Chapter 6
Chemical and Nutritional Properties of Brown Rice

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Introduction

Rice, one of the oldest food crops, is the staple food for about half of the world population. The annual world production of paddy (rough rice) is about 740 MT at present (Anon 2016). Most of the rice is produced in the Asian countries mainly in China, India, Indonesia, Vietnam, Thailand, Bangladesh, etc. Rice is a good source of easily digestible starch and good quality protein due to the presence of high content of lysine compared to other cereal grains. Rice, in its whole form, is a good source of vitamins like thiamine and niacin and minerals like iron, phosphorus, and magnesium (Juliano 1985). However, table rice is usually eaten as its milled form, where the husk as well as the bran is removed during milling. Thus, the concept of brown rice has emerged; it can be described as the dehusked or dehulled whole grain rice with its bran and germ. Since it contains the bran and germ layers, it is believed to be nutritionally superior to milled rice; it is the only form of grain which contains vitamin E and offers a cholesterol-lowering effect. Brown rice has a mild nutty flavor but exhibits fat-degraded rancid flavor because of the presence of bran and germ. In some countries, the milled rice is fortified with thiamine, niacin, and essential minerals to enrich the grain. However, in many countries where rice constitutes the main diet, enrichment is not the common practice. A diet containing brown rice diet is better than that of milled rice considering nutritional status. The photographs of paddy (rough rice), brown rice, and milled (polished) rice are shown in Fig. 6.1. The brown rice has a dull brown or light yellow color compared to corresponding polished rice.

Thus, there is an increasing inclination of consuming brown rice although white rice is the most popular form among the rice eaters throughout the world. Brown

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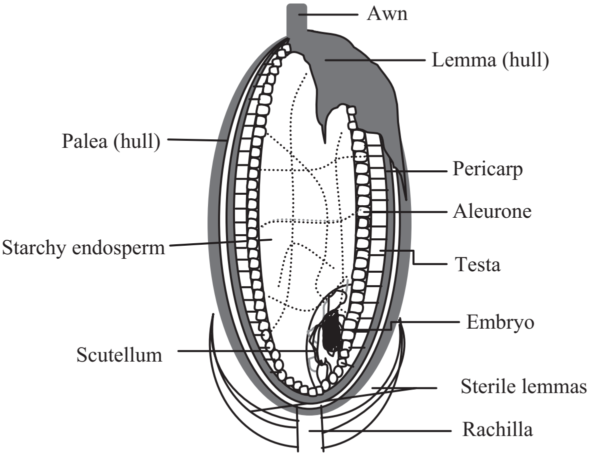
A. Manickavasagan et al. (eds.), *Brown Rice*,
DOI 10.1007/978-3-319-59011-0_6

Fig. 6.1 Photographs of (**a**) paddy, (**b**) brown rice, and (**c**) milled rice

Fig. 6.2 Cross-sectional view of rice kernel



rice has a shelf life of about 6 months at the ambient condition but can be extended further by hermetic storage or by refrigeration. Some of the brown rice-based products have been developed recently and possess a good scope for commercial exploitation. These products include expanded brown rice, popped rice, brown rice flakes, brown rice chips, brown rice vermicelli, brown rice noodles, brown rice instant semolina, etc.

Structure and Milling Quality of Rice

Whole rice grain with its husk, bran, and endosperm is called rough rice or paddy. Rice is covered by inedible two thick glumes known as lemma and palea which are removed by shelling. Two glumes are joined by interlocking. The typical structure of rice is shown in Fig. 6.2. The firm interlocking of lemma and palea gives a good

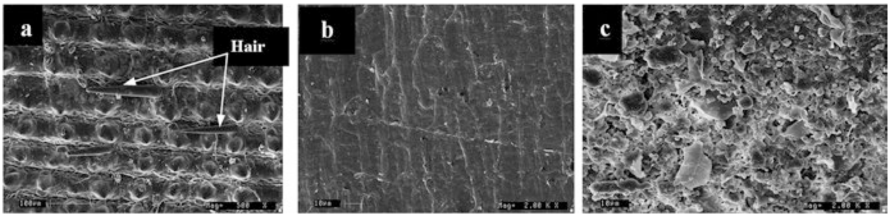


Fig. 6.3 Photomicrographs of the outer surface of (**a**) paddy, (**b**) brown rice, and (**c**) milled rice at magnifications of 500×, 2000×, and 2000×, respectively

storage life and puffing characteristics in the paddy but makes the shelling process difficult and tricky. Moreover, the presence of minute hairs (Fig. 6.3a) on the rough surface glume causes more wear and tear of machinery employed for polishing/shelling. During the grain development stages, due to the pressure of husk, the longitudinal grooves and ridges (Fig. 6.3b) are formed on the surface of the brown rice. Varieties having deep grooves require more extent of polishing and thus offer higher nutritional losses. Hence, milling quality is markedly influenced by the structure of the grain. Dehusked whole grain, called brown rice, is covered by the caryopsis coat consisting of pericarp, seed coat or testa, and aleurone layer. Milled rice endosperm is composed of starch, protein, and fat (Fig. 6.3c).

