Nutrient-focused Processing of Rice

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Chapter 10

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1. INTRODUCTION

Rice, the staple food of Asia, provides on average 30% of the daily calorie intake across the continent. It accounts for about a quarter of the world's cereal production volume per annum—672 Mtonne paddy rice (FAOSTAT 2010; Table 10.1). Rice production ranks second to maize (844 Mtonne) while being comparable to that of wheat (651 Mtonne). Importantly, and in contrast to these two crops, the vast majority of rice goes to human consumption (>80%), with little used as seed or for animal feed.

The Asian subcontinent accounts for ≥90% of the world's rice production and consumption (Figure 10.1), China and India alone for 50%. The gross domestic product (GDP) growth and population magnitude of these two countries alone challenge the capability to supply. Greater than 50% of the daily caloric intake in Indonesia, Vietnam, Bangladesh, Cambodia, Laos, and Myanmar comes from rice (International Rice Research Institute, 1999). The International Monetary Fund predicts GDP growth rates of >5% (2010–2015) for these countries and increasing population.

The importance of rice in the Asian region as a staple food, energy and nutrient provider of economic and political leverage will increase in the coming years. Agricultural practices will be modernized and paddy farm capacities increased. However, supply will only match demand with improvements in logistics management and processing efficiencies to eliminate waste and spoilage, increase yield, and decrease processing costs per kg. A sustainable value chain requires more than capacity and efficiency improvement, as it also needs to deliver the highest quality both in sensorial pleasure and in food safety.

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TABLE 10.1 Production of Different Cereals Worldwide in 2010

Cereal	Cereal Crop Production 2010	
	(Mtonne)	(% Total Production)
Maize	844	34
Paddy rice	672	28
Wheat	651	27
Barley	124	5
Sorghum	56	2
Millet	29	1
Oats	20	1
Other cereals	37	2

Source: FAOSTAT.

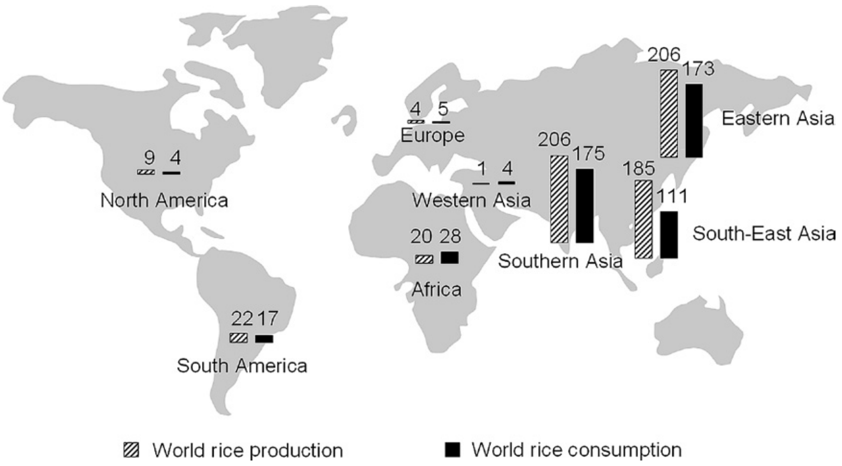

FIGURE 10.1 Rice production and consumption in different regions of the world in 2007, shown as Mtonne paddy rice equivalent. *Source: FAOSTAT.*

2. NUTRIENT COMPOSITION OF RICE FRACTIONS

Rice is predominantly consumed in dehulled and milled form, i.e., as white head rice. Figure 10.2 shows the typical microstructures of a paddy rice kernel (left) as well as a detail view of the endosperm, bran layers, and hull. Compared

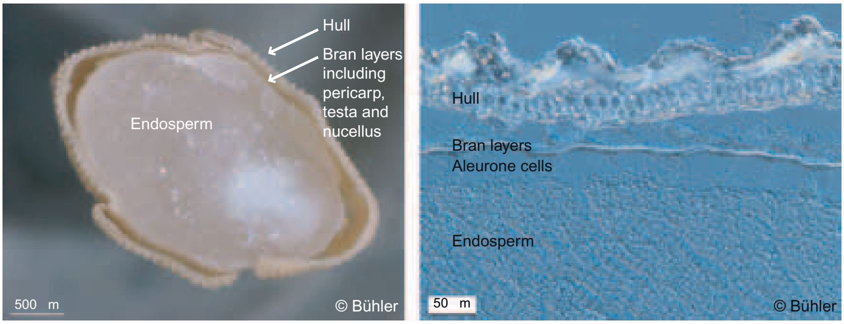

FIGURE 10.2 Macroscope image of rough rice kernel cut transversely and photographed with a Leica DC500 on a Photomakroskop Wild M400 in incident light (left). Differential Interference Contrast Microscopy of typical structures in rice hull, bran layers, and endosperm including the aleurone layer (right).

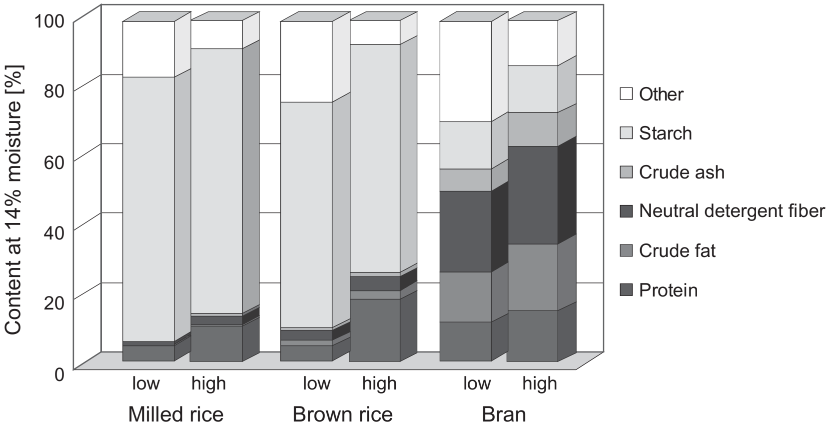

FIGURE 10.3 Low and high values of macronutrients found in different edible fractions of the rice kernel. *Data source: Champagne et al. (2004).*

with milled rice, brown rice contains 2–10 times more minerals, 2–3 times more fiber, and 5 times more lipids (Champagne et al., 2004).

2.1 Macronutrients

The rice hull represents about 20% of the rough rice grain and is not edible. Its major components are non-starch carbohydrates, and it contains about 20% of silica, 9–20% lignin as well as 2–6% cutin. The main constituent of white rice is starch (~78%, see Figure 10.3), followed by protein (5–11%). Fat, fiber, and ash content are low at 0.3–0.5%, 0.7–2.3%, and 0.3–0.8%, respectively. In contrast, bran as one of the co-products of milling is nutritionally valuable and contains significant amounts of fat (15–20%), neutral detergent fiber (24–29%), and ash (7–10%), as well as slightly elevated amounts of protein (11–15%). The starch content of rice bran is about 14% only, with some variation depending on the degree of milling (Champagne et al., 2004). Fat from rice bran is nutritionally valuable since it contains high fractions of mono- and polyunsaturated fatty acids (38.4% oleic acid C18:1, 34.4% linoleic acid C18:2, 2.2% α-linolenic acid C18:3) and only about 25% saturated fatty acids consisting of myristic acid C14:0, palmitic acid C16:0, and stearic acid C18:0 (Orthoefer and Eastman, 2004). γ-oryzanol, a unique mixture of triterpene alcohols and sterol ferulates present in rice bran oil, has been reported to have hypocholesterolemic activity in various animal and human studies (Patel and Naik, 2004).

