Review

Value of Wholegrain Rice in a Healthy Human Nutrition

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Abstract: Rice is one of the most widely consumed cereals in the world. The husks of harvested, unprocessed rice are not digested by humans and need to be removed to obtain edible grains, whereas the bran can be partially (brown rice) or totally removed (white rice). Brown rice is a wholegrain cereal and, as such, is known to have beneficial effects on human health. Recent epidemiological studies have shown that the consumption of whole grains can reduce the risk of metabolic disorders, cardiovascular diseases, and some types of cancer. However, white rice is preferred for reasons connected to appearance, taste, palatability, ease of cooking, tradition, safety, shelf-life, and lack of awareness about its benefits and availability. In this review, the latest scientific reports regarding the nutritional composition of brown rice and the evolution of the technology for its production will be briefly reviewed together with research on nutritional implications of brown rice consumption also in relation to cancer development in humans. A specific chapter is devoted to pigmented rice which, thanks to its composition, has attracted the growing interest of consumers worldwide. The need for further studies to help promote the consumption of wholegrain rice are also discussed.

Keywords: brown rice; nutritional quality; brown rice technology; pigmented rice; glycemic response; cancer

1. Introduction

Rice, together with wheat, is one of the most widely consumed cereals in the world. It is the seed of the grass species belonging to the genera *Oryza* and *Zizania*. The most commonly grown species are *Oryza sativa* L. (Asia) and *Oryza glaberrima* Steud. (Africa). Rice requires specific growing conditions that involve, in most cases flooding, to be successfully cultivated.

According to FAO statistics, 755,473,800.00 tonnes of paddy rice were produced in 2019. If we examine the production share of paddy rice by region (average, 1994–2019) we see that Asia produced 90.6% followed, at a great distance, by the Americas (5.2%), Africa (3.5%), Europe (0.6%), and Oceania (0.1%) [1]. Within the Asian region, China is the main producer with almost 200,000,000.00 tonnes followed by India with almost 150,000,000.00 tonnes and Indonesia with about 50,000,000.00 tonnes. However, the country with the largest per capita rice consumption is Bangladesh (based on a comparison of 154 countries in 2017) with 269 kg per capita per year followed by Laos and Cambodia. China ranks 15th with 125 kg per capita per year.

The harvested unprocessed rice is known as paddy rice and needs to undergo milling for human consumption [2]. As part of the processing, the protective hull is removed, leaving only the actual rice kernel which is called brown rice. Paddy rice comes in many different colors, including brown, red, purple, and even black.

The brown rice is composed of bran layers (6–7% of its total weight), embryo (2–3%), and endosperm (about 90%) [3]. It is a wholegrain cereal and, as such, is known to have beneficial effects on human health. However, the edible brown rice, is rarely consumed as most populations prefer the white polished rice for reasons connected to appearance, taste, palatability, ease of cooking, tradition, safety, shelf life, and lack of awareness about its benefits and availability, which limits market potential [4,5]. It is, in fact, well known that the polishing process has evolved to improve rice cooking and eating quality and to

extend its shelf life. For example, in South India, nearly half of daily energy intake comes from refined grains and white polished rice constitutes more than 75% of refined grain intake [6]. In China, brown rice is rarely consumed [7].

Rice is rich in genetic diversity with thousands of varieties grown in the world. There are different types of rice available worldwide which generally fall under the category of short, medium, or long grain size. Moreover, rice varieties can also be categorized as Indica, Japonica, glutinous, and aromatic. Glutinous rice is common in Japan. It is a short-grain variety whereas most of the aromatic cultivars are long-grain rice. Different cultures have different preferences regarding the taste, texture, color and stickiness of the rice varieties they consume, and many countries have signature rice recipes such as sushi, paella, risotto, and curry. Many other food products are made from rice such as noodles, sweets, cakes, cookies, snacks, and beverages.

