Review Article
Food Science and Technology

ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.5327/fst.00292

Rice (*Oryza sativa* L.) and its products for human consumption: general characteristics, nutritional properties, and types of processing

Bruna Lago TAGLIAPIETRA[1], Camille Flores SOARES[2], Maria Teresa Pedrosa Silva CLERICI[1]*

Abstract
Rice (*Oryza sativa* L.) is one of the most important cereals globally, serving as an energy source for approximately 50% of the world's population. In this review, we present and discuss the main aspects related to its characteristics, nutritional properties, and the types of processing carried out by the food industry. The nutritional composition of the grains varies according to the type of industrial process. After the husk is removed, both brown and polished rice can be obtained, and both types can also be parboiled. Products such as rice flour and starch have expanded the market for this cereal, as they are ingredients used in the production of various rice-based foods, owing to their hypoallergenic nature, gluten-free attributes, and mild flavor.

Keywords: *Oryza sativa* L.; processing; brown, polished, parboiling; nutritional quality; rice flour, starch.

Practical application: Encourage research, consumption by the population, and safe and sustainable processing of rice.

1 INTRODUCTION

The dietary habits of the population have undergone significant changes in recent decades, especially concerning the rise in the consumption of processed foods. However, there are fundamental foods that continue to be a constant presence on consumers' tables, regardless of passing trends. A notable example is rice (*Oryza sativa* L.), whose consumption spans two-thirds of the global population, serving as a staple for about 50% of the world's population (FAO, 2022). Both its agricultural production and industrialization, as well as consumption, are undeniably the most important economic activity on the planet, as nearly half of the world's population consumes rice at least once a day (Wang et al., 2023).

For approximately half of this population, including various countries in Latin America, Asia, and the Pacific Islands, rice plays a crucial role as the main energy source in the diet (Zafar & Jianlong, 2023). This popularity is attributed, in large part, to the financial accessibility of rice, its ease and quick preparation, and its versatility, as it pairs well with various cooking methods (Das et al., 2023).

Rice not only feeds a large number of people but also constitutes the majority of the diet for many low-income individuals, making its nutritional value crucial in the diet (Bhattacharya, 2013). When consumed as polished rice, it is the primary source of starchy carbohydrates, providing quick energy when cooked, and is widely consumed in main meals. It contains approximately 7% protein, while other nutrients are present in quantities below 1–2%, as shown in Table 1. In terms of minerals, rice offers a variety, including magnesium, phosphorus, and calcium, as well as traces of iron, zinc, copper, and manganese (Verma et al., 2019).

However, the proportion of each nutritional component in rice is susceptible to various factors such as genetic variations, climatic conditions, fertilizer use, soil quality, processing, and storage (Zhou et al., 2002). This sensitivity can result in grains with distinct nutritional profiles (Fresco, 2005). Various post-harvest processing methods, such as polishing and/or parboiling, have the potential to impact the chemical composition of rice, leading to variations in measures relevant to nutrition. These variations, in turn, can affect the nutrient content in the diet.

In addition to consuming rice in its grain form, it is transformed into derivatives such as flour and starch, which are utilized by the food industry. Rice flour is gluten-free, making it a suitable alternative for individuals intolerant or sensitive to this protein (Qian & Zhang, 2013). In the food industry, it is used in gluten-free products such as bread, cakes, cookies, and pasta (Clerici & El-Dash, 2006). On the contrary, rice starch is employed as a thickener, stabilizer, and texture agent in a variety of food products. Its ability to form gels under specific processing conditions is suitable for enhancing the consistency and sensory quality of processed foods (Tong & Bao, 2018).

Considering this overview that underscores the relevance of rice, the objective of this review is to address the main aspects regarding its agronomic characteristics, nutritional properties, and the types of processing conducted by the food industry.

2 AGRONOMIC IMPORTANCE

Rice is an annual grass that encompasses 24 species of the *Oryza* genus, of which only two have become agronomically productive and important for human consumption: *Oryza sativa* of Asian origin and *Oryza glaberrima* of African origin (Vaughan,

Received 01 Mar., 2024.
Accepted 16 Mar., 2024.
[1]*Universidade Estadual de Campinas, School of Food Engineering, Department of Food Science and Nutrition, Campinas, São Paulo, Brazil.*
[2]*Latin American Fund for Irrigated Rice, Palmira, Colômbia.*
*Corresponding author: mclerici@unicamp.br

1994). Of the two cultivated species, sativa is the most widely used and can be classified into three widely cultivated varieties:

- *Indica:* This is a long and slender grain used in tropical and subtropical Asia, South, and North America. The high amylose content, associated with a lower amount of amylopectin, gives this variety a less sticky consistency (Wei & Huang, 2018). This variety has a firmer and glassy texture (Kowsalya et al., 2022);
- *Japonica:* This is a short/medium and rounded grain cultivated in temperate regions such as Japan and northern China. This type of rice provides a softer and stickier texture due to higher amounts of amylopectin, contributing to the adherence, a characteristic of the grains, and the opacity of the final product (Kowsalya et al., 2022; Wei & Huang, 2018);
- *Javanica:* This is a medium grain cultivated in the Philippines and the mountainous areas of Madagascar and Indonesia (IRRI, 2013).

Currently, rice is cultivated in more than a hundred countries, producing around 500 million tons of paddy rice annually, distributed over approximately 165 million hectares (FAO, 2022). Across the world, 93 million hectares of lowland irrigated rice fields provide 75% of global rice production (Lampayan et al., 2015). Some areas in South Asia, parts of Southeast Asia, and all of Africa use rainfed lowland agriculture, responsible for producing 20% of global rice. Upland rice cultivation under rainfed conditions accounts for 4% of the world's total rice production (IRRI, 2013). Given that 75% of production is under irrigation, rice is responsible for 30% of global irrigation water use, as well as 14% of fertilizers and 10% of pesticides (Grube et al., 2011; Heffer, 2013). In addition, it is a significant source of greenhouse gas emissions, accounting for 30% of methane (CH_4) and 11% of nitrous oxide (N_2O) in global agriculture (IPCC, 2021; Linquist et al., 2012).

Brazil, which is ranked as the ninth largest global producer, lags behind powerhouses such as China with 150.5 million tons, India, and Indonesia, as well as other prominent Asian countries (CONAB, 2021). In terms of production in South America, Brazil takes the lead, accounting for over 75% of the total production in Mercosur, surpassing Uruguay, Argentina, and Paraguay, respectively. The most prominent Brazilian state in this scenario is Rio Grande do Sul, leading production with an annual average of 8.1 million tons (CONAB, 2021).

