1995)

rice and the high demand for good quality rice among Nigerians, and especially urban dwellers, who consume large amounts of imported rice (Erhabor and Ojogho, 2011), have prevented this policy from bringing substantial improvements to domestic rice production and the imported commodity continues to flood Nigerian markets. This problem is exacerbated by the highly fragmented and poorly serviced nature of the domestic rice value chain.

Although Nigeria is a multi-ethnic nation with a variety of food cultures and tastes, Nigerians share in common, a preference for long-grain rice that is free from foreign matter and fluffy and tender when cooked (Danbaba *et al.*, 2011). This explains why Nigerians prefer imported and polished parboiled rice of premium quality. Consequently, efforts to increase the consumption of locally produced rice have to be geared toward promoting and improving the production of clean and table-ready parboiled long-grain rice, which is also the predominant type grown in Nigeria. Grain classifications according to length and length-to-width ratio are presented in Table 1.

Concept of rice quality

Grain quality, which is a summary of the physical and chemical characteristics of the rice grain, is based on a combination of subjective and objective factors (Abdullahi, 2004). These factors can also be classified as intrinsic or induced. Whereas factors such as bulk density, size, shape, and composition can be characterized as intrinsic factors that are genetically controlled, factors such as yield, foreign matter content, cracked grain content, and milling degree are induced factors that are generally introduced during postharvest handling. Quality itself is a complex property that depends on a number of factors, such as genotype, cultural factors, and postharvest management (Fofana *et*

al., 2011). It has many components, such as nutritional value, appearance, and cooking and eating quality (Fig. 2). These components also include attributes with values that are determined not only by their physicochemical properties but also by the history and cultural traditions of consumer communities (Tan *et al.*, 1999).

Desirable rice quality also varies from one geographical location to another, and consumers prefer specific cooking characteristics (Danbaba *et al.*, 2011). According to Tan *et al.*, (1999), deterioration in the cooking and eating qualities of rice grains is among the most serious problems in many rice-producing areas of the world. He attributed this problem to the intrinsic characteristics of the rice cultivars widely grown, especially the *indica* cultivars, which are the type mostly consumed in Nigeria (Tan *et al.*, 1999). However, milling-related characteristics are also of major concern to consumers and are therefore very important in quality evaluation.

Rice grain quality is best when the rice reaches physiological maturity, and the way in which the product is managed from that point onward further determines the final quality of the processed milled rice and rice products. Many researchers have reported that Nigerian rice is of poorer quality than rice imported into the country (Gbabo, 2004; Akpokodje *et al.*, 2003; Bamidele *et al.*, 2010). The factors that contribute to the poor quality of milled rice range from poor paddy rice and postharvest practices to a lack of adequate knowledge of paddy rice handling and the use of obsolete and ineffective rice-milling equipment (NFRA, 2010). Gbabo (2004) attributed the undesirable quality of locally processed Nigerian rice to a lack of knowledge about improved processing techniques among farmers and processors; incomplete use of imported technologies and the non-self-sustaining



Paddy, brown and polished rice from Ibaraki Minami Country Elevator, Japan



Polished, parboiled rice from a rice processing company in Thailand



Paddy and milled rice from the target areas in Nigeria

Fig. 2. Paddy and milled rice qualities

nature of some available technologies owing to the non-availability of spare parts; complexity of operation and maintenance of equipment; and a lack of skilled labour for repairs and maintenance.

In Nigeria more than 90% of rice is produced by resource-poor small-scale farmers, whereas the remaining 10% is produced by corporate or commercial farmers. In the same vein, about 95% of processors are small-scale ones who use low-capacity, obsolete mills. About 80% of rice trading in Nigeria is retail and is done by rural women; the remaining 20% of trading is conducted by wholesalers (USAID, 2009).

The National Rice Development Strategy (NRDS)

The Nigeria National Rice Development Strategy (NRDS) is the current program of the Nigerian Government intended to accelerate the production of high-quality rice in Nigeria in line with the Coalition for Africa Rice Development (CARD) goals of doubling rice production in sub-Saharan Africa within the next 10 years. The CARD initiative was launched

at the Tokyo International Conference on African Development (TICAD IV) in May 2008 and is being implemented with complete African ownership and leadership, as embodied in the Comprehensive Africa Agriculture Development Program, and with strong links to existing structures, programs, networks, and initiatives such as the Forum for Agricultural Research in Africa and the African Rice Initiative. CARD was jointly developed by the Alliance for Green Revolution in Africa and the Japan International Cooperation Agency. The overall goal set by the NRDS for development of the rice sector in Nigeria is to increase production from 3.4 million tonnes of paddy rice in 2007 to 12.85 million tonnes by 2018. The NRDS found that paddy rice processing remains the major bottleneck to increasing national rice supply. National processing capacity is low and a huge processing gap exists — for example, in 2007 paddy rice production stood at 3.4 million tonnes and only 1.4 million tonnes was processed due to lack of adequate processing capacity. Modern rice-processing equipment needs to

be introduced to bridge this gap. The NRDS has also stressed the urgent need to improve rice quality to meet export standards through (i) improving processing capacity and (ii) promoting the use of modern and mechanized harvesting and post-harvest processing facilities nationwide, complemented by adequate training of rice farmers and processors, in order to overcome the present poor quality of the product and poor market competitiveness. The NRDS has adopted the value chain approach to address improvement of every step of the rice value chain from production to delivery. Three major priority areas have been identified. They are:

- a) processing and marketing
- b) land development, irrigation development, and paddy rice production
- c) development of supplies of seed and other rice production inputs.

The strategies outlined by the NRDS seek generally to create a better policy environment for rice sector development and specifically to address the various challenges identified in each step of the rice value chain (NFRA, 2010). One such challenge is the inability of the sector, given current processing capacity limitations and quality-control practices, to ensure a clean milled rice of international standard quality, free from impurities and other foreign materials. As a result, locally processed rice is uncompetitive, not only in the international but also in the domestic market, and the average Nigerian is reluctant to consume locally processed rice and rice products (Bamidele *et al.*, 2010). The shortfall in the country's capacity to process its annual paddy rice production and the corresponding shortfall in table-ready milled-rice production had led to a wide gap between demand and production, amounting to over 1 million tonnes. Successful implementation of the NRDS, as laid out in the program document (NFRA, 2010) is therefore essential for improving processing capacity and the quality of Nigerian paddy rice.

Consumer rice-consumption criteria

According to the statistics from rice consumption survey conducted in 2003, annual per capital consumption of rice in urban areas is above 47 kg with cities like Lagos, Abuja and Makurdi having per capita consumption of 64, 64 and 72 kg/annum. This is against the annual national average of 27 kg in 2007 (USAID, 2009). According to USAID (2009), three distinct rice

market segments exist in Nigeria, and each market segment has its own rice-consumption criteria. Urban consumers emphasize cleanliness, swelling capacity, taste, and ease of preparation and have low sensitivity to price. Another segment accepts lower quality rice but is more price sensitive and prefers the taste of local rice. The third segment is the institutional/food service market. These consumers purchase processed milled rice in bulk and then cook and sell. They are concerned mainly with cleanliness and swelling capacity and therefore prefer imported brands.

