# Chapter 2
# Variations in Brown Rice Quality Among Cultivars

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## Introduction

In Asia, more than 2000 million people obtain their 60–70% calories from a wide variety of rice cultivars and its products (Lin et al. 2011). The chemical composition of rice grain varies widely, depending on variety, soil and environment. Brown rice is the name given to dehusked paddy which retains the embryo and bran layers of the grain. Brown rice is rich in fibres, minerals, vitamins and phytochemicals mostly present in the bran layer (Min et al. 2012).

There are about more than 40,000 varieties of rice, but only a few varieties are familiar to most of us. Diversity in quality parameters of rice varieties depends mostly on the genetic background and climatic and soil conditions during the rice grain development, which affect the physicochemical, functional and nutritional properties of a particular variety and have a great impact on consumer preferences (Dendy 2005; Singh et al. 2011). The physicochemical properties of grains have been widely investigated with respect to the variety difference. Large pools of rice genotypes differ in their amylose content which was investigated for the variability of their flour by examining their functional properties (Lin et al. 2011). Moreover the development of specific rice-based products depends on physicochemical properties of rice varieties. Hence, the knowledge about the characterization of rice varieties is important for the industry to develop the desired rice products with

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high consumer acceptability. Recently, new rice varieties have been developed to improve the eating quality of cooked rice, to develop food products with enhanced nutritional properties and to improve processing characteristics of rice-based food products.

## Origin and Botany of Rice

The cultivation of rice extends over a wide range of climatic, soil and hydrological conditions – from tropical to semi-arid and warm temperate regions, from heavy clay to poor sandy soils and from dry land to swampy land in fresh or brackish water. Geographically, rice is grown between the latitudes of 53°N (in Northeast China) and 35°S (in New South Wales, Australia). However, it grows best between the latitudes of 45°N and 40°S (Dendy 2005). Rice cultivation extends from below sea level to an altitude of more than 2500 m in the Himalayas. Topographical conditions vary from uplands in hilly or plateau regions, with problems of deficit soil moisture, to medium lands with efficient water management and lowlands with excess water up to a depth of 5 m (Kent and Evers 1994). In South and Southeast Asian countries, two to three crops are harvested in a year by extending cultivation to the dry season with the help of irrigation (Laborte et al. 2012).

Rice is harvested as paddy with the hull comprising of about 20%, the bran and embryo 8–12% and the endosperm part 70–72% (Gujral et al. 2012). Paddy after removal of husk gives brown rice that is further polished to remove the bran and germ resulting in white rice. The rice produced in different parts of geographical conditions varies significantly in physical and functional properties, composition and cooking quality. Genetic diversity and environmental factors are mainly responsible for variation in the quality characteristics of rice (Singh et al. 2005; Kesarwani et al. 2013).

Rice is divided into two types – *japonica* and *indica* – and these differ in their characteristics and appearance. The grains of *japonica* rice are round and do not break easily. The cooked rice is sticky and moist and is produced mostly in Japan. The grains of *indica* rice are long and tend to break easily. When cooked, the rice is fluffy and does not stick together. Most of the rice produced in Southern Asia, including India, Southern China, Thailand and Vietnam is *indica* rice. Both the *japonica* and *indica* types of rice include non-glutinous and glutinous forms. Non-glutinous rice is popularly used generally for cooking purpose which is somewhat transparent and when cooked is less sticky than glutinous rice. Glutinous rice tends to be white, opaque and very sticky when cooked. It is commonly used to make rice products like cakes and various kinds of desserts, or processed to make rice snacks (Kent and Evers 1994).

## Factors Affecting Variety Difference

Many types of rice which have evolved through the centuries of extensive rice culture vary widely in their range of adaptability. In tropical humid regions, tall rank-growing long-season varieties are usually cultivated. In tropical Asian countries, varieties requiring a growing season of over 180 days are common. These tropical varieties grow tall, tiller profusely and produce rank vegetative growth on soils that are annually cropped to rice. In temperate regions, short-season varieties maturing in 85–146 days are grown. They are usually hardy, somewhat short stature types that can withstand wide variations in daily temperatures and produce satisfactory yield even when grown in cold irrigation water (Abrol and Gadgil 1999; Nanda and Agrawal 2006).

The rapid rise in rice production in the recent years stemmed from expanded irrigation areas, increased use of fertilizers, effective control of pests, double rice cropping, use of innovative technologies and the adoption of improved genetic materials. The combined use of nitrogen fertilizers and high-yielding varieties has made possible the cultivation of high yield in irrigated areas. The new genetic information and genetic diversity provide the foundation for more efficient breeding programs for rice production (Luh 1980).

### *Varieties*

The first concern of the farmer in selecting seed must always be the reliability of the cultivar; will the variety sprout, survive to maturity and yield well under the conditions it will encounter in his fields? The actual yield under the conditions of fertilizer application and cultural practices which will be applied is the next consideration. Hybridization programs conducted at the rice experiment stations have brought about the development of new varieties by intercrossing commercially grown strains and foreign ones. The main objective of breeding experiments is to increase yield and stabilizing productions, as well as providing a range of grain types.