The embryo or germ is located on the ventral side of the caryopsis and is attached to the endosperm portion by the scutellum. The inedible husk contributes 18–28% of the rough rice, and the remaining 72–82% is brown rice. Brown rice constitutes about 1–2% pericarp, 2–3% aleurone, 4–6% seed coat, and 2–3% germ, and the remaining is the endosperm. The cell walls of the pericarp are 2 μm in thickness and contain protein, hemicellulose, and cellulose (Juliano 1972). Next to pericarp, there exists a layer of seed coat or tegmen. Beneath the tegmen, the aleurone layer of a thickness of about 2 μm encloses the endosperm and the embryo. The aleurone layer is composed of protein, cellulose, and hemicellulose. The embryo is present on the outer side of the aleurone layer. For obtaining brown rice from rough rice, two rubber rolls with a rubber belt operating against a ribbed steel roll can be used for effective milling. The abrasive hulls damage the rubber rolls and thus frequent replacement of them is necessary. Since rubber rolls are less bruising on the surface of the brown rice, the produced brown rice is more stable to lipase attack.

Influencing Factor for Composition

Environmental factors such as wider spacing of plants during cultivation, the use of high nitrogen-containing fertilizer, and ambient temperature during the growth of plants and ripening increase the protein and ash contents of brown rice but possess a nonsignificant effect on the fat content of the rice kernel. Protein content tends to increase with the short growth duration of plant and due to cloudy weather during grain development (Liu et al. 2014). Stresses such as drought condition, salinity, and alkalinity of water and soil; higher or lower temperature of environment; occurrence of diseases; and attack by pests increase the protein content of rice grain but decrease the starch content. The contents of total nitrogen and minerals (such as calcium, copper, and molybdenum) and the total chlorine content of soil also affect the protein content of the rice grain. Environmental conditions thus affect the rate of starch and protein deposition during grain development. An increase in protein content reduces the starch content in the grain. An increase in the duration of plant growth also decreases the protein content of brown rice. The mineral content of the grain is obviously affected by the mineral content of the soil as well as water used for irrigation. Sulfur deficiency in the soil reduces grain yield without having any adverse effect on the cysteine and methionine contents of the rice protein.

Nutritional Composition of Rice

Nutritional composition of rice is highly varietal as well as environmental dependent. The same variety of rice may show variations in the composition due to different climatic and soil conditions. The proximate composition (as dry basis) of brown rice indicates that it contains 2.4–3.9% fat, 1.5–2.1% ash, 0.8–2.6% fiber, and 7.3–15.4% protein (N × 5.95); the energy content is 1520–1610 kJ/100 g, while the bulk density is 676–683 kg/m^3 (Juliano et al. 1964; Matz 2014). Carbohydrate or starch is distributed mostly in the endosperm cells of brown rice. The linear fraction of the starch (called amylose) constitutes 8–37% of its starch content in non-waxy rice, whereas the branched fraction (called amylopectin) is the major fraction of starch in the waxy type (glutinous) of rice. Rice starch shows the characteristic A-type X-ray diffraction pattern of cereal starches and has a similar granule size and gelatinization temperature (Wani et al. 2012). Gelatinization temperature is a range of temperature when starch granules start to swell in hot water and lose its birefringence. Gelatinization temperature may vary from 55°C to 80°C depending on the variety and environmental conditions such as the differences in the temperature during the development of the grain. Differences in the cooking time of rice also may be observed due to the differences in gelatinization temperature.

The superior protein quality of rice compared to other cereals is due to the presence of high content of the limiting amino acid such as lysine. Further, the major rice protein fraction is called glutelin which is soluble in dilute acid or alkali. Since the contents of protein and amino acid vary in different fractions of the grain, there is a considerable variation in the total protein content as well as the amino acid sequence of the milled fractions of the brown rice. Further, a high degree of milling adversely affects the nutritive value of the milled rice. The process of milling removes the pericarp, seed coat, aleurone layer, and embryo to yield milled rice. Hence, there is a loss in the contents of fat, protein, fiber, minerals, thiamine, riboflavin, niacin, and α-tocopherol. However, the high content of phytic acid and dietary fiber present in the bran layers hinders the bioavailability of the minerals in the brown rice.