Rice is an important source of protein in Asia, especially in tropical Asia, where it accounts for 35–40% of the dietary protein (Juliano, 1993). The protein content in rice is relatively low, but its quality and bioavailability are nevertheless good (Bhattacharya, 2011). However, similar to other cereals, rice protein is deficient in the essential amino acid lysine but contains the essential sulfur-containing amino acids cysteine and methionine in abundance. A diet combining rice and legumes balances out amino acid composition quite well (Rand et al. 1984, Eggum et al., 1987) because pulses are rich in lysine but poor in sulfur amino acids.

2.2 Micronutrients

Milled rice contains little in the way of vitamins and minerals (Figure 10.4). Rice bran on the other hand contains considerable amounts of thiamin

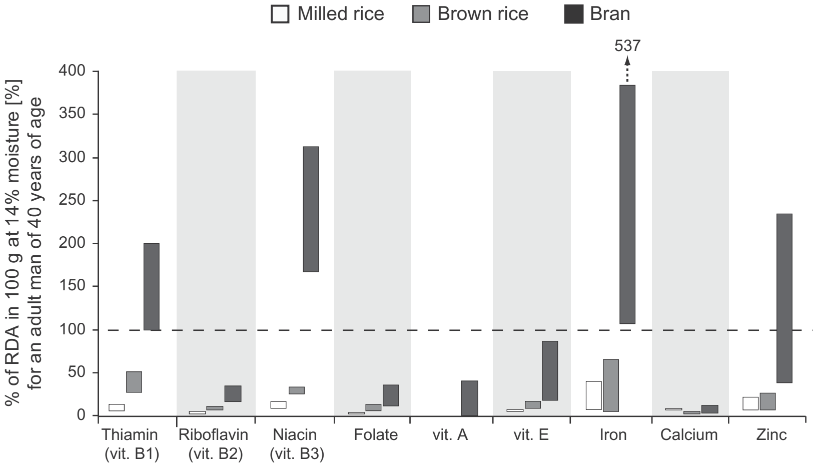

FIGURE 10.4 Micronutrient content of different edible rice fractions. Bars represent range in contents. *Data sources: for content in vitamins and minerals, Champagne et al. (2004); for recommended dietary allowances (RDA), USDA (2010).*

(vit. B1), niacin (vit. B3), iron and zinc, with values in 100 g rice bran clearly exceeding the recommended daily allowances. In contrast, rice contains moderate amounts of vitamin E, very little vitamin A, folate, riboflavin and calcium and nearly no vitamin C and iodine (values not shown). Phosphorus content is substantial (1.7–4.3 mg/g in brown rice at 14% moisture), with half of it in the form of phytic acid which is only partially bioavailable and acts as a potent inhibitor of iron, zinc, and calcium absorption (Hurrell et al., 1992).

3. HEALTH PROBLEMS IN RICE CORE REGIONS

According to Juliano (1993), the most important nutritional problem in rice-consuming countries is an inadequate and unbalanced dietary intake of nutrients. Protein-energy malnutrition and unsatisfactory levels of fat consumption are the nutritional challenges on the macronutrient side. With respect to micronutrient status, nutritional anemia is common, particularly from iron deficiency. The prevalence of iron deficiency is estimated to be about 30% of the world's population (WHO, 1992). This makes iron the most widespread nutrient deficiency worldwide by far. Poor pregnancy outcomes, including increased mortality of mother and children, reduced psychomotor and mental development in infants, decreased immune function, tiredness, and poor work performance can be the consequences (Cook et al., 1994). Absorption of iron depends on its source and is worse for non-heme iron from plant sources than for heme iron contained in meat. In developing countries, iron is mostly consumed in the form of non-heme iron from grain and legume staples in which phytic acid acts as a potent inhibitor of absorption (Lucca et al., 2001). Additional nutritional concern stems from vitamin A and iodine deficiency disorders, the latter due to naturally low iodine levels in soil in some regions or leaching of iodine by rainwater and floods (Dexter, 1998). Deficiencies in thiamine, riboflavin, calcium, vitamin C, and zinc are also prevalent.

Not all of the nutritional concerns are directly caused by the consumption of rice *per se* but reflect an overall impact of multiple causative factors similar to those in other developing countries where rice is not a major staple. Beriberi, however, caused by thiamine deficiency, is a characteristic disease of communities that consume polished rice as a staple. As shown in Figure 10.4, milling leads to a drastic loss in thiamine. Further losses occur during washing and cooking. Akroyd et al. (1940) first showed that brown rice contains sufficient thiamine (3–4 μg/g) whereas machine-milled raw rice contains little (0.5–1.3 μg/g). The same authors showed that the thiamine content of milled rice is significantly higher after parboiling (2.0–2.5 μg/g). These observations were corroborated by the relatively lower prevalence of beriberi in populations in India consuming parboiled rice (Kik and Williams, 1945).

4. RICE PROCESSING

Rice milling differs from wheat and maize milling in so far as the intactness of the rice kernel after milling is of utmost importance. The intact white rice kernel, the so-called head rice, has a much higher monetary value than broken kernels. Depending on taste, storage, cooking, way of eating, and nutritional preferences, rice is milled fresh, goes through an aging phase, is steamed, or parboiled before milling.

The milling result is strongly affected by pre-existing natural factors like tightness of husk interlocking or imperfect grains. Indudhara Swamy and Bhattacharya (1984) showed that whatever the grain type and quality and whatever the milling conditions, the total grain breakage almost never exceeded the total count of imperfect grains. The entire processing chain, including pre-milling steps, is of utmost importance with respect to end product quality as well. This can be exemplarily shown by the fact that head rice yield can be significantly improved by proper grading of grains into groups of uniform length and thickness (Sun and Siebenmorgen, 1993).

The harshness of rice milling itself determines whether fissured kernels stay intact or break apart. Milling can follow various flow paths for different reasons, of which one is rice variety. The flow path described in this section is usually applied to non-sticky, long grain *Indica* rice varieties cultivated throughout tropical Asia. Figure 10.5 shows an overview of the typical processing steps for *Indica* rice from harvest to white rice. Rice is dried, stored, optionally parboiled or steamed (not included in the figure), cleaned using sieves and classifiers, hulled, whitened (4 passes), polished (1–3 passes), sorted and graded. If the dried paddy rice is taken as the reference input material (100%), an average white head rice yield of 49% can be achieved. Edible products are rice bran (~10%) and brokens of different kernel length (~15%). Head-rice yield is in general significantly higher for parboiled rice and can be close to 64% if pre-processing and drying after parboiling are properly done (Bhattacharya, 1969).