The variety of rice cultivar is very important which significantly affects the quality of brown rice. The variety of rice cultivars is selected according to the need of consumers and the industry. The selection of particular variety also depends on the geographic region and climatic conditions. Characteristics that influence rice quality include those under genetic control. The modern technologies of rice breeding programs continuously refine and improve genetic characteristics influencing quality traits. Breeding and selection for desirable physicochemical, cooking and processing qualities in hybrid selections, breeding lines and new cultivars are essential components of varietal improvement programs. New varieties developed in these programs should meet the quality parameters before being released for commercial production (Luh 1980).

### *Climatic Conditions*

A major factor influencing the quality of rice is the environment in which the crop is grown. Primarily, rice production is controlled by climatic variables that ideally should provide adequate water during the growing season, relatively high air and soil temperatures, adequate solar radiation, a moderately long growing season and relatively rain-free conditions during the ripening period. Once a new variety is released for commercial production, it spreads to wherever it can be produced advantageously compared to already grown varieties. Therefore, before release, new varieties are tested agronomically and for quality traits over their likely production area. These trials permit the-+evaluation of the quality parameters of new varieties over wide ranges of environmental conditions such as soil, climate and cultural practices (Abrol and Gadgil 1999).

### *Soil Types*

Rice is grown on a wide range of soil types. The lack of adequate irrigation water is more apt to be a limiting factor than is soil type. Soil pH can vary from 4.0 to 8.0 without serious damage to the plant's growth. The rice plant has a high tolerance for alkaline soils and is sometimes grown for reclaiming such lands. Soils with impervious subsoils capable of holding floodwater or level prairies that can be readily flooded make ideal rice lands. Deep soils tend to give higher yields than soils that have an impenetrable layer at a shallow depth. Medium or heavy clays, clay loams, silt loams, or fine sandy loams with slowly permeable subsoils are preferred for rice cultivation.

### *Fertilizers*

Fertilizers are widely used throughout the rice regions and are essential for crop growth. The fertilizer type and dose significantly affect the quality of rice. The proper mixture and percentage of fertilizer at appropriate period are necessary for rice plant which affects the quality of rice variety. If the nutrients are not provided in appropriate quantity to the rice crop, the variations were observed in landmark properties of rice and ultimately affect the consumer and industrial acceptability (Nanda and Agrawal 2006).

In addition to genetic differences, fertilizer, soil type and climatic conditions affect the bran quality such as bran oil content, biochemical properties of bran and overall brown rice quality. However, the effect of other climatic factors on brown rice quality is not available in public domain. More research is required in this area to encourage the agricultural scientists to include these factors in the crop improvement programs which could increase the productivity without losing grain characteristics.

## Brown Rice Qualities in Different Varieties

Rice produced in different parts of the world differs in physical properties, composition and functional and cooking properties. The differences in these properties have been attributed to the differences in their genetic make-up and climatic conditions. The modern technologies of rice breeding programs continuously refine and improve genetic characteristics influencing quality traits.

### *Physical Properties of Brown Rice*

Rice varieties with different properties are available in the market. Rice is marketed and preferred by the industry and consumers according to grain size and shape, i.e. long, medium and short. Grain size and shape are among the first quality properties considered in developing new varietie0073 (Table 2.1). The kernel dimensions are primary quality factors in most operations of processing, breeding and grading. Intensive genetic selection is practiced to eliminate heritable abnormalities in rice grain such as deep creases, which tend to leave bran streaks on milling; irregularly shaped kernels; sharp-pointed extremities, which break easily in milling; and oversized germs, which detract from milling quality and grain appearance.

Significant variation in physical and mechanical properties has been shown among rice varieties produced in different parts of the world with the influence of diverse genetic and environmental factors (Izawa 2008; Mir et al. 2013). Physical and mechanical properties play an important role in deciding the rice processing operations, which directly affect the quality of rice at industrial scale and hence determine its consumer acceptability. Several authors have reported about the physical and mechanical characteristics of rice, which influence the milling, cooking quality and consumer preference (Mohapatra and Bal 2006; Correa et al. 2007; Varnamkhasti et al. 2008).

The differences in the physical properties of rice grain are of practical concern for processing, handling and storage. The knowledge of physical properties of grain is helpful for designing appropriate machineries for process operations like sorting, drying, heating and milling and finds the solutions to problems associated with these processes (Sahay and Singh 1994; Mir et al. 2013). These properties are also important in the construction of storage structures and the calculation of the dimensions of storage bins of a particular capacity (Thompson and Ross 1983). The axial dimensions of rice grains are useful in selecting sieve separators and calculating the

