25 Improving Grain Quality of Locally Produced Rice in Africa

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Introduction

Consumption of rice is growing faster than that of any other food commodity in Africa, because it has become a convenience food for the growing urban populations. Imports of rice (close to 10 million tonnes (Mt) per year) cost the African continent more than US$5 billion in 2009 (e.g. Seck *et al.*, 2012). There is an urgent need to substitute imported rice with locally produced rice, but this requires improving the quality of the latter to standards set by the consumer: locally produced rice is often not competitive vis-à-vis imported rice because of a perceived lower quality. In Nigeria, consumers dislike locally produced rice compared to imported rice mostly because of the impurities (stones and other foreign matter) it contains (Tiamiyu *et al.*, 2011). Similarly, 71% of 390 consumers interviewed in Accra, the capital of Ghana, preferred imported over local rice mostly because of impurities (inclusion of foreign matter) and unavailability of local rice in sufficient quantities all year round (Diako *et al.*, 2010).

Grain quality may mean very different things from one country or region to another (see also Rutsaert *et al.*, Chapter 23, this volume). For example, rice with low grain breakage is preferred in most countries, but broken rice is liked in Senegal. Red rice is sold at a higher price than white rice in Kumasi (the second largest city in Ghana), but this is not true for other markets in the country (Sakurai *et al.*, 2006). Nigerians generally prefer cooked rice of a 'harder' texture than consumers in neighbouring countries.

Watanabe *et al.* (2002a,b, 2006) showed that many grain quality characteristics such as grain breakage, grain whiteness after milling, and protein and amylose content were significantly different among 47 rice cultivars cultivated under wet- and dry-season growing conditions in Côte d'Ivoire. In a different trial, where effects of different harvesting dates on milling and related traits were examined in several varieties, interactive effects of harvesting dates and varieties were significant for husking recovery and head-rice ratio, while no significant interactive effects were observed in grain dimensions, milling recovery and chalkiness (Futakuchi *et al.*, 2001 – see definitions of grain quality below). These results illustrate that grain quality is a function of the variety (intrinsic factors) and the production and processing environment (extrinsic factors). It also underlines the importance of conducting grain quality assessments under standardized cultivation and postharvest practices.

Enhancing grain quality of locally produced rice in Africa needs to consider: (i) clear grain

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quality targets based on a good understanding of consumer preferences; and (ii) achieving these targets through the choice of the variety and by improving the conditions under which rice is produced, stored and processed.

This chapter starts with an overview of definitions of rice grain quality. Next a case study is presented on consumer preferences for rice as observed in four regions of Benin. Ways to improve grain quality are discussed, ranging from the choice of the variety to management factors before and after harvest. The chapter concludes with recommendations for making African produced rice more competitive vis-à-vis imports.

Defining Rice Quality

We distinguish between rice grain quality indicators in terms of: (i) physical appearance before and after the milling process; and (ii) cooking and eating quality. (For a full description see, e.g., Food Agency, 1995; Manful, 2011.)

Physical appearance before and after milling

- Size and shape – a good rice variety should have a characteristic and stable grain size and shape; consumers generally prefer milled rice of a particular size and shape. The Standard Evaluation System (SES) for rice (IRRI, 1996) provides the following scales: for size, 1 (extra-long, length >7.5 mm), 3 (long, length 6.6–7.5 mm), 5 (medium, length 5.51–6.6 mm), 7 (short, length ≤5.5 mm or less). For shape, 1 (slender, length–width ratio >3.0), 3 (medium, ratio 2.1–3.0), 5 (bold, ratio 1.1–2.0), 9 (round, ratio <1.1). These scores are recorded for brown rice to evaluate these traits as genetic characteristics avoiding the effect of milling on size and shape.
- Impurity – presence of stones and other foreign matter.
- Husking recovery – the percentage of brown rice to paddy on a weight basis after dehusking.
- Milling recovery – the percentage of milled (polished) rice to brown rice on a weight basis after milling.
- Head-rice ratio – the proportion of 'head rice' in milled rice on a weight basis. Any milled grain that is less than three-quarters the size of the whole grain is classified as 'broken'. Milled rice grains after removal of damaged (broken, discolored, etc.), dead and immature grains are referred to as head rice. Breakage is a major damage and high head-rice ratio is considered as an indication of less grain breakage.
- Chalkiness – levels of 'chalkiness', i.e. chalky appearance either in the centres or edges of milled grains due to diffused reflection of light; a chalky grain denotes a grain in which the starch granules are not tightly packed and consequently grain filling can be termed as 'incomplete'. Grains with high chalkiness are generally softer, more likely to break during milling. The scales of chalkiness by SES (IRRI, 1996) are as follows: 0 (none, no chalky area in the kernel), 1 (small, chalky area <10%), 5 (medium, chalky area 11–20%), 9 (large, chalky area >20%).
- Grain colour – colour is an important attribute to the food industry, including for rice. Consumers frequently look at a rice sample and make a judgment decision based largely on overall appearance including colour. Frequently, degree of whiteness is representatively used as a description of colour. The degree of whiteness can be determined by readings (%) of a milling/whiteness meter, with higher values for greater degrees of whiteness.
- Translucency – translucency of milled grains is one of the milled grain traits related to appearance. A milling/whiteness meter also provides a value (%) of translucency and a higher value means that the grain is more transparent.
- Aroma – aromatic rice is sold at a higher price (premium) in most regions. Existence of aroma can be judged with milled grains and is a consumer selection criterion in the market. Aroma is also a factor included in the eating quality.