Carbohydrate

Carbohydrate is the major component of any cereal grain. The bran layers of brown rice contain the maximum content of hemicellulose (about 1.4–2.1% pentosans) of which 43% is distributed in the bran layers and 8% in germ (Juliano et al. 1964). The water-soluble hemicelluloses of bran have an arabinose/xylose ratio of 1.8. The bran layer also contains some galactose and protein, whereas alkali-soluble hemicelluloses contain about 37% arabinose, 34% xylose, and 11% galactose with a trace amount of glucose along with protein and uronic acid. Brown rice also contains a high amount of cellulose (about 62% in the bran) due to the presence of seed coat, aleurone layer, and thick pericarp cell walls. Starch is the major constituent of rice. The amylopectin constitutes 25–50% by number and 30–60% by weight of amylose. The iodine affinity of amylose from rice is 20–21% by weight, while for amylopectin it is 0.4–0.9% in low- and intermediate-amylose rice, whereas it is 2–3% in high-amylose rice. Based on the starch-iodine color absorption, rice is classified as waxy (1–2%), very low-amylose (2–12%), low-amylose (12–20%), intermediate-amylose (20–25%), and high-amylose (25–33%) rice. The waxy endosperm is opaque due to the presence of air spaces among the starch granules, which have a lower density than the non-waxy granules. Viscoamylograph characteristics of waxy and non-waxy rice flour show that waxy rice has the lower peak viscosity than the non-waxy rice flour possibly due to the presence of non-starch constituents, mainly water-insoluble rice proteins in waxy rice which hinder the swelling of the starch granules. Common rice starch has an amylose/amylopectin ratio of about 20:80 (Xie et al. 2008). These varieties have small granule sizes in the range of 3–8 μm; irregularly shaped polygons are present in the waxy rice to exhibit compound granules (Hegenbart 1996). Non-starch polysaccharides consist of water-soluble polysaccharides and insoluble dietary fiber (Juliano 1985) which form complexes with starch and may have a hypocholesterolemic effect.

In brown rice, the total free sugars present are about 0.8–1.4% of which 0.1–0.13% are the reducing sugars mainly as glucose and a trace amount of fructose. Brown rice contains about 0.2% of phytin or myoinositol hexaphosphate, an important constituent of the bran layers. Ribonucleic acid is the main nucleic acid in brown rice and constitutes about 0.2–0.3% of the rice and 2–3% of brown rice protein; deoxyribonucleic acid constitutes about 0.01% of brown rice (Juliano et al. 1964).

Protein

Brown rice contains about 8–15% (dry weight basis) protein of which 14% is distributed in bran and about 80% in the endosperm. There are discrepancies of the reported amino acid content due to the differences in the methodological conditions followed by the researchers. A wide range of reported lysine content values is also noticed indicating the existence of high lysine varieties. The bran and germ fractions in the brown rice contain higher levels of lysine and lower levels of glutamic acid than the starchy endosperm. Both waxy and non-waxy rice have the similar pattern of amino acid distribution. The brown rice and milled rice have the same pattern of amino acid content for most of the cases; however, some amino acids particularly the lysine content vary negatively and tyrosine and phenylalanine contents positively with the total protein content of the brown rice sample. Protein solubility fractions are unevenly distributed in brown rice and milled rice fractions. Rice protein is mainly alkali-soluble protein glutelin (78–79%), salt-soluble globulin (10–11%), and water-soluble albumin (7–8%), and the alcohol-soluble fraction is the least (3%). Albumin and globulin contents are higher in brown rice than milled rice as they are more concentrated in the germ and aleurone layers. The proportion of albumin and globulin in protein is high at the periphery of the kernel but gradually decreases toward the center, whereas glutelin content is distributed inversely. Albumin distribution is 51% in bran, whereas globulin distribution is 40% in bran. Globulin is composed of 43% glutamic acid and arginine, 4–9% cysteine, and 6.6% methionine. Prolamin can be extracted by 70% ethanol followed by acetone precipitation from ethanolic extraction. Prolamin distribution is about 21% in bran, whereas glutelin distribution is only 5% in bran. Glutelin has the highest molecular weight among the rice protein fractions. Aspartic and glutamic acids are the major amino acids present in glutelin. The soluble protein fractions vary with an increase in protein content; glutelin and prolamin contents also increase. Protein bodies of rice are composed of about 60% protein, 10–28% lipid, and 12–29% carbohydrates along with a small amount of ash, ribonucleic acid, phospholipid, phytic acid, and niacin (Tanaka et al. 1980).

Amino acid compositions of brown rice, reported as g/16 g of N (mentioned by Anon (1969) and cited by Juliano (1972)), are alanine, 5.5–6.5; arginine, 7.9–9.5; aspartic acid, 9.0–10.5; cysteine, 1.2–2.1; glutamic acid, 16.9–19.9; glycine, 4.5–5.4; histidine, 2.1–2.9; isoleucine, 4.1–4.8; leucine, 7.9–8.9; lysine, 3.5–4.6; methionine, 1.9–2.9; phenylalanine, 5.3–6.0; proline, 4.4–5.5; serine, 4.6–5.9; threonine, 3.6–4.4; tryptophan, 0.9–1.6; tyrosine, 4.4–5.4; and valine, 5.9–7.0. Free amino acids constitute about 0.7% by weight of brown rice protein of which the major free amino acids are aspartic and glutamic acids. Amino acid composition of the four protein fractions of brown rice reveals that albumin has the highest lysine content followed by glutelin, globulin, and prolamin. If the albumin content is higher, the higher is the lysine and the lower is the glutamic acid content which reflects the better protein quality in germ and bran in rice. Among the cereal proteins, rice protein offers the best nutritional status due to its high lysine content, although lysine is still the limiting amino acid followed by threonine. It is observed that there is a further increase in the nitrogen balance of the food for children if rice is fortified with methionine, threonine, and tryptophan instead of lysine alone. For brown rice, a wide range of protein efficiency ratio (PER) has been reported because of the differences of the experimental conditions employed; the reported PER values are between 1.73 and 1.93, and biological values are 67–89 (Juliano 1972). Improved nutritional status is noticed for high protein rice samples containing higher levels of all essential amino acids; this fact encourages the breeders to provide more effort on the breeding of high protein containing rice varieties rather than on improving their protein quality.

