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Black Rice: A comprehensive review of functional and nutritional potential and instant foods

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Abstract

Black rice (*Oryza sativa* L. indica) has emerged as a nutrient-dense and functionally rich grain gaining popularity in the development of health-oriented food products. This review provides a comprehensive overview of black rice with a focus on its nutritional composition, phytochemical profile, functional properties, and potential role in instant food formulations. Black rice is rich in anthocyanins, dietary fibre, essential amino acids, vitamins, and minerals. Black rice is also the good source of antioxidant, anti-inflammatory, and anti-diabetic benefits. Its unique pigment characteristics contributes to its functional efficacy, making it a valuable ingredient in functional food development. The study also explores recent advancements in processing techniques and drying methods that preserve its bioactive components and enhance shelf stability. Special emphasis is placed on the incorporation of black rice in instant food applications such as upma mix, poha mix, and beverage mix. These applications highlight black rice's potential to improve nutritional quality, sensory attributes, and overall consumer acceptability. The current article aims to provide a scientific foundation for further research and industrial adoption of black rice in ready-to-eat and convenience food sectors.

Keywords: Black rice, anthocyanins, functional foods, instant foods, nutritional composition
Abbreviations: BH – Butylated Hydroxytoluene, RTE – Ready-To-Eat, RTC – Ready-To-Cook, ROS – Reactive Oxygen Species, TNF-α Tumor Necrosis Factor-alpha, IFN-γ – Interferon-gamma, IL-6 – Interleukin-6

1. Introduction

Black rice, also called forbidden rice, purple rice, emperor's rice, fortune rice, and king's rice, is a type of rice, *Oryza sativa* L. indica, that is primarily grown in several Asian countries, including China, Japan, India, Sri Lanka, Thailand, Indonesia, Myanmar, and Bangladesh [48]. Manipur, Assam, and Meghalaya are among the north-eastern Indian states that are the main producers of black rice. In these areas, it is referred to by various names. While it is known as Kola Sowl in Assam, it is named Chakhao in Manipur. The three main tribes in Meghalaya have different names for it: the Khasi and Jaintia call it Jaiong, while the Garo call it Migisim [49]. Around the world, black rice comes in more than 200 variants. More than 54 contemporary, high-yielding black rice varieties with several resistance features have been produced in China alone, which produces 62% of the world's black rice. Following it as the top producer of black rice are Sri Lanka (8.6%), Indonesia (7.2%), India (5.1%), and the Philippines. Thailand is the ninth-largest producer of black rice [50, 51, 78]. According to botany, black rice is made from the ripened ovary of the rice flower and has a distinctive pear-like shape. It usually ranges in length from 5 to 12 mm. It belongs to the Poaceae family's genus *Oryza*, which has 22 species, only two of which-O. *Sativa* and O. Glaberrima-are grown. While O. Glaberrima is indigenous to West Africa, the dominant species, O. *Sativa*, is thought to have descended from Asian wild rice species like O. *Nivara* and O. *Rufipogon*. Anthocyanins found in the bran layer give black rice its characteristic dark purple to black colour and are also responsible for some of its health-promoting qualities [42].
With much higher concentrations of phytochemicals,

especially anthocyanins, black rice has a better nutritional profile than both brown and white rice [52, 53]. Along with protein and dietary fibre, black rice is a great source of minerals including phosphorus, potassium, magnesium, copper, iron, and zinc, as well as important vitamins like tocopherol, thiamine, riboflavin, and niacin. It is a very important and adaptable functional food ingredient because of these qualities. A viable substitute for conventional wheat flour, black rice flour greatly improves the nutritional value of baked items and everyday meals. Its diverse range of bioactive substances aids in the creation of functional food items. Black rice flour is therefore frequently used in the baking sector and in the creation of basic dishes [54]. Enhancing rice output requires efficient weed control. In drip-irrigated aerobic rice farming, it has been demonstrated that effectively managing weeds and increasing yield and revenue may be achieved by applying the pre-emergence herbicide pendimethalin at 1.0 kg/ha, followed by a post-emergence treatment of bispyribac sodium at 25 g/ha after 20 days of sowing (DAS) [65].