3 RICE PROCESSING

Rice processing is a procedure aimed at separating rice grains from straw, husk, and impurities, resulting in final products ready for consumption. Various products are obtained from this process, with the main ones described below.

3.1 Brown rice

Derived from the initial processing stage, after dehusking, brown rice retains the bran layer and germ (Figure 1). This gives brown rice a higher content of fiber, B-complex vitamins, and antioxidant minerals and is considered a more nutritious option compared with white rice (Wu et al., 2023). However, it is more susceptible to degradation due to the presence of lipids and enzymatic activity (Lang et al., 2020).

In recent years, brown rice has shown an increase in consumption due to its nutritional and health benefits, such as reducing cardiovascular diseases (Ti et al., 2014), lowering postprandial glycemic response (Wu et al., 2013), inhibiting LDL-C synthesis due to its abundant oryzanol content, and being associated with a reduced risk of type 2 diabetes mellitus (Imam et al., 2012). Despite this, brown rice is not widely consumed due to its lower culinary performance, rough texture (Ti et al., 2014), cost-effectiveness, and dietary habits of the population. These factors can be addressed by promoting the consumption of brown rice and its inclusion in basic food baskets, school

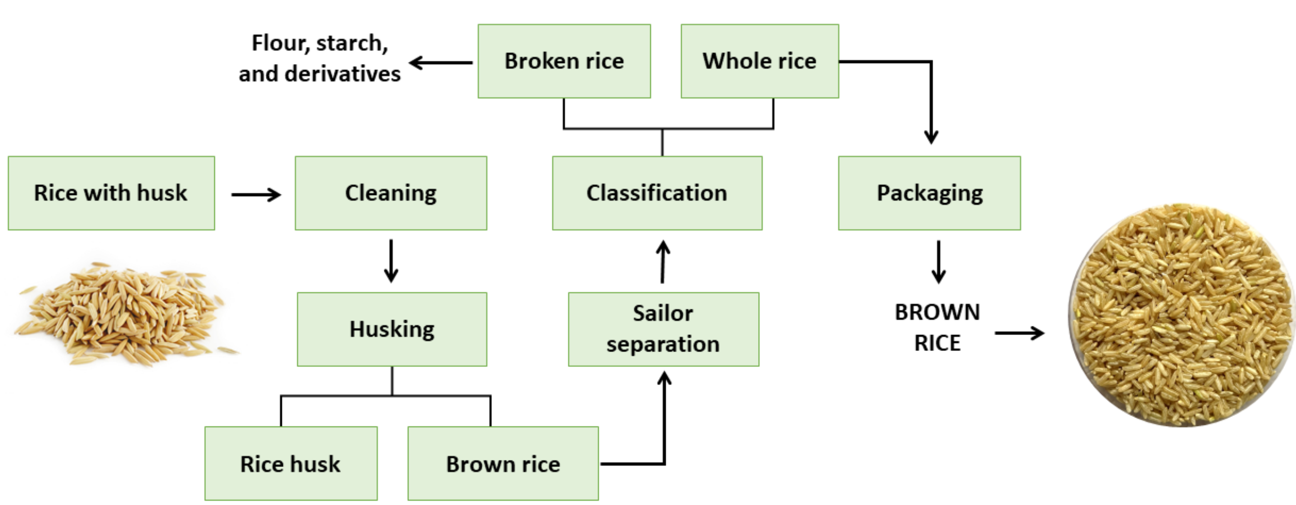


Figure 1. Conventional brown rice processing process.

meals, hospital meals, and popular restaurants, with subsidies and training for handlers who can make it more palatable to consumers, reviving the habit of its consumption, which was lost with industrialization.

Recently, RDC No. 712, dated July 1, 2022 (ANVISA, 2022), established labeling requirements for foods to be identified as "whole foods." It was established that for this expression to be highlighted on product labels, it needs to contain a minimum of 30% whole ingredients, and the quantity of whole ingredients must exceed the quantity of refined ones, which can be an incentive for the use and increased consumption of whole grains.

When focusing on sustainability in food production and environmental benefits, it is essential to highlight that brown rice production can be more sustainable, as it requires fewer processing steps (Figure 1), resulting in lower consumption of water and energy compared with the rice polishing process (Figure 2), which requires more steps and inputs, and also yields a higher amount of whole grains.

3.2 Polished white rice

White rice is a significant source of starch and carbohydrates, which is the most common and consumed form of rice in many cultures around the world (Oliveira & Amato, 2021). The conventional process (Figure 2) involves cleaning, dehusking, and separating paddy grains (grains that remain with husk are separated from dehusked ones based on density difference), followed by milling (the stage where the pericarp and germ, which transform into bran, are removed) and polishing, with the purpose of enhancing the final appearance of the product, giving it a glossy and scratch-free look (Ferreira et al., 2020). After these stages, the rice is classified, where broken grains are separated and subsequently categorized, as per Brazilian regulations.

Normative Instruction No. 06, dated February 16, 2009 (Brasil, 2009), classifies grains into three classes:

- long slender: grains with a size equal to or greater than 6 mm;
- long: grains with a size greater than 6 mm;
- medium: grains with a size smaller than 6 mm and greater than 5 mm;
- short: grains with a size smaller than 5 mm. Grains with a size smaller than 4.49 mm are classified as broken.

In this classification stage, grains with defects (chopped, stained, damaged, and scorched grains) are also removed using optical sensors for identification and separation based on color, where grains with a different color from the standard are separated from the rest (Lang et al., 2020). Subsequently, packaging is carried out and is considered the finalization of the industrial process.

3.3 Parboiled rice

The parboiling process is a pre-cooking technique for rice grains while still in the husk before undergoing traditional processing to become white rice. As illustrated in Figure 3, this method involves three main stages: hydration, steaming, and drying.