Vitamins and Minerals

Brown rice is rich in vitamins like thiamine (0.29–0.61), riboflavin (0.04–0.14), niacin (3.5–5.3), and tocopherol (0.90–2.50) and minerals like calcium (10–50), phosphorus (170–430), iron (0.2–5.2), and zinc (0.6–2.8); values are shown here as mg/100 g of flour (Juliano 1985; Pedersen and Eggum 1983). Vitamins are mostly concentrated in the aleurone layers of the brown rice. The overall composition of rice is not affected by storage, but vitamin content decreases progressively. Juliano (1972) has indicated that brown rice is an important source of thiamine and niacin and also tocopherol which is about 0.9–2.3 mg/100 g of brown rice. Since the B vitamins are more concentrated in the bran layer, the major nutritional advantage of brown rice over milled rice is its high content of vitamin B. About 50% of the total thiamine is in the scutellum portion of the grain, and 80–85% of the niacin is present in the pericarp and aleurone layers; the embryo accounts for more than 95% of total tocopherols. The thiamine of brown rice is mostly concentrated in the bran (65%), and 22% is present in the milled rice fraction (Juliano and Bechtel 1985). About 39% riboflavin and 54% niacin are present in the bran, respectively. The minerals are also concentrated mostly in the outer layers of brown rice. A major portion (90%) of the phosphorus in bran is phytin phosphorus. Studies on the same subjects have shown lower apparent absorption rates for sodium, potassium, and phosphorus; a lower phosphorus balance has been reported for the brown rice diet when the protein intake is low (Miyoshi et al. 1987). In case of a standard protein intake, even if the potassium, phosphorus, calcium, and magnesium levels are higher in the brown rice diet, the absorption rates of potassium and phosphorus are significantly lower for the brown rice diet (Miyoshi et al. 1987). The important factor is the high phytate level in the bran fraction (aleurone and germ). Pigmented brown rice shows higher riboflavin but similar thiamine contents compared to nonpigmented IR rice (Deepa et al. 2008). The selenium content of brown rice, grown in Japan, is reported to be 30–40 mg/g (Miller and Engel 2006); 13% Se is present in the hull, 15% in bran, and 72% in rice kernel.

Lipid

In brown rice, 80% of lipid is present in the aleurone layer and bran, specifically as lipid bodies or spherosomes. The lipid characteristics for brown rice, bran, and germ are similar. The unsaponifiable matter of bran oil is composed of 42% sterols, 24% higher alcohols, 20% ferulic acid, and 10% hydrocarbons (Juliano 1972). Oryzanol, a ferulate ester of unsaturated triterpenoid alcohols, is a potent antioxidant present in the bran oil at a level of 0.96–2.89%. Brown rice also contains another potent antioxidant called tocopherols at 5% level of which 47% is the principal tocopherol, i.e., α-tocopherol which is present at a level of 0.005–0.015% of the brown rice lipids. Other two tocopherols, such as β-tocopherol and γ-tocopherol, are present at about 26% levels. The wax content of rice bran oil is 3–9%. Brown rice contains significantly higher levels of linoleic, palmitic, and oleic acids but has lower contents of myristic, palmitic, palmitoleic, and stearic acids compared to the milled rice. About 43% oleic, 28% palmitic, and 25% linoleic acids (Herting and Drury 1969) are the major fatty acid components in brown rice and are concentrated mostly in the bran and germ portions of the grain. Free fatty acids and mono- and diglycerides mainly comprise palmitic, oleic, and linoleic acids. Waxy and non-waxy rice have a similar fatty acid composition.