**Table 2.1** Physical properties of brown rice from various varieties

| Variety | Length (mm) | Width (mm) | Thickness (mm) | Bulk density (kg/m$^3$) | Surface area (mm$^2$) | Thousand kernel weight (g) | Reference |
|---|---|---|---|---|---|---|---|
| Pusa-3 | 8.32 | 2.02 | 1.79 | 736 | 35.84 | 21.84 | Mir et al. (2013) |
| Jehlum | 6.29 | 2.55 | 1.84 | 794 | 25.85 | 21.84 | |
| K-332 | 4.74 | 2.80 | 2.04 | 790 | 23.80 | 18.81 | |
| SKAU-345 | 6.62 | 2.62 | 2.00 | 805 | 28.77 | 22.92 | |
| Koshar | 5.00 | 3.03 | 2.10 | 817 | 26.43 | 21.65 | |
| ITA 150 | 7.76 | 2.80 | 2.05 | 860 | 35.56 | 33.85 | Shittu et al. (2012) |
| WAB 189 | 6.87 | 2.94 | 2.00 | 870 | 31.76 | 28.39 | |
| WAB 450 | 7.11 | 2.56 | 1.83 | 840 | 28.48 | 25.42 | |
| Pusa Basmati | 8.23 | 1.86 | 1.64 | 716 | 25.26 | 18.47 | Mohapatra and Bal (2012) |
| Swarna | 5.75 | 2.27 | 1.71 | 749 | 21.41 | 15.72 | |
| ADT37 | 5.21 | 2.75 | 1.96 | 807 | 24.45 | 19.62 | |
| Y9 | 4.83 | 2.90 | 2.09 | 765 | 25.11 | 17.97 | Liu et al. (2009) |
| N42 | 4.96 | 3.05 | 2.05 | 766 | 26.04 | 19.54 | |
| T559 | 5.41 | 3.18 | 2.40 | 757 | 31.46 | 22.34 | |
| K818 | 6.33 | 2.50 | 1.89 | 728 | 26.07 | 19.19 | |
| S5 | 6.73 | 1.98 | 1.78 | 708 | 23.03 | 15.06 | |
| PR 116 | 7.01 | 2.17 | 1.73 | 857 | 11.83 | 19.87 | Thakur and Gupta (2006) |

energy requirement during the milling process. They can also be used to calculate surface area and volume of kernels which are important during modelling of grain drying, heating and cooling operations (Shittu et al. 2012).

Seven cultivars of brown rice, namely, Jehlum, K-332, Koshar, Pusa-3, SKAU-345, SKAU-382 and SR-1, grown in the Indian temperate climates, were studied for the variety difference in their physical properties. Results reported that the significant difference in the physical properties including length (4.74–8.32 mm), width (2.02–3.03 mm), thickness (1.79–2.10 mm), equivalent diameter (3.03–3.28 mm), surface area (23.80–35.84 mm$^2$), sphericity (37.40–63.44%), aspect ratio (0.24–0.61), volume (14.54–18.51 mm$^3$), bulk density (736.49–817.85 kg/m$^3$), true density (1270.81–1484.42 kg/m$^3$), porosity (41.06–46.70%), thousand kernel weight (18.81–22.92 g) and angle of repose (29.93–33.04°) was observed among the different brown rice varieties. The hardness value significantly varied from 131.48 to 73.99 N, with the highest hardness found in the brown rice of Jehlum variety (Mir et al. 2013). Shittu et al. (2012) observed the significant difference in physical properties of brown rice of some improved rice varieties. The length of brown rice varied from 6.87 to 7.76 mm, while their width varied from 2.46 to 2.94 mm, respectively. The thickness ranged from 1.82 to 2.05 mm. The thousand grain weight ranged from 25.42 to 33.85 g, while the bulk and true density ranged from 0.83 to 0.87 g/cm$^3$ and 1.41 to 1.57 g/cm$^3$, respectively. The wide variations were observed in the physical properties of brown rice in different geographical areas of the world, which affects their industrial and consumer acceptability.

Joshi et al. (2014) studied the physical properties of 12 different varieties of *indica* rice. The length of the brown rice grains varied from 5.34 to 6.67 mm, width from 1.76 to 2.24 mm and thickness from 1.46 to 1.8 mm, classifying them into long- and medium-grain varieties. The true density and bulk density of the brown rice varied from 1373 to 1743 kg/m$^3$ and 730 to 813 kg/m$^3$, respectively. The compressive hardness as measured by textural analyser varies between 86 and 160 N. The rice hardness is important as harder grains tend to prevent breakage during milling.

Razavi and Farahmandfar (2008) studied the physical properties of three rice varieties, namely, Fajr, Neda and Tarom Mahali, at three levels of processing, viz. paddy, brown rice and milled rice. The thousand kernel weight, porosity and volume decreased significantly with the level of rice processing; however, the bulk density value increased. The paddy of each variety showed the lowest value of true density. The results showed that static coefficient of friction was affected by cultivars, levels of processing and frictional materials. The angle of repose for all rice varieties decreased with different levels of processing.