In contrast to the flow path shown in Figure 10.5, *Japonica* rice usually passes through huller, abrasive mill (1 pass), degerminator (2–3 passes), and polisher (1–3 passes). *Japonica* varieties are usually short grain with a sticky cooked texture. It is the type of rice cultivated in temperate East Asia, in upland areas of Southeast Asia, and at high elevations in South Asia. Degerminators are necessary during milling of *Japonica* rice since the germ is more deeply embedded in the kernel than in *Indica* varieties. Vertical friction machines, in which the rice moves upwards, are usually applied as degerminators. Sometimes horizontal friction machines are used instead.

The processing steps drying, parboiling, hulling, whitening, polishing, sorting, and grading are described in more detail in the following sections.

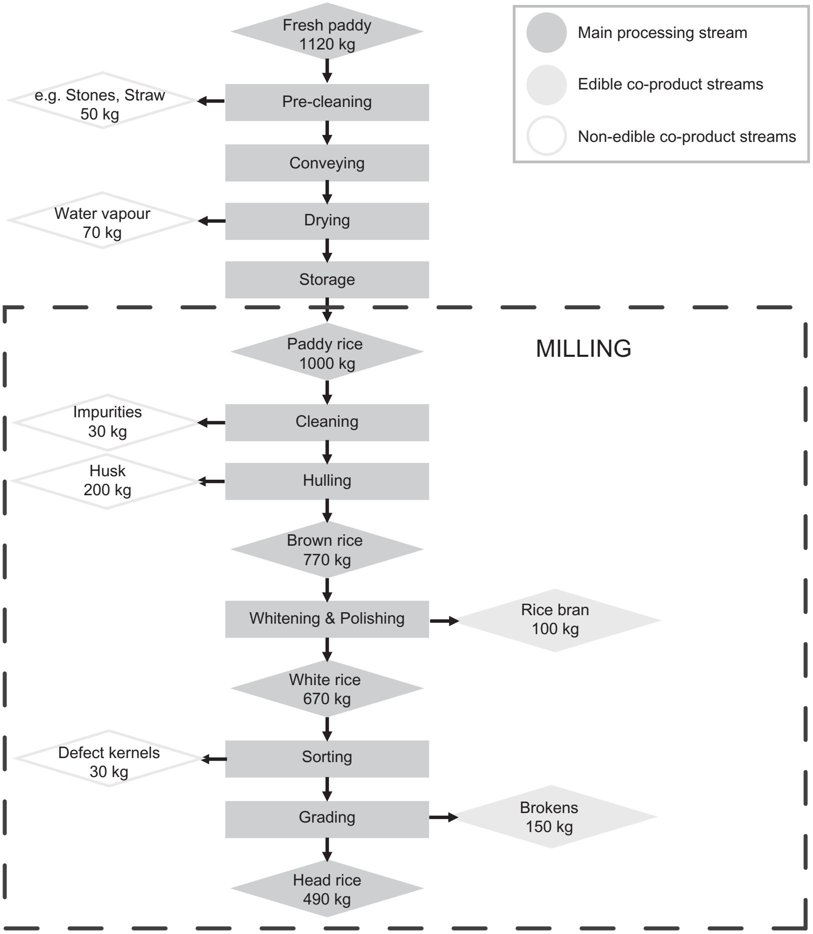

FIGURE 10.5 Mass stream of rice during processing from field to freshly milled *Indica* rice, including main product stream, edible co-products, and inedible co-products. Numbers are valid for raw rice.

4.1 Drying

Paddy rice is typically harvested with 16–24% (wb) moisture, depending on the season and on weather conditions before and during harvest. This moisture content is well above critical limits with respect to spoilage, i.e., enzymes, molds, yeasts, and even some bacteria are active (Labuza et al., 1970). Rice is, thus, dried to a moisture content of about 12% (wb) which is safe for long-term storage. Swedish scientists (Gustavsson et al., 2011) found that, in countries such as those in south and southeast Asia, food loss mostly occurs in the early and middle steps of the food supply chain, namely during agricultural production and post-harvest handling, where in each step up to 6% losses occur.

Since rice kernels are predominantly eaten as intact white kernels, any breakage during milling is undesirable. The grain is not easily susceptible to structural damage by thermal stress, but is susceptible to moisture stress upon hydration or dehydration (Bhattacharya, 2011). Thus, besides having a major impact on spoilage-related losses, correct drying of rice is an essential step for ensuring milling quality.

Improper drying and cooling may lead to rice fissuring which promotes breakage during milling (Bhattacharya, 2011). The critical moisture content for fissuring is related to the glass transition temperature, the threshold between a rubbery and glassy state of the kernel (Figure 10.6, right). Rice that is cooled directly after drying develops fissures some time after the drying process is complete. However, grain breakage can be avoided by hot tempering at the drying temperature for several hours. The reason for this fissuring phenomenon is that during the drying process the moisture content of the surface of the grain decreases faster than that in the centre of the kernel (see Figure 10.6, left). As a consequence, the moisture dependent glass transition temperature T_g of the surface layer is higher than that in the center. Therefore, if the product is cooled immediately after the drying is concluded, the surface enters the glassy state while the center remains rubbery. The resulting change in state evokes differential stresses within the grain that can cause the grain to fissure (Perdon et al., 2000; Cnossen and Siebenmorgen, 2000). If, on the other hand, drying is followed by a tempering step in the rubbery state, continued moisture diffusion is facilitated. As a consequence, the moisture within the kernel gradually equalizes, and stresses caused by moisture gradients disappear. Cooling down becomes uncritical once the moisture within the kernel is homogeneous.

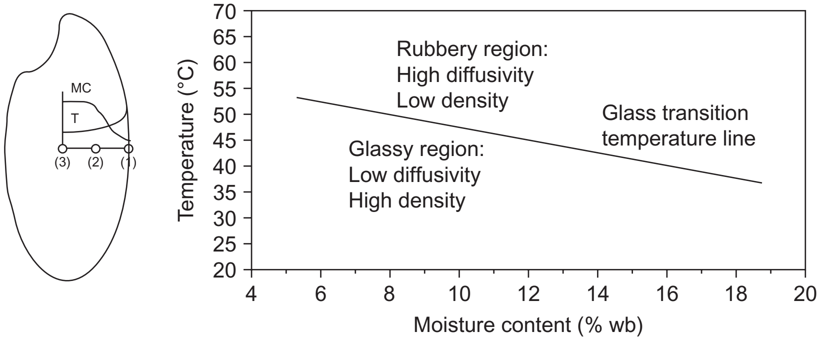

FIGURE 10.6 Left: Hypothetical temperature (T) and moisture content (MC) distribution within a rice kernel during drying, plotted onto a rice kernel. Points 1, 2, and 3 on the x-axis of the plot correspond respectively to the surface, mid-point between surface and center, and center of the kernel. Right: Glass transition relationship for Bengal brown rice (Sun et al., 2002). *Reprints with permission from (left) Cnossen and Siebenmorgen (2002), (right) Cnossen et al. (2002).*

The type of rice drying depends on the extent of mechanization. Traditionally, rice is dried in batches in the open air. Industrial drying methods include batch drying in bins as well as continuous drying in a flow column, rotary bed, or fluid bed. Methods where temperature and moisture can be controlled are clearly advantageous with respect to kernel fissuring. Two-stage or multistage drying that includes tempering between stages, where the rice is held for hours at the drying temperature, is usually applied in industrial processes to avoid structural damage to the kernels.