The factors influencing Nigerian consumers' rice choices are shown in Fig.3. The majority of imported rice is of high consistency in terms of size, (shape) variety, colour, and cleanliness; this has favoured the preference of Nigerians for imported foreign rice. Bamidele *et al.* (2010) studied patterns rice consumption in Nigeria and reported that the choice of rice is not influenced substantially by market price but by its quality in terms of physical appearance, taste, and cooking characteristics.

Rice processing in Lafia, Nigeria

Lafia is a town in North Central Nigeria. It is the largest and capital city of Nasarawa State. It has a population of 330,712 inhabitants according to the 2006 census results. Lafia is noted and very popular in Nigeria for paddy rice processing and has been reported to have the largest rice processing cooperative association in Nigeria. As practised in most parts of Nigeria, in Lafia, paddy rice processing is generally done away from the farm; rice stalks are cut by sickle and transported home, where they are manually threshed and winnowed to obtain rough (paddy) rice. With the exception of milling, rice processing in Lafia is carried out manually (Fig. 4).

Most Nigerian rice is parboiled before it is milled. Parboiling is done traditionally in Lafia, in the following way. The paddy rice is soaked in water at 60 to 70°C for 10 to 12 h (usually overnight). Thereafter, it is steamed for 20 to 90 min, depending on its quantity and the type of container used, until the kernels split. The steamed paddy is evacuated at the onset of kernel splitting and laid out on drying slabs (usually not elevated), tarpaulins, or mats to sun dry. At this stage, there is a danger of small stones becoming mixed in with the rice grains, thus reducing their marketability. All of these processes are done manually and can be laborious. According to Adewuyi (2004), the parboil-

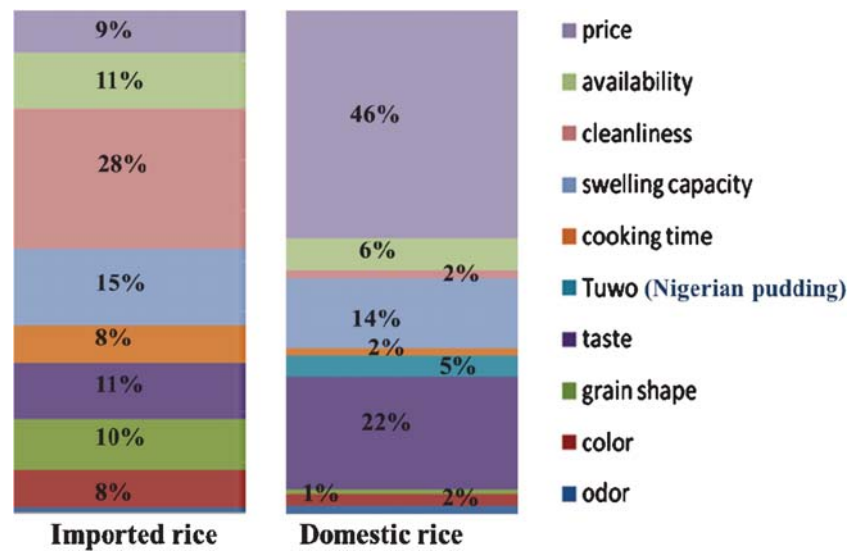


Fig. 3. Rice consumption patterns of consumers in Nigeria (Source: USAID, 2009)



Fig. 4. Rice processing in North Central Nigeria

ing process takes over 16 h for a batch of 50 kg. However, the use of very large parboiling tanks, especially in Lafia, has made it possible to handle more paddy rice (from 400 to 600 kg per batch).

The milling operation, which is the final stage of paddy processing to table rice, is traditionally done in Nigeria with mortar and pestle at the homestead level. Although mechanical rice mills and hullers are available in commercial plants in Nigeria, much of the rice milling is done by co-operatives, the largest of which is in Lafia, where there are more than 700 small Engleberg type abrasive mills which dominate the commercial processing of Nigerian domestic paddy rice (Overseas Development Institute, 2000).

Study objectives

It is essential for Nigeria to produce premium quality rice if it is to gain control of both its domestic and international rice market and reduce its import bill, which in 1999 was in excess of US\$259 million (Akpokodje *et al.*, 2003). In 2010, Nigeria imported over 2 million tonnes of rice from Thailand and over 73,000 tonnes from the United States, with a total estimated value of over US\$1 billion (USDA, 2011). To achieve and maintain self-sufficiency in rice production, a major development challenge for the Nigerian rice sector is therefore to improve the quality of domestic rice to international standards, increase its quantity, and at the same time bring down its cost to an internationally competitive level. Only then will Nigerians likely be willing to substitute domestic rice for imported rice and cut down the substantial loss of foreign exchange incurred on importation.

Postharvest handling and processing of rice are paramount to the production of clean, edible, high-quality milled rice from paddy rice. Thus, a clear, and deep understanding of the postharvest technology required to produce quality table rice is of crucial importance if rice processors are to meet market-competitive standards of quality.

The overall objective of this study was therefore to evaluate the postharvest handling methods and practices employed by rice farmers and millers in North Central Nigeria. The study further compared these methods and practices with more advanced methods used in other countries, particularly Thailand and Japan, which are noted for the production of high-quality milled rice, with the aim of helping to bring about much-needed improvement in the processing

sub-sector of the rice value chain in Nigeria.

Specifically, the study had the following objectives:

- i. to identify the stakeholders and their levels of involvement in the rice value chain.
- ii. to identify the present methods of postharvest paddy rice handling in selected areas of Nigeria.
- iii. to compare the methods identified with those available and in use in Thailand and Japan.
- iv. to assess these methods on the basis of a quality analysis of rice samples from the three countries.
- v. to suggest effective and appropriate ways of improving postharvest paddy rice handling in Nigeria.

Materials and Methods

Target area and study sites

The study was conducted in two rice-processing communities in the Lafia Local Government Area of Nasarawa State, the Federal Republic of Nigeria. Nasarawa State is located in the North Central Region, the largest rice-producing region in Nigeria, which in 2000 accounted for 47% of the country's total rice output (Ezedinma, 2006). The state is located at lat. 8°32' N, long 8°18' E and has a total land area of 27,116.8 km². It is bounded in the north by Kaduna State, in the west by the Federal Capital Territory, in the south by Kogi and Benue States, and in the east by Taraba and Plateau States (Fig. 5). It lies within the Guinea savannah region and has a tropical climate. Rainfall is moderate; the mean annual rainfall is 1311.75 cm. The topography of the state is plains and hills, which reach up to 100 m above sea level at some points. According to the 2006 national census, the population of Lafia Local Government Area was 330,712, comprising 169,398 males and 161,314 females (National Bureau of Statistics, 2006).

The state's agrarian economy and proximity to the federal capital guarantee a ready, fast-moving market for its various agricultural crops and products, which include yam, maize, rice, cassava, guinea corn, beans, tomatoes, *acha*, (*Digitaria* spp.) groundnuts, cotton, millet, oranges, bananas, apples and wheat.