In this review, the latest scientific reports regarding the nutritional composition of brown, wholegrain rice, and the evolution of the technology for its production will be briefly reviewed together with research findings on nutritional implications of brown rice consumption also in relation to cancer development in humans. A specific chapter will be devoted to pigmented rice which, thanks to its chemical composition, has attracted the growing interest of consumers worldwide. The value of wholegrain rice in a healthy human nutrition, i.e., in a diet that favors nutrient-dense foods containing many essential nutrients per calorie and bioactive substances, are illustrated. Gaps and needs for further studies useful to promote the consumption of wholegrain rice are also discussed in the concluding chapter.

2. Methodology

This review is based on personal knowledge gained by working for over 30 years in a laboratory for cereal science and technology of the Research Centre for Food and Nutrition of the Council for Agricultural Research and Economics (CREA) in Rome, Italy and on critical reading of the published literature available by searching the Scopus database. The search included the period 2000–2021 and the keywords used were: wholegrain rice, brown rice, pigmented rice, rice nutritional quality, rice processing, rice cooking, rice anthocyanin, and rice phenolic acids. For data on rice production and consumption the statistics of the Food and Agriculture Organization of the United Nations were used.

3. Nutritional Values of White and Wholegrain Rice

As with other cereals, rice is regarded as an energetic food. If we have a look at the chemical composition of both white and brown rice as reported in Table 1, we can see that carbohydrates and starch in particular make up about 80% of the grain dry matter whereas proteins account for around 7%. The amino acid profile of rice shows that it is high in glutamic and aspartic acid while lysine is the limiting amino acid [8].

Both white and brown rice are low-fat foods even if brown rice has more than four times the amount of lipid found in white rice, mainly polyunsaturated fatty acids (Table 1). Brown rice is also richer in dietary fiber, minerals, and vitamins, in particular of the B group. Besides the mentioned substances, brown rice contains γ-oryzanol, GABA (gamma-aminobutyric acid), tocopherols, tocotrienols, carotenoids, β-sitosterol, anthocyanins, proanthocyanidins, and other phenolic compounds [5,9–11].

Ma et al. [12] recently investigated the reduction of phenolic profiles, dietary fiber, and antioxidant activities of rice after treatment with different milling processes. They found that as the milling degree increased, the loss percentages of total phenolics, flavonoids, and anthocyanins of Dao Huaxiand rice were 52.8–76.4%, 43.3−72.9%, and 100%, respectively, which is similar to the reduction percentages of the Jiangxi Indica rice which were 56.5−77.4%, 58.7−87.7%, and 87.5−100%, respectively. Antioxidant activities showed the same trend as phenolic profiles.

Being rich in several interesting substances, rice bran and defatted rice bran have been proposed to improve the nutritional and functional quality of cakes [13], pasta [14], fresh noodles [15], brown rice noodles [16], wheat bread [17], and gluten-free bread [18].

Table 1. Comparison of the nutritional components of white and brown rice (%) *.

Nutrient	White Rice	Brown Rice
Water (g)	12.0	12.0
Energy (Kcal)	334	341
Proteins (g)	6.7	7.5
Lipids (g)	0.4	1.9
Available carbohydrates (g)	80.4	77.4
Starch (g)	72.9	69.2
Soluble carbohydrates (g)	0.2	1.2
Total dietary fiber (g)	1.0	1.9
Soluble dietary fiber (g)	0.08	0.12
Insoluble dietary fiber (g)	0.89	1.8
Minerals		
Sodium (mg)	5	9
Potassium (mg)	92	214
Calcium (mg)	24	32
Magnesium (mg)	20	-
Phosphorus (mg)	94	221
Iron (mg)	0.8	1.6
Copper (mg)	0.18	-
Zinc (mg)	1.3	-
Selenium (μg)	10	-
Vitamins		
Thiamine (mg)	0.11	0.48
Riboflavin (mg)	0.03	0.05
Niacin (mg)	1.3	4.7
Vitamin C (mg)	0.0	0.0
Vitamin A retinol equivalent (μg)	0.0	0.0
Vitamin E (mg)	tr	0.7

* Data from CREA food composition tables, 2021 [19].