Anti-nutritional Factors

Rice contains the least amount of anti-nutritional and allergenic substances among all other cereals. Rice is the best among the cereals in most of the aspects of nutritional point of view, though the bran layer in rice contains some anti-nutritional factors like phytates, trypsin inhibitor, oryza cystatin, hemagglutinin-lectin, etc. which are mostly concentrated in the embryo and aleurone layer (Juliano 1985). These are protein in nature and except phytate, others can be denatured by heat treatment. Phytin phosphates readily form a complex with the essential minerals like Fe, Ca, and Zn and also with protein and make these minerals unavailable to the system (Miyoshi et al. 1987). Phytates can be inactivated by soaking and cooking of brown rice; the cooking process also inactivates the hemagglutinin-lectin and trypsin inhibitors. Wet heat treatment is more effective to inactivate trypsin inhibitor than the dry heat treatment of the embryo. Hemagglutinin-lectins can bind the specific carbohydrate receptor sites in the intestinal mucosal cells and thus interfere the nutrient absorption across the intestinal wall. Inhibitors and lectins are mostly located in the embryo. Oryzacystatin is another protease inhibitor present in brown rice but decreases its activity when subjected to a high temperature (45% at 120°C). Oryzacystatin can effectively inhibit cysteine proteinases such as ficin, papain, chymopapain, and cathepsin C but hardly affects the serine proteinases (subtilisin, trypsin, and chymotrypsin) or carboxyl proteinase (pepsin).

Digestibility Characteristics

Starch digestibility of brown rice is significantly lower than of milled white rice (Juliano 1972). It indicates that the rate at which brown rice starch is digested and the appearance of glucose in blood are also significantly lower compared to milled rice sample. Insulin response of cooked brown rice is much lower than cooked milled rice which has 70–90% starch digestibility (Miller et al. 1992). Brown rice shows approximately the same protein digestibility as that of milled rice in their cooked form (Bradbury et al. 1984). A slightly lower true digestibility for the brown rice protein is observed in rats compared to milled rice. On the other hand, both rice show similar biological value (BV, a measure of the proportion of absorbed protein from the food) and net protein utilization (NPU, the ratio of amino acid converted to proteins to the ratio of supplied amino acids) (Eggum et al. 1982). Brown rice has a true nitrogen digestibility of 99.7% and biological value of about 74%, and net protein utilization is 96.3% (Eggum 1979).

Stabilization

In spite of nutritional advantages, consumption of brown rice is limited. A short shelf life of only 3–6 months of brown rice is one of the major causes restricting its mass consumption. Fat-degraded off-flavors and off-odors have limited the commercial production and consumption of it. During dehusking, the outer bran layer of rice gets damaged and thus gets exposed to hydrolytic and oxidative deterioration, leading to the hydrolysis of the oil in rice. Hence, for stabilizing brown rice, three approaches are conventionally followed such as (1) inactivation and denaturation of lipases present in rice kernel by heat treatment, (2) free oil removal by employing an organic solvent, and (3) inactivation and denaturation of lipase and lipase-producing bacteria and mold by ethanol extraction. However, the oxidative degradation is rather difficult to prevent completely. However, by maintaining a low oxygen level (below 1%) in the packaging system, storing of brown rice at a low temperature can reduce oxidative rancidity. Storage in a dark environment under modified atmospheres or under vacuum can also control it but cannot completely prevent oxidative changes.

Constraint

Although brown rice is believed to be nutritionally superior, it has been recently challenged due to concerns over arsenic levels. Brown rice has been reported to possess about 80% more inorganic arsenic on average than that of white rice of the same type. Rice readily absorbs more arsenic than many other plants. If consumed over time, the presence of arsenic may lead to cancer and skin lesions. Researchers now are in a hope to obtain rice plants that express increased levels of *Oryza sativa* C-type ATP-binding cassette (ABC) transporter (OsABCC) family, OsABCC1, or to genetically engineer a rice sample to overexpress the transporter. This approach may solve the problem of arsenic contamination of rice and the rice-based products in a cost-effective manner (Song et al. 2014). Some semi-dwarf *indica* rice in Japan has shown a high cadmium level; major causes of epidemic of "itai-itai" disease in Japan are due to the high cadmium content in rice (Kasuya et al. 1992).

Trends in Brown Rice Research

Though brown rice is an old concept emphasizing a nutritious product, there have been a few recent researches that focus on the nutritious status of brown rice (Table 6.1). Anthocyanin content in different colored rice has been identified and quantified to evaluate its potential application as the functional food ingredients (Abdel-Aal et al. 2006). The total anthocyanin pigment content varies widely. However, red and black rice contain a few pigments of which the most abundant anthocyanin is cyanidin 3-glucoside in black and red rice.

Colored rice cultivars show stronger antioxidant activities and free-radical scavenging activities than that of white (polished) rice. The antioxidant properties are mainly due to the presence of phenolic compounds other than anthocyanin pigments. The antioxidant capacity results mainly from the outer seed coat, and not from the endosperm (Chen et al. 2012). This phenomenon may help the future breeding researchers to have a beneficial effect on rice milling process with distinct desirable colors of brown rice.

Massaretto et al. (2011) have investigated the inhibitory effect of phenolic compounds on the activity of angiotensin I-converting enzyme (ACE); the effect of cooking on phenolics and their inhibitory activities for several pigmented and nonpigmented rice varieties is also studied. Pigmented rice shows significantly higher inhibitory effect than that of nonpigmented rice on ACE. Further, cooking significantly reduces the content of total phenolics and ACE inhibition.