Organized and controlled rice processing and marketing are performed at two rice-processing communities (Lafia and Assakio) in the target area (Fig. 5). In each community, there is an association comprised of different stakeholders in the rice value chain. Specific days are allocated to groups of association members involved in rice processing to process and mill their

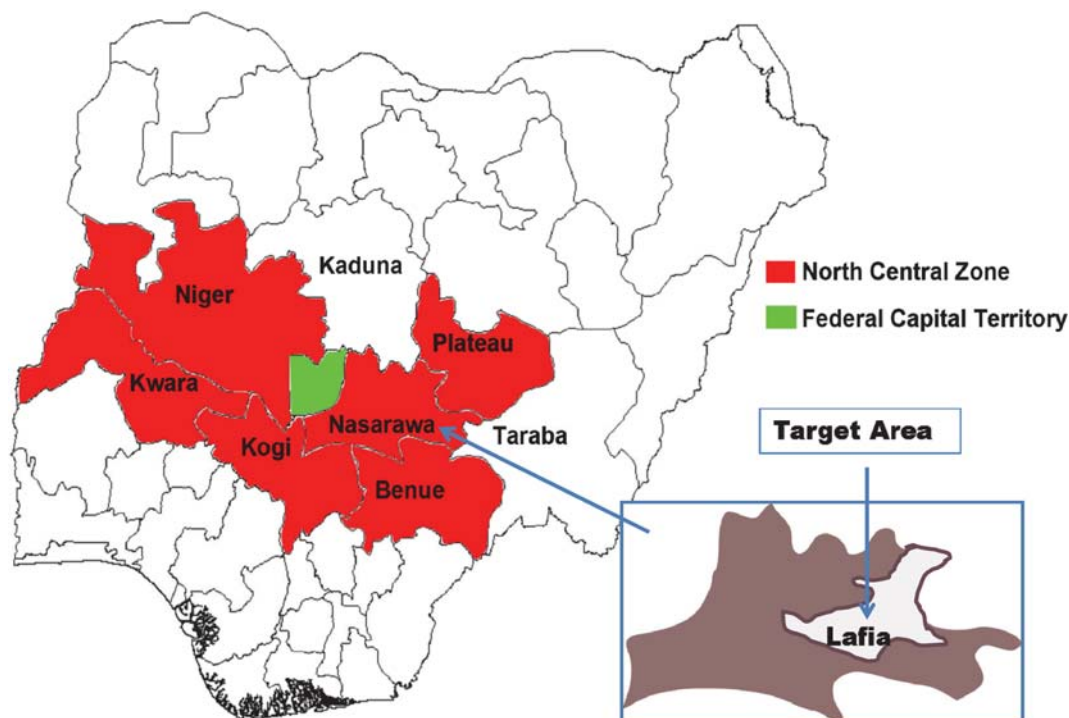


Fig. 5. Map of Nigeria showing the target area

paddy rice for sale to buyers, who flock to the processing and marketing sites of each association on its designated marketing days.

Baseline data on postharvest activities

Baseline data on the postharvest activities of the two cooperative associations in the target area were collected by using a simple structured questionnaire (Appendix 1). Questionnaires were administered in December 2010 and January 2011. The questionnaire was divided into six sections (A to F) to gather basic information on the involvement and activities of stakeholders in the rice value chain in the two target groups. Samples of local rice were also collected from the two communities for specific quality analysis.

Stakeholder identification

Different stakeholders in the rice value chain, especially in the postharvest subsector, were identified. Five categories of stakeholder were identified:

Farmers	They cultivate and sell their paddy rice, but may process small quantities for home consumption only. They do not sell milled rice.
Farmers/millers	They produce paddy rice but do

Millers only

Processors/millers

Traders

not sell it; instead they process it and sell only milled rice.

They own rice mills and offer milling services to customers for a fee. They do not grow rice, neither do they buy nor process paddy rice.

They purchase paddy rice from farmers, process it, and sell the milled, parboiled rice. They do not have their own farms, but support farmers to grow and produce paddy rice.

They come to the milling houses to purchase milled rice. Normally they buy rice in bulk, and then package it into 100-kg bags to sell to retailers mainly outside the production areas.

Each category of stakeholders has a defined and specialized role in the rice value chain and is expected to contribute significantly to any future efforts to improve the quality of Nigerian domestic rice. The level of involvement and activities of each stakeholder group were studied and compared with those of counterparts

in Thailand and Japan.

Study visit to processing facilities in Thailand and Japan

On-the-spot field assessment visits were made to some rice farms and processing facilities in Thailand, where most of the parboiled rice imported into and consumed in Nigeria is grown and processed. The paddy rice handling methods and quality assurance practices were studied and compared with those in use in the target areas in Nigeria. Similar study visits were made to relevant rice processing equipment manufacturer and rice handling facilities in Japan.

Grain quality analysis

Experimental samples

Four samples of long-grain parboiled milled rice were randomly collected from the target area; the samples consisted of three locally processed samples and one imported sample to serve as a control. These samples were representative of the different categories of milled rice consumed in Nigeria. Another sample

was collected in Japan to represent short-grain non-parboiled *japonica* rice, serving as an additional control sample. The samples, which had all been milled, were designated *Lafia 1*, *Lafia 2*, *Assakio*, *Thailand*, and *Japan* (Fig. 6). Samples were brought to Japan for laboratory analysis to determine their physical and cooking qualities.

The samples were chosen to all be in the long grain category and have similar grain morphology as *Thailand* which was used as the basis for comparison. This is because of the preference of Nigerian consumers for rice imported from Thailand. The methods of Fofana *et al.* (2011) and Parnsakhorn and Noomhorm (2008) were used to determine the cooking qualities of the milled rice samples. The methods have also been described by The Food Agency (1995).

Experimental analysis was conducted at the Post-harvest Engineering Laboratory at the University of Tsukuba, Tsukuba, Japan.

Moisture content

The moisture content of the grain samples was determined with a digital moisture analyzer (MX-50,



Fig. 6. Rice samples studied

A&D Company Limited, Tokyo, Japan). The moisture analyzer was equipped with a Win CT (Windows Communication Tool) system, which enables the transfer of data being measured to the computer for processing. The moisture analyzer also uses RsTemp and RsFig software to determine the optimum heating temperature and to produce the graphics interpretation of the process. The data recorded were saved in CSV (comma-separated-value) pseudo-file format. Three replications of moisture content determination were done and the mean value calculated.

Grain shape

Ten whole grains were randomly selected from each sample of milled rice, and their length, width, and thickness were measured with a digital caliper (CD-15CPX, Mitsutoyo Corp. Kawasaki, Japan). The mean values of these parameters were noted.

Head rice ratio

A 20-g sample was used to measure the head rice ratio with a digital electric balance (FX-3000i WP, A&D Company Limited, Tokyo, Japan). Each grain was carefully examined visually. Grains that were 75 % or more of the length of a full grain were considered to be head rice and separated from the sample and weighed; the rest were considered to be broken rice. The head rice ratio was calculated as:

Head rice ratio = weight of head rice / total weight of rice sample.

The procedure above was performed three times, and the mean values were determined.

Broken rice ratio

The broken rice ratio was determined in similar manner as that used to determine the head rice ratio. Broken grains that were less than 75% of the mature whole grain length were separated from a grain sample (20 g) and weighed. The broken rice ratio was calculated as:

Broken rice ratio = weight of broken rice / total weight of rice sample.

This measurement and the ones below were also done in triplicate, and mean values were determined.