A diet rich in wholegrain cereals is considered a healthier option than one where refined cereals are consumed, and rice is no exception [20]. Recent epidemiological studies have shown that the consumption of whole grains can reduce the risk of metabolic disorders, in particular type 2 diabetes mellitus [21], cardiovascular diseases [22,23], and some types of cancer [24]. A nutrition rich in brown rice may help in appetite control and weight loss due to higher fiber content compared to white rice. This also aids in the reduction of LDL cholesterol.

The exact mechanisms by which wholegrain cereals convey beneficial effects on health are not clear. Han et al. [25] studied the effects of polished rice, refined wheat, unpolished rice, and whole wheat on short-chain fatty acids (SCFA) and gut microbiota in ileal, cecal, and colonic digesta of normal rats. They found that animals fed with unpolished rice and whole wheat diets exhibited higher total SCFA in cecal and colonic digesta compared with those fed with polished rice and refined wheat diets. They concluded that unpolished rice and whole wheat could modulate gut microbiota composition and increase the SCFA

concentration with wheat being superior to rice in this regard. It is likely that several factors are involved, i.e., micronutrient content, fiber content, and/or glycemic index [26].

However, as scientific evidence accumulates on the beneficial role of wholegrains in human health, dietary guidelines worldwide recommend introducing wholegrains in the diet and they give qualitative prescriptions such as in Belgium, Czech Republic, France, Italy, Malta, or Poland ("prefer whole grain" or "replace white-flour bakery products with whole-grain bakery products"), semi-quantitative as in Bulgaria or Hungary ("prefer wholemeal bread and other wholegrain products. Replace at least half of the white bread with wholemeal", "swap refined grains with wholegrains and consume at least one serving of wholegrain food as bread, pastry, or side dish a day"), or quantitative as in The Netherlands or Denmark ("eat at least 90 g of brown bread, wholemeal bread or other wholemeal products/4–5 servings of whole-grain foods every day", "eat whole-grain foods —at least 75 g of wholegrains per day or more") [27].

4. Technology of Brown Rice Production

In parallel with the increasing knowledge on the nutritional potential of wholegrain rice, there has been a development of processing technologies aimed at producing high quality brown-rice products that could retain the content of interesting bioactive substances, have fewer antinutritional factors, and be more palatable and attractive for consumers. In fact, the presence in the rice grain of bran and germ is responsible for the limited acceptability of brown rice by most of the consumers who perceive a hard texture and chewing palatability [28] and experience prolonged cooking time [29] and greater susceptibility to oxidation and off-flavor formation compared to white rice [30], or know about the presence of antinutritional factors such as phytic acids and tannins [31].

There are several methods to improve the quality of brown rice such as germination, milling, enzymatic treatment, and pre-soaking [9,32–36]. Brown rice with a high milling degree (i.e., most of the outer layers of bran have been removed) has superior sensory quality and market value but lacks some nutrients which are removed during the milling process [37]. Liu et al. [35,38] reported that there is no linear correlation between the loss of some nutrients and the milling degree and acceptable sensory qualities, and nutrient retention can be achieved by controlling the milling degree of brown rice. Enzymatic treatment is another way to obtain polished brown rice with better nutritional properties than mechanically milled rice [33].

A systematic review to summarize the effects of different conventional and innovative processing strategies on the quality characteristics and health benefits of brown rice samples was published by Xia et al. in 2019 [39]. The studies conducted to enhance the quality and palatability of brown rice by means of innovative approaches have been classified by Xia et al. [39] into two categories, i.e., bioprocess-based approaches and nonthermal processing techniques. The first category includes germination, fermentation, and the use of hydrolytic enzymes at various processing stages. The second category comprises the use of high hydrostatic pressure, pulsed electric fields, cold plasma, ultrasound, and irradiation.

The parboiling process is a traditional heating treatment designed to improve nutritional and textural quality and storage stability of rice and it can also be applied to produce brown rice. High temperature heating significantly inactivates deteriorative enzymes and stabilizes brown rice during storage but can also cause some negative effects such as degradation of bioactive components and browning [5,40,41].