Cooking and eating qualities

- Apparent amylose content – this is a major factor affecting rice eating texture (usually, the lower the amylose content the softer the rice).

- Gelatinization temperature – the time required to cook rice is determined by the temperature at which the crystalline structures of the starch in the grain begin to melt when heated in the presence of water. This is known as the gelatinization temperature (GT) and it ranges from 55°C to 85°C. Rice with high GT takes a longer time to cook and the cooked rice has a harder texture, while low-GT rice takes a shorter time to cook and has softer to intermediate texture.
- Gel consistency – when rice flour is cooked in excess water it liquefies into a gel. The consistency of the gel can be indicative of the cooked rice texture.
- Viscosity of cooked rice flour – several viscosity parameters (maximum, minimum, breakdown, final and setback viscosities) can be read in the amylograph, which can be drawn by a Brabender viscogram or other similar equipment with a rice flour sample (Food Agency, 1995) and the parameters are associated with eating texture. For those who eat rice after it has cooled, the parameters at low temperatures (final and setback viscosities) are important.
- Protein content – high protein content makes eating texture harder. Amylose content has a much greater effect on texture than protein content (Watanabe *et al*., 2002a).
- Water-uptake ratio, elongation ratio and swelling ratio – water-uptake ratio is weight of absorbed water during cooking per unit weight of raw rice; elongation ratio is a ratio of the length of a cooked grain to that of a raw grain; swelling ratio is a ratio of the volume of a rice sample after cooking to that of the rice sample before cooking.
- Cooking time.

Comparing Local and Imported Rice: A Case Study in Benin

Consumer preferences

A survey was conducted in Cotonou (the commercial capital of Benin in the southern region, where people are highly exposed to imported rice), Lokossa (a town in southwest region), and Materi and Tangieta (both towns in the northern region) (Study 1). At each site, 125 consumers compared the grain qualities of two imported rice brands (Gino and Sultana), two local – already cultivated in the country – rice varieties (Beris 21 and Tox long) and three newly introduced NERICA varieties (NERICA 1, NERICA 3 and NERICA 4) (Fofana *et al*., 2010a). The consumers were asked to rate milled and cooked rice samples using the following scale: 1, dislike very much; 2, dislike; 3, neither dislike nor like (neutral); 4, like; 5, like very much. In the test of milled (raw or uncooked) rice, imported rice (Gino and Sultana) and NERICA 1 were appreciated by consumers across Benin; local varieties and NERICA 3 and NERICA 4 were rated lower (Table 25.1). However, cooked rice was appreciated very differently depending on the region (Table 25.2). The imported brands (Gino and Sultana) and NERICA 4 were liked in Cotonou, but they were neutral or disliked and NERICA 4 was disliked in the other areas. NERICA 1 was disliked very much in Cotonou, but received neutral or higher ratings in the other regions. Beris 21 and Tox long were generally disliked and their ratings were especially low in Cotonou. For the three regions other than Cotonou, no rice varieties or brands received a score of 4 or 5. Cotonou stood out as very different from the other regions (Table 25.2).

Preference for imported rice in the raw (uncooked) state seemed to be common across the country, so matching the quality of imported rice can be an excellent target for the improvement of locally produced rice. However, preferences for cooked rice were very site specific. The study also revealed that there can be large variation in consumer preferences even within a relatively small country like Benin. This may suggest a wide range of preference variation in other larger countries and also across Africa, and the necessity to collect more information to expand the study.

Physical appearance

To compare varietal characteristics of local rice with imported rice (Study 2), AfricaRice cultivated

Table 25.1. Consumer acceptability scores[a] for raw (uncooked) rice in the four locations in Benin. (Modified from Fofana *et al.*, 2010a.)