The hydrothermal parboiling process involves the following operations (Lang et al., 2020), as demonstrated in Figure 3 and described below:

- *Hydration:* The husked grains are immersed in hot water, around 60–70°C for several hours (4–7 h). Water is absorbed by the grains, increasing their moisture content (optimal moisture for parboiling is 30%). Temperatures above 60°C discourage the enzymatic activity of α-amylases, which is responsible for breaking starch chains and increasing reducing sugars, causing darkening via the Maillard reaction (Oliveira & Amato, 2021);

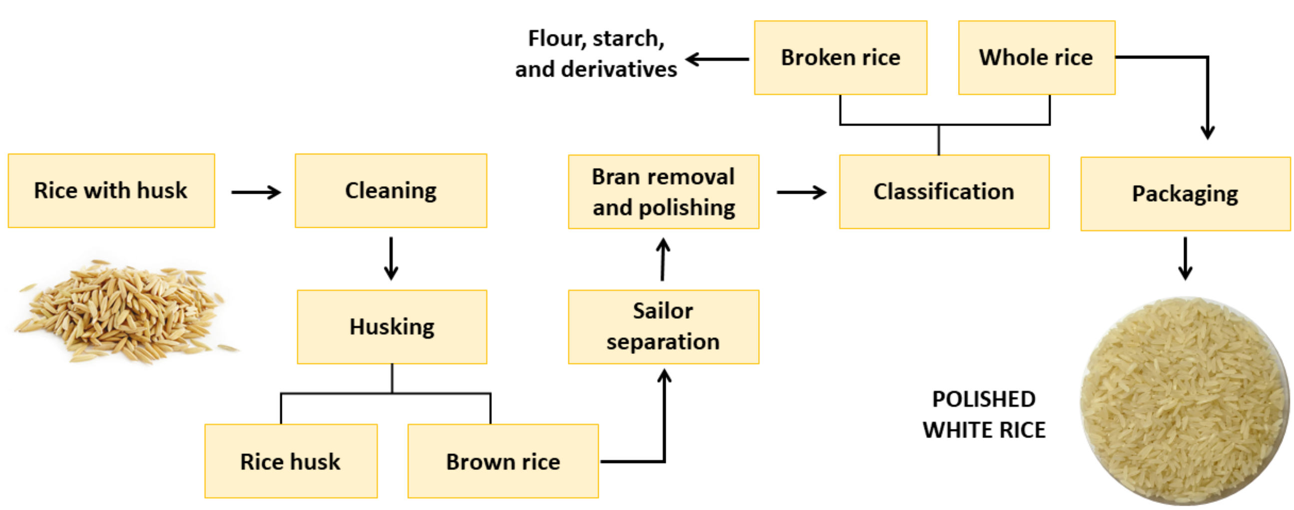


Figure 2. Conventional process of polishing white rice.

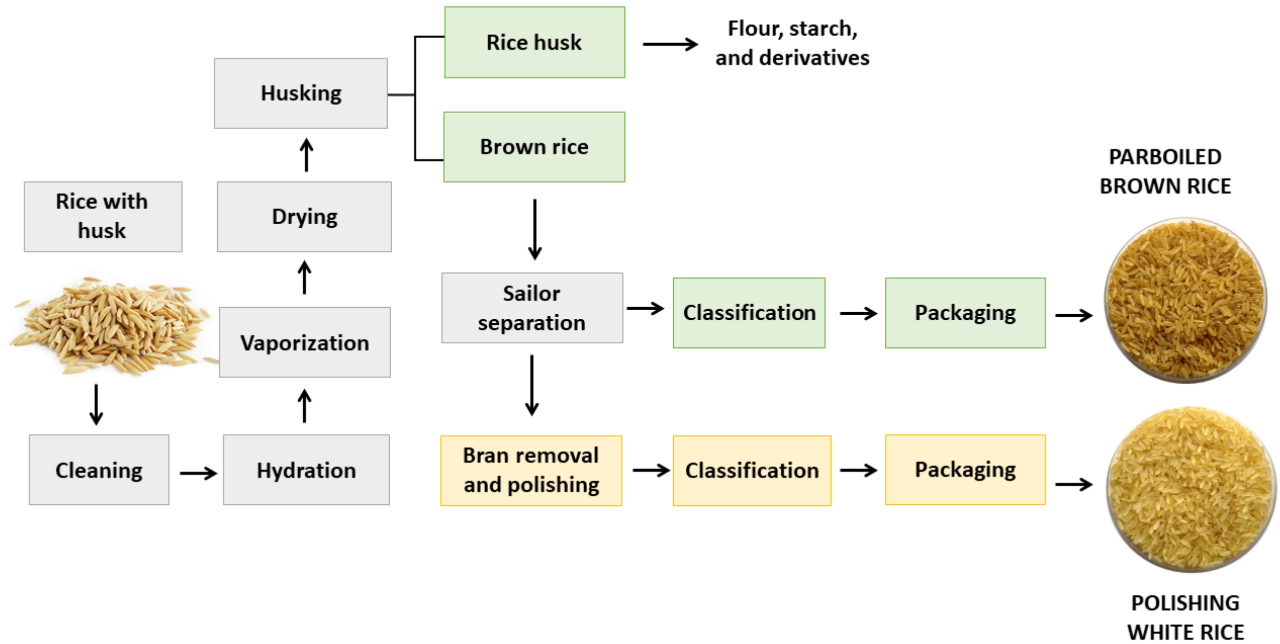


Figure 3. Conventional parboiling process of brown and white rice.

- *Steaming*: After immersion, the moist grains are subjected to steaming. They are exposed to high-pressure water vapor. The heat from the steam penetrates the grains, causing the gelatinization of the starch in the endosperm. Gelatinization transforms starch into a firmer form resistant to overcooking;
- Drying: Parboiled grains undergo a drying process to remove the moisture acquired during hydration and steaming, aiming to reduce the moisture to an optimal level for processing (about 13%) and inhibit the growth of microorganisms and insects.

After completing these stages, parboiled rice grains are dehusked and polished, transforming them into white grains ready for consumption.

The advantages of the parboiling process include minimizing grain breakage during processing, increasing the yield of whole grains, resistance to pests and moisture, and non-clumping, resulting in lower solid loss (Bhattacharya, 2013). The grains absorb more water during cooking, increasing volume (Lang et al., 2020). There is partial or total inactivation of enzymes, eliminating biological processes such as germination and fungal growth (Bhattacharya, 2013).

It is worth noting that the parboiling process not only alters the texture of rice, making it more resistant to breakage during cooking, but also preserves some nutrients that would normally be lost during the processing of white rice. On the contrary, the disadvantages of the parboiling process include the development of aroma and flavor, the possibility of fermentation due to soaking, solubilization of albuminoids due to maceration time, and high temperature (Bhattacharya, 2013).

4 STRUCTURE AND CHEMICAL COMPOSITION OF GRAINS

4.1 Grain structure

Understanding the morphological characteristics of the grain is essential for comprehending the physical and chemical properties of rice grain (Walter et al., 2008). Also known as a caryopsis, the grain consists of the pericarp, endosperm, and embryo or germ, enclosed by a non-edible husk that is hard and siliceous, consisting of two “modified” leaves, the palea and lemma (Juliano & Tuaño, 2019) (Figure 4).