Investigations of the antioxidant activity and the lipophilic and hydrophilic components of total phenolic contents for some cereal grains from China reveal that these cereals possess diverse antioxidant capacities. Phenolic compounds such as gallic acid, kaempferol, quercetin, galangin, and cyanidin 3-glucoside are widely found in those cereals (Deng et al. 2012). Further, it has been claimed that the pigmented or colored cereals, such as black rice, red rice, and purple rice, can be important sources of natural antioxidants for health promotion and reduction in disease risk as they possess the highest antioxidant capacities and total phenolic contents among other cereals.

Finocchiaro et al. (2007) have investigated on the total antioxidant capacities and chemical constituents of the antioxidants for dehulled red rice and dehulled white rice. Dehulled red rice possesses three times more antioxidant capacity than dehulled white rice, and the antioxidants present are the proanthocyanidins and phenolic compounds. During milling of red rice, bran gets removed causing a significant loss of antioxidants. Further, during the cooking, additional loss of antioxidants occurs, although cooking in limited water can minimize the loss to a small extent. Thus, from a nutritional point of view, cooking of brown rice or partially milled rice in limited water is a preferred choice for consumption.

Table 6.1 Studies on the composition and nutritional status of brown rice

Area of research	Important finding	References
Aroma compounds in four varieties of cooked brown rice employing aroma extract dilution analyses (AEDA)	Forty one odor-active compounds have been found of which three major aroma compounds like 2-amino acetophenone, 2-acetyl-1-pyrroline, and 3-hydroxy-4,5-dimethyl-2(5H)-furanone are the prominent flavor components	Jezussek et al. (2002)
Extraction of soluble and insoluble phenolic compounds from white rice, brown rice, and germinated brown rice	Phenolic compounds are present in higher quantities in brown rice or germinated brown rice compared to that of white rice. Ferulic acid content increases to one-and-half times, and sinapinic acid content increases to ten times in germinated brown rice compared to that of non-germinated brown rice	Tian et al. (2004)
Nutraceutical qualities of the fat-soluble nutraceuticals such as oryzanol, tocopherols, and tocotrienols contents of three varieties of brown rice and their corresponding milled rice	Highest tocopherol and tocotrienol contents are observed in the parboiled brown rice of *Basmati* variety. The higher amount of saturated fatty acids is in the milled rice oil than that of brown rice. The total lipid content is about four times higher in brown rice compared to that of the milled rice	Khatoon and Gopalakrishna (2004)
Identification and quantification of anthocyanin contents in different colored rice	Red and black rice contain a few pigments of which the most abundant anthocyanin is cyanidin 3-glucoside	Abdel-Aal et al. (2006)
Effect of nutraceutical lipid content during milling of brown rice	An increase in the degree of milling of brown rice significantly decreases the lipid content and also a simultaneous decrease in tocopherols. An increase in the degree of milling of brown rice markedly decreases the concentrations of γ-oryzanol, squalene, and octacosanol	Ha et al. (2006)
Content of γ-oryzanol and steryl ferulates of 30 different varieties of brown rice samples of European origin	Cycloartenyl ferulate and 24-methylenecycloartanyl ferulate are the major components of the γ-oryzanol	Miller and Engel (2006)
Dehulled red and white rice analyzed for their total antioxidant capacities and chemical constituents of the antioxidants	Dehulled red rice possesses three times more antioxidant capacity than dehulled white rice, and the contributed antioxidants are due to the proanthocyanidins and phenolic compounds	Finocchiaro et al. (2007)

(continued)

Table 6.1 (continued)

Area of research	Important finding	References
Fat-soluble phytochemicals such as tocotrienols and γ-oryzanol in 32 rice genotypes including the subspecies of *japonica* and *indica* varieties	A significant variation in the contents of vitamin E isomers and the γ-oryzanol in the rice genotypes have been observed. The α-tocopherol, α-tocotrienol, and γ-tocotrienol are the most abundant compounds present in *japonica* rice, while γ-tocotrienol, α-tocopherol, and α-tocotrienol are in *indica* rice	Heinemann et al. (2008)
Investigation on the inhibitory and cooking effects of phenolic compounds for several pigmented and nonpigmented rice varieties	Pigmented rice shows significantly higher inhibitory effect than that of nonpigmented rice on angiotensin I-converting enzyme (ACE)	Massaretto et al. (2011)
Determination of the contents of γ-oryzanol, total phenolics, individual phenolic acid profile, and the antioxidant activity of different rice milling fractions	About 94% of γ-oryzanol content is reduced in milled rice compared to the brown rice sample	Tuncel and Yilmaz (2011)
Investigation on the antioxidant properties of colored rice cultivars	Colored rice cultivars exhibit stronger antioxidant activities and free-radical scavenging activities than that of white rice	Chen et al. (2012)
Investigation of the antioxidant activity and the lipophilic and hydrophilic components of total phenolic contents for some cereal grains from China	These cereals possess diverse antioxidant capacities. Phenolic compounds such as gallic acid, kaempferol, quercetin, galangin, and cyanidin 3-glucoside are widely found in those cereals. Black, red, and purple rice can be the important sources of natural antioxidants	Deng et al. (2012)
Investigation of several *indica* and *japonica* rice varieties for their composition and distribution of vitamin E	The contents of vitamin E and total tocopherol are much higher in *japonica* rice than in *indica* rice. The γ-tocotrienol is the most abundant component in *indica* rice, while α-tocopherol is the major component in the *japonica* rice	Zhang et al. (2012)
Investigation on traditional red and brown rice for their antioxidant properties and phenolic contents	Proanthocyanidin-containing traditional red rice possesses markedly higher antioxidant properties and phenolic contents than light brown rice varieties	Gunaratne et al. (2013)
Study on the nutritional status of rice having red- or purple-colored bran	The presence of the intact bran layer of whole grain rice or brown rice makes it nutrient dense	Bett-Garber et al. (2013)