Variety/brand	Cotonou N[b] = 125	Lokossa N = 125	Materi N = 125	Tangieta N = 125	Total N = 500
Gino (imported)	4.4	4.1	4.2	4.3	4.3
Sultana (imported)	4.6	4.4	4.5	4.6	4.6
Beris 21 (local)	2.5	2.8	3.1	2.9	2.9
Tox long (local)	2.5	2.5	2.8	3.1	2.8
NERICA 1 (newly introduced)	4.2	3.8	4.1	4.2	4.1
NERICA 3 (newly introduced)	3.1	2.8	2.5	2.8	2.9
NERICA 4 (newly introduced)	3.4	3.1	2.7	2.7	3.0

[a]1, dislike very much; 2, dislike; 3, neither dislike nor like; 4, like; 5, like very much.
[b]N, number of consumers participating in the test.

Table 25.2. Consumer acceptability scores[a] for cooked rice in the four locations in Benin. (Modified from Fofana *et al.*, 2010a.)

Variety/brand	Cotonou N[b] = 125	Lokossa N = 125	Materi N = 125	Tangieta N = 125	Total N = 500
Gino (imported)	4.2	3.3	3.4	2.6	3.6
Sultana (imported)	4.6	3.1	2.8	2.6	3.5
Beris 21 (local)	2.1	2.9	3.1	2.9	2.8
Tox long (local)	2.2	2.8	3.0	2.7	2.7
NERICA 1 (newly introduced)	1.0	3.0	3.7	3.6	2.6
NERICA 3 (newly introduced)	2.9	1.8	2.1	1.8	2.1
NERICA 4 (newly introduced)	4.2	2.2	1.8	1.9	2.8

[a]1, dislike very much; 2, dislike; 3, neither dislike nor like; 4, like; 5, like very much.
[b]N, number of consumers participating in the test.

five local varieties and five NERICA varieties (three of the five have been introduced to Benin). The harvested samples were processed using a laboratory husker and polisher, and their grain qualities compared to five imported rice brands in 2010 (Fofana *et al.*, 2011a; Table 25.3). The imported rice brands were less chalky, more translucent and had more slender grain shapes than the local rice and the NERICA varieties. According to the standard evaluation system (SES) for rice (IRRI, 1996), the chalkiness scores 0, 1, 5 and 9 indicate non-chalky, small (less than 10% of kernel area), medium (11–20% of kernel area) and large (more than 20%) chalkiness, respectively. As the average of three samples, the imported rice brands had scores of 0 or 1, while the local rice had scores of 4 or 5 (except Adny 11). NERICA varieties also had a high score of 4. For grain hardness, two local varieties (Beris 21 and IDSA 1) and four NERICAs (NERICA 3, 4, 6 and 7) showed low values compared to the imported brands. These varieties also have chalky grains (soft and chalky grains are likely to break). However, the imported brands were not whiter than the other two groups, local and NERICA varieties. In the sensory evaluation of raw (uncooked) rice, imported brands (Gino and Sultana) were highly preferred compared over local varieties (Beris 21 and Tox long) and NERICA varieties (NERICA 3 and 4) (Table 25.1). From these results it follows that efforts to improve local and NERICA varieties in

Table 25.3. Physical characteristics of imported, locally cultivated and NERICA rice. (Modified from Fofana *et al*., 2011a.)

Rice variety/ brand	Grain size[a]	Grain shape[a]	Chalkiness[a]	Hardness (kgw)[b]	Whiteness (%)	Translucency (%)
Elephant (imported)	Long	Slender	1	7.6	70.8	3.0
Gino (imported)	Long	Slender	0	7.7	66.2	3.4
Savana (imported)	Long	Slender	1	7.2	62.5	3.6
Special rice (imported)	Long	Slender	1	7.0	63.4	3.4
Sultana (imported)	Long	Slender	1	8.3	64.7	3.7
Adny 11 (local)	Long	Intermediate	1	8.9	60.7	2.5
Beris 21 (local)	Long	Intermediate	5	5.5	65.7	2.4
IDSA 1 (local)	Long	Intermediate	5	6.1	68.7	3.4
IR 841 (local)	Long	Intermediate	4	8.1	63.2	2.9
Tox long (local)	Medium	Intermediate	5	7.6	74.6	1.2
NERICA 1 (newly introduced)	Long	Intermediate	4	7.2	73.2	2.7
NERICA 3 (newly introduced)	Long	Intermediate	4	6.5	71.3	2.8
NERICA 4 (newly introduced)	Long	Intermediate	4	5.9	65.3	3.3
NERICA 6	Medium	Intermediate	4	6.1	68.0	3.1
NERICA 7	Long	Intermediate	4	5.9	70.0	3.2

[a]Ranks of a grain size, a grain shape and chalkiness scores were based on Standard Evaluation System (IRRI, 1996). Although brown rice is used for the determinations of the size and shape in SES (IRRI, 1996), milled rice was used here, since the imported rice was all milled rice.
[b]Hardness was measured by grain-hardness tester (Kiya Co Ltd). The units of the meter are kilogram weight (kgw).

terms of appearance should focus on greater grain slenderness, less chalkiness and higher translucency. NERICA 1 was liked as much as the imported brands Gino and Sultana (Table 25.1), although it did not have similar grain slenderness, chalkiness and translucency (Table 25.3). This is most probably due to the wide appreciation of NERICA 1 in Benin for its aroma.