Looking into the functional properties of black rice it has anthocyanins, a powerful antioxidant compounds-are present in the kernel in small amounts. People consume this rice primarily for its high nutritional value and the associated health benefits [55]. Because it was customarily saved for the emperor's eating, it is frequently referred to as "Imperial rice" and has been acknowledged for its nutritional and health benefits throughout history [56].

In recent years, one of the most notable social trends has been the growing consumer awareness of the connection between diet and health. Recent studies indicate that modern consumers are increasingly choosing nutritious foods to help prevent illness and promote overall well-being [43]. People now seek health-oriented products that align with their core values, such as achieving longevity and maintaining a healthy lifestyle. This heightened health consciousness is further fueled by the widespread availability of health-related information, alongside aging populations and the rising prevalence of lifestyle-related diseases [44]. Over the past decade, consumer food purchasing and transport behaviors have undergone significant transformation driven by increasing health consciousness and demand for convenience. Between 2010 and 2019, consumers showed a marked preference for healthier food options such as fresh, organic, and minimally processed products, reflecting a growing awareness of nutrition and wellness. Concurrently, the rise of busy lifestyles propelled demand for convenient foods, including ready-to-eat and ready-to-cook products that reduce meal preparation time. Moreover, transportation methods adapted to prioritize speed and flexibility, ensuring rapid access to nutritious and convenient food items. This shift underscores the dynamic nature of consumer behavior in response to broader societal trends in health and convenience [1].

The impact of shifting consumer preferences on food retailing formats, highlighting a pronounced transition driven by increased demand for convenience, health-oriented products, and greater variety. Consumer preference trends toward fresh, nutrient-dense, and ready-to-eat food products have necessitated innovations in product assortment strategies, store design, and service delivery mechanisms. Furthermore, evolving lifestyle patterns have accelerated the adoption of e-commerce, fundamentally altering food purchasing behaviors. These developments underscore the adaptive strategies employed by the food retail sector to align with emergent consumer priorities centered on health, convenience, and experiential value [2].

In India, where traditional cooking once thrived, modern lifestyles have made food preparation challenging, leading to a rise in instant food demand. Since the 1990s, home cooking has declined as people turned to dining out and exploring new cuisines. Industrialization and modernization have further shifted diets from fresh to processed foods [57]. Instant foods, available in ready-to-eat and ready-to-prepare forms, are rapidly expanding to meet the growing demand for quick and convenient meals. As time becomes increasingly valuable, more people are turning away from traditional cooking, driving a global rise in prepared food consumption [58]. Instant food, requiring little to no preparation, is gaining popularity due to urbanization, increasing female employment, and fast-paced lifestyles. Seen as a convenient and practical choice, it offers easy, on-the-go meal solutions for busy consumers, especially while traveling [59].

Traditional dishes such as idli, dosa, poha, and upma remain culturally significant, there has been a noticeable shift toward more convenient options like ready-to-eat and instant foods. This shift reflects the growing need for meals that are quick to prepare yet nutritionally adequate. Those working professionals, especially women, and younger consumers aged 18–35 are more inclined to choose packaged or ready-to-cook breakfast options due to their busy schedules [45]. Formulation approaches typically involve fortification with protein-rich ingredients such as legumes, pulses, or plant-based protein isolates to improve the protein content without compromising texture or taste. Processing techniques, including precooking and dehydration, are optimized to ensure rapid rehydration and acceptable shelf life, aligning with consumer demand for convenient, nutrient-dense breakfast options. These advancements demonstrate potential for creating value-added instant poha products that cater to health-conscious consumers seeking traditional foods with improved nutritional benefits [3].

2. Nutritional properties of black rice

Anthocyanin, a substance with strong antioxidant and nutritious qualities, is what gives the pericarp, the outer layer of rice grains, their characteristic black colour [72]. Proteins and lipids can be found in the germ, which makes up 2–3% of the weight of the paddy rice. Sticky black rice is really good for you because it's full of important nutrients like fibre, protein, B vitamins, minerals, and key amino acids. It has more nutritional diversity than any other type of rice. Black rice is a whole grain that is naturally free of gluten, cholesterol, sugar, salt, and fat. It is also high in fibre, antioxidants, anthocyanins, iron, vitamins B and E, thiamine, niacin, magnesium, and phosphorus [73].