4.2 Parboiling

The term parboiling refers to a partial boiling of rice, mostly done while still in the husk and sometimes in the form of brown rice. About a fifth of all rice is parboiled before milling, and 90% of all parboiled rice is produced in South Asia. Diverse ways of parboiling are known, which can be grouped into three main categories (Bhattacharya, 2004):

- "conventional parboiling" including the steps soaking, draining, cooking, and drying,
- "low-moisture parboiling" where partial soaking is followed by high-pressure steaming, and
- "dry-heat parboiling" with soaking followed by a combined conduction heating/drying step.

Parboiled rice differs from raw rice in many ways (Bhattacharya and Ali, 1985). In contrast to raw rice, parboiled rice appears glassy, translucent and has an amber color before cooking. After cooking, it is firmer, fluffier, and less sticky. Even though parboiling leads to a decrease in the thiamine content of brown rice, milled parboiled rice contains more thiamine than milled raw rice at the same degree of milling. This observation is commonly explained by an inward diffusion of the vitamin during parboiling (Padua and Juliano, 1974). Similar trends were observed for nicotinic acid and riboflavin (Akroyd et al., 1940), whereas fat-soluble vitamins are not introduced into the kernel during parboiling but migrate outwards. As an additional positive consequence of parboiling, head rice yield is increased to near-maximum if parboiling and subsequent drying are properly done (Bhattacharya, 1969). The probable explanation is that the swelling of the starchy endosperm during cooking heals pre-existing defects like chalky parts or fissures.

4.3 Rice Milling

The term milling usually subsumes the core processing steps—i.e., hulling, whitening, and polishing—in the case of *Indica* rice processing. The principal aim is the separation of hull and bran from the endosperm while keeping the white rice kernel intact.

4.3.1 Hulling of Paddy Rice

The purpose of hulling is to remove the husk from the paddy grain without damaging the bran layer and limiting kernel breakage to a minimum. The efficiency of the huller is determined by the percentage of kernels dehulled at one pass. This is called the degree of hulling. Under-runner disk hullers were the most popular machines before the introduction of the rubber roll huller. Under-runner disk hullers consist of two plates with adjustable gap size, one fixed and the other rotating. Paddy is fed in at the center of the fixed plate. Due to an abrasive coating and the pressure between the plates, the husks are sheared off. Since the abrasive material is coated on the moving plate and husk is also highly abrasive, an uneven surface develops on the plate over time. As a consequence, the percentage of broken kernels rises and the degree of hulling declines. The rubber roll huller has now replaced this machine almost completely.

The rubber roll huller consists of two rolls that rotate in opposite directions with a difference in speed of 1:1.25 to 1:1.35. The paddy is fed in between the rolls and the shear force exerted tears the husk off. The rubber wears off due to the abrasive nature of the husk and, hence, the gap has to be adjusted to maintain the degree of hulling. In modern-day machines this is done automatically. Hulling efficiency with rubber roll hullers is much better than with under-runner disk hullers. In addition, rubber rollers do not damage the bran layer, which explains why the number of broken kernels is much lower. Following hulling, loose husks are removed in a husk separator using aspiration. Figure 10.7 shows the principles of the rubber roll huller and husk separator.

Hulling degree is maintained at 90% on modern hullers for most rice varieties except in long grains, where the efficiency is reduced to 80% to minimize the brokens generated. As a consequence of the incomplete hulling, separation of unhulled paddy from brown rice is necessary. This is done in paddy separators. There are different types of these machines—tray type, compartment type, and screen separators—of which only tray type separators are described here. Tray type separators are nowadays preferred for their high efficiency of separation. They consist of inclined, oscillatory moving trays with an indented surface. The mechanism of separation is based on differences in specific gravity, grain length, and friction coefficients. Brown rice is forced to move towards the upper end, while paddy rice floats on top and moves towards the lower end of the table.

4.3.2 Abrasive Milling or Whitening

Abrasive milling, also called whitening, is used to separate the major part of the bran layers as well as the germ from the starch-rich core of the kernel. The principle of abrasive milling is that brown rice travels through a gap between an inner rotating abrasive cylinder and an outer perforated metal cage

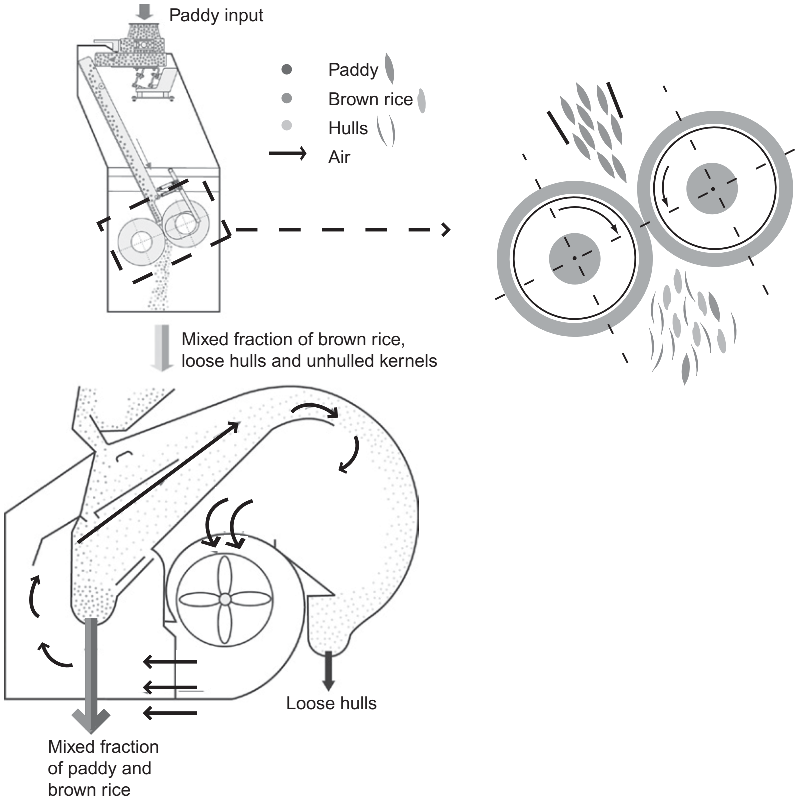

FIGURE 10.7 Principle of Bühler rubber roll huller and husk separator (left). Schematic drawing of rubber rollers (right).

(Figure 10.8, right). Bran is abraded from the kernel while passing through the gap. Different types of abrasive rice mills are available. Their main differences are in the design of the milling stone and the orientation of the milling zone: i.e., horizontal versus vertical setting and conical versus cylindrical stone geometry.

Vertical abrasive cones were the first machines to be invented, in the late nineteenth century by Douglas and Grant in Scotland. Rice is fed from the top into the gap and flows downwards under the influence of gravity. Rubber brakes slow down the flow of rice and build up pressure. Any loose bran is removed through a wire mesh by suction. The cone diameter is largest on top. Peripheral speed is, hence, highest at the rice inlet, and the resulting quick acceleration of rice kernels leads to physical stresses and high numbers of broken kernels. Another disadvantage of this set-up is that underloading results in non-uniform whitening and uneven wear and tear on the machine.