(continued)

Table 6.1 (continued)

Area of research	Important finding	References
Investigation on the effects of parboiling, storage, and cooking of brown rice on their biological activities	The γ-tocotrienol is the major constituent of the total tocols, whereas α-tocopherol, α-tocotrienol, and γ-tocopherol are present in small quantities. The parboiled rice, after 6 months of storage followed by cooking, shows about 90% losses of tocopherols	Pascual et al. (2013)
Effect of the anti-colitis effects of brown rice and identification of the anti-oxidative and inhibitory effects	The inhibitory effects of pro-inflammatory cytokines, myeloperoxidase activity, neutrophil infiltration in the colonic mucosa, and activation of nuclear factor kappa B for brown rice are determined because these are the major factors responsible for anti-colitis effects	Shizuma (2014)

Proanthocyanidin-containing traditional red rice (Sri Lankan variety) has been shown to possess over sevenfold higher antioxidant properties and phenolic contents than that of light brown rice varieties. Further, it is observed that these traditional red varieties also contain a significant amount of protein, well-balanced amino acids, and a higher content of fat, fiber, and vitamin E compared to the new types (Gunaratne et al. 2013).

The cooking quality of aromatic pigmented and nonpigmented rice on the physical and physicochemical properties, color, and viscosity profile and the effect of cooking on phytochemical contents and antioxidant capacities have been investigated by Saikia et al. (2012); these examined samples have different sizes and shapes. Pigmented varieties contain the highest amount of total phenolics, total flavonoids, and antioxidant properties. A drastic reduction has been reported for all these contents and also their antioxidant properties due to cooking.

Zhang et al. (2012) have investigated several *indica* and *japonica* rice varieties for their composition and the distribution of vitamin E in the rice kernel. The content of tocopherols or tocotrienols in brown rice of these varieties has been determined using a reverse phase HPLC method. Results reveal that the contents of vitamin E between these two types differ significantly; the contents of vitamin E and total tocopherol are much higher in *japonica* rice than in *indica* rice. The γ-tocotrienol is the most abundant component in *indica* rice, while α-tocopherol is the major component in the *japonica* rice.

Shizuma (2014) has investigated the anti-colitis effects of brown rice by employing experimental colitis model and identified the anti-oxidative and inhibitory effects of pro-inflammatory cytokines, myeloperoxidase activity, neutrophil infiltration in the colonic mucosa and activation of nuclear factor kappa B; these are the major factors responsible for anti-colitis effects. In addition, dysbiosis may have some relation to the anti-colitis effects.

Pascual et al. (2013) have studied the effects of parboiling, storage, and cooking of brown rice on their biological activities especially hypocholesterolemic, antiinflammatory, and antioxidant activities. The γ-tocotrienol is the major constituents (~75%) of the total tocols, whereas α-tocopherol, α-tocotrienol, and γ-tocopherol are present in small quantities. The parboiled rice, after 6 months of storage followed by cooking, shows about 90% losses in tocopherols. However, parboiled rice, after 6 months of storage, shows about 60% retention of γ-oryzanol, which is stable after cooking.

Tian et al. (2004) have extracted the soluble and insoluble phenolic compounds from white rice, brown rice, and germinated brown rice; it is concluded that all these phenolic compounds are present in higher quantities in brown rice or germinated brown rice compared to that of white rice. However, in all these cases, the insoluble phenolic content is significantly higher compared to the soluble phenolic compounds. Ferulic acid content increases to one-and-half times, and sinapinic acid content increases to ten times in germinated brown rice compared to that of nongerminated brown rice samples. Hence, these researchers have suggested that brown rice consumption is a good practice, but germinated brown rice may offer even higher health benefits.

Tiwari and Cummins (2009) have reviewed the importance of tocopherols in human health and nutrition that are mostly concentrated in the germ and bran fractions in the grains. The content of tocopherols in a product depends on the unit operations employed during food processing including the milling steps. Hence, the by-products obtained from milling operations may be incorporated in different formulations to develop nutritious brown rice-based functional foods.