Beyond its high carbohydrate content, black rice has significant nutritional benefits because of its high protein, vitamin, mineral, fibre, and anthocyanin content. Both proteins and lipids can be found in the germ, which makes up around 2-3% of the weight of paddy rice. Although the main purpose of rice is to provide energy, black rice also

makes a substantial contribution to protein consumption because the majority of the protein is found in the kernels. Rice proteins are classified according to their solubility: albumins (water-soluble; 5%), prolamins (alcohol-soluble; 25%), globulins (salt-soluble; 10%), and glutelin's (alkali-soluble) comprise roughly 60% of the total protein [20]. Approximately 10% of the daily required consumption of protein can be obtained from a single serving of black rice [60].

Additionally, black rice is a great source of vital vitamins and minerals that support a number of physiological processes. In comparison to white rice, it has higher levels of manganese (Mn), phosphorous (P) (264 mg), iron (Fe) (1.8 mg), and zinc (Zn). The type of rice and the state of the soil might affect the mineral profile. Red blood cell production and energy consumption depend on iron, whereas muscular growth is supported by potassium [7, 39, 77]. Black rice also contains vitamin A, vitamin E, and B-complex vitamins, all of which support cardiovascular health and the prevention of disease [7, 18, 40]. As a fat-soluble antioxidant, vitamin E, particularly alpha-tocopherol, strengthens the immune system, lowers the risk of blood clots, and guards against free radical damage. Even though it is uncommon, nerve-related problems could result from its insufficiency [60].

Black rice is more nutritious than white rice in terms of dietary fibre. It is typically offered un milled, preserving its high-fiber husk, which makes it a low-fat, low-sodium, gluten-free, and cholesterol-free choice [18]. Roughly 75% of its fiber content is insoluble, and its consumption contributes about 8% of the recommended daily fiber intake [20, 60]. Insoluble fiber supports digestive health and prevents constipation, while soluble fiber helps regulate body weight. The cholesterol-lowering effects of black rice are believed to result from the combined action of dietary fiber and bioactive compounds like polyphenols [41].

Black rice's high anthocyanin content, which gives it its deep purple to black colouring, is one of its primary characteristics. Compared to other coloured grains, the concentration of these water-soluble flavonoids is much higher in the pericarp, aleurone layer, and seed coat. Strong antioxidant qualities found in anthocyanins aid in scavenging free radicals, shielding blood vessels, and avoiding DNA damage [41]. Acetylated procyanidins, which have anti-inflammatory, detoxifying, and free radical scavenging properties, are particularly abundant in black rice. Glycosides and acyl glycosides are among the substances that may also stop tumour growth by stopping the production of new blood vessels [61, 62].

Black rice is a very nutrient-dense food option since it is full of vital nutrients that promote human growth and development [60]. Compared to the widely consumed white rice and even other coloured types like brown and red rice, black rice is thought to be more nutritious [6]. The table below compares the nutritional makeup of black rice and ordinary rice.

Table 1: Nutritional Composition of Different Rice Varieties [78].

Rice Variety	Protein	Carbohydrate	Fat	Fibre
Black rice	9.61	76.20	2.15	4.32
Brown Rice	8.71	86.85	3.16	1.3
Red rice	7.94	77.24	2.92	3.5
White rice	7.2	75.77	2.5	1.6

Black rice offers the most balanced nutritional profile among rice varieties, with the highest protein (9.61%) and fiber (4.32%) content, making it a superior choice for health and digestion. While brown and red rice provide moderate nutrients, white rice has the lowest levels of protein and fiber, making it the least nutritious. Overall, black rice stands out as the healthiest option.

3. Bioactive compounds of black rice

These substances are essential for advancing human health. Numerous advantageous phytochemicals, such as γ-oryzanol, zeaxanthin, lutein, flavonoids, and other phenolic compounds, are present in black rice. Particularly, flavonoids have potent antioxidant properties and provide other health advantages. Black rice and other dark-coloured fruits and vegetables have a high antioxidant content, which has been associated with a lower risk of a number of illnesses [64].