From Figure 4, it can be observed that the rice husk protects the caryopsis (grain) and has been associated with the grain’s resistance to insect infestation during storage, besides shielding it from primary pests. Rice husks stored under controlled humidity conditions can be stored for years. The outermost layers, namely, aleurone and pericarp, exhibit the highest concentrations of proteins, lipids, fibers, minerals, and vitamins, while the endosperm consists of starch and proteins, and the germ is the region with the highest lipid concentration (Juliano & Tuaño, 2019; Walter et al., 2008).

4.2 Nutritional composition

The composition varies according to the type of industrial process. The processing operations, discussed in the subsequent section, may involve the extraction of the germ and bran, resulting in decreased levels of proteins, lipids, and minerals (Kowsalya et al., 2022).

Carbohydrates make up about 75–80%, with starch representing approximately 90% of these, which is the predominant component, accompanied by fibers and free sugars such as fructose, raffinose, and glucose (Arsha et al., 2021). The endosperm is composed of starch and proteins, while the bran contains fibers and the germ contains lipids, with small amounts of other types of carbohydrates (Walter et al., 2008).

Starch is a polysaccharide composed of amylose and amylopectin chains. The ratio of these chains varies among different genotypes, allowing the classification of grains into categories such as waxy (99% amylopectin), very low amylose content (2–12%), low (12–20%), intermediate (20–25%), and high (25–33%) (Juliano & Tuãno, 2019). The amylose content is a parameter used to determine the technological and consumption quality of rice. Generally, grains with higher amylose content exhibit a firmer texture after cooking, being preferred in various regions, including Brazil. However, other factors such as the structure of amylopectin chains and protein content also influence this characteristic (Ong & Blanshard, 1995).

The metabolic response during rice consumption is related to the amylose and amylopectin ratio, as a higher amylose content in rice, as well as in other starchy foods, is associated with a lower glycemic and insulinemic response (Miller et al., 1992). These physiological variations are of significant interest in the prevention and treatment of diseases such as diabetes, as a reduction in carbohydrate digestion and absorption contributes to maintaining regular blood glucose levels (Mahan et al., 2013).

Table 1 presents the nutritional composition of different types of rice, where it is observed that, in general, the highest carbohydrate levels are found in polished rice.

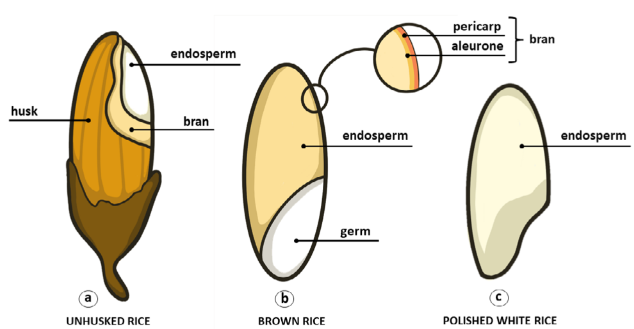


Figure 4. Morphological characterization of rice grain in the husk, brown, and polished white.

The protein content of rice can vary depending on the type of processing employed (Table 1), as well as the cultivation method, nitrogen fertilization, solar radiation, and temperature during grain development (Walter et al., 2008). The main proteins found in rice are prolamins and glutelins. Similar to other cereals, rice has lysine as the limiting amino acid and significant amounts of cysteine and methionine. Nutritionally, the combination with beans (2:1) provides all essential amino acids to the body. In this context, identifying cultivars with higher protein content may be relevant to develop strategies aimed at reducing protein-energy malnutrition. Furthermore, to improve the amino acid profile, research has been conducted to increase the concentration of certain amino acids, such as lysine, methionine, and cysteine, through genetic modification (Zafar & Jianlong, 2023).

The lipids in rice are predominantly composed of triglycerides, phospholipids, and free fatty acids, deposited mainly in the germ (one-third of the total germ) (Tong & Bao, 2018). As brown rice has a higher lipid concentration (Table 1), it is more susceptible to lipid oxidation than polished white rice, which has reduced lipid content due to polishing. Regarding fatty acids, 95% of the composition is represented by palmitic acid (16:0), oleic acid (18:1), and linoleic acid (18:2), which play important roles in various physiological processes and, as they are not synthesized by the body, need to be ingested through the diet (Walter et al., 2008).

Although lipids constitute a small proportion of rice compared with other elements such as carbohydrates and proteins, they play an important role in determining the taste and nutritional value of rice, as they have a significant correlation with sensory attributes (Park et al., 2012). Additionally, changes in the fatty acid profile are the main factor affecting aging during grain storage, as lipids undergo oxidation and degradation under the action of endogenous and microbial lipases during storage, resulting in a deterioration of taste and palatability (Tong & Bao, 2019).

Minerals are present in the rice grain mainly in the outer layers; consequently, whole grains have a higher mineral content compared with polished ones. In the husked grain, silicon is the dominant component, while in whole and polished grains, phosphorus, potassium, and magnesium stand out (Walter et al., 2008). The mineral content is influenced by cultivation conditions, geographical region, and processing (Du et al., 2013). For example, in parboiling, minerals in the aleurone layer (Figure 1) are solubilized in water and migrate from the outer layer of the

Table 1. Nutritional composition of different types of rice.

Types of rice	Composition (g/100 g b.s.)[1]					References
	Carbohydrates	Dietary fiber	Protein	Lipids	Ashes	
Polished white rice	87.53	2.87	8.94	0.36	0.30	Denardin et al. (2014)
	83.70	nd	10.76	2.76	1.21	Yuliana and Akhbar (2020)
Polished parboiled rice	85.08	4.15	9.44	0.69	0.67	Denardin et al. (2014)
	81.07	4.18	10.73	1.07	1.24	Fagundes (2010)
Brown rice	74.12	11.76	10.46	2.52	1.15	Denardin et al. (2014)
	73.22	10.14	8.09	1.82	1.14	Saleh et al. (2019)
Parboiled brown rice	80.00	6.67	9.65	3.90	nd	Amostra comercial

[1]Data transformed from wet to dry basis from the sources consulted, for comparison; b.s: dry basis; nd: not determined.

grain to its interior (endosperm), resulting in an increase in mineral content (Lang et al., 2020).