In another survey conducted in 2010 (Study 3), AfricaRice collected 110 milled rice samples (comprising eight varieties) from local millers in both urban and rural areas of eight towns (Cove, Dassa, Glazoue, Lokossa, Malanville, Parakou, Savalou and Save) in Benin. For Cotonou and Porto-Novo (political capital of Benin), no local millers were found in either the cities or the rural areas near the cities. Impurity, head-rice ratio, whiteness and translucency were determined on the samples (Table 25.4). The average whiteness obtained (67.3) is comparable to that of the imported rice (Table 25.3), but the translucency is low compared to that of the local varieties (Table 25.3, it is important to note that the processing in Study 2 was done in the laboratory). This suggests rather poor processing practices of local millers. Impurity was 0.01–5.30% with an average of 1.09% and head-rice ratio was 1.4–71.6% with an average of 28.4%. Although the same measurements were not made on imported rice at the same time, most of the milled rice samples collected from local millers were of poorer quality. For example, in the Philippines, grade 3 (lowest rating for grain quality) rice has 50–60% of head-rice ratio and 0.20–0.50% impurities (Sampang, 1992). Poor quality in appearance may be partly caused by varietal characteristics, but inappropriate postharvest handling can negatively affect the appearance – the

Table 25.4. Physical characteristics of 110 raw (uncooked) rice samples collected from local millers.

	Impurity (%)	Head-rice ratio (%)	Whiteness[a] (%)	Translucency[a] (%)
Average	1.09	28.4	67.3	1.6
SD	0.84	20.2	7.2	0.7
Max	5.30	71.6	83.0	3.6
Min	0.01	1.4	54.0	0.3

[a]One red rice sample found was removed since it was a different type.

current situation requires improvement of post-harvest processing for some traits (impurity, head-rice ratio and translucency).

Cooking and eating quality

In Study 2, amylose content, protein content, gel consistency, water-uptake ratio, elongation ratio, swelling ratio and cooking time were also measured (Table 25.5). The first three factors can affect eating quality. In the sensory test for cooked rice, imported rice (Gino and Sultana), NERICA 1 and NERICA 4 were preferred in some regions of Benin, while local rice (Beris 21 and Tox long) and NERICA 3 were not liked in any region. There could be varietal differences in the varieties and brands tested for characteristics associated with eating quality. All the local varieties, NERICA varieties and imported brands had similar amylose content (21–24%). However, the NERICA varieties had higher protein content than the other two rice categories (higher protein content can make eating texture harder). In gel consistency, the local varieties (except Adny 11) showed lower gel consistencies than the imported and NERICA rices (rice of lower gel consistency can have harder eating texture). These results suggest that the imported rice may have slightly softer eating texture than the others. However, the difference of rating among NERICA 1, NERICA 3 and NARICA 4 in the sensory test of cooked rice (Table 25.2) cannot be explained by these factors – other factors, which were not measured, appear to affect their eating quality. The average scores of the sensory test of cooked rice across all regions were higher for the imported rice brands than the others (Table 25.2), although the imported rice was not liked in the northern regions. The direction of varietal improvement might be to make eating texture a little softer. Since high protein content of the NERICA varieties can be an asset for nutrition supply, improvement of eating texture should be made through the reduction of amylose content, not of protein content.

The local rice (except Adny 11) had higher water-uptake ratio than the other two categories, although one imported brand (Special rice) also had a high value. For elongation rate, most of the varieties and brands showed similar values, but ratios of Tox long (local) and NERICA 1 were relatively high. Swelling ratio was generally higher in the NERICA varieties than in the local varieties. In the imported brands, values of swelling ratios varied greatly, from 3.835 (Savana) to 4.933 (Gino). All five NERICA and three local varieties (Beris 21, IDSA 1 and IR 841) had long cooking times (22.0–25.6 minutes) compared to the imported rices (17.0–19.6 minutes).

From the sensory tests of raw rice and cooked rice (Study 1), we cannot capture the preference for cooking characteristics. However, it is considered that, in general, consumers prefer rice that increases in volume during cooking and short cooking time will be appreciated, especially by urban consumers. The swelling ratio of the existing NERICA varieties (4.202–4.600; average 4.460) is not inferior to that of imported brands (3.835–4.933; average 4.284); however, shortened cooking time will be the point of improvement for the NERICA varieties.