## *Colour Properties of Brown Rice*

Brown rice exists in different colours, which varies among the varieties (Table 2.2). There are some varieties with a distinctly darken, even almost black, pericarp. Such coloured-pericarp brown rice is not entirely uncommon, being more often found among upland rice in hilly and mountainous regions, for instance, in the north-eastern mountainous states in India. It is generally believed that some of these

**Table 2.2** Colour properties of brown rice from various varieties

| Variety | L* | a* | b* | Reference |
|---|---|---|---|---|
| Chindeul | 56.89 | 5.69 | 25.24 | Lee et al. (2016) |
| Jehlum | 66.98 | 4.19 | 23.42 | Mir et al. (2016a) |
| SKAU-345 | 63.95 | 4.69 | 23.59 | |
| SKAU-382 | 62.42 | 5.04 | 22.28 | |
| Khao Dawk Mali 105 | 59.00 | 3.1 | 18.00 | Sirisoontaralak et al. (2015) |
| SR-1 | 58.10 | 7.73 | 23.95 | Mir et al. (2013) |
| Pusa-3 | 55.99 | 7.44 | 25.33 | |
| Koshar | 63.02 | 6.25 | 26.29 | |
| ITA 150 | 81.31 | 1.81 | 21.80 | Shittu et al. (2012) |
| ITA 301 | 82.90 | 2.29 | 21.21 | |
| WAB 189 | 72.35 | 2.58 | 19.79 | |
| WAB 450 | 80.34 | 2.09 | 20.53 | |

coloured pericarp rice varieties have medicinal properties. Most consumers are already aware that conventional brown rice is nutritionally superior to white rice in terms of fibre and beneficial functional components because of its outer layer and mostly select the rice by the colour.

The colour of rice kernels is one of the important physical properties from the industry and consumer point of view. Coloured rice varieties have been found to be potent source of functional components (Sompong et al. 2011). The colour varieties have better antioxidant properties than colourless varieties. Thus it can be concluded that colour varieties could be used as a natural antioxidant source (Moko et al. 2014). The colour analysis of brown rice showed that L*, a* and b* values ranged from 55.99 to 67.19, 4.23 to 7.73 and 22.41 to 26.29, respectively (Mir et al. 2013). Itagi and Singh (2015) also reported a significant difference in colour values of brown rice. The L* value for brown rice varied from 23.5 to 59.3, a* from 4.4 to 14.2 and b* from 4.8 to 22.6. The variation in colour of the rice kernels may be due to the difference in genetic make-up, composition and coloured pigments.

## *Cooking Properties of Brown Rice*

Rice is mostly consumed in cooked form. However, its cooking properties differ due to the diversified cultivation of rice which affects its physicochemical properties and results in varied cooking properties. The demand of brown rice for cooking purpose is increasing nowadays due to consumer consciousness about their health, and they prefer the foods which have functional properties in addition to the nutritional value. As cooked rice is the staple food for most of the population, it is the easiest way to enhance the consumption of functional components as in the form of cooked brown rice.

Cooking quality of rice is one of the important factors influencing the acceptability of consumers (Soponronnarit et al. 2008). Cooking is the most important processing step to provide desirable texture to the rice grain. The rice grains are boiled in limited or excess amount of water during cooking. The chief constituent of rice is starch, which is made up of two major components, amylose and amylopectin. The starch of grain absorbs moisture and swells during cooking due to its gelatinization (Yadav and Jindal 2007). During cooking amylose leaches out from the starch granule and retrogrades when cooled, whereas amylopectin remains in the gelatinized granule. Amylose content is one of the key determinants of cooking and eating quality of rice (Juliano 1985). The wide varietal difference in cooking rice is mainly due to the bran layer which varies among the cultivars and provides the significant effect on the cooking properties.

Cooking quality preferences vary within the country and geographical regions, within ethnic groups and from one culture to another (Soponronnarit et al. 2008; Mir et al. 2016b). Desired quality of rice may also vary from one geographical region to another and consumer demand of certain varieties and favours specific quality traits of rice for cooking. The cooking methods and textural preferences of rice vary from place to place (Suwannaporn and Linnemann 2008; Son et al. 2013).

Cooking time varies for rice varieties and is the time when 90% of the starch in the grain no longer shows opaque centre when pressed between two glass plates. Cooking time is an important parameter which determines tenderness of cooked rice as well as its stickiness (Shinde et al. 2014). Brown rice is also used for cooking purpose in some parts of the world, but it takes longer time to cook as compared to polished rice. Cooking time of rice depends on coarseness of the grain and its gelatinization temperature. Rice with low gelatinization temperature require less than 20 min for cooking, while rice with intermediate gelatinization temperature require more than 20 min for cooking (Singh et al. 2005).

Variety differences were observed in cooking properties of brown rice. Cooking time, water uptake ratio, gruel solid loss and elongation ratio varied from 33.63 to 46.71 min, 1.74–2.85, 1.97–3.32% and 1.14–1.81, respectively. Textural attributes of cooked brown rice showed significant variation among the varieties with the hardness varied from 2.27 to 6.00 N (Mir et al. 2016b). The water absorption by rice during cooking is considered as an economic quality parameter, because it gives the estimate of the volume increase during cooking. During cooking, rice grains absorb sufficient water and increase in volume through increase in length and breadth. Lengthwise increase without increase in girth is desirable characteristic in high-quality rice (Shinde et al. 2014).

Gujral and Kumar (2003) reported that the cooking time for brown rice varies from 35.0 to 51.0 min, elongation ratio from 32.3 to 35.4%, water uptake from 84.69 to 136.75%, solid loss from 1.1 to 6.8% and hardness from 6.995 to 10.939 N. Deepa et al. (2008) reported that the cooking time of dehusked Jyothi and IR 64 rice varieties was found to be 30 min, while Njavara needed longer time to cook (38 min).