Rice mainly contains B-complex vitamins and α-tocopherol (vitamin E), and like minerals, the highest concentrations are available in the outer part of the grain (Walter et al., 2008). Both for vitamins and minerals, biofortification emerges as an effective process to increase the levels of micronutrients present in rice and is a sustainable and viable strategy to alleviate micronutrient deficiencies in less privileged people with limited access to the food market (Ghosh et al., 2019; Paine et al., 2005). Among these research efforts, one of the main focuses is to increase the carotenoid levels in rice grains (Endo et al., 2019; Paine et al., 2005) through the combination of molecular biology and genomic approaches. Bai et al. (2016) managed to increase the total carotenoids up to 25.83 μg/g through genetic modification.

Another important component is the bioactive compounds present in rice, which are mainly found in the form of phenolics, divided into phenolic acids, flavonoids, condensed tannins, lignins, and lignans (Soto-Vaca et al., 2012). Phenolics are synthesized in rice plants in response to ecological and physiological stresses, such as pathogens, insects, and ultraviolet radiation (Park et al., 2012). Depending on the grain color, i.e., the variety, different concentrations and compounds may be present. For example, anthocyanins are the main pigment responsible for the black and red color of rice grains (Kowsalya et al., 2022) and show a higher concentration of bioactive compounds compared with white rice varieties. Bioactive compounds have gained increasing attention due to their known physiological functions, as they can exert antioxidant effects and help prevent cellular damage (Ryan, 2011).

Most rice is consumed in the form of cooked grains, but it has other uses, such as bran in animal feed, oil extraction, obtaining flour, and starch for use in food and pharmaceutical products. The next section discusses functional and technological properties, focusing on rice flour and starch used in baking and extruded pasta, among others.

5 CONSUMER PRODUCTS

5.1 Rice flour

Rice flour, obtained from finely ground rice, plays a crucial role as a fundamental ingredient in the production of various rice-based foods, including noodles, bread, and cakes, among others (Rosell et al., 2021). Due to its hypoallergenic nature as a raw material and its white color and mild flavor, rice flour has seen significant expansion in its use (Baxter et al., 2014). The current trend emphasizes the development of an increasing variety of products incorporating rice flour, with the expectation of exploring more versatile manufacturing processes for the inclusion of new raw materials.

Rice flour can be produced from whole or broken rice grains (Tavares et al., 2012). In the context of sustainability, it is noteworthy that rice flour produced in Brazil is derived from broken rice, a by-product of the polishing of white rice, characterized by lower commercial value (Nabeshima & El-Dash, 2004). Valuing local production and expanding its use are fundamental factors in this scenario, considering that approximately 14% of rice grains are broken during milling processes (Castro et al., 1999).

Rice flour has several benefits and has found applications in various products, especially for patients with celiac disease, who are allergic to gluten, which is a wheat protein. Its non-allergenic nature represents a significant reason for the growing adoption of rice flour in the food industry (Kadan et al., 2003) (Figure 5).

The quality of rice flour depends greatly on the chemical profile inherent in each sample and also on its preparation method and the degree of gelatinization (Amagliani et al., 2016). For example, waxy rice flour is used in the food industry as a thickening agent for sauces and puddings, as it can prevent syneresis when these products are frozen, stored, and subsequently thawed, providing notable stability and versatility in culinary applications. Baby foods, beer, and breakfast cereals are mainly produced with low amylose (12–20%), and intermediate amylose (20–25%) rice is used for noodle production (Bao & Bergman, 2018).

5.2 Rice starch

Starch, constituting between 72 and 82% of the dry weight of the whole rice grain, emerges as the predominant composition in the grain (Biduski et al., 2018; Frei et al., 2003). Its main components are amylose and amylopectin, with amylopectin being a highly branched molecule with branching points through α-(1,6) linkages and generally representing 65–85% of the matter in starch granules. On the contrary, amylose is composed of glucose molecules linked by α-1,4 in long chains, with some α-1,6 branching points (Bao, 2019). Its linear nature confers unique properties, including the ability to form complexes with iodine.

The distinction between rice starch and flour lies in the removal of most proteins and lipids native to flour, resulting in a protein content in isolated rice starch generally of 0.5% or less. The interest in using rice starch is due to its mild flavor and creamy appearance in its gelatinized form and the small size of its granules, ranging from 3 to 8 μm (Bao & Bergman, 2018). This interest is mainly focused on the food industry as ingredients in desserts, baked goods, breakfast cereals, baby food, and hypoallergenic foods (Figure 5) and is also used as a fat substitute (Colussi et al., 2015).

The functional properties of rice starch, described below, play a crucial role in its final use (Bao, 2019).

- *Swelling Properties:* The starch granule swells several times its initial size as a result of the loss of crystalline order and water absorption inside the granular structure;

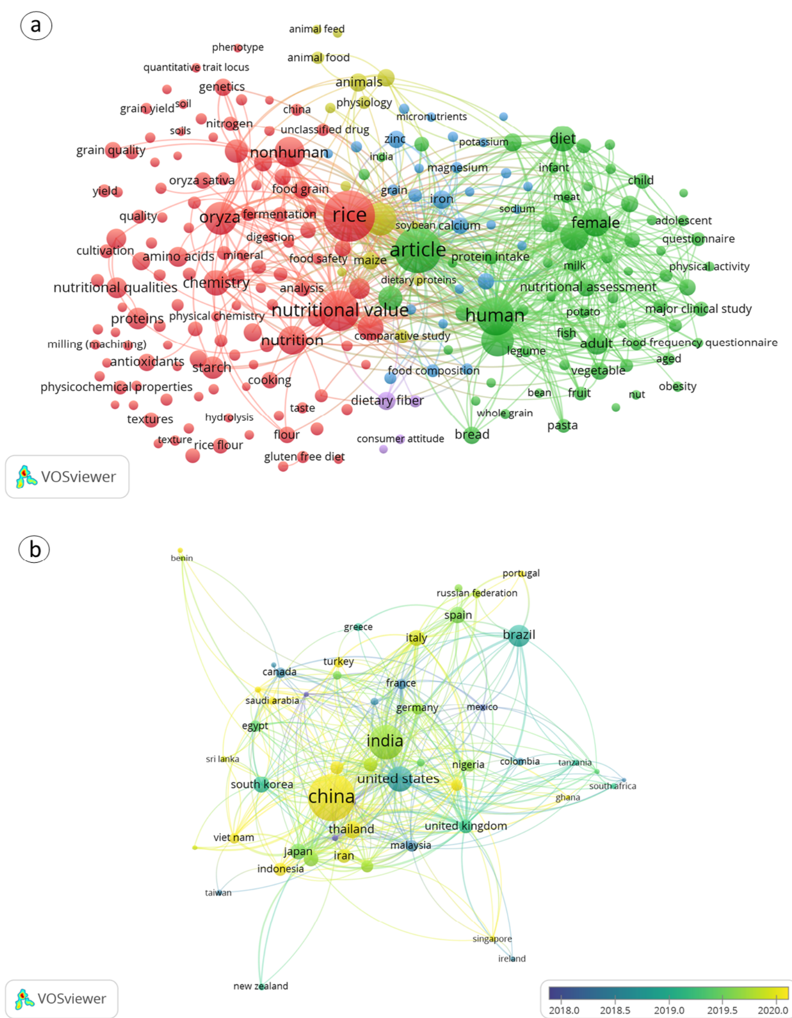
Figure 5. Products derived from rice flour and/or rice starch available in the market, namely: (A) whole grain rice pasta; (B) rice pasta; (C) whole grain rice biscuit.