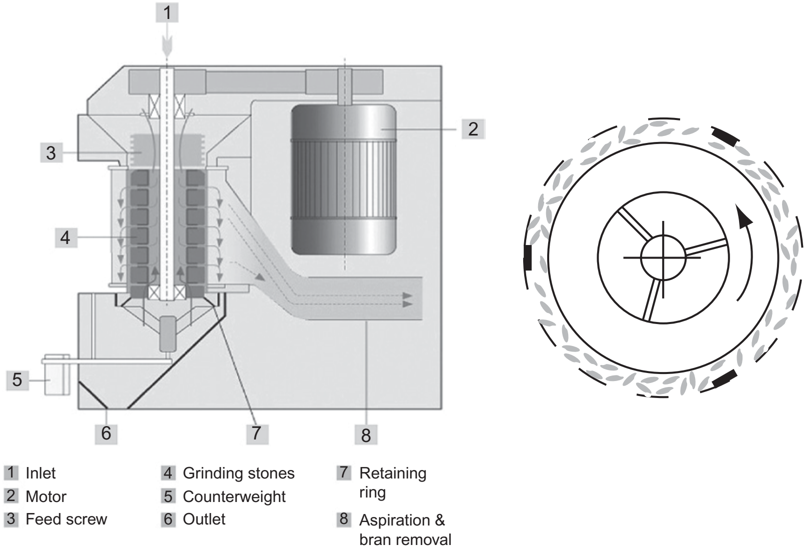

FIGURE 10.8 Schematic drawing of Bühler whitener (left). Principle of whitening where bran abrasion is achieved between an abrasive rotating inner cylinder and a perforated cage (right).

In horizontal whiteners with cylindrical stone geometry, the circumferential speed is the same throughout the length of the machine. A higher and more uniform degree of whiteness can be achieved. However, as a result of the horizontal alignment, rice is only discharged by the back pressure of incoming rice. Another drawback is that only the bottom half of the machine is completely filled. Friction is high in this area, which results in an undesired heating of the rice. To counter this heating, air is blown into the machine, with the result that head rice yield decreases. Modern vertical whiteners (Figure 10.8, left) prefer cylindrical stones in a vertical setting and include a feed screw. This design guarantees uniform rice distribution and limited acceleration of the kernels at the inlet. The rotor is assembled from individual stones. Angled slots in the sieve enclosure mirror the spiral path taken by rice in the milling gap and ensure maximum bran removal with a minimum of broken kernels. The whitening degree is controlled by a counter weight arrangement at the outlet which ensures that the filling degree of the milling chamber is optimized and optimal back pressure is generated. In modern rice mills, rice passes through one (for short grains, e.g. China), two (for some specific varieties in Europe), three (short and medium grain), to four (long grain) consecutive abrasive mills to minimize the number of brokens while maximizing the throughput. After whitening, the kernel surface is still rough. This is why in most industrial rice mills, abrasive milling is followed by friction milling or polishing steps.

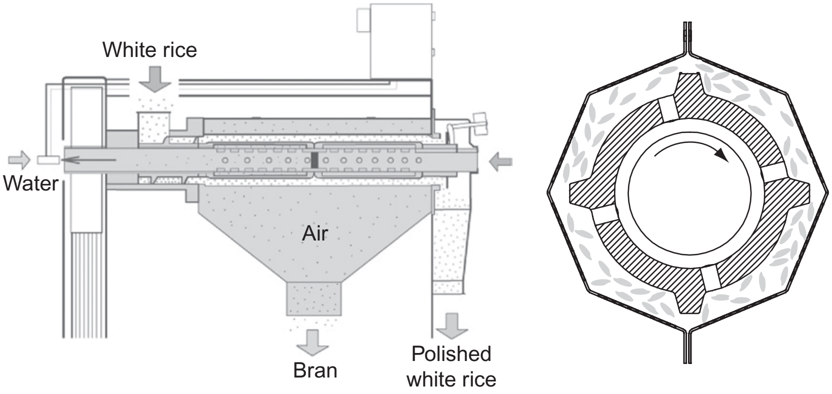

FIGURE 10.9 Schematic drawing of Bühler water mist polisher (left). Principle of polisher, where friction between kernels is created by ribbed cams (right).

4.3.3 Friction Milling or Polishing

In contrast to whitening, where grains are abraded between a rotating inner cylinder and an outer cage, polishing uses friction between the kernels created by ribbed cams (Figure 10.9, right). The remaining traces of bran are removed and any scratches created during whitening filled. As a consequence, the shelf life of rice is increased and a glossy finish achieved.

Polishing machines are almost always horizontal and include the option of water addition. Older machines did not add water and relied solely on friction to achieve a lustrous look and feel. Due to the very high heat generated, they also generated a large number of brokens. To counteract this, a hollow shaft was added, through which air was blown in to cool the rice, but this proved ineffective. Modern water mist polishers use atomized water to humidify the rice grain and thereby increase friction. Temperatures remain lower in this type of machine and the rice surface does not dry out. The addition of water also helps to create a slip layer between the bran fragments and the rice kernel, thus ensuring better bran removal. The result is a much better look, longer shelf life of rice, and a higher head rice yield. The application of one to three consecutive polishing machines of this type is now the industry standard worldwide (Figure 10.9, left).

Figure 10.10 shows the surface and near surface layers of a Basmati rice kernel before and after different milling steps, achieved using a Bühler Basmati line. The images clearly show how first the hull is removed. The resulting brown rice kernel is still covered by intact bran layers. Following this, four passes of whitening were undertaken. With each whitening pass, more of the bran layers are removed ending with a near-white kernel with a jagged surface. Polishing then evens out the surface by removing residual bran