## *Chemical Composition of Brown Rice*

The chemical composition of brown rice varies widely, depending on variety, soil and environment. Brown rice consists of bran layers (6–7%), embryo (2–3%) and endosperm (about 90%) (Chen et al. 1998). Starch is the major constituent of brown rice, whereas other components are also present in significant proportion. Non-starch constituents like protein, fat, ash, fibre and lignin are higher in brown rice than in milled rice. In addition to that, free sugars, free amino acids and aroma compounds are also present which are more concentrated in the bran fraction of the rice kernel (Itani et al. 2002; Ohtsubo et al. 2005; Lamberts et al. 2007). Brown rice is also a rich source of vitamins, minerals and rare amino acids (Liu et al. 2009; Mir et al. 2016b). During the milling process, from brown rice to white rice, the losses of proteins and total minerals reached 28.6% and 84.7%, respectively (Lamberts et al. 2007).

Brown rice retains the bran layer (containing many vitamins and minerals as well as fibres), as this has not been polished off to produce white rice. Red rice is known to be rich in iron and zinc, while black and purple rice are especially high in protein, fat and crude fibre. Red, black and purple rice get their colour from anthocyanin pigments, which are known to have free radical scavenging and antioxidant capacities, as well as other health benefits.

Protein is the second highest component after starch in rice kernel. Protein is available in varying amounts in brown rice, mostly ranging from 6.5% to 8.7% with some exceptions, where it varies from the main range (Cao et al. 2004; Mir et al. 2016b). Protein content varies among the rice varieties and decreased linearly with the increase in the degree of polishing as it is mainly concentrated in the peripheral layers of the grain (Zhou et al. 2002). Protein is the most abundant in the subaleurone layers of rice grain. In addition to that, small quantities are also present in aleurone cells (Azhakanandam et al. 2000). Rice protein is more nutritious because of its relatively well-balanced amino acid profile and is superior in lysine content than other cereal crops (Mohan et al. 2010).

The lipid or fat content of rice is concentrated in the bran layers where it can contribute up to 20% by mass, particularly as lipid bodies or spherosomes. The lipid content of brown rice varies and is available in the varieties from 0.5% to 3.5% (Dendy 2005). Singh et al. (1998) reported the lipid contents of six varieties of brown rice ranged from 2.1% to 3.2% and 0.61% to 0.95%. Charoenthaikij et al. (2012) reported the lipid content ranged from 2.65% to 3.24% in brown rice flour, whereas Mir et al. (2016b) reported in the range 2.38–2.84%. In brown rice, 51% of crude oil is found in germ, 32% in the bran layer and only 17% in the endosperm. In the endosperm part of the rice grain, lipids are unevenly distributed having highest percentage in the outer layers and decreasing progressively towards the centre of the grain (Dendy 2005).

Brown rice contains notable amount of vitamins which are essential for the human health. Vitamins are mostly present in higher levels in brown rice than in milled rice. Rice is a good source of vitamin $B_1$, vitamin $B_2$, vitamin $B_3$ and vitamin $B_6$, and a wide variation is observed among the different varieties. Deepa et al. (2008) investigated the level of vitamins in brown rice of three varieties, namely, Njavara, Jyothi and IR 64 Njavara. They reported that the vitamin $B_1$ content varied from 0.04 to 0.05 mg/100g, vitamin $B_2$ from 0.053 to 0.071 mg/100g, vitamin $B_3$ from 4.68 to 7.32 mg/100g and folic acid from 0.04 to 0.05 mg/100g. However, Njavara rice contained higher amounts of vitamin $B_1$ (27–32%), vitamin $B_2$ (4–25%) and vitamin $B_3$ (2–36%) as compared to the other two rice varieties.

Mir et al. (2016b) observed the wide variation in vitamin content of brown rice varieties. The vitamin $B_1$ content ranged from 0.09 to 0.16 mg/100 g, $B_2$ from 0.10 to 0.27 mg/100 g, $B_3$ from 4.02 to 5.41 mg/100 g and $B_6$ from 0.08 to 0.19 mg/100 g. Kyritsi et al. (2011) reported that brown rice contains 0.403, 0.065, 5.433 and 0.563 mg/100 g of vitamin $B_1$, $B_2$, $B_3$ and $B_6$, respectively. The difference in vitamin content of rice may be due to the variation in genetic background among the rice varieties.

## *Minerals Composition of Brown Rice*

Minerals are essential nutrients for human being, and they play a vital role in the effective functioning of the body activities. The mineral composition of the rice grain depends considerably on the availability of soil nutrients during crop growth and variety (Heinemann et al. 2005; Wang et al. 2011). It is noteworthy that the analysed brown rice contains, on an average, significantly greater concentrations of copper, potassium, magnesium, manganese, sodium, phosphorus and zinc in comparison to polished rice samples. Wide genetic diversity in the mineral elements of brown rice accessions was observed (Table 2.3). These mineral elements were affected by genotype as well as environment (Huang et al. 2016). Antoine et al. (2012) analysed 25 rice brands for 36 essential and non-essential elements using four different instrumental techniques. The mean values of minerals as reported by them are as follows: for calcium (127 mg/kg; 104 mg/kg), copper (1.65 mg/kg; 2.96 mg/kg), iron (22.3 mg/kg; 20.1 mg/kg), magnesium (371 mg/kg; 1205 mg/kg), manganese (10.5 mg/kg; 26.5 mg/kg), molybdenum (0.790 mg/ kg; 0.770 mg/kg), phosphorus (1203 mg/kg; 3361 mg/kg), potassium (913 mg/kg; 2157 mg/kg), selenium (0.108 mg/kg; 0.131 mg/kg), sodium (6.00 mg/kg; 15.1 mg/kg), sulphur (1131 mg/kg; 1291 mg/kg) and zinc (15.6 mg/kg; 20.2 mg/kg) for polished and brown rice, respectively.