Xia et al. [39] concluded that non-thermal innovative approaches can shorten cooking time and soften texture while maintaining and improving the bioactivities of wholegrain brown rice. The immediate increase in the content of bioactive components after treatments could be the result of their enhanced extractability. However, few investigations have been conducted on the mentioned techniques and to better understand the mechanisms behind the physicochemical properties and biological responses derived from innovative techniques, omics approaches should be introduced.

Investigations on the influence of the effects of emerging texture-improved processing techniques such as high hydrostatic pressure, high intensity ultrasonication, and germination pretreatments on lipid stability i.e., hydrolysis and oxidation development of wholegrain brown rice during storage were conducted by Xia et al. [42].

5. Glycemic Response to Brown Rice Consumption

Rice starch is composed of two glucose polymers, a linear one, amylose and a branched one, amylopectin. There are different types of rice which differ in the amount of the two polymers [8] and in the postprandial blood glucose response they produce. Glycemic index studies of rice report values ranging from 64 to 93 [43], however, most rice varieties are of high glycemic index [44]. Rice starches with a higher amount of amylose are more resistant to human digestion [45]. In addition to the amylose content of paddy rice, post-harvest processing such as milling, parboiling, and quick-cooking, and home cooking and cooling processes can influence starch digestibility.

Considering the impact of postprandial glycemia on health and in disease prevention and the fact that low glycemic indices are preferable over high ones, Boers et al. [46] performed a systematic search of the literature characterizing the range of postprandial glucose responses to rice and the primary intrinsic and processing factors known to affect such responses. They reported that the milling process shows a clear effect when compared at identical cooking times, with brown rice always producing a lower postprandial glucose and postprandial insulin response than white rice. However, they concluded that at the longer cooking times, normally used for the preparation of brown rice, smaller and inconsistent differences are observed between brown and white rice.

Musa-Veloso et al. [47] conducted a systematic review and meta-analysis of randomized controlled trials comparing the effects of wholegrain wheat, rice, and rye with those of each grain's refined counterpart on postprandial blood glucose area under the curve (AUC). The consumption of intact (wholegrain) rice, compared with white rice was associated with a significant reduction in blood glucose AUC so they concluded that wholegrain rice significantly attenuates the postprandial blood glucose response.

Recently, RamyaBai et al. [48] studied the glycemic index in association with the microstructure of four cereal grain foods determined by scanning electron microscopy and concluded that wholegrain or wholemeal flour may not necessarily be low in glycemic index. Intact wholegrain foods are a healthier alternative to milled wholegrains. They also noted that instant quick-cooking brown rice exhibited a high glycemic index, due to the processing method. Regular brown rice may be a healthier option.

6. Brown Rice and Cancer

Intake of wholegrains and higher levels of serum enterolactone have been related to reduced risk for cardiovascular diseases and some cancers and maybe connected to the higher amount of lignans present in the outer layers of wholegrains. Jacobs Jr et al. [49] carried out a crossover feeding study in which overweight, hyperinsulinemia, non-diabetic men and women ate wholegrain foods based on wheat, oats, and rice for 6 weeks. They concluded that serum enterolactone concentrations can be raised by eating a diet rich in wholegrains.

Cereal phenolic extracts have been investigated for their potential anticancer properties. One possible mechanism is the induction of apoptosis which is characterized by cell shrinkage, protein fragmentation, and DNA degradation followed by rapid engulfment of cell debris by macrophages. Rao et al. [50] studied the ability of phenolic extracts from pigmented rice to induce apoptosis in colorectal cancer cells SW480 and concluded that phenolic compounds present in purple rice may suppress cancer cell proliferation through the activation of apoptosis.

In 2016 Zhang et al. [51] published a scientific paper on rice consumption and cancer incidence in US men and women. They had access to several long-term studies which included a total of 45,231 men and 160,408 women who were free of cancer at baseline.

They found that long-term consumption of total rice, white rice, or brown rice was not associated with risk of developing cancer in US men and women.