Cracked grains

From a 20-g sample, the cracked grains were separated manually and weighed. The percentage of cracked grain was calculated as:

Cracked grain percentage = (weight of cracked grain / total weight of rice sample) \times 100

Damaged grain, foreign matter, red-streaked grain, and chalkiness

In the same way, the percentages of damaged grain, foreign matter, red-streaked grain, and chalky grain in 20-g rice samples were calculated:

Damaged grain percentage = (weight of damaged grain / total weight of rice sample) \times 100

Foreign matter percentage = (weight of foreign matter / total weight of rice sample) \times 100

Red-streaked grain percentage = (weight of red-streaked grain / total weight of rice sample) \times 100

Chalkiness ratio = weight of chalky grain / total weight of rice sample.

Grain colour

This was assessed with the whiteness index of the grains. Whiteness was measured with a whiteness tester for rice (C300, Kett Electric Laboratory, Tokyo, Japan) at the Grain Analysis Centre of Satake Corporation, Hiroshima, Japan. The equipment was first calibrated against a standard pure white plate. Rice samples were thereafter put into the tester's sample holder, which was inserted into the receptacle. The reading on the display was recorded. The process was repeated and the mean value of three replicates was taken as the whiteness index of the sample.

Grain hardness

The hardness of raw milled rice was determined with an Orientec Universal Testing Machine, (STA-1225, Orientec Co. Ltd. Tokyo, Japan) coupled with a data analyzer (AD7703, A&D Company Limited, Tokyo, Japan). The machine determines the force required to produce a range of strain values for a single sample grain. The hardness of 10 individual grains of a particular sample was determined and the mean value recorded for the sample.

Cooking time

Distilled water (135 ml) in a 400-ml beaker was brought to a boil on a laboratory stirrer/hot plate, (PC-420D, Corning Incorporated, Mexico). A rice sample (5 g) was poured into the boiling water, the beaker was covered with a watch glass, and the water and rice were left to boil for 10 min. At 10 min and every minute thereafter, 10 grains were taken out and pressed between two Petri dishes. The grains were considered cooked when at least nine out of 10 no longer had opaque centres. The time was then recorded and the mean values of three replicates were determined.

Swelling ratio

Ten grams of milled rice was put into a wire-mesh

cooking basket (diameter 40 mm). The height (H_0) of the raw rice in the cooking basket was measured with a digital caliper. The cooking basket with the rice was lowered into a beaker containing 160 ml of boiling distilled water and covered with a watch glass. The rice was allowed to cook under the conditions described above. The cooking basket with the sample was then lifted out of the beaker just after the cooking times determined above were reached and held erect for 5 min for the water to drain off. Then the height (H_1) of the cooked rice in the cooking basket was measured with the digital caliper.

$$\text{Swelling ratio} = H_1/H_0.$$

Mean values of three replicates were calculated.

Grain elongation on cooking

The lengths (L_1) of 10 milled grains were measured with a digital caliper. The grains were then put into a wire-mesh cooking basket. The basket was placed into 135 ml of boiling distilled water in a 400-ml beaker on the laboratory stirrer/hot plate. The sample was cooked in accordance with the method and cooking time determined above. The basket with grains was then removed and excess water was allowed to drain off for 2 min. The lengths (L_2) of the 10 cooked grains were again measured. Grain elongation (GE) was calculated as:

$$GE = \text{Mean } L_2 / \text{Mean } L_1$$

Mean values of three replicates were calculated.

Water uptake ratio

Distilled water (160 ml) was boiled in a 400-ml beaker on the laboratory stirrer/hot plate. Milled rice (10 g) in a wire-mesh cooking basket (initial weight of basket and rice = W_0) was put into the boiling water. The sample was cooked in accordance with the procedure described above. The sample and the cooking basket were removed just after the cooking times determined above were reached and the water was allowed to drain off for 2 min. The final weight of the basket with the cooked grain (W_1) was then determined. This procedure was performed in triplicate. The water uptake ratio was calculated as follows:

Water uptake ratio = $(W_1 - W_0) / \text{weight of uncooked rice sample}$.

Statistical analysis

The statistical significance ($p < 0.05$) of differences in the analytical results (frequencies, percentages, or means) were determined by analysis of variance followed by Tukey's HSD parametric multiple compari-

sons test.

Results and Discussion

The efficiency and appropriateness of postharvest rice handling and quality control was assessed by evaluating the quality of the milled rice produced.

Harvesting and pre-parboiling

Because rice harvesting is basically manual in Nigeria, farmers can be faced with a lack of labour to meet harvest schedules; when labour is available, they are further faced with the need to pay high, and sometimes unaffordable, wages. The lack of available labour and excessive competition for existing labour can result in delayed harvesting and thus a poor quality harvest. Quality control of un-husked and un-milled rice presents additional problems in postharvest processing. In addition, weather extremities lead to high percentages of broken rice.

Threshing, winnowing, drying, and cleaning (all of which are performed before parboiling and milling), and in some cases storage, are all still largely performed manually. This makes paddy rice processing very slow and encourages deterioration and subsequent poor quality of the milled rice. My field studies and visits to Japan and Thailand revealed that harvesting there is done mechanically with combine harvesters, which also simultaneously thresh, winnow, and clean the grain. In contrast, in Nigeria, the rice straw is cut with a sickle, transported home over a distance, and then threshed by being beaten with sticks on earthen threshing floors. These traditional threshing methods introduce impurities such as stones and other foreign materials into the rice and are inefficient and labour intensive. The threshed rough rice is also winnowed manually by using the natural flow of the wind, and winnowing efficiency depends on the wind intensity, speed, and direction, as well as the height of fall of the rice.

My investigations also revealed that farmers still heavily rely on the sun to dry both rough rice and parboiled paddy rice. Direct sun-drying is done by the roadside on bare ground or on tarpaulins or used plastic bags spread on the ground. As with the threshing, this practice introduces substantial amounts of foreign matter, small stones, and other impurities. Platforms are not often used for drying the rice.

Farmers do not use scientific instruments to check the moisture content of the dried paddy rice; Likewise

Table 2. Rice parboiling methods in the target areas

Community	Quantity /batch (kg)	Soaking		Source of water	Steaming time (min)	Heat source	Drying method
		Time (h)	Temp. (°C)				
Lafia	300-600	10-16	60-70	Wells, rivers, ponds	40-90	Firewood	Sun-drying
Assakio	200	10-16	60-70	Wells, rivers, ponds	20-35	Firewood	Sun-drying

Table 3. Rice-milling methods in the target areas

Community	Own mill (%)	Mill use for a fee (%)	Mill does husking and polishing (%)	Mill does husking only (%)	Mill has destoner (%)	Mill has sorter and grader (%)
Lafia	56	44	0	100	0	0
Assakio	37	63	0	100	0	0

in Lafia, processors access the adequacy of drying only by feeling and biting the kernels, which leads to irregularly dried and over-dried rice, which does not favour good quality milling and reduces the head yield of rice.

Tables 2 and 3 give an overview of the rice parboiling and milling processes as performed in the target area. These data were obtained from survey responses from the two rice-processing communities. The two rice-processing communities process rice under similar conditions and use similar methods for drying, parboiling, and milling. Soaking during parboiling operations is usually done overnight (10 to 16 h), and the soaking temperature is between 60 and 70°C. The sources of water for parboiling operations include wells, rivers, and ponds, and firewood is the major fuel used to supply heat for parboiling and steaming. The difference in the duration of steaming between the two clusters results from differences in size of the parboiling tanks. Parboiling is done in large cylindrical tanks at Lafia, whereas the processors at Assakio use old 200-litre oil drums with less paddy holding capacity per batch.