Wavelength dispersive X-ray fluorescence spectrometer analysis showed that brown rice is rich source of minerals including calcium, iron, potassium, magnesium, manganese, phosphorus, sulphur and zinc. Significant difference was observed in the mineral composition of brown rice from different varieties. The most abundant mineral was potassium (93.15–110.35 mg/100 g) followed by phosphorus (76.30–89.80 mg/100 g), sulphur (20.75–26.90 mg/100 g) and magnesium (17.15–20.90 mg/100 g), whereas the lowest was zinc (2.10–2.45 mg/100 g). The results showed that amounts of minerals were significantly different among the varieties which depend on the genetic make-up of the variety. The brown rice rich in minerals can be considered as cost-effective and promising approach to alleviate malnutrition and other health-related problems (Mir et al. 2016b).

## *Starch Properties of Rice*

Even though the brown rice contains significant amounts of functional and nutritional components which are concentrated in the bran layer, it also contains the starch in high proportion which affects its physicochemical properties. Physicochemical properties of rice starch depend largely on the variety of the rice and their genetic background (Bao et al. 2004; Wani et al. 2012; Mir and Bosco 2014). Literature has reported the starch characterization from rice varieties grown in different areas of India (Sodhi and Singh 2003; Singh et al. 2007), Thailand (Noosuk et al. 2005), Africa (Lawal et al. 2011) and China (Wang et al. 2010). Starch properties also

**Table 2.3** Mineral composition of brown rice from various varieties

| Variety | Calcium (mg/100 g) | Iron (mg/100 g) | Potassium (mg/100 g) | Magnesium (mg/100 g) | Manganese (mg/100 g) | Zinc (mg/100 g) | Sodium (mg/100 g) | Copper (mg/100 g) | Reference |
|---|---|---|---|---|---|---|---|---|---|
| Azucena | 10.6 | 0.92 | 312.10 | 156.66 | – | 3.15 | 4.45 | 0.28 | Huang et al. (2016) |
| Dular | 9.09 | 0.92 | 295.30 | 144.10 | – | 2.50 | 1.14 | 0.13 | |
| Pokkali | 12.00 | 0.40 | 346.30 | 167.60 | – | 2.09 | 1.70 | 0.18 | |
| Swarna | 8.18 | 0.49 | 281.10 | 162.80 | – | 1.90 | 0.99 | 0.24 | |
| K-332 | 5.05 | 2.75 | 104.10 | 19.70 | 2.30 | 2.10 | – | – | Mir et al. (2016b) |
| Kohsar | 5.35 | 2.95 | 110.35 | 19.45 | 3.20 | 2.45 | – | – | |
| Pusa-3 | 6.65 | 3.05 | 104.25 | 20.40 | 2.70 | 2.15 | – | – | |
| SKAU-382 | 5.70 | 3.25 | 93.15 | 20.90 | 1.80 | 2.30 | – | – | |
| SR-1 | 6.40 | 2.76 | 100.95 | 17.15 | 2.55 | 2.40 | – | – | |
| ZN7 | 2.25 | 2.28 | – | 171.7 | 3.05 | 2.73 | – | – | Wang et al. (2011) |
| ZN60 | 1.67 | 2.43 | – | 181.4 | 4.24 | 2.91 | – | – | |
| ZN34 | 1.42 | 1.55 | – | 150.8 | 2.81 | 2.40 | – | – | |
| Pusa basmati | 2.65 | 2.72 | – | 15.82 | – | 0.69 | – | – | Das et al. (2008) |
| Njavara | 11.6 | 1.93 | 304 | 216 | – | – | 30.9 | – | Deepa et al. (2008) |
| Jyothi | 9.70 | 3.95 | 268 | 150 | – | – | 22.6 | – | |
| IR 64 | 9.20 | 2.73 | 248 | 163 | – | – | 27.8 | – | |
| Brazilian brown rice | 6.85 | 0.57 | 181.71 | 16.88 | 0.36 | 1.98 | 0.54 | 0.16 | Heinemann et al. (2005) |
| Australian brown rice | 3–11 | 0.5–5.7 | 210–300 | 100–130 | 2.5–6 | 1.3–2.1 | 0–19 | 0.14–1.3 | Marr et al. (1995) |

depend upon the soil and climatic conditions during rice grain development (Wani et al. 2012). The rice starch contains amylose and amylopectin components with α 1–4 and α 1–4 and α 1–6 linkages, respectively, whose percentage varies among the varieties (Vandeputte et al. 2003; Fitzgerald et al. 2009).