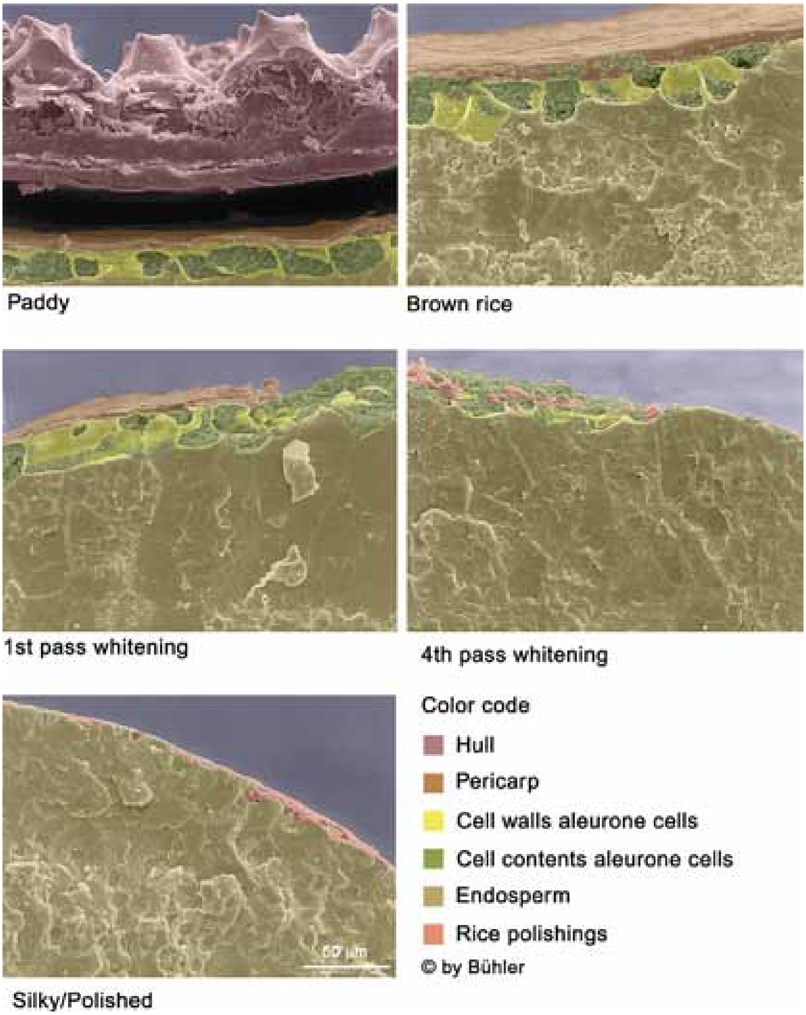

FIGURE 10.10 Scanning electron microscope images of the surface layers of a Basmati rice kernel before and after the different milling steps: hulling, whitening, and polishing. Rice kernels were defatted with petrol ether and dried at room temperature. Cross sections were produced by cutting the kernels transversely with a razor blade. The samples were then mounted on SEM object holders with conductive carbon cement and, prior to the examination with SEM, sputtered with gold. *Images were subsequently colored with Photoshop CS4.*

parts and filling the indentations with loose material which mainly consists of starch. The end product is a white kernel with a silky finish.

4.3.4 Sorting and Grading

After milling, rice is optically sorted and graded, although in some cases rice is sorted after grading. Optical sorting improves the product quality by

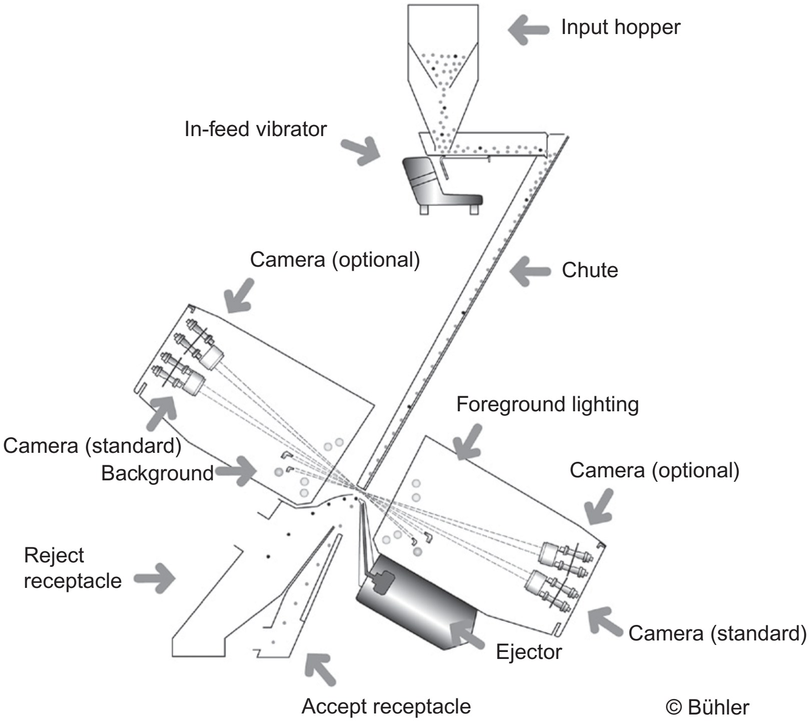

FIGURE 10.11 Schematic drawing of a Bühler Sortex Z optical sorter.

identifying and removing defective grains such as "Yellows", "Peck Defects", "Brown Defects", "Purples" and "Chalkies". The optical sorter will also remove foreign material such as weed seeds and mud balls.

A typical optical sorter is made up of four elements:

- the feed system consisting of a vibrator and inclined chute arrangement which presents the product to the vision system as a cascading plane of rice of uniform speed and distribution;
- a vision system where high-speed cameras and lighting create a continuously rolling image of the product which is digitized and processed;
- the sorting electronics in which digital images are processed relative to user defined criteria and grains are classified as either "accept" or "reject"; and
- the pneumatic ejector array where grains or objects identified as reject material are removed from the product stream with a short blast of air.

Figure 10.11 shows a schematic drawing of a Bühler Sortex Z optical sorter.

Grading for removal of broken grains after rice milling is achieved with indent cylinders. The indent cylinder is a constantly rotating drum. Broken grains collect in the indents as the drum is rotated and are lifted from the product stream. Acceptable grains are too large to get caught in the indents and simply pass through the cylinder.

5. POTENTIAL USAGES OF EDIBLE CO-PRODUCTS

Whitening and polishing of brown to white rice results in about 30% edible co-products in the form of broken kernels and rice bran. These are valuable sources of macro- and micronutrients and should be considered as raw materials for further food processing.

5.1 Rice Brokens—Case Study: Reconstituted Rice

Broken kernels are comparable to head rice with respect to storage properties and composition, and re-enter the food chain to a large extent. Brokens are either sold as low-value rice, added to compound products like breakfast cereals, or are ground to flour. Rice flour can then be used as an ingredient for sauces and soups or to create unique products like rice pasta or reconstituted rice kernels. The following information on processes and principles of the formation of reconstituted rice is also true for gluten-free pasta, even if the same variability in end product properties is not desired.

Reconstituted kernels are commonly produced using cold or hot extrusion. Pasta equipment with or without the addition of steam as well as twin-screw extruders are commonly applied. Rice flour of varying granulation plus an optional vitamin/mineral premix is extruded to form rice kernels closely resembling natural rice. Rice does not contain any gluten, and thus no networks can be formed which support and hold the structure together during cooking. Instead, starch acts as the main structuring agent. The starch matrix can be tailored by varying the degree of starch gelatinization. Clear differences in the state of starch during processing, between cold and hot extrusion, can be seen in Figure 10.12. During cold extrusion, temperature and moisture conditions are such that amylopectin melts to a very limited extent only, whereas it is mostly in its molten state during hot extrusion. Color and transparency adjustment of the kernels can be influenced by selecting the raw material characteristics amylose/amylopectin ratio and granulation as well as adapting the mechanical and thermal energy input during processing.