Black rice's strong antioxidant and health-promoting qualities are attributed to its abundance of several bioactive components. Of these, flavonoids are important; the most prevalent is tricin (77%) followed by luteolin (14%), apigenin (6%), quercetin (3%), isorhamnetin (1%), kaempferol (<1%), and myricetin (<1%). These flavonoids increase black rice's antioxidant capability by preventing lipid peroxidation.

The presence of anthocyanins, specifically cyanidin-3-glucoside (C3G) and peonidin-3-glucoside (P3G), which also have considerable antioxidant action, is chiefly responsible for the grain's distinctive black to purple colouration. About 88% of the anthocyanins in black rice are C3G. Varieties like Luem Pua and Khao Hom Nin BD exhibit noticeably higher C3G content than P3G, indicating that genetic regulators like Ra, Rc, and Rd affect pigmentation in the pericarp [23, 25].

Black rice's phenolic acids further support its anti-inflammatory and antioxidant qualities. These include bound phenolics like ferulic, coumaric, and caffeic acids, which add to the grain's resistance index, and soluble phenolics including gallic, protocatechuic, and cinnamic acids [23]. Ferulic, vanillic, and p- coumaric acids make up the majority of the phenolic acid content, which varies from 7.4 to 10.5 mg/100 g [26]. Other phenolic acids, including cinnamic acid, are derived from compounds like p-coumaric acid, isoferulic acid, sinapic acid, 2,5-diphenylbenzoic acid, and ferulic acid. While red and white rice contain pinellic acid, black, red, and brown rice also contain syringic acid. The phytochemical profile of black rice is further enhanced by the presence of hydroxybenzoic acid [63].

High concentrations of iron, manganese, potassium, and phosphorus are among the minerals found in black rice. These elements are necessary for the production of red blood cells, reproductive health, and electrolyte balance. Interestingly, compared to non-pigmented rice types, black rice has higher levels of manganese (Mn) and zinc (Zn) [20].

Black rice contains tocols, including α-tocopherol and γ-tocotrienol, which are lipid-soluble antioxidants. Because of the free hydroxyl group in their chromanol ring, these molecules have antioxidant properties [22]. α-tocopherol is the predominant tocol in Taiwanese and American black rice types [27]. Furthermore, rice bran contains γ-oryzanol, a

combination of ferulic acid esters with phytosterols that has anti-hyperlipidemic, cholesterol-lowering, and hormone-regulating qualities [27]. Compared to red and white rice, black rice bran has a much greater level of it (ranging from 3.95 to 7.72 mg/g dry matter) [24], with Hom-nin black rice bran oil having up to 281.95 mg/g [28].

4. Health benefits of black rice

Anthocyanin pigments promote neurological and visual health and aid in the prevention of non- communicable diseases. Their potent antioxidant qualities shield the body from harm caused by free radicals. These pigments can help treat critical disorders like diabetes, heart disease, and cancer as well as more minor ones like infections and high blood pressure. Eating black rice boosts immunity, improves general health, and is very nutrient-dense [69, 70, 71].

4.1 Antioxidant, anti-inflammatory, and cardioprotective effects

Black rice is a rich source of anthocyanins, particularly cyanidin-3-O-β-D-glucopyranoside, which exhibit potent antioxidant and free radical scavenging properties superior to that of white rice varieties. These antioxidants neutralize reactive oxygen species (ROS), reducing oxidative stress and cellular damage, and are effective in preventing DNA mutations and carcinogenesis. Black rice bran contains higher antioxidant levels than blueberries and includes vitamin E and dietary fibre, contributing to its superior health effects. Its anti-inflammatory potential is significant, with the capacity to downregulate systemic inflammation by increasing anti-inflammatory mediators such as superoxide dismutase. This action supports the prevention and management of conditions like asthma, atherosclerosis, joint disorders, and skin inflammation. Cardiovascular benefits include reduced arterial plaque formation, improved lipid profiles (increased HDL and reduced LDL, cholesterol, and triglycerides), and prevention of atherosclerosis [7]. Black rice effectively helps treat chronic inflammatory disorders. Studies show that black rice and its compounds reduce inflammatory gene expression and proinflammatory cytokines in cells. Its aqueous extract exhibits strong anti-inflammatory effects by modulating immune cells and decreasing key inflammatory markers [66, 67].