Starch granules of rice are the smallest known to exist in cereal grains, with the size observed in the range of 2–7 μm (Vandeputte and Delcour 2004). Starch granules of rice varieties are mainly polyhedral in shape. These granules may also be oval, angular, irregular or smooth in shape. The size of granules varies between non-waxy and waxy rice starches, and it also differs from variety to variety. Starch properties depend mostly on the factors including amylose/amylopectin ratio, granule shape and size and the presence of other constituents present in the starch (Wani et al. 2012). The variability in amylose and amylopectin molecules is due to the complexity of starch biosynthesis which reflected the diversity of granule morphology. The variation, particularly in granular shape and size, is associated with various techno-functional properties in different food products (Lu et al. 2009; Lawal et al. 2011).

Amylose and amylopectin are the major constituents affecting the physicochemical properties of rice starch, and their role in the properties of rice starch has been widely investigated (Li et al. 2008; Wang et al. 2010). Large pools of rice varieties differing in their amylose content are found in different geographical regions of the world. Amylose is controlling almost all the properties of rice starch due to its influence on thermal properties, pasting properties, syneresis, solubility, swelling and other techno-functional properties (Lu et al. 2009). Waxy rice starches have high solubility and swelling properties and larger crystallinity degree than non-waxy starches. However, non-waxy rice starches have observed a higher gelatinization temperature as compared to waxy starches (Zavareze et al. 2010). From the industrial standpoint, it is a practical approach to simplify the rice variety categorization in order to control the rice quality. Hence, it is reliable to classify the rice starches categorized on the basis of their similarity after selecting on the basis of food applicable properties for appropriate control of rice starch quality.

## *Antioxidant Properties of Brown Rice*

Many epidemiological studies have shown that consumption of brown rice is highly correlated to reduce incidences of chronic diseases (Anderson 2003). Epidemiological investigations reported that the low incidence of certain chronic diseases in brown rice-consuming areas of the world might be associated with the antioxidant properties of rice. Rice has been recognized as an excellent source of unique complex naturally occurring antioxidant compounds (Chotimarkorn et al. 2008). The scavenging effect of bioactive components, such as phenolic compounds, flavonoids, anthocyanins, proanthocyanidins, tocopherols and oryzanol, which are rich in the rice grains, may be a mechanism whereby whole grains have their protective effects (Slavin 2003). Most of the phytochemicals in the brown rice grain are present in the bran fraction consisting of bran layers and the germ. Rice, as one of the main foods in the diet of most populations, has an important role in the concentration of antioxidants ingested daily. In addition to phytochemicals, brown rice also contains dietary fibre that adds bulk to the gastrointestinal tract in humans which indirectly promotes cardiovascular health. These functional components exist mainly in the bran and germ layers in the brown rice and are lost when it is polished to white rice (Champagne et al. 2004).

The health benefit properties of brown rice are attributed mainly due to the phenolic compounds, which has received the increasing attention because of its potent antioxidant properties (Liu 2004; Kim et al. 2012). Brown rice was reported to have higher phenolic content and stronger antioxidant capacity than polished rice (Shen et al. 2009; Zhang et al. 2010). Major anthocyanin components of brown rice were identified as cyanidin-3-gluoside and peonidin-3-glucoside, and these compounds possessed prominent antioxidant activities (Hu et al. 2003; Zhu et al. 2010). Therefore, brown rice is more preferred by the consumers because of its high functional properties.

The markable difference in antioxidant properties of brown rice was observed in different varieties (Table 2.4). Brown rice was proved to have potent antioxidant activity with a significant variation in total phenolic (0.81–1.64 mg gallic acid equivalent/g), flavonoid content (50.67–79.41 μg catechin eq/g), 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity (46.18–70.51%) and total reducing power (7.34–17.14 μmol ascorbic acid equivalent/g) among varieties (Mir et al. 2016b).

**Table 2.4** Antioxidant properties of brown rice from various varieties

| Variety | Phenolics (mg gallic acid equivalent/100 g) | | | Flavonoids (mg catechin equivalent/100 g) | | | Reference |
|---|---|---|---|---|---|---|---|
| | Free | Bound | Total | Free | Bound | Total | |
| Longjing 25 | 59.85 | 60.28 | 120.13 | 65.51 | 44.76 | 110.27 | Gong et al. (2017) |
| Sonjing 16 | 63.77 | 51.52 | 115.29 | 80.70 | 31.33 | 112.03 | |
| Tianyouhuazhan | 42.09 | 30.36 | 72.45 | 52.03 | 23.87 | 75.90 | |
| Wuyou 308 | 67.86 | 46.43 | 114.29 | 76.82 | 33.56 | 110.38 | |
| Fenghuazhan | 58.09 | 44.70 | 102.78 | 62.15 | 41.89 | 104.04 | |
| Japonica rice | 65.60 | 34.80 | 100.40 | 42.60 | 34.30 | 76.90 | Liu et al. (2015) |
| Indica rice | 62.00 | 37.30 | 99.30 | 56.30 | 55.70 | 112.10 | |
| Tianyou 998 | 100.30 | 73.70 | 174.00 | 61.10 | 63.90 | 124.90 | Ti et al. (2014) |
| DV 123 | 67.00 | 41.00 | 108.00 | 28.00 | 13.00 | 41.00 | Min et al. (2014) |
| HB1 | 220.00 | 60.00 | 280.00 | 99.00 | 17.00 | 116.00 | |
| IAC 600 | 490.00 | 75.00 | 565.00 | 180.00 | 18.00 | 198.00 | |
| Kechengnuo4 | 44.00 | 61.00 | 105.00 | 20.00 | 24.00 | 44.00 | Min et al. (2012) |
| Cocodrie | 62.00 | 63.00 | 125.00 | 23.00 | 26.00 | 49.00 | |
| Bengal | 58.00 | 46.00 | 104.00 | 22.00 | 24.00 | 46.00 | |
| Heugjinjubyeo | 1640.00 | 176.00 | 1820.00 | 317.00 | 22.00 | 339.00 | Kong and Lee (2010) |
| Heugkwangbyeo | 1180 | 153 | 1330 | 197.00 | 16.00 | 213.00 | |