Figure 10.13 shows a selection of reconstituted rice kernels produced from raw material of different granulation processed on a Bühler twin-screw extruder with different screw configurations resulting in different specific mechanical energy inputs. In addition to the differences in color, surface properties, and transparency shown here, different shapes can be achieved by exchanging dies. The microstructure of natural and reconstituted kernels differs significantly. Natural rice kernels exhibit a pronounced cellular microstructure with native starch kernels arranged in endosperm cells. In addition, there is a clear gradient in starch–protein distribution between kernel core and surface. Reconstituted kernels, on the other hand, consist of a near-completely gelatinized starch

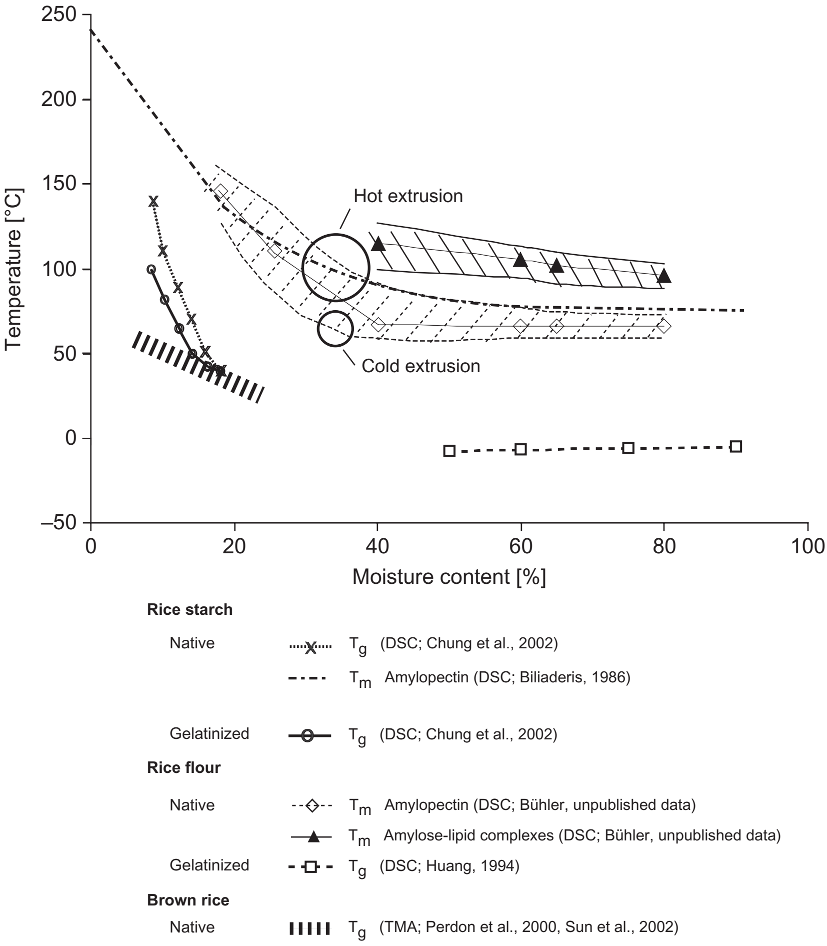

FIGURE 10.12 State of starch during cold and hot extrusion, based on literature data and on measurements undertaken by Bühler. (Biliaderis et al. (1986); Chung et al. (2002); Huang et al. (1994))

matrix throughout the kernel that merely contains some endosperm fragments and protein coagulates (Mueller-Fischer and Conde-Petit, 2009).

5.2 Rice Bran

Nowadays, rice bran is still mostly burnt, a small part added to feed, and an even smaller part used for food. Rice bran is applied in food in its entirety or after partial or full fractionation. Typical fractions of rice bran that are commercially sold are rice bran oil, rice bran solubles, and rice bran protein. In addition, high-value bioactive components like γ-oryzanol can be separated (see section 2.1).

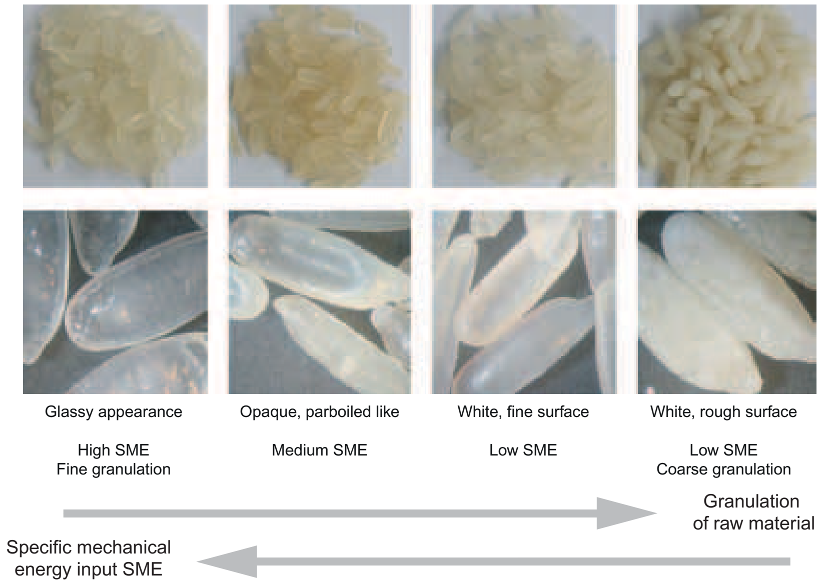

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FIGURE 10.13 Visual appearances of reconstituted rice kernels, varying from translucent and smooth to opaque and rough. All rice kernels were produced on a Bühler twin-screw extruder. Raw material granulation was varied and different screw configurations applied, the latter resulting in different specific mechanical energy (SME) inputs.

Rice bran is a food material which is difficult to handle. It contains about 15–20% of oil (Luh et al., 1991) which is rich in unsaturated fatty acid prone to lipid oxidation. If not properly stabilized, rice bran deteriorates within hours due its very active lipolytic enzyme system from both endogenous and microbial origin. Oxidative rancidity and bran build-up in pipes due to the material's stickiness are additional concerns. Stabilization needs to be done within hours after milling and, to achieve the highest quality rice bran, within 1 hour.

Most industrially available systems for enzyme inactivation apply combined heat and moisture in the form of steam to inactivate both lipase and lipoxygenase (Orthoefer and Eastman, 2004). The most common processes are single- or twin-screw extrusion, where mechanical impact on the protein denaturation plays an additional role. Heat stabilization of this kind is a trade-off between stabilization against enzymatic oxidation on the positive side, losses in vitamins, darkening of bran and oil color as well as initiation of oxidative rancidity on the possible negative side. This can be seen in Figure 10.14 where data for free fatty acid, hexanal, and vitamin E development over time is shown. In addition, oil color of unstabilized rice bran and of hydrothermally stabilized rice bran either treated at atmospheric pressure with no shear or at elevated pressures with shear is also given.