4.2 Glycemic control and diabetes management

Black rice anthocyanins exhibit antidiabetic properties by enhancing insulin sensitivity, preserving pancreatic β-cell function, increasing insulin secretion, and inhibiting carbohydrate digestion. These effects are largely attributed to their antioxidant mechanisms and enzymatic modulation, suggesting a therapeutic role in managing type 2 diabetes mellitus [7]. Black rice helps prevent diabetes since it is high in fibre and low in sugar. It maintains appropriate blood pressure by stabilising blood sugar levels [68].

4.3 Weight management and digestive health

Black rice's high fibre content-double that of brown rice-helps with weight management by promoting satiety and lowering total energy intake. The dietary fiber enhances gastrointestinal motility and binds toxins, aiding in waste elimination and improving gut health [7].

4.4 Potential anti-cancer and neuroprotective roles

Anthocyanins in black rice demonstrate anti-cancer properties through inhibition of oxidative stress, modulation of apoptosis, and suppression of tumour proliferation and metastasis. Studies confirm their role in protecting endothelial cells and inducing cancer cell death via peonidin and cyanidin derivatives. Due to antioxidant-driven brain protection, neuroprotective effects include enhanced memory and learning ability as well as a decreased risk of cognitive decline and neurodegenerative diseases like depression and Alzheimer's [7].

4.5 Prevention of constipation

Because black rice has twice as much fibre as brown rice, it can help relieve chronic constipation and ease digestive pain. In the colon, its fibre attaches itself to toxic compounds, making it easier to eliminate them through stool. By lowering gas and bloating and preventing constipation, the high fibre level also enhances digestion. Additionally, black rice supports relief from gastrointestinal conditions such as acid reflux, duodenal ulcers, diverticulitis, and hemorrhoids [7].

5. Functional properties of black rice

Black rice's high concentration of bioactive substances, especially phenolics and anthocyanins, makes it a powerful functional food. Black rice, in contrast to white rice, has a low postprandial glycaemic response, which lowers the risk of metabolic diseases like obesity, hypertension, and dyslipidaemia as well as Type 2 diabetes. It has potent anti-inflammatory, anti-cancer, antioxidant, and cardiovascular protective properties. Its medicinal qualities are attributed to compounds such as tricin, cyanidin-3- glucoside, and ferulic acid, which improve lipid profiles, modulate inflammation, and lessen oxidative stress. Black rice is a very nutrient-dense and health-promoting grain that has also demonstrated promise in treating neurological and gastrointestinal conditions [20]. Because of its many varieties and bioactive ingredients, black rice has a wide range of useful qualities. Each of the four primary types of jasmine rice-Black Thai, Black Italian, Black Japonica, and Black Glutinous-has special qualities. Short to medium-grain black japanica rice is prized for its earthy taste with hints of sweetness and spice. Black glutinous rice is a short-grain kind that is frequently used in Asian desserts. It has an irregular colour and a sticky texture. While Black Thai Jasmine rice, which combines Chinese black rice with jasmine rice, has a subtle flowery flavour, Black Italian rice is a long-grain variant with a rich buttery aroma. Black rice's functional qualities make it a useful component for creating innovative, health-conscious dishes, such as pasta and baked goods [74].

6. Role of anthocyanins in colour of black rice and its antioxidant activity

Black rice's characteristic dark purple to black hue is caused by water-soluble pigments called anthocyanins, which are mostly made up of substances like cyanidin-3-glucoside and peonidin-3- glucoside. By scavenging free radicals and neutralising reactive oxygen species, these pigments not only give black rice its distinctive visual appeal but also demonstrate strong antioxidant activity. Anthocyanins'

antioxidant ability is essential for shielding cellular constituents from oxidative damage, which helps to promote health advantages such a lower risk of cancer, inflammation, and cardiovascular disorders. The stability and effectiveness of anthocyanins as antioxidants are also influenced by their chemical structure, which includes their aglycon forms. Aglycons frequently exhibit increased radical- scavenging action.

However, during food preparation and storage, anthocyanins' colour intensity and antioxidant efficacy may be impacted by environmental conditions like pH, temperature, and light. In order to stabilise these bioactive pigments and guarantee that their functional advantages are maintained in food products made from black rice, methods such as membrane separation and spray drying have been investigated [10].