Rice parboiling

Parboiling is the main rice-processing activity in Nigeria, because it alters the structure and texture of the rice grain. It hardens the grain and softens the

outer layer for good milling. Parboiling facilities are usually established close to farm areas, threshing floors, and mills to allow for simultaneous operations. Official parboiling manuals are not available, the process is thus non-uniformly carried out and the procedure used depends on the experience of the processor.

My visit to processing facilities in Thailand revealed that there the parboiling operation is done in an automated parboiling plant. However, in Nigeria, despite the importance placed on parboiling, the operation is still done traditionally, which exposes the processors to numerous health, social, and environmental hazards. In most cases, steaming is overdone: the parboiling tank is often left exposed to continuous heat because the processor is not around or has limited or no assistance. A major quality determinant in the parboiling operation is the quality of the water used for paddy soaking and steaming. Processors use water from various sources, including ponds, wells, and rivers. In some cases, however, boreholes, with better water quality are sunk for use by processors.

Milling operation

Milling is the only rice-processing operation that is performed mechanically. This operation is, however, done using old and poorly efficient Engleberg-type

abrasive rice hullers. The milling process in the target areas can best be described as hulling, as there is no effective bran removal. Although the Engleberg mill was designed to perform both husking and polishing in a single pass (The Food Agency, 1995), almost all of the milled rice, upon physical examination, had low degree of milling. According to The Food Agency (1995), it is best to use a husker for de-hulling and an Engleberg machine for rice polishing for a better head yield. However, in the target area, despite its age and low efficiency, the Engleberg machine is still being used for both milling operations.

There is no functional destoner in Lafia; almost none of the rice milled in this part of North Central Nigeria is mechanically cleaned or destoned either before or after milling. This likely explains the presence of stones and other impurities in the market-ready milled rice produced in the target areas. The milled rice is also heaped onto the old, damaged concrete floors of the mills to await sale to rice traders, who later package the rice into 100-kg polyethylene bags. Thus the rice is further exposed to contamination by rats, birds, insects, and sand before it is bagged.

Grain physical qualities

Because rice, unlike most other cereals, is consumed as a whole grain, physical properties and general appearance are of utmost importance and are used as first criteria to determine the quality of milled rice (Dipti *et al.*, 2003). Assessment by the human eye is a subjective evaluation in terms of grain size and shape, uniformity, translucency, chalkiness, colour, and the content of damaged or imperfect grains. The physical properties of the milled rice samples are shown in Table 4.

Head grain yield and appearance

Significant differences between locally milled Nigerian rice and foreign (Thailand and Japan) milled rice were found in the percentages of head rice, broken rice, cracked grains, damaged rice, and foreign matter, and in the whiteness index. These findings clearly indicate that rice produced in Thailand and Japan is of better quality in terms of physical characteristics than Nigerian rice. There were no damaged or red-streaked grains and no foreign matter in the rice processed in Japan and Thailand, whereas the Nigerian rice contained significant levels of damaged grains, and foreign matters. The reduction in the physical qualities of locally milled rice (*Lafia 1*, *Lafia 2*, and *Assakio*), as evident in the low head rice percentages, the high levels of cracked grain, and the presence of foreign materials and damaged grain, was likely a result of the improper postharvest handling, described above. In contrast, Thailand and Japan use improved methods of processing, with better machinery and good quality-control measures and standards. Because rice is usually harvested at high moisture content (between 20% and 25% wet basis), and manual postharvest handling carried out in Nigeria is relatively slow, deterioration of the paddy rice sets in quickly leading to poor quality milled rice. Moreover, the drying temperature cannot be controlled when the rice is being sun dried. Temperatures on the drying slabs can exceed 50°C during the day, causing fissuring. The tendency to over dry parboiled paddy rice leads to breakages during milling. The irregularities, inconsistencies, and inefficiency of the milling operations also contribute to the poor quality of the locally processed rice.

Grain colour

The colour of parboiled rice generally affects con-

Table 4. Physical properties of rice samples^{1,2}

Sample	Head rice (%)	Broken rice (%)	Cracked grain (%)	Red streak (%)	Damaged (%)	Foreign matter (%)	Whiteness index
<i>Lafia 1</i>	64.10 ^a	25.90 ^a	4.40 ^a	4.70 ^a	3.10 ^a	0.50 ^a	19.50 ^a
<i>Lafia 2</i>	76.00 ^b	16.30 ^b	2.60 ^{ab}	1.40 ^a	3.10 ^a	0.20 ^b	21.13 ^b
<i>Assakio</i>	49.60 ^c	37.70 ^c	4.10 ^a	1.40 ^a	6.70 ^b	0.10 ^{bc}	20.63 ^b
<i>Thailand</i>	94.40 ^d	0.70 ^d	0.07 ^{bc}	0.00 ^a	0.00 ^c	0.00 ^c	24.97 ^c
<i>Japan</i>	97.80 ^d	2.20 ^d	0.01 ^c	0.00 ^a	0.00 ^c	0.00 ^c	50.57 ^d
SD	20.32	15.75	2.12	1.92	2.78	0.21	13.14

¹ Values represent means of 3 replicates. ² In a column, means with the same superscript do not differ significantly ($p < 0.05$).

Table 5. Dimensions and rice classification^{1,2}

Sample	Length L (mm)	Width, W (mm)	Thickness (mm)	L/W	Classification ³	
					Length	Shape
<i>Lafia 1</i>	6.65 ^a	2.35 ^a	1.84 ^a	2.83	Long	Medium
<i>Lafia 2</i>	6.82 ^a	2.46 ^a	1.88 ^a	2.77	Long	Medium
<i>Assakio</i>	8.11 ^b	2.39 ^a	1.90 ^{ab}	3.39	Extra long	Slender
<i>Thailand</i>	7.41 ^c	2.03 ^b	1.79 ^a	3.65	Long	Slender
<i>Japan</i>	4.91 ^d	2.82 ^c	2.02 ^b	1.74	Short	Bold
SD	1.19	0.28	0.09	0.74		

¹ Values represent means of 10 replicates. ² In a column, means with the same superscript do not differ significantly ($p < 0.05$).

³ The Food Agency, (1995)

Table 6. Hardness characteristics of rice samples^{1,2}

Sample	Moisture content (% wet basis)	Chalkiness (%)	Hardness (Newton)
<i>Lafia 1</i>	12.72 ^a	0.9 ^a	93.49 ^a
<i>Lafia 2</i>	13.24 ^b	1.5 ^a	88.26 ^a
<i>Assakio</i>	14.61 ^c	2.0 ^a	100.23 ^a
<i>Thailand</i>	14.28 ^d	0.6 ^a	97.78 ^a
<i>Japan</i>	15.46 ^e	6.8 ^b	45.82 ^b
SD	1.09	2.54	22.43

¹ Values represent means of 3 replicates. ² In a column, means with the same superscript do not differ significantly ($p < 0.05$).

sumer preferences and hence the grain's market value (Miah *et al.* 2002). Table 4 shows the whiteness index values of the tested rice samples. Compared with the imported rice, Nigerian domestic rice is more yellow and contains grains that are not homogenous in colour. This can be attributed to the poor conditions of handling and processing. According to Miah *et al.* (2002), the rate of cooling of hot-steamed parboiled paddy rice affects the colour and strength of the rice. Rapid cooling of the steamed paddy rice is important to obtain soft cooking quality and a light translucent colour.