Farvid et al. [52] evaluated individual grain-containing foods and whole and refined grain intake during adolescence, early adulthood, and premenopausal years in relation to breast cancer risk in the Nurses' Health Study II in the USA which included 90,516 premenopausal women aged between 27 and 44 years. They found that brown rice consumed by adults was associated with lower risk of overall and premenopausal breast cancer and they concluded that high wholegrain food intake may be associated with lower breast cancer risk before menopause. In a previous study, published in 2010 by Sung et al. [53], the association between the risk of breast cancer and total carbohydrate intake, glycemic load, and glycemic index and different types of rice consumption was studied in a hospital-based case-control/clinical study in South Korea. They found that a higher consumption of mixed brown rice may be associated with a reduced risk of breast cancer, especially in overweight postmenopausal women.

In a recent paper by Shin et al. [54] the association between dietary patterns and multi-grain rice intake and the risk of breast cancer was also studied in a large-scale prospective cohort study in Korean women. Their study also suggests that a multi grain rice diet may be associated with lower risk of breast cancer in Korean women.

Grains are exposed to arsenic found in the soil and water and it is well known that this element can be dangerous for human health [55]. Brown rice contains more arsenic than white rice. In a study published in 2019 by Signes-Pastor et al. [56] the relationship between rice consumption and incidence of bladder cancer in the United States population was considered on the basis that inorganic arsenic is an established human bladder carcinogenic. They concluded that while their findings do not provide clear evidence that rice contributes to the overall incidence of bladder cancer, the potential risk of brown rice consumption in the presence of elevated arsenic in water warrants further investigation in larger studies.

With regard to colorectal cancer risks, Tantamango et al. published a paper in 2011 [57] on foods and food groups associated with the incidence of colorectal polyps and concluded that consumption of brown rice at least once per week reduced the risk by 40%.

7. Pigmented Rice

The issue of wholegrain rice consumption is particularly relevant for pigmented rice where a substantial proportion of nutritionally valuable components is located in the bran layers and in the germ.

The potential health benefits of this kind of rice have been primarily attributed to the presence of polyphenols which have been demonstrated to have antioxidant [58], anti-inflammatory [59], and anti-adipogenic potential [60] in *in vitro* and *in vivo* experiments with murine models. Moreover, human dietary intervention studies have shown wholegrain pigmented rice consumption to reduce serum low density lipoprotein, total cholesterol, and total triglyceride levels [61].

Anthocyanins and proanthocyanidins are two major classes of bioactive phenolic compounds that have been identified in cereal grains which are mainly present in the pericarp of pigmented varieties [62]. The most abundant anthocyanins were identified as cyanidin 3-glucoside in black and red rice [63]. They are flavonoids well recognized as antioxidants and for their health-beneficial effects such as reduction in the risk of obesity, diabetes, cardiovascular diseases, and certain types of cancer [64–68].

Consumption of the purple rice pericarp as a supplement was reported to inhibit atherosclerotic plaque formation in mice more strongly than the same product from non-pigmented rice due to the reduction of cholesterol accumulation, oxidative stress, and inflammation [69].

A wide variation in anthocyanin accumulation has been reported in different genotypes from different countries. For example, in Thailand, anthocyanin in different purple rice varieties ranged from 9.8 to 245.4 mg 100 g^{-1} [70].

In addition to variety, cultivation conditions can have an impact on the content of bioactive substances in pigmented rice. Jaksomsak at al. [71] in Thailand studied, for two years, grain anthocyanin, zinc, and iron concentrations of eleven purple rice varieties grown under wetland and aerobic conditions. They found that wetland conditions were more favorable than aerobic culture for intense pigmentation in the production of purple rice as well as higher Zn and Fe concentrations.

A study by Rao et al. [62] in Australia, found that the cultivation location had a significant impact on phenolic composition and antioxidant activity of pigmented rice cultivars, and this is important for breeding high-value rice varieties with specific phenolic compositions.

In the case of pigmented rice, the milling process from paddy grain to polished white rice was reported to remove more than 90% of free phenolics from black and red rice grains [72]. Sapna et al. [73] also found that milling and thermal treatments induce changes on phenolic components and antioxidant activities of pigmented rice flours which depend on the studied variety.