7. Utilization of black rice and its components in the food industry

Black rice is increasingly recognized for its superior nutritional and visual qualities compared to other rice varieties. It contains high levels of protein, fat, riboflavin, thiamine, zinc, tocopherols, and iron. Due to these nutritional benefits, black rice is gradually gaining popularity as a healthier substitute for white rice. Incorporating black rice into various food products can improve their nutritional content and support the development of functional foods [30]. Such functional foods have the potential to aid in managing health issues like diabetes, obesity, hypertension, and cardiovascular diseases [31]. Despite its benefits, black rice remains relatively unfamiliar to the general public and presents a promising, nutritious alternative for future food innovations. Its inclusion in food processing industries could significantly enrich the nutritional profile of traditional food item [18].

8. Starch characteristics and cooking behaviour of black rice in instant foods

Drying temperature plays a critical role in determining the structural integrity and cooking quality of black rice. The drying temperature increases, significant changes occur in the starch structure, particularly in the crystalline and amorphous regions. Higher drying temperatures (above 60 °C) were shown to induce partial gelatinization of starch granules, which led to reduced crystallinity and altered pasting behaviour. This structural disruption affects the gelatinization temperature and peak viscosity, thereby impacting the texture and cooking behaviour of black rice. Specifically, rice dried at elevated temperatures exhibited lower water absorption and elongation ratios during cooking, resulting in firmer and less sticky cooked rice. These modifications are attributed to the limited swelling of starch granules and restricted leaching of amylose caused by the thermal damage during drying. Consequently, optimal drying conditions must be carefully controlled to preserve the functional properties of starch and maintain desirable cooking qualities in black rice [8].

The cooking behaviour of black rice is significantly influenced by water migration within the grain, which directly impacts its eating qualities such as texture and palatability. Black rice starch, characterized by its unique physicochemical properties including amylose and amylopectin ratios, gelatinization temperature, and granule morphology, governs the absorption and movement of water during cooking. The high amylose content in certain black rice varieties results in slower water penetration and gelatinization, producing a firmer and less sticky texture, whereas low-amylose varieties tend to absorb water more rapidly, yielding a softer and stickier product. The polyhedral shape and small granular size of black rice starch (3–8 μm) facilitate water swelling, influencing pasting behaviour and texture development. As water migrates into the endosperm during cooking, it causes starch granules to swell and gelatinize, altering the rice's physical properties such as stickiness, chewiness, and overall sensory acceptability (Chen, year). Additionally, bioactive compounds like anthocyanins may interact with starch molecules, potentially modifying water absorption and thermal properties, thus affecting cooking time and texture stability [42]. Understanding these water migration dynamics is essential for optimizing cooking methods and developing black rice-based ready-to-cook products with desirable eating qualities [9].

9. Textural and sensory properties of instant foods

Instant food refers to meals that can be prepared and ready to eat within a few minutes. Nowadays, with busy daily schedules, most people prefer quick and easy food options. Especially in metropolitan cities, where time is limited, individuals often choose ready-to-cook foods that require minimal time and effort to prepare [75]. Noodles, chapati mix, parotta mix, idli/dosa mix, rava dosa mix, bhaji mix, biryani mix, puliyodara mix, gulab jamun mix, and chatni mix are among the types of rapid dishes that are frequently offered. These products typically require simple preparation such as boiling, heating, or mixing with water [76].

Burma black rice-based instant beverage mix (BBIBM) provides valuable insights into the textural and sensory attributes of instant food formulations. The research emphasized that black rice, known for its rich anthocyanin and fiber content, imparts a unique colour and a pleasant roasted aroma to the beverage mix after processing. Sensory evaluation revealed high acceptability of the BBIBM in terms of color, flavour, texture, mouthfeel, and overall appeal. The product exhibited a smooth and uniform texture upon reconstitution, indicating good dispersibility and minimal sedimentation [46]. The textural and sensory attributes of instant upma are critical factors influencing consumer acceptance and overall product quality. Johari and Kawatra observed that the processing of pearl millet into an instant upma mix resulted in a product with desirable texture characteristics, including appropriate firmness and cohesiveness that mimic traditional homemade upma. The instant mix showed a pleasing mouthfeel, neither too dry nor too sticky, which is essential for consumer preference. Sensory evaluation conducted by trained panels highlighted favourable scores for appearance, aroma, taste, and overall acceptability, indicating that the instant upma retained the characteristic flavour and sensory appeal despite the convenience-oriented processing. These findings suggest that properly processed pearl millet-based instant upma can successfully replicate the sensory experience of conventional upma, making it a promising product for consumers seeking both nutrition and convenience [11].