The brown rice had phenolic contents ranging from 108.1 to 1244.9 mg gallic acid equivalent/100 g (Choi et al. 2007). Goffman and Bergman (2004) reported that the phenolic contents in the red, purple and white rice ranged from 34 to 424, 69 to 535 and 25 to 246 mg gallic acid equivalent/100 g, respectively.

In brown rice, phenolic acids are mainly present in three forms, soluble free, soluble conjugated and insoluble bound (Butsat et al. 2009; Huang and Ng 2012). Most of the phenolic acids in the grains are in the bound form (Adom and Liu 2002; Irakli et al. 2012). The most abundant bound phenolic acid in brown rice was ferulic acid, which accounts for almost 50–65% of total bound phenolic acids (Qiu et al. 2010). Ferulic acid has a wide range of therapeutic effects against many chronic conditions such as inflammation, cancer, apoptosis, cardiovascular, diabetes and neurodegenerative diseases, so the consumption of brown rice is helpful to reduce the incidence of chronic diseases in human beings (Srinivasan et al. 2007).

The antioxidant properties of eight whole rice grain varieties varying in colour, total phenolics, flavonoids and 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity of solvent-extractable free and bound fractions were studied by Min et al. (2012). The free and soluble phenolic fraction content varied from 0.44 to 6.97 and 0.46 to 2.28 mg gallic acid equivalent/g, respectively. The total free flavonoid content showed the variation from 0.16 to 2.28 and 0.24 to 0.43 mg catechin equivalents/g and radical scavenging content from 1.19 to 41.95 and 0.99 to 10.55 μmol Trolox equivalents/g, for free and soluble fraction, respectively. Red and purple rice grains showed the higher phenolic content, flavonoid content and antioxidant capacities than light-coloured rice varieties.

Ti et al. (2014) quantified free and bound phytochemicals in the endosperm and bran/embryo of different *indica* rice varieties. Phytochemicals mainly existed as free form in the bran/embryo and as both free and bound forms in the endosperm. The average values of total phenolic content and flavonoid content in the bran/embryo were 3.1 and 10.4 times higher than those in the endosperm, respectively. In whole brown rice, the bran contributed 59.2% and 53.7% of total phenolics and flavonoids, respectively. Seven individual phenolics including gallic, protocatechuic, chlorogenic, caffeic, syringic, coumaric and ferulic acids were detected with most coumaric and ferulic acids in the bran.

Niu et al. (2013) investigated the antioxidant properties of 22 red rice samples grown in Zhejiang. The total phenolic contents ranged from 433 to 2213 mg ferulic acid equivalents/g, whereas the cyanidin-3-O-glucoside concentration was 11.6–16.5 mg/g in the red rice samples. The distribution of phenolic acids and anthocyanins in endosperm, embryo and bran of white, red and black rice grains was investigated by Shao et al. (2014). Total phenolic content was highest in the bran, averaging 7.35 mg gallic acid equivalent/g and contributing 60%, 86% and 84% of phenolics in white, red and black rice, respectively. The average total phenolic content of the embryo and endosperm was 2.79 and 0.11 mg gallic acid equivalent/g accounting for 17% and 23%, 4% and 10% and 7% and 9% in white, red and black rice, respectively. The antioxidant capacity determined using 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity and oxygen radical scavenging capacity shows a similar trend to total phenolic content. Free/conjugated phenolic acids in white, red and black rice bran accounted for 41%, 65% and 85% of total acids. Bound phenolic acids in bran of brown rice accounted for 90% of total acids in rice grain.

## Conclusion

The wide differences in rice varieties were observed in physical and cooking properties, composition, minerals, starch and antioxidant properties. The diversity in properties of brown rice may be due to the difference in genetic make-up and climatic and soil conditions of grain during development. The quality characteristics desired vary considerably, being ultimately related to final consumer acceptance of each rice product. The brown rice from different varieties provides opportunities to promote the nutritional benefit of food products from rice varieties and could have implications for commercial practice in the food industries. Further research is required on the effect of agronomic and climatic conditions on different rice varieties.

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