Nutraceutical qualities of the fat-soluble nutraceuticals such as oryzanol, tocopherols, and tocotrienols contents of three varieties of brown rice and their corresponding milled rice have been investigated by Khatoon and Gopalakrishna (2004). The total lipid content is about four times higher in brown rice compared to that of the milled rice. However, the parboiling process reduces the tocopherol and tocotrienol contents significantly, while oryzanol content is not affected. Highest tocopherol and tocotrienol contents are observed in the parboiled brown rice of *Basmati* variety. The higher amount of saturated fatty acids is present in the milled rice oil than that of brown rice. The cause of lowering of the ratio of saturated to monounsaturated fatty acid in milled rice may be due to the change in the fatty acid composition of the brown and milled rice.

Ha et al. (2006) have studied the effect of nutraceutical lipid content during milling of brown rice. An increase in the degree of milling of brown rice significantly decreases the lipid content accompanied by a simultaneous decrease in the content of tocopherols. An increase in the degree of milling of brown rice markedly decreases the concentrations of γ-oryzanol, squalene, and octacosanol in the milled rice.

The content of γ-oryzanol and steryl ferulates of 30 different varieties of brown rice samples of European origin has been analyzed for their composition (Miller and Engel 2006). Cycloartenyl ferulate and 24-methylenecycloartanyl ferulate are the major components of the γ-oryzanol. The content of γ-oryzanol ranges from 26 to 63 mg/100 g of the brown rice sample. The environmental conditions influence the variation in the γ-oryzanol content and steryl ferulates composition. However, the degree of maturity of the grains does not affect these components.

Tuncel and Yilmaz (2011) have determined the γ-oryzanol content and total phenolics, individual phenolic acid profile, and the antioxidant activity of the free and bound extracts of the different rice milling fractions. About 94% reduction in γ-oryzanol content occurs in the milled rice compared to the brown rice. It is worth mentioning here that the rice bran fraction is a rich source of γ-oryzanol, phenolics and antioxidants.

Heinemann et al. (2008) have analyzed the fat-soluble phytochemicals such as tocotrienols and γ-oryzanol in 32 rice genotypes including the subspecies of *japonica* and *indica*. A significant variation in the contents of vitamin E isomers and the γ-oryzanol in the rice genotypes has been observed. The α-tocopherol, α-tocotrienol, and γ-tocotrienol are the most abundant compounds present in *japonica* rice, while γ-tocotrienol, α-tocopherol, and α-tocotrienol are in *indica* rice. Total vitamin E content in *japonica* is reported to be about 24 mg/kg which is significantly higher than that of *indica* rice (about 17 mg/kg).

Bett-Garber et al. (2013) have indicated that the presence of the intact bran layer of whole grain rice or brown rice makes it nutrient dense. Further, rice having red- or purple-colored bran shows higher contents of phenols and flavonoids, and it is also associated with some flavor attributes. The variation of the mass of bran and its thickness is attributed due to the proportions of bran, hay, and straw, whereas amylose content negatively correlates well with the sweet taste of the bran. The hardness of the kernel is attributed to the kernel density and bran thickness which in turn also varies with the cooking time of rice.

Jezussek et al. (2002) have found 41 odor-active compounds when aroma compounds are analyzed in four varieties of cooked brown rice employing the aroma extract dilution analyses (AEDA). Three major aroma compounds like 2-amino acetophenone (medicinal, phenolic like), 2-acetyl-1-pyrroline (popcorn like aroma), and 3-hydroxy-4,5-dimethyl-2(5H)-furanone (seasoning like) are the prominent flavor components reported for these three varieties of brown rice. The *indica* variety differs most in its overall aroma from these three Asian brown rice samples.

Quality Factors and Standards

There are different sets of the US standards for rice practiced for commercial purposes to serve as the foundation for purchasing specifications. The US standard for brown rice is defined as “Rice (*Oryza sativa* L.), which consists of more than 50% of kernels of brown rice, and which is intended for processing to milled rice” (Anon 2009). As per the percent content of paddy kernels, red rice, damaged kernels, objectionable seeds, chalky kernels, broken kernels, well-milled kernels, etc., there are five numbered grades for each of long grain, medium grain, and short grain and mixed type of rice grains.

Codex standard for rice (Anon 1995) defines husked rice (brown rice or cargo rice) is the paddy rice from which the husk is only removed. Similarly, Indian Standard (Anon 1999) indicates that brown rice is the paddy from which husk only has been removed. The process of husking and handling may result in some loss of bran. The products covered by the provisions of this standard shall be free from heavy metals in amounts which may pose a health hazard to human. The pesticide residues for rice shall comply with those maximum residue limits established by the Codex Alimentarius Commission for this commodity.

Conclusion

Brown rice is the dehusked or dehulled whole grain rice possessing the bran and germ. The presence of bran and germ makes the brown rice to contain a significant amount of dietary fiber, important vitamins, and minerals which are present in negligible quantities in the milled white rice. The composition and nutritional characteristics of brown rice indicate the health-benefitting aspects for human consumption.

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