Black rice has demonstrated encouraging impacts on texture and sensory qualities when added to instant food compositions. A black rice-based instant idli mix was developed and optimised, and the results showed that black rice flour not only improves the nutritional content but also gives the finished product unique textural and sensory qualities. According to the texture profile research, idlis made with a black rice mix were somewhat firmer and more cohesive than those made with regular rice. This is probably because black rice has more bran and fibre. A trained panel's sensory evaluation revealed positive ratings for general acceptability, colour, taste, and scent [47].

10. Consumer acceptance of instant black rice products

Consumer acceptance of black rice products is influenced by a combination of sensory attributes such as appearance, texture, aroma, and taste, along with physicochemical properties that affect product quality and shelf life. Studies indicate that while black rice is often favoured for its unique dark colour and distinctive nutty flavour, consumer preferences can vary depending on the type of product and its processing method. Products that successfully balance the slightly firmer texture and earthier taste of black rice with familiar preparation styles tend to receive higher acceptance scores. Additionally, awareness of the health benefits associated with black rice, including its antioxidant properties and nutritional richness, positively impacts consumer preference and willingness to incorporate black rice products into their diets. Sensory evaluations often reveal that consumers appreciate black rice in forms such as rice-based snacks, porridges, and bakery items, provided that the products maintain desirable sensory qualities comparable to traditional rice products. Overall, consumer acceptance hinges on a combination of sensory appeal and the perceived functional benefits of black rice products [12].

That black rice formulations, particularly those used in staple food items like breads or porridges, showed high acceptability scores among sensory panelists. Participants positively evaluated the appearance, flavour, and texture of black rice products, indicating that the inclusion of black rice did not adversely affect the organoleptic qualities when compared to conventional white rice-based formulations. The distinct pigmentation and rich taste were even found to be appealing to many consumers, especially when paired with appropriate processing techniques that enhanced palatability. These findings suggest that black rice has strong potential for wider adoption in health-oriented and functional food markets, as consumer willingness to incorporate such products into their diets remains high when sensory quality is maintained [13].

The deep purple-black pigmentation of black rice, attributed to anthocyanins, is generally well-received due to its association with health benefits. However, consumer preferences can vary based on the intensity of colour and aroma, with milder aromatic profiles and moderately firm textures showing higher acceptability. The researchers found a strong correlation between instrumental data (e.g., hardness, adhesiveness) and perceived sensory quality, indicating that consumers tend to favour black rice varieties that are moderately soft, slightly sticky, and rich in colour but not overly aromatic. These findings underscore the importance of aligning product development with consumer expectations for sensory quality to ensure market success of black rice-based products [14].

11. Market demand for functional and convenience food

The growing market demand for functional and convenience foods, driven by evolving consumer lifestyles and health awareness. The authors emphasize that as more individuals, especially working professionals and urban populations, seek time-saving meal options, there is a marked shift toward products that combine convenience with added health benefits. Functional foods-those providing additional health value beyond basic nutrition-are particularly attractive to health-conscious consumers who prioritize attributes such as low fat, high fiber, and added vitamins or antioxidants. The study also reveals that demographic factors such as income level, education, and age significantly influence purchasing decisions, with younger, higher-income, and better-educated consumers more likely to opt for convenient functional food options. Thus, the convergence of health and convenience trends is shaping the modern food market, fostering demand for products that are both easy to prepare and nutritionally enhanced [15].

The increased workforce participation, urbanization, and higher disposable incomes have led to a shift in consumer preferences toward ready-to-eat (RTE) and ready-to-cook (RTC) food products that offer both nutritional value and minimal preparation time. Functional foods-those offering added health benefits beyond basic nutrition-are increasingly preferred when combined with the convenience factor. Consumers tend to associate convenience foods with modernity, and their willingness to pay a premium increase when such products also offer perceived health advantages. This has prompted food manufacturers