Grain shape

Grain shape (Table 5) is also directly related to the percentage of broken rice found in the various samples. *Assakio* had a significantly higher percentage of broken grains than all other samples, because the grain is of the extra-long type and was processed under poorly suitable conditions. Although *Thailand* is also long and slender, the use of appropriate processing condi-

tions gave 0% broken grains.

Grain hardness and moisture content

The hardness characteristics of the rice samples are presented in Table 6. All of the parboiled rice samples had significantly higher hardness values than that of *Japan*, which was not parboiled. The low hardness of *Japan* can be attributed to its higher degree of chalkiness. Parboiling reduces chalkiness and increases grain hardness (Fofana *et al.*, 2011).

Moisture content differed significantly among all grain samples; the highest value being that of the non-parboiled *Japan*. Among the three local cultivars, *Assakio* had the highest moisture content and chalkiness values but the greatest hardness value. Hardness is considered a very important physical property of parboiled rice because it improves the head yield of the rice during milling (Islam *et al.* 2001). Also, harder grains are more resistant to insect attack and less susceptible to mould development (Fofana *et al.*, 2011).

Table 7. Cooking quality characteristics of rice samples^{1,2}

Sample	Cooking time (min)	Swelling ratio	Elongation ratio	Water-uptake ratio
<i>Lafia 1</i>	19.67 ^a	3.05 ^a	1.41 ^a	1.81 ^a
<i>Lafia 2</i>	22.67 ^b	3.04 ^a	1.35 ^{ab}	1.77 ^a
<i>Assakio</i>	15.33 ^c	2.86 ^{bc}	1.26 ^b	1.54 ^c
<i>Thailand</i>	17.33 ^{ac}	2.92 ^b	1.35 ^{ab}	2.07 ^d
<i>Japan</i>	16.33 ^c	2.83 ^c	1.58 ^c	1.98 ^a
SD	2.94	0.10	0.12	0.21

¹ Values represent means of 3 replicates. ² In a column, means with the same superscript do not differ significantly ($p < 0.05$).

Despite the greater hardness values of the four par-boiled rice samples compared with the non-parboiled *Japan* (Table 6), there were no significant differences in hardness between the locally parboiled samples and *Thailand*, which was parboiled and milled in Thailand. Rice grain hardness depends on the quality of the par-boiling process. *Assakio*, with the greatest hardness value, had the greatest percentage of heat-damaged grains and cooked faster than the other samples (Table 7). This shows that it was subjected to longer heat treatment than the other rice samples. This result agrees with those of many reports that grain hardness increases with increasing temperature and duration of steaming during the parboiling operation (Islam *et al.*, 2001). It further attests to the fact that postharvest rice handling methods in Nigeria need to be improved.

Grain cooking qualities

The results of the cooking quality tests are presented in Table 7. In this study, the rice was cooked in excess water without pre-soaking, which is the main cooking method used in Nigeria.

Cooking time

Cooking time was significantly lower in the non-parboiled *Japan* white rice sample than in some of the parboiled rice samples. Whereas the cooking time of *Japan* was 16.33 min, it was between 17.33 and 22.67 min for the parboiled rice samples, with the exception of *Assakio*, which cooked in the shortest time (15.33 min). These findings are in agreement with those of Danbaba *et al.* (2011) and Fofana *et al.* (2011). Par-boiled rice can be expected to have a longer cooking time because of the physicochemical changes that occur in the grain during parboiling. The low cooking time in *Assakio* may have been due to the combined

effects of its high percentages of chalky and broken grains, and longer heat treatment which may have resulted from improper postharvest handling.

Dimensional changes during cooking

Grain elongation results (Table 7) showed no significant differences between the local rice (*Lafia 1*, 1.41; *Lafia 2*, 1.35; *Assakio*, 1.26) and foreign rice (*Thailand*, 1.35). However, *Japan* had a significantly greater elongation value (1.58) than any of the other rice samples. These results are consistent with those of Fofana *et al.* (2011) who reported values of between 1.2 and 1.4 for parboiled rice and Dipti *et al.* (2003) who also reported elongation ratio of 1.3–1.6 for raw milled rice. According to Juliano (1972), grains with opaque centres (in other words, grains with high percentage chalkiness), such as *Japan*, are expected to show extreme elongation upon cooking. Among the parboiled rice samples there were no significant differences in chalkiness, and the only significant difference in grain elongation ratio was between *Lafia 1* and *Assakio*.

With the exception of *Assakio*, parboiled rice samples had a significantly greater swelling capacity than *Japan* white rice. Also, the two parboiled *Lafia* cultivars swelled significantly more than their parboiled counterpart from Thailand upon being cooked in excess water.

Nevertheless, the swelling ratios in the local rice samples *Lafia 1* and *Lafia 2* fell below the values of 4.3 reported by Dipti *et al.* (2003) for non-parboiled rice and 5.41 reported by Fofana *et al.* (2011) for parboiled rice. The results suggest that handling method did not affect the swelling capacity of the rice, in agreement with Dipti *et al.* (2003), who attributed grain swelling ability to the amylose content of the

rice. The swelling characteristics can thus be said to depend on intrinsic characteristics of the cultivar, but also possibly, on the cooking method.

Water uptake

According to Danbaba *et al.*, 2011, the water uptake ratio in rice during cooking is considered an economic quality because it provides some estimate of the volume increase. Water uptake by *Assakio* (1.54) was significantly less than that by the two imported rice (2.07 for *Thailand* and 1.98 for *Japan*), and uptake by the three domestic rice was also significantly less than that for *Thailand*. The difference may be attributed to the postharvest processes that the grains have been subjected to which might have altered their textures non-uniformly. According to Danbaba *et al.* (2011), good cooking-rice cultivars have water uptake values of between 1.75 and 2.75. There is therefore a significant effect of post handling methods on the water uptake capacity of the Nigerian domestic rice.

Conclusion

Rice is an increasingly important crop in Nigeria, and its relevance to the country's economic development cannot be overemphasized. Despite the huge amount of paddy rice produced in the country, the poor quality of the locally processed rice has continually encouraged the importation of high-quality milled rice to satisfy the tastes and preferences of Nigerians. This has negatively affected the development of domestic rice production and correspondingly the incomes of rice farmers and processors.

This study evaluated the methods of postharvest handling of rice in two target areas, with a view to identifying and solving the rice processing problems in Nigeria. In doing this, particular attention was focused on the physical and cooking characteristics of the domestic milled rice produced by using local methods, because rice is consumed as a whole grain and consumers, both local and international, put particular emphasis on these characteristics in rating rice quality.