- *Thermal Property:* Gelatinization, which is evidenced by irreversible changes such as granular swelling, loss of birefringence, and starch solubilization, is determined by differential scanning calorimetry (DSC), which measures gelatinization parameters such as onset, peak, and end temperatures, as well as the gelatinization enthalpy (ΔH). This property is essential for determining the rice cooking temperature;
- *Retrogradation Property:* It is a process in which a heated starch paste cools below the melting temperature of starch crystallites, resulting in increased viscosity, hardening of the gel, and texture. Amylose and amylopectin associate with swollen starch granules, contributing to long-term rheological and structural changes;
- *Starch Digestive Property:* Starch can be categorized as rapidly digestible (RDS), slowly digestible (SDS), and resistant (RS). AR is positively correlated with the amylose content in rice starch, while SDS decreases with increasing amylose content. SDS and RS are related to a slow increase in postprandial blood glucose levels over time compared with RDS, which is advantageous for satiety and diabetes control. Therefore, SDS is the most desirable type from a nutritional standpoint.

These characteristics highlight the relevance of rice starch in culinary applications and its implications for human health.

6 RESEARCH AND FUTURE TRENDS

Rice has been studied worldwide, with over 100,000 scientific publications in the last 10 years (SCOPUS, 2023). Figure 6 presents a network visualization map of publications on "rice" and "nutritional quality" from the last 10 years (2014–2024),



*Representation obtained through the VOSviewer software version 1.6.19, with data obtained from a search conducted on SCOPUS (December 2023) using the equation TITLE-ABS-KEY ("rice" AND "nutritional quality").

Figure 6. Network visualization map of publications on rice and nutritional quality, namely, (A) co-occurrence keyword clustering and (B) country co-authorship from 2014 to 2024.

where each color represents a cluster. During this period, 1524 scientific articles were found, which were divided into five areas of interest involving nutritional value (red), human consumption (green), micronutrients (blue), animal feed (yellow), and consumer attitudes and perception (purple) (Figure 6A). Most of these studies were conducted in Asian countries, led by China and India, followed by the United States and Brazil (Figure 6B).

7 GENERAL CONSIDERATIONS

Rice and its derivatives already have a consolidated potential as an ingredient in the food industry, offering improvements in the nutritional, technological, and sensory aspects of various products. However, continuing to promote and expand research that deepens nutritional composition is essential to determine potential health benefits. It is important to analyze the effects of processing on the nutritional and techno-functional characteristics of products based on rice flour or starch. This approach can promote the development of derivatives with higher added value, such as snacks with the addition of industry by-products or new ingredients, bakery products, and an ingredient of extreme importance to the industry due to the absence of gluten, which can create business opportunities, product innovation, and market expansion, benefiting both consumers and the food industry.

ACKNOWLEDGMENTS

The authors would like to thank the National Council for Scientific and Technological Development (CNPq), Brazil, for the scholarships awarded to B. L. Tagliapietra and M. T. P. Clerici (Processes 140805/2020-6 and 312660/2023-5, respectively). Additionally, the authors express gratitude to the Coordination for the Improvement of Higher Education Personnel (CAPES, financial code 001), Brazil, for supporting the Graduate Program in Food Technology at the Universidade Estadual de Campinas (UNICAMP), São Paulo, Brazil.

REFERENCES

Agência Nacional de Vigilância Sanitária (ANVISA) (2022). *RDC nº 712, 1 de julho de 2022.* dispõe sobre os requisitos de composição e rotulagem dos alimentos contendo cereais para classificação e identificação como integral e para destaque da presença de ingredientes integrais. ANVISA.

Amagliani, L., O'Regan, J., Kelly, A. L., & O'Mahony, J. A. (2016). Physical and flow properties of rice protein powders. *Journal of Food Engineering*, *190*, 1-9. https://doi.org/10.1016/j.jfoodeng.2016.05.022

Arsha, R. S., Rasane, P., & Singh, J. (2021). Rice: Bioactive compounds and their health benefits. *The Pharma Innovation Journal*, *10*(5), 845-853.

Bai, C., Capell, T., Berman, J., Medina, V., Sandmann, G., Christou, P., & Zhu, C. (2016). Bottlenecks in carotenoid biosynthesis and accumulation in rice endosperm are influenced by the precursor-product balance. *Plant Biotechnology Journal*, *14*(1), 195-205. https://doi.org/10.1111/pbi.12373

Bao, J. (2019). Rice starch. *Rice: Chemistry and Technology*, 55-108. https://doi.org/10.1016/B978-0-12-811508-4.00003-4

Bao, J., & Bergman, C. J. (2018). Rice Flour and Starch Functionality. *Starch in Food: Structure, Function and Applications*, 373-419. https://doi.org/10.1016/B978-0-08-100868-3.00010-X

Baxter, G., Blanchard, C., & Zhao, J. (2014). Effects of glutelin and globulin on the physicochemical properties of rice starch and flour. *Journal of Cereal Science*, *60*(2), 414-420. https://doi.org/10.1016/j.jcs.2014.05.002

Bhattacharya, K. R. (2013). Introduction: rice in historical and social perspectives. *Rice Quality*, 1-25. https://doi.org/10.1533/9780857092793.1

Biduski, B., Silva, W. M. F. da, Colussi, R., Halal, S. L. de M. El, Lim, L. T., Dias, Á. R. G., & Zavareze, E. da R. (2018). Starch hydrogels: The influence of the amylose content and gelatinization method. *International Journal of Biological Macromolecules*, *113*, 443-449. https://doi.org/10.1016/J.IJBIOMAC.2018.02.144

Brasil (2009). Ministério da Agricultura, Pecuária e Abastecimento. Aprova o Regulamento Técnico do Arroz, definindo o seu padrão oficial de classificação, com os requisitos de identidade e qualidade, a amostragem, o modo de apresentação e a marcação ou rotulagem. *Diário Oficial da União*.