Different domestic cooking methods can affect the physical appearance, phenolic content, starch physicochemical characteristics, and starch digestibility of pigmented rice. Zaupa et al. [74], in studying the total antioxidant capacity (TAC) and polyphenolic compounds of differently pigmented rice varieties and their changes during domestic cooking, found that the content of these compounds and the TAC decreased after cooking in all the three studied varieties but to a lesser extent after the risotto method which allows a complete absorption of water. Melini and Acquistucci [75] reported on the anthocyanin content in raw and cooked Khao Nim Thai black rice and Jasmin Thai red rice. Cooking involved water absorption. For the black rice they observed a significant increase in the cyanidin-3-O-glucoside possibly because of an increased pigment extraction, whereas they observed a significant decrease in peonidin-3-O-glucoside possibly due to a degradation of pigments during cooking or to a low sensitivity in the methods used.

Aalim and Luo [76] recently investigated the effects of roasting and frying on brown and red wholegrain rice. Red rice was characterized by superior phenolic content and the presence of proanthocyanidins which were enhanced by roasting. However, brown rice showed greater phenolic stability compared with red rice. Chromatographic separation showed that red rice was dominated by protocatechuic acid and (-)-epicatechin, whereas brown rice showed high contents of p-hydroxybenzoic acid, (-)-epicatechin, and syringaldehyde.

8. Conclusions

Polished white rice consumption provides, worldwide, most of the daily calories from rice, particularly in Asian countries. In Asian populations where rice is a staple food, high white rice consumption has been associated with elevated risks of developing diabetes and metabolic syndrome and in the USA some prospective cohort studies have linked regular consumption of white rice with a higher risk of type 2 diabetes [77].

These and other studies exploring the content of health-beneficial components in brown rice have prompted the scientific community to promote wholegrain consumption in place of refined grains. We must also consider that, to date, new rice varieties biofortified with nutrients such as iron, zinc, and beta-carotene have been produced, useful for improving deficiencies such as anemia, stunted growth, and xerophthalmia in some populations. It is clear that benefits are maximum if rice is consumed in its wholegrain version as brown rice [78].

However, brown rice, as we have seen, is not favored by most of the populations who prefer the white polished rice. It was recently observed by some researchers that the intervention of nutritional information improves the lower brown rice attributes with respect to white rice [79], so consumer education campaigns can be seen as useful in promoting wholegrain rice consumption.

Opportunities for enhancing the texture and nutritional quality of brown rice also come from the innovative processing techniques previously described which should also aim at being low-cost. Some of these techniques have only been applied at laboratory or

pilot plant scale and their application at the industrial scale needs further investigation even if they appear very promising.

Another important challenge for brown rice comes from the fact that its shelf life is shorter than white rice at room temperature because of oxidation phenomena of lipids present in the germ and bran layers. Efficient and cost-limited storage and packaging techniques to extend shelf-life and stability of wholegrain rice are also necessary.

We must also consider that most of the scientific evidence on the health benefits of wholegrain rice comes from compositional, in vitro, or in vivo studies with animal models. Results are very encouraging but more studies involving human subjects are needed to assess and validate the role of wholegrain rice in human nutrition.

Therefore, the promotion of wholegrain production and consumption must be tackled at several levels that involve agronomy, biochemistry, processing, storage, marketing, and consumer science. Finally, future rice breeding programs should take into account the preferable consumption of rice as wholegrain rice and focus on the quality traits that are related to this issue and that need to be considered.

The above-reported findings and considerations can be summarized as follows:

- The chemical composition of brown rice is very relevant for human nutrition.
- Cultivation techniques and post-harvest processing should aim at reducing contaminants in brown rice as much as possible.
- Shorter shelf life of brown rice should be extended by suitable processing and packaging techniques.
- Cooking quality and sensory attributes of brown rice need to be improved by applying innovative processing technologies.
- Domestic cooking methods are important for maintaining nutritionally positive attributes.
- Consumer education campaigns could help in increasing brown rice consumption.
- More studies on the evaluation of brown rice in human subjects are needed.
- Breeding could help in providing rice varieties for wholegrain human consumption.

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