The results showed that processing methods have a substantial influence on the physical characteristics of milled rice. The pre-parboiling and post-parboiling handling methods and technologies used in Nigeria appear to contribute to the undesirable physical qualities of the locally processed rice. Manual methods of paddy rice handling are generally slow, ineffective, and time-consuming. They expose the rice to contamination by stones and other foreign materials and

initiate deterioration of the grains, resulting in discoloration, cracking, breakage, and damage. This is further compounded by poor parboiling and milling methods, lack of adequate equipment, and disregard for proper quality-control practices, such as cleaning, sorting, grading, and packaging. *Thailand* and *Japan*—foreign rice processed with better methods and post-harvest practices—contained 0.7% and 2.2% broken grains and 0.07% and 0.01% cracked grains, respectively, and 0% foreign matter, red streaked and damaged grains. In contrast, *Lafia 1*, *Lafia 2*, and *Assakio*, which were processed in Nigeria using less efficient methods, contained more broken grains (about 16% to 38%) and cracked grains (2.6% to 4.4%), as well as 0.1 % to 0.5% foreign matter, 1.4% to 4.7% red streak, and 3.1% to 6.7% damaged grains (Table 4).

However, the cooking characteristics of the rice were not uniformly affected by the processing methods. The locally processed rice with the exception of *Assakio* generally had better swelling ratios than the foreign rice. However, because acceptability and price are based primarily on the physical appearance of the rice grains, Nigerian processing methods still need to be improved if the local rice is to compete well in both local and international markets.

Recommendations

To achieve the desirable paddy rice-processing capacity in terms of the quantity and quality of table-ready milled rice available in Nigeria, adequate attention needs to be paid to the following points.

1. Farmers should be encouraged and motivated to produce high-quality paddy rice, as no amount of good postharvest practices can produce good quality rice from poor quality paddy. High-quality paddy rice production can be helped by giving the farmers access to high-yielding, disease-resistant cultivars, as well as other farm inputs. Mechanization of rice harvesting by the use of combine harvesters should be encouraged, as this reduces the time spent on harvesting operations and eliminates the manual threshing and winnowing operations that have greatly contributed to the introduction of stones and other foreign matter into the processed rice. Additional support services provided by agricultural extension officers would ensure the use of good cultural practices throughout the production period.

2. Over the years, attention has been centred on increasing paddy rice production, with little concern for

postharvest handling and control. As a matter of urgency, government should focus on improving the country's rice processing and quality-control capacities. The current proposals of the NRDS should be conscientiously implemented to overcome the problems identified in processing methods and technologies. Specifically, parboiling operations and equipment should be standardized and processors and millers trained in the optimum procedures for parboiling and milling operations.

3. Rice milling is a cottage industry in Nigeria. Therefore, government efforts to establish integrated rice-processing complexes in rice-producing and -milling communities in Nigeria should be complemented by efforts to improve the products of existing small-scale rural mills. This can be done by encouraging investment in support equipment such as destoners, polishers, sorters, and packaging machines to improve the physical quality of locally produced rice. State and local governments should be encouraged to purchase and install these machines for use by processors and millers at affordable fees.

4. Rice-processing operations should be fully mechanized to reduce the time required for paddy rice handling and to minimize deterioration, which is a major contributor to poor milled-rice quality.

5. Establishment and enforcement of Nigerian rice quality standards for local and international trade will be a step in the right direction. Regulation of the quality of rice offered for sale to consumers will encourage the consumption of locally processed rice. Branding of domestic rice and rice products should also be encouraged.

6. One of the findings of this study was that long, thin rice kernels are more susceptible to breakage during milling. Therefore, it is strongly recommended that Nigerian scientists and rice breeders should develop cultivars with improved kernel morphology which will be able to withstand the stress of milling operations and produce higher head yields under optimum processing conditions.

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References

- Abdulahi, A. S., 2004. Standardization of rice processing in Nigeria: Prospects for a National Rice Industry Standard. In: Abo, M.E., Abdullahi, A.S., Ike, E., (Eds.). *The Nigeria Rice Memorabilia*. Project Synergy Limited, Abuja, Nigeria, pp. 455-472.
- Adewuyi, M.A.A., 2004. Postharvest technologies in rice production in Nigeria. In: Abo, M.E., Abdullahi, A.S., Ike, E., (Eds.). *The Nigeria Rice Memorabilia*. Project Synergy Limited, Abuja, Nigeria, pp. 474-481.
- Akpokodje, G., Lancon, F., Olaf, E., 2003. *Nigeria's Rice Policy and Development: A Review*. WARDA, Abidjan, Cote d'Ivoire.
- Aliyu S.A., 2004. Standardization and regulation of rice processing in Nigeria: prospects for a national rice industry standard. In: Abo, M.E., Abdullahi, A.S., Ike E. (Eds.), *The Nigeria Rice Memorabilia*. Project Synergy Limited, Abuja, Nigeria, pp. 455-472.
- Bamidele, F.S., Abayomi, O.O., Esther, O.A., 2010. Economic analysis of rice consumption patterns in Nigeria. *J. Agric. Sci. Technol.* 12, 1-11.
- Danbaba, N., Anounye, J.C., Gana, A.S., Abo, M.E., Ukwungwu, M.N., 2011. Grain quality characteristics of *Ofada* rice (*Oryza sativa* L.): Cooking and eating quality. *Int. Food Res. J.* 18, 629-634.
- Dipti, S.S., Bari, M.N., Kabir, K.A., 2003. Grain quality characteristics of some Beruin rice varieties of Bangladesh. *Pak. J. Nutr.* 2 (4), 242-245.
- Erhabor, P.O.I. and Ojogho, O., 2011, Effect of quality on the demand for rice in Nigeria, *Agric. J.*, 6 (5), 207-212.
- Ezedinma, C. 2006. Impact of Trade on Domestic Rice Production and the Challenges of Self Sufficiency in Nigeria. Retrieved on 10th September, 2011, from <http://www.>