Castro, E. M., Vieira, N. R. A., Rabelo, R. R., & Silva, S. A. (1999). *Qualidade de grãos em arroz*. Embrapa Arroz e Feijão.

Clerici, M. T. P. S., & El-Dash, A. A. (2006). Farinha extrusada de arroz como substituto de glúten na produção pão sem glúten. *Archivos Latinoamericanos de Nutrición*, *56*(3), 288-294.

Colussi, R., El Halal, S. L. M., Pinto, V. Z., Bartz, J., Gutkoski, L. C., Zavareze, E. da R., & Dias, A. R. G. (2015). Acetylation of rice starch in an aqueous medium for use in food. *LWT - Food Science and Technology*, *62*(2), 1076-1082. https://doi.org/10.1016/J.LWT.2015.01.053

CONAB (2021). *Grain supply and demand*. CONAB. Retrieved from https://www.conab.gov.br/info-agro/analises-do-mercado-agropecuario-e-extratividade/analises-do-mercado/oferta-e-demanda-de-graos

Das, M., Dash, U., Mahanand, S. S., Nayak, P. K., & Kesavan, R. K. (2023). Black rice: A comprehensive review on its bioactive compounds, potential health benefits and food applications. *Food Chemistry Advances*, *3*, 100462. https://doi.org/10.1016/j.focha.2023.100462

Denardin, C. C., Silva, L. P., Storck, C. R., & Nörnberg, J. L. (2004). Mineral composition of brown, parboiling and white rice cultivars. *Alimentos e Nutrição*, *15*(2), 125-130.

Du, J., Zeng, D., Wang, B., Qian, Q., Zheng, S., & Ling, H. Q. (2013). Environmental effects on mineral accumulation in rice grains and identification of ecological specific QTLs. *Environmental Geochemistry and Health*, *35*(2), 161-170. https://doi.org/10.1007/s10653-012-9473-z

Endo, A., Saika, H., Takemura, M., Misawa, N., & Toki, S. (2019). A novel approach to carotenoid accumulation in rice callus by mimicking the cauliflower Orange mutation via genome editing. *Rice*, *12*(1), 81. https://doi.org/10.1186/s12284-019-0345-3

Fagundes, G. A. (2010). *Effects of soaking time on technological and nutritional evaluation parameters of parboiled rice* [Master's Dissertation, "Eliseu Maciel" Faculty of Agronomy, Universidade Federal de Pelotas].

Ferreira, C. D., Oliveira, M., & Ziegler, V. (2020). *Tecnologia Industrial de Grãos e Derivados.* CRV.

Food and Agriculture Organization (FAO) (2022). *FAOSTAT online database*. FAO. Retrieved from http://faostat.fao.org/data

Frei, M., Siddhuraju, P., & Becker, K. (2003). Studies on the in vitro starch digestibility and the glycemic index of six different indigenous rice cultivars from the Philippines. *Food Chemistry*, *83*(3), 395-402. https://doi.org/10.1016/S0308-8146(03)00101-8

Fresco, L. (2005). Rice is life. *Journal of Food Composition and Analysis*, *18*(4), 249-253. https://doi.org/10.1016/J.JFCA.2004.09.006

Ghosh, S., Datta, K., & Datta, S. K. (2019). Rice vitamins. *Rice: Chemistry and Technology*, 195-220. https://doi.org/10.1016/B978-0-12-811508-4.00007-1

Grube, A., Donaldson, D., Kiely, T., & Wu, L. (2011). *Pesticides Industry Sales and Usage: 2006 and 2007 Market Estimates*. U.S. Environmental Protection Agency. Retrieved from http://nepis.epa.gov/Adobe/PDF/3000659P.pdf

Heffer, P. (2013). *Assessment of Fertilizer Use by Crop at the Global Level*. International Fertilizer Industry Association. Retrieved from www.fertilizer.org/ifa/Home-Page/LIBRARY/Publication-database

Imam, M. U., Azmi, N. H., Bhanger, M. I., Ismail, N., & Ismail, M. (2012). Antidiabetic properties of germinated brown rice: A systematic review. *Evidence-Based Complementary and Alternative Medicine*, *2012*, 816501. https://doi.org/10.1155/2012/816501

International Rice Research Institute (IRRI) (2013). *World Rice Statistics 2013*. IRRI.

IPCC (2021). *Climate Change: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Juliano, B. O., & Tuaño, A. P. P. (2019). Gross structure and composition of the rice grain. *Rice: Chemistry and Technology*, 31-53. https://doi.org/10.1016/B978-0-12-811508-4.00002-2

Kadan, R. S., Bryant, R. J., & Pepperman, A. B. (2003). Functional properties of extruded rice flours. *Journal of Food Science*, *68*(5), 1669-1672. https://doi.org/10.1111/j.1365-2621.2003.tb12311.x

Kowsalya, P., Sharanyakanth, P. S., & Mahendran, R. (2022). Traditional rice varieties: A comprehensive review on its nutritional, medicinal, therapeutic and health benefit potential. *Journal of Food Composition and Analysis*, *114*, 104742. https://doi.org/10.1016/J.JFCA.2022.104742

Lampayan, R. M., Rejesus, R. M., Singleton, G. R., & Bouman, B. A. M. (2015). Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Research*, *170*, 95-108. https://doi.org/10.1016/J.FCR.2014.10.013

Lang, G. H., Goebel, J. T., & Oliveira, M. (2020). Tecnologia e industrialização de grãos de arroz. In C. D. Ferreira, M. Oliveira & V. Ziegler (Eds.). *Tecnologia Industrial de Grãos e Derivados* (p. 98-122). CRV.

Linquist, B., Van Groenigen, K. J., Adviento-Borbe, M. A., Pittelkow, C., & Van Kessel, C. (2012). An agronomic assessment of greenhouse gas emissions from major cereal crops. *Global Change Biology*, *18*(1), 194-209. https://doi.org/10.1111/j.1365-2486.2011.02502.x

Mahan, L. K., Escott-Stump, S., & Raymond, J. L. (2013). *Krause: Alimentos, nutrição e dietoterapia* (13ª ed.). Elsevier.