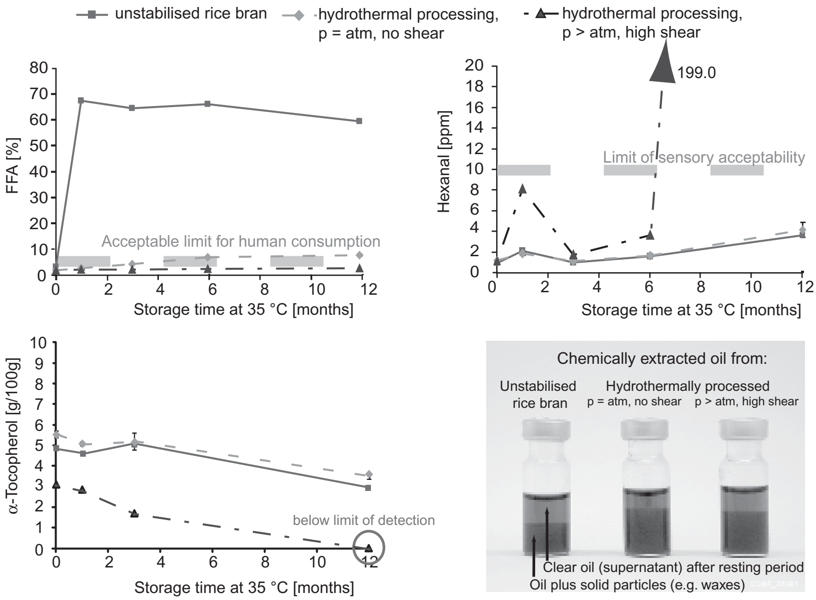

FIGURE 10.14 Development of enzymatic rancidity (free fatty acids, FFA, as indicator), oxidative rancidity (hexanal as indicator), vitamin E content (here represented by α-tocopherol) over the course of one year storage at 35°C. In addition, the color of chemically extracted oil is shown. The performance of unstabilized rice bran is compared with two hydrothermally stabilized rice bran samples: one treated at atmospheric pressure without shear, one at pressures above atm and high shear. All results are based on measurements undertaken by Bühler.

Newer systems under development for rice bran stabilization apply alternative physical as well as biological and chemical principles or a combination thereof (e.g., Ramezanzadeh et al. 2000, Gangadhara and Prakash, 2009). Promising technologies for the future should keep the nutritional quality of the product intact while protecting the lipids against oxidation and should also guarantee food safety with respect to pathogen microorganisms.

Contaminants are an additional issue in rice bran. Similar to other cereals, vegetative microorganism and spore counts are higher in bran than in the endosperm. Mycotoxins, as major biological contaminants with fungal origin, can be present, while the heavy metal arsenic is the most critical contaminant from the chemical side.

Mycotoxins are secondary metabolites of fungal origin. Mycotoxin-producing molds grow if agricultural practices are subpar, climatic conditions adverse, or if grain is not properly dried before storage. Mycotoxins can induce a variety of toxic and carcinogenic effects when contaminated food or feed is ingested (Matić et al., 2008). In the case of rice, aflatoxins are the most frequently reported mycotoxins. Overall, the extent of grain contaminated with mycotoxin is less frequent for rice than for other cereals (Reddy et al., 2008). Various techniques are available for the detection of mycotoxin in commodities at typical levels in the ppb to ppm range, including rapid methods (Goryacheva and Saeger, 2011).

In contrast to mycotoxins, arsenic contamination is not directly dependent on climatic or storage conditions but on geographic origin and agricultural practices. Rice readily takes up arsenic from the soil and irrigation water and deposits the element in the rice grain. Transfer of arsenic from soil to grain is ten times higher in rice than in wheat and barley (Williams et al., 2007a). Speciation and concentration depend on the origin. The major component species of total arsenic in the rice grain is inorganic arsenic in the form of arsenate and arsenite. Inorganic arsenic is a class 1, non-threshold carcinogenic (Meharg et al., 2009). Meharg et al. analyzed 901 polished (white) rice samples originating from 10 countries from 4 continents and found total arsenic contents varying from 0.04 mg/kg to 0.28 mg/kg. Inorganic arsenic levels in white rice can be problematic for population groups that consume most of their daily calories in the form of white rice. This is the case in large parts of Asia where the daily rice consumption lies between 200 and 500 g with extremes going up to 650 g. Assuming daily ingestions of white rice of 200 g, arsenic levels of <0.05 mg/kg are necessary to stay below the WHO limit for water of 0.01 mg/L (Stone, 2008). At 500 g daily consumption, the values should consequently stay below 0.02 mg/kg polished rice (Meharg et al. 2009). Further risk groups are infants and sufferers of Celiac disease (Williams et al., 2007b). Inorganic arsenic levels in commercially purchased as well as freshly milled rice bran are 10–20 fold higher than concentrations found in polished rice (Sun et al., 2008). Future solutions envisage a reduction of arsenic in rice grains by a combination of breeding and adapted agricultural techniques. Until then, the risk of elevated arsenic levels has to be taken into account when developing products from rice bran and its fractions.

6. FUTURE SCENARIOS OF NUTRIENT-FOCUSED RICE PROCESSING

Macro- and micronutrient contents available in brown rice and rice bran have the potential to lessen some of the nutritional deficiencies in “the rice countries”. Therefore, optimized, “nutrient-focused” rice processing could bring about a clear benefit. It should combine the maximization of macro- and micronutrient retention, increase nutrient bioavailability, and eliminate contaminants whilst keeping or enhancing the sensory experience.

Some established processes like parboiling and germination have a long tradition in parts of Asia. These processes take us in the right direction in the sense that they lead to an improved nutritional value of rice. Germination (also called “sprouting”) is an interesting natural approach to improve the intrinsic nutritional value of brown rice. The germination process consists of soaking the grains in water, draining the water and letting the grain germinate until the sprout (also called "germ") emerges and grows. The term partial or pre-germination indicates that germination is stopped as soon as the nutritive value is enhanced but before the sprout is fully developed. Subsequent gentle drying makes the product stable for storage but does not affect the nutritional quality. Germinated grains are nutritionally superior to their respective "non-germinated" grains, i.e., they contain higher levels of nutrients (such as vitamins), lower levels of antinutrients (such as phytic acid), contain more easily digestible protein and starch, and have better bioavailable minerals. Studies focusing on the effects of germination on the nutrient content of rice are available (Kayahara and Tsukahara, 2000; Kayahara, 2001; Kayahara et al., 2001; Moongngarm and Saetung, 2010). Quantitative results vary depending on differences in soaking, germination, and drying procedures as well as on rice varieties used. The amount of lysine, an essential amino acid that rice is deficient in, is significantly increased. Enhanced levels of the vitamins E, B1, B3, and B6 and of the minerals magnesium, potassium, and zinc were found as well, while antinutritive factors like phytic acid are lowered. Of special interest are the elevated levels of the bioactive ingredients γ-oryzanol and γ-aminobutyric acid (GABA). In comparison with untreated brown rice, the sensory properties are positively affected. Untreated brown rice is often not desired by consumers due to its hard and chewy texture. Germinated rice requires less cooking time and is sweeter, more mellow, and softer than cooked regular brown rice (Jiamyangyuen and Ooraikul, 2008; Patil and Kahn, 2011). The study of the effect of partial germination seems to be mostly limited to brown rice. Only one source reports increases in α-tocopherol and tocopherol of 13% in germinated white rice (Chattopadhyay and Baneriee, 1952).

In response to the growing market interest in intrinsically fortified products both in the form of whole grains and as ingredients for innovative formulations, industrial solutions based on the principle of germination have been developed. Bühler's "pargem®" is an example of an innovative process and technology for controlled partial or full germination of cereals, pulses, and other grains.

While partial germination can not yet fulfill the ambitious goal of combining all the goodness of brown rice with the pleasure of eating white rice, it is nevertheless a step in the right direction. A step from which we can learn and upon which we can build on our path towards nutrient-focused rice processing.

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