- warda.cgiar.org/workshop/RicePolicy/Chuma.E/Chuma.E.Nigeria.Paper.pdf
- Federal Ministry of Agriculture, 2006. International Conference on Agrarian Reform and Rural Development, Porto Alegre, 7–10 March 2006. Retrieved on 27 October 2011 from www.icarrd.org/en/icard_doc_down/national_Nigeria.doc.
- FMINO, 2006. The Obasanjo Reforms, Rice Initiative. A publication of the Federal Ministry of Information and National Orientation, Radio House, Abuja, Nigeria.
- Fofana, M., Wanvoeke, J., Manful, J., Futakuchi, K., Van Mele, P., Zossou, E., Bléoussi, T.M.R., 2011. Effect of improved parboiling methods on the physical and cooked grain characteristics of rice varieties in Benin. *Int. Food Res. J.* 18, 715–721.
- Gbabo, A., 2004. Status of rice processing machinery development in Nigeria. In: Abo, M.E., Abdullahi, A.S., Ike E. (Eds.), *The Nigeria Rice Memorabilia*. Project Synergy Limited, Abuja, Nigeria.
- Hawthornth, D.L., 1985. Foreword. In: Ou, S.H. (Ed) *Rice Diseases*. CMI Slough, UK CAB. 380 pp.
- Hossain, M.F., Bhuiya, M.S.U., Ahmed, M. Mian M.H., 2009. Effect of harvesting time on the milling and physicochemical properties of aromatic rice. *Thai J. Agric. Sci.* 42 (2), 91–96.
- Islam, M.D., Shimizu, N., Kimura, T., 2001. Quality evaluation of parboiled rice with physical properties. *Food Sci. Technol. Res.* 7(1), 57–63.
- Juliano, B.O., 1972. Physicochemical properties of starch and protein in relation to grain quality and nutritional value of rice. In: *IRRI Rice Breeding*. IRRI, Los Banos, Philippines, pp. 389–405.
- Liverpool, L.S.O., Ayoola, G.B., Oyeleke, R.O., 2009. Enhancing the competitiveness of agricultural commodity chains in Nigeria: Identifying opportunities with cassava, rice, and maize using a Policy Analysis Matrix (PAM) framework. *Nigeria Strategy Support Program (NSSP), Background Paper No. NSSP 013*. Retrieved on 27th October, 2011 from <http://www.ifpri.org/sites/default/files/publications/nssppb12.pdf>
- Miah, M.A.K., Haque, A., Douglass, A.P., Clarke, B., 2003. Parboiling of rice. Part II: Effect of hot soaking time on the degree of starch gelatinization. *Int. J of Food Sci. and Technol.* 37, 539–545
- NFRA, 2010. National Rice Development Strategy (NRDS): Implementation Document for the NRDS in Nigeria. Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria.
- National Bureau of Statistics, 2006. Census Figures by State & LGA, 2006. Retrieved from <http://www.nigerianstat.gov.ng/> on 28 October 2011.
- National Bureau of Statistics, 2011. Economic Outlook: 2011 GDP Forecast for Nigeria. National Bureau of Statistics, Abuja, Nigeria. Retrieved on 28 October 2011 from <http://www.nigerianstat.gov.ng/uploads/latestRelease/77453f2463e9e78a10afffe27091935bdf45f12a.pdf>.
- Ochigbo, A.A., Gbabo, A., 2004. Appropriate rice machinery and processing technologies: Small scale as option for Nigeria's self-sufficiency in rice production. In: Abo, M.E., Abdullahi, A.S., Ike E. (Eds.). *The Nigeria Rice Memorabilia*. Project Synergy Limited, Abuja, Nigeria, pp. 421–433.
- Ogundele, O.O., Akpokodje, G. 2004. Rice trade and marketing in Nigeria. Prospects for a National Rice Industry Standard. In: Abo, M.E., Abdullahi, A.S., Ike E. (Eds.). *The Nigeria Rice Memorabilia*. Project Synergy Limited, Abuja, Nigeria, pp. 503–510.
- Overseas Development Institute, 2000. Rice production in Nigeria: country profile background paper. Multi Agency Partnerships for Technical Change in West African Agriculture. Retrieved from www.odi.org.uk/resources/download/3044.pdf on 28 October 2011.
- Parnsakhorn, S., Noomhorm, A. 2008. Changes in the physicochemical properties of parboiled brown rice during heat treatment. *Agric. Eng. Int.: the CIGR. E-journal*, manuscript FP 08 009, Vol. X. August, 2008.
- Singh, B.N., Fagade, S., Ukwungwu, M.N., William, C., Jagtap, S.S., Oladimeji, O., Efisue, A., Okhidiebie, O. 1997. Rice growing environments and biophysical constraints in different agroecological zones of Nigeria. *Met.J.2* 1, 35–44.
- Tan, Y.F., Li J.X., Yu, S.B., Xing, Y.Z., Xu, C.G., Zhang, Q., 1999. The three important traits for cooking and eating quality of rice grains are controlled by a single locus in an elite rice hybrid, Shanyou 63. *Theor. Appl. Genet.* 99, 642–648.
- The Food Agency, 1995. *Rice Postharvest Technology*. Hosokawa, A. (Ed.) Ministry of Agriculture, Forestry and Fisheries, Japan.
- USAID, 2009. Nigeria Rice Value Chain Analysis. Retrieved on 28 October 2011 from www.microlinks.org/ev_en.php.
- USDA, 2011. GON Bans Rice Imports through Land Borders, Nigeria. Rice Trade Quart. GAIN Report No: NI1012, 2/25/2011
- Wudiri, B.B., Fatoba, I.O., 1992. Cereal in the food economy of Nigeria. In: Lawani, S.M., Babaleye, T. (Eds.). *Proceedings of Workshop on Recent Development in Cereals production in Nigeria*. Kaduna, Sept. 2–4, IITA, Ibadan, Nigeria, pp.: 13–32

Appendix 1

Assessment of Postharvest Handling and Quality Control Practices of Rice in North Central Nigeria: A case study of Lafia, Nasarawa State

Survey Questionnaire

Section A General Information on Respondent

1. Name.....
2. Sex: 3. Age: 4. Marital Status.....
5. Educational Level: Primary/Secondary/Tertiary
6. Previous Occupation.....
7. Association/Group
8. Level of involvement in the rice value chain: Farming/Processing/Milling/Marketing

Section B Rice Farming

1. Do you plant rice? YES / NO
2. Location of farm.....
3. Size of farm
4. How do you harvest rice?
Equipment used.....
5. Do you thresh rice? How?
Equipment used.....
6. Do you winnow your paddy rice?
Equipment used.....
7. Method of drying paddy rice.....
8. Do you store, sell, or process your paddy rice.....
9. If you store paddy rice, how?

Section C Rice Processing – Parboiling

1. Source of paddy.....
2. a. Do you clean your paddy rice before processing?
b. Why?
c. If you do, how?
d. Equipment used.....
3. a. Do you destone your rice?
b. Why?
c. If you do, how?
d. Equipment used.....
4. Quantity of paddy rice processed daily/weekly
5. a. Do you parboil your paddy rice?
b. Why?

- c. If you do, how?
- d. Equipment used.....
- e. Do you soak in hot or cold water?
- f. Duration of soaking.....
- g. Source of water.....
- h. Do you use the same water for many batches?
- i. Do you steam?
- 6. Briefly describe the method of parboiling.....
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- 7. a. Where do you parboil your paddy rice?
- b. No of parboiling drums/units..... Capacity of each unit.....
- 8. What are your main parboiling problems?

Section D Rice Milling

- 1. How do you mill? (Locally by pounding; mechanically)
- 2. Description of the type of equipment used.....
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- 3. a. Do you pass the rice more than once through the machine?
- b. If yes, why?
- 4. How do you determine the right moisture content at milling?
- 5. Quantity of paddy rice milled per day/week/month.....
- 6. a. Do you pack milled rice?
- b. If not, why?
- c. Method and equipment used for packing.....
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Section E Rice Marketing

- 1. Do you sell milled rice?
- 2. Do you mill the rice you sell?
- 3. What quantity/units do you sell?
- 4. Do you bag your rice for sale?
- 5. Do you sell in the street, or in-shop?

Section F Rice Quality Control

- 1. Is your rice of the same quality as imported rice? YES / NO
- 2. Are the following present in your finished milled rice?
 - a. Stones YES / NO%
 - b. Chaff/husk YES / NO%
 - c. Black/coloured grains YES / NO%
 - d. Other foreign matter YES / NO%
 - e. Broken rice YES / NO%
- 3. Give reasons for the above.....

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4. Do you think you should change your method/equipment for:

a. Parboiling: YES / NO b. Milling: YES / NO