Improving Grain Quality

In this section, various ways to improve grain quality are discussed in more detail.

Table 25.5. Cooking and eating characteristics of imported, locally cultivated and NERICA rices. (Modified from Fofana *et al.*, 2011.)

Rice variety/ brand	Water-uptake ratio	Elongation ratio	Swelling Ratio	Cooking time (min)	Protein content (%)	Amylose content (%)	Gel consistency (mm)
Elephant (imported)	2.074	1.593	4.073	17.3	7.2	23.4	100.0
Gino (imported)	2.221	1.453	4.933	19.6	6.4	23.4	99.5
Savana (imported)	2.191	1.567	3.835	19.3	7.4	22.7	100.0
Special rice (imported)	2.420	1.490	4.364	19.0	7.3	23.0	99.3
Sultana (imported)	2.018	1.539	4.217	17.0	7.0	23.6	99.3
Adny 11 (local)	2.289	1.503	4.117	18.6	7.7	22.9	100.0
Beris 21 (local)	2.516	1.504	4.260	25.6	7.1	22.7	71.3
IDSA 1 (local)	2.386	1.512	4.045	22.3	7.1	21.2	66.8
IR 841 (local)	2.610	1.564	4.132	23.3	7.4	23.1	63.0
Tox long (local)	2.690	1.760	4.365	19.6	6.8	22.6	71.3
NERICA 1 (newly introduced)	2.200	1.603	4.202	26.0	10.6	23.8	99.6
NERICA 3 (newly introduced)	1.895	1.556	4.401	22.0	10.5	23.8	99.0
NERICA 4 (newly introduced)	2.100	1.532	4.600	24.0	10.6	22.8	99.1
NERICA 6	2.004	1.574	4.595	23.0	10.7	22.5	98.8
NERICA 7	1.895	1.542	4.503	24.0	10.8	24.1	95.0

Selecting the right variety

In the case of Benin described above, the breeding target for raw (uncooked) rice appearance is apparently imported rice. It is desirable for new varieties to have less chalkiness, greater translucency and more slender grains than the existing ones. Aromatic rice, NERICA 1, was also preferred in the country, so aroma is also a target. For eating quality, it might be better to aim for a cooked rice texture that is a little softer than that of the existing varieties if consumers in large population cities are targeted (imported rice with a softer eating texture than the existing local rice was rated high in Cotonou). Cooking time of new varieties should also be as short as that of imported rice.

Exact information on consumer preferences is not available in many countries in Africa. In such cases, varietal development for quality is largely dependent on expert knowledge. National agricultural research systems (NARS) may concentrate on developing varieties that match local preferences, as determined by expert knowledge or information from surveys. Given the sensory test results across Benin (preferences related to cooked rice were different across regions, but those related to raw rice were commonly for imported rice) and the fact that a lot of imported rice is consumed in Africa, imported rice can be a model of varietal selection for milled rice appearance. For eating quality, which is more region specific, breeders are best advised to avoid developing ‘extreme’ varieties.

For instance, all local and NERICA varieties and imported brands evaluated in Study 2 have similar amylose content in the range 21–24%; it will not be necessary to develop varieties with extremely high or low amylose contents. For cooking quality, high swelling ratio and short cooking time are generally desirable breeding directions.

Development of premium-quality rice – non-chalky, translucent, slender and aromatic rice – can be a breeding objective; the 'ORYLUX series' developed by AfricaRice and NARS partners is an example (Futakuchi *et al.*, 2011). However, there are diverse and wide-ranging requirements for varieties and it will be difficult to develop a variety that fulfils all the requirements (high yield potential, resistances to all possible constraints in a target ecosystem, etc.) plus premium quality. In contrast, it will be important for all newly developed varieties – whatever the main breeding objective is – to possess acceptable quality (i.e. not disliked by consumers). For this purpose, the breeders at AfricaRice check all of their materials in terms of basic grain quality characteristics for raw rice appearance from the F_4 generation and unacceptable (poor-quality) progenies (high chalkiness, etc.) are eliminated from further selection.

Most quality traits – such as grain dimensions, grain hardness, whiteness, chalkiness and absence/existence of aroma – are easy to measure on a small sample. Conventional breeding will still be effective for the improvement of these traits. For traits which cost more and take more time to measure, marker-assisted selection (MAS, see Ndjiondjop *et al.*, Chapter 12, this volume) will be a convenient approach. For example, major and minor genes for amylose content occur on chromosomes 6 and 5, respectively, and for gel consistency two QTLs have been identified on chromosomes 2 and 7 (He *et al.*, 1999). Grain breakage (low head-rice ratio) is a highly complicated characteristic associated with various quality traits like grain dimension, chalkiness and hardness, and controlled by a large number of genes. In the comparison of head-rice ratios of 50 varieties between two cropping seasons, a significant correlation was observed ($P < 0.05$). However, its correlation coefficient was low ($r = 0.337$) compared to grain slenderness (length/width ratio) ($r = 0.920$, $P < 0.001$), for example (Watanabe *et al.*, 2002b), suggesting that head-rice ratio is a varietal characteristic but its heritability will be very low compared to grain slenderness. Consequently, selection of head-rice ratio using data from actual measurement will be inefficient. It may be useful to pyramid each characteristic associated with high head-rice ratio by MAS.

Pre-harvest cultivation practices

Sowing seeds that are a mixture of different varieties usually results in asynchronous heading in the same field, which makes harvesting difficult, which will often result in high grain breakage (see below). Farmers usually use their own seeds (harvested the previous season); thus, seed selection and handling should be done carefully. It is recommended that farmers renew their seeds every few years by purchasing certified seeds.

Zhang *et al.* (2012) compared rice grain yield and quality between a conventional lowland irrigation scheme in China and a water-restricted irrigation scheme, where about 16% of the water of the conventional scheme was used. Although yield and 1000-grain weight were lower in the restricted irrigation, quality was higher (higher head-rice ratio and lower chalkiness). Fofana *et al.* (2010b) showed that drought during maturity in upland rice did not affect yield, but decreased grain breakage and amylose content. These results provide some evidence that a water-saving irrigation system may produce rice with a higher head-rice ratio without sacrificing yield.

Fertilizer applications may affect grain quality substantially. Wopereis-Pura *et al.* (2002) showed that late application of 30 kg N/ha at booting stage, in addition to farmers' standard fertilizer management (116 and 127 kg N/ha in the wet and dry seasons, respectively) increased head-rice ratio by 12% and 24% in the wet and dry seasons, respectively, in northern Senegal (Sahel). The late N application also increased yield by 0.4 t/ha and 1.0 t/ha, respectively, in the wet and dry seasons. However, the practice is useful only for rice farmers who can afford to apply additional fertilizer.

Timing of harvest is crucial for grain quality and appropriate timing is often compromised because of competing activities or lack of labour for harvesting. Futakuchi *et al.* (2001) showed that late harvesting (45 days after 50% flowering) decreased head-rice ratio by 7.9% compared to the harvesting at 30 days after 50% flowering in M'bé (in the transition zone between Guinea savannah and forest areas of Côte d'Ivoire). Since lower air humidity during paddy drying decreases head-rice ratio (Aguerre *et al.*, 1986), the negative effect of late harvesting on head-rice ratio will become more severe in the Sahel.

Some insects and diseases may intervene in the field during grain-filling stage. Blast disease reduced head-rice ratio (Hai *et al.*, 2007) and infections of panicle blast increased the number of damaged grains (Shim *et al.*, 2005). Grains attacked by shield bugs (stink bugs) can be damaged with dark spots (Noda and Ishii, 1983) and the spots do not disappear after milling. Management to control pests will be important to produce quality rice. However, little is known about the extent of quality losses caused by these pests in Africa (see also Nwilene *et al.*, Chapter 18, this volume).

Harvesting and threshing

In the harvesting of upland rice, where subsistence farmers are dominant, panicles are harvested with knives; harvested panicles are bundled and kept at home (in humid environments, panicles are stored in the relatively less-humid kitchen). In lowland rice systems, the stems are cut at several centimetres above the base by sickle and manually threshed – for instance, farmers flay harvested plants against a metal barrel or a log. Threshed paddy is dried, sometimes on the ground in direct sunlight. These practices can introduce impurities and induce low head-rice ratio upon milling.

Manual harvesting is a labour-intensive process and proper timing of harvesting may be difficult. As mentioned in the section above, appropriate harvesting time is important for grain quality. For large irrigated lowland plots in the Sahel, a mechanical harvester is a solution to this constraint, and attempts to introduce such a technology have been started by AfricaRice. Introduction of threshing machines, such as the ASI thresher–cleaner (Rickman *et al.*, Chapter 27, this volume), is crucial and has already been carried out in some Sahelian areas. However, this requires an initial investment and backup systems to maintain the machines.

It is important to dry paddy on plastic sheets or tarpaulins to avoid contamination with soil or other foreign materials. It is well known that fast drying of harvested paddy leads to a higher percentage of broken grains (Rhind, 1962). Practices to avoid quick drying of paddy are relatively easy to adopt. One recommendable practice is simply to dry paddy in the shade, in an area with the lowest available relative humidity, not in direct sunshine. In areas where this is difficult, a possible practice is to have a thick layer of paddy on the ground and stir the paddy more frequently during the drying process.

Milling

Most subsistence rice farmers carry out milling by themselves using mortar and pestle and subsequently winnow it in the wind. In this process, almost all grains are broken; meanwhile, professional millers may grade milled rice before it is sold on the market. In Kumasi (Ghana), both Engelberg and so-called 'one-pass' mini rice mills are used (Sakurai *et al.*, 2006). In an Engelberg mill, a steel roller with grooves rotates in a metal casing and paddy grains are husked and then polished by friction between the grooves and grains and among the grains; the machine was developed in 1888 in the USA and is still manufactured and used in South-east Asia (Satake Cooperation, 2006a). The one-pass mini rice mill was developed in Japan in 1956. This machine operates on the same principle of 'friction milling' as the Engelberg, but has a different style of dehusking and polishing with a larger capacity, and the rice husks and bran are removed by aspiration (Satake Cooperation, 2006b). Rice milled by the mini rice mill had significantly higher head-rice ratio and lower levels of impurity than that milled by Engelberg mills in Ghana (Sakurai *et al.*, 2006).

In Benin, all 110 millers from whom AfricaRice collected milled rice samples (Study 3), used Engelberg mills. Their output is of poor quality (see 'Physical appearance' above). To improve the quality of milled rice on the local market, the introduction of improved mini rice mills is one necessary measure. The mini rice mill has greater capacity than the Engelberg type, so a miller who adopts it could process more rice and collect more fees – the fee for milling a unit volume of rice was not affected by technologies of milling, but by location of the mills (Sakurai *et al.*, 2006). The introduction of a new type of rice mill requires a large initial investment and it is important to consider location and effective dissemination modes. Of the 110 millers using Engelberg mills in Benin, 48 used locally produced machines and the remaining 62 used machines imported from Asia. The average levels of impurities and head-rice ratios were 1.02% and 24.4%, respectively, for the locally produced mills and 1.14% and 31.6%, respectively, for the imported mills. Impurity may depend on the condition of the paddy brought to the millers and imported mills produced slightly higher head-rice ratio. Before a shift from Engelberg types to mini rice mills, some improvement could be possible in the local capacity for making mills. Stones that contaminate paddy (through inappropriate threshing and drying) can damage the mills. It is also important to improve local capacity to repair and maintain mills.

More information on rice mills can be found in Rickman *et al.* (Chapter 27, this volume).

Storage conditions

Stored grains may be attacked by weevils or other insects (for more details see Nwilene *et al.*, Chapter 18, this volume). Storage condition and duration may affect grain quality. Bleoussi *et al.* (2011) tested four NERICA varieties and one *Oryza sativa* variety in relation to the effect of storage duration (paddy under room temperature and humidity) on some grain quality traits up to 64 weeks and showed that with the elapse of storage time, husking recovery, milling recovery, head-rice ratio and grain hardness increased, but whiteness decreased; there was no effect on grain chalkiness, but some changes in cooking and eating characteristics caused by extended storage were observed. Little information is available on the effect of existing storage conditions in Africa on grain quality. A study of existing storage practices would be helpful in determining which indigenous practices are appropriate for storing rice and what new practices could be introduced. In Asia, some storage technologies to improve quality and reduce damage to rice are available; for example, IRRI has developed a storage bag for crops (not only for rice but also for other crops such as coffee) called the 'Super Bag'. This is a hermetic storage bag and prevents both oxygen and water from entering from the outside – the following positive effects are expected: approximate doubling of the germination life of seeds; control of insects without using chemicals; improved head-rice recovery of stored grain by about 10% (IRRI, 2005). Such a reputable technology could be directly introduced to Africa relatively easily.

Parboiling

Parboiling is a hydrothermal process in which the crystalline form of starch present in the paddy rice is changed into an amorphous one as a result of the irreversible swelling and fusion of starch. This is accomplished by soaking in cold and then hot water or steam at low pressure, before drying and milling the rice. There are many methods of parboiling rice, but the central processes are essentially the same. The process of parboiling results in physical, chemical and organoleptic changes in the rice, with economic and nutritional advantages (Choudhury, 1991). Parboiled rice is consumed worldwide, except in East Asia, and its consumption is increasing in Africa and Central and South America (Kimura, 1995). Parboiled rice is strongly preferred in some African countries such as Nigeria, where almost all locally produced rice is parboiled. In an assessment of consumer preferences in Benin (Mhlanga, 2010), consumers of all regions – except the south (including Cotonou) – preferred parboiled rice to non-parboiled rice. In countries such as Benin and Nigeria, therefore, there could be a large potential in parboiling technologies to increase incomes, especially for women processors – the main producers of parboiled rice. Fofana *et al.* (2011b) show that a method to steam paddy instead of boiling resulted in a better-quality product with fewer heat-damaged grains, higher head-rice ratio and greater translucency. This method of direct steaming is being disseminated to rice parboilers in Benin by AfricaRice and the Institut national de recherches agricoles du Bénin (INRAB, the Beninese NARS).

Bleoussi *et al*. (2011) report significant interactive effects of paddy storage duration and parboiling on several grain quality traits (grain hardness, husking recovery, head-rice ratio, whiteness, translucency, cooking time, swelling ratio and gel consistency), but not milling recovery. In consideration of the importance of parboiled rice in Africa, further study will be necessary on this topic.

Other factors

Ghanaian rice farmers near Kumasi take paddy directly to millers and pay them on a milled-rice volume basis. Farmers then sell milled rice to brokers or retailers (Sakurai *et al*., 2006). Sakurai *et al*. (2006) observed that low grain breakage had a significantly positive effect on the rice price in the urban areas of Kumasi but not in the rural areas around the city. For goods to be sold at the right price (i.e. high-value goods sell at high prices and low-value goods at low prices), market information should be available to all actors. In the urban area of Kumasi, there are several clusters of rice millers. In contrast, in the rural areas, millers are much more scattered.

If rice with higher (more appreciated) quality is sold at a higher price, rice value-chain actors will be more motivated to improve the quality of rice; in this example, this is more likely to occur with rice sold in the urban areas than that sold in the rural communities around Kumasi.

Conclusions

Improving the market competitiveness of locally produced rice is crucial for reducing the amount of imported rice and contributing to food security in Africa. The competitiveness of locally produced rice against imported rice in the market depends primarily on its acceptance by the consumer.

Sensory tests were conducted in four regions in Benin using two imported brands, two local (already cultivated) varieties and two newly introduced NERICA varieties with 125 consumers at each site. Preference for raw (uncooked) rice was common across regions with a high preference for imported rice brands and NERICA 1. For cooked rice, preferences differed with region. Cotonou showed very different results (imported rice and NERICA 4 were liked there) from the other regions, most probably due to the fact that its population is more exposed to imported rice compared to the other three regions. The local varieties did not receive high preference scores as either raw (uncooked) rice or cooked rice samples in any region.

Comparing the sensory tests with the study on grain quality traits of imported rice brands, local varieties and NERICA varieties, it was shown that low chalkiness, high translucency, slender grains and aroma are factors that are commonly preferred across Benin for raw (uncooked) rice. The third study showed that locally produced rice was generally of poor quality because of impurities, and a poor head-rice ratio and translucency. These are important indicators to be considered in the improvement of varieties, and with respect to pre- and postharvest practices. Although preference for cooked rice was different among regions, the imported rice brands received relatively high preference scores on average across regions. With respect to cooked-rice characteristics, imported rice possessed a softer texture than the local and NERICA varieties, which was preferred by most consumers.

The diversity of preferences for cooked-rice attributes within a small country like Benin may suggest that there could be huge variations in cooked-rice preferences across the continent. Precise information is not available for most countries in Africa and further consumer-preference surveys will be necessary in those countries. On the other hand, preference attributes for imported raw rice in all regions of Benin was fairly uniform. The physical quality attributes of imported rice could therefore be the benchmark target for breeding, pre- and postharvest practices in many areas in Africa. It has been reported that despite some superior eating properties of local rice, it is not competitive against imported rice in terms of physical quality in Nigeria (Tiamiyu *et al*., 2011; Ogundele and Diagne, unpublished data).

In all steps along the value chain where the quality of locally produced rice is affected – i.e.

varietal selection (breeding), cultivation, harvesting and threshing, milling, storage and parboiling – there are some issues to be addressed. Possible improvements in each step are discussed in this chapter based on detailed studies in Ghana and Benin and available knowledge (documents and expert knowledge).

In order to achieve a better physical quality of rice, especially fewer impurities and higher head-rice ratio, the harvesting, threshing and milling processes are crucial with mechanization being important for all these operations. Results from Benin show that locally manufactured rice mills generally produce lower-quality rice than imported mills of the same type. Improvement of the local capacity to construct these mills is needed and this may also contribute to better maintenance of the mills.

Apart from factors such as varietal selection and pre- and postharvest practices discussed above, the socio-economic environments surrounding value-chain actors may have an influence on the quality of locally produced rice. If locally produced rice of better quality is sold at a higher price, the actors will be more motivated to improve rice quality. In our example from Ghana, this was the case in the urban area of Kumasi but not in the surrounding rural areas. This difference between urban and rural areas is because of differences in access to price information (Sakurai *et al.*, 2006). Therefore, better access of value-chain actors to price information is an important prerequisite for rice quality improvement.

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