Miller, J. B., Pang, E., & Bramall, L. (1992). Rice: a high or low glycemic index food? *The American Journal of Clinical Nutrition*, *56*(6), 1034-1036. https://doi.org/10.1093/AJCN/56.6.1034

Nabeshima, E. H., & El-Dash, A. A. (2004). Modificação química da farinha de arroz como alternativa para o aproveitamento dos subprodutos do beneficiamento do arroz. *Boletim do Centro de Pesquisa de Processamento de Alimentos*, *22*(1), 107-120. https://doi.org/10.5380/cep.v22i1.1183

Oliveira, M., & Amato, G. M. (2021). *Arroz: Tecnologia, processos e usos.* Edgard Blucher.

Ong, M. H., & Blanshard, J. M. V. (1995). Texture determinants of cooked, parboiled rice. II: Physicochemical properties and leaching behaviour of rice. *Journal of Cereal Science*, *21*(3), 261-269. https://doi.org/10.1006/jcrs.1995.0029

Paine, J. A., Shipton, C. A., Chaggar, S., Howells, R. M., Kennedy, M. J., Vernon, G., Wright, S. Y., Hinchliffe, E., Adams, J. L., Silverstone, A. L., & Drake, R. (2005). Improving the nutritional value of Golden Rice through increased pro-vitamin A content. *Nature Biotechnology*, *23*(4), 482-487. https://doi.org/10.1038/nbt1082

Park, S. Y., Kwak, C. Y., Shayman, J. A., & Kim, J. H. (2012). Globoside promotes activation of ERK by interaction with the epidermal growth factor receptor. *Biochimica et Biophysica Acta - General Subjects*, *1820*(7), 1141-1148. https://doi.org/10.1016/j.bbagen.2012.04.008

Qian, H., & Zhang, H. (2013). Rice flour and related products. *Handbook of Food Powders: Processes and Properties*, 553-575. https://doi.org/10.1533/9780857098672.3.553

Rosell, C. M., Benavent-Gil, Y., & Garzón, R. (2021). Rice flour breads. *Trends in Wheat and Bread Making*, 405-429. https://doi.org/10.1016/B978-0-12-821048-2.00014-3

Ryan, E. P. (2011). Bioactive food components and health properties of rice bran. *Journal of American Veterinary Medicine Association*, *285*(5), 593-600. https://doi.org/10.2460/javma.238.5.593

Saleh, A. S. M., Wang, P., Wang, N., Yang, L., & Xiao, Z. (2019). Brown Rice Versus White Rice: Nutritional Quality, Potential Health Benefits, Development of Food Products, and Preservation Technologies. *Comprehensive Reviews in Food Science and Food Safety*, *18*(4), 1070-1096. https://doi.org/10.1111/1541-4337.12449

Soto-Vaca, A., Gutierrez, A., Losso, J. N., Xu, Z., & Finley, J. W. (2012). Evolution of phenolic compounds from color and flavor problems to health benefits. *Journal of Agricultural and Food Chemistry*, *60*(27), 6658-6677. https://doi.org/10.1021/jf300861c

Tavares, J.-A. S., Soares Júnior, M. S., Becker, F. S., & Costa, E. E. (2012). Mudanças funcionais de farinha de arroz torrada com micro-ondas em função do teor de umidade e do tempo de processamento. *Ciência Rural*, *42*(6), 1102-1109. https://doi.org/10.1590/s0103-84782012000600025

Ti, H., Zhang, R., Zhang, M., Li, Q., Wei, Z., Zhang, Y., Tang, X., Deng, Y., Liu, L., & Ma, Y. (2014). Dynamic changes in the free and bound phenolic compounds and antioxidant activity of brown rice at different germination stages. *Food Chemistry*, *161*, 337-344. https://doi.org/10.1016/j.foodchem.2014.04.024

Tong, C., & Bao, J. (2018). Rice lipids and rice bran oil. In J. Bao (Ed.). *Rice: Chemistry and Technology* (p. 131-168). AACC International Press. https://doi.org/10.1016/B978-0-12-811508-4.00005-8

Vaughan, D. A. (1994). *The Wild Relatives of Rice: A Genetic Resources Handbook*. International Rice Research Institute.

Verma, D. K., Srivastav, P. P., & Mohan, M. (2019). Nutritional Quality Evaluation. In *Agronomic Rice Practices and Postharvest Processing* (p. 299-361).

Walter, M., Marchezan, E., & De Avila, L. A. (2008). Rice: Composition and nutritional characteristics. *Ciência Rural*, *38*(4), 1184-1192. https://doi.org/10.1590/s0103-84782008000400049

Wang, X., Chang, X., Ma, L., Bai, J., Liang, M., & Yan, S. (2023). Global and regional trends in greenhouse gas emissions from rice production, trade, and consumption. *Environmental Impact Assessment Review*, *101*, 107141. https://doi.org/10.1016/J.EIAR.2023.107141

Wei, X., & Huang, X. (2018). Origin, taxonomy, and phylogenetics of rice. In *Rice: Chemistry and Technology* (p. 1-29). AACCI, Elsevier. https://doi.org/10.1016/B978-0-12-811508-4.00001-0

Wu, F., Yang, N., Touré, A., Jin, Z., & Xu, X. (2013). Germinated Brown Rice and Its Role in Human Health. *Critical Reviews in Food Science and Nutrition*, *53*(5), 451-463. https://doi.org/10.1080/10408398.2010.542259

Wu, X., Guo, T., Luo, F., & Lin, Q. (2023). Brown rice: a missing nutrient-rich health food. *Food Science and Human Wellness*, *12*(5), 1458-1470. https://doi.org/10.1016/j.fshw.2023.02.010

Yuliana, N. D., & Akhbar, M. A. (2020). Chemical and physical evaluation, antioxidant and digestibility profiles of white and pigmented rice from different areas of Indonesia. *Brazilian Journal of Food Technology*, *23*, 1-13. https://doi.org/10.1590/1981-6723.23818

Zafar, S., & Jianlong, X. (2023). Recent Advances to Enhance Nutritional Quality of Rice. *Rice Science*, *30*(6), 523-536. https://doi.org/10.1016/J.RSCI.2023.05.004

Zhou, Z., Robards, K., Helliwell, S., & Blanchard, C. (2002). Composition and functional properties of rice. *International Journal of Food Science and Technology*, *37*(8), 849-868. https://doi.org/10.1046/j.1365-2621.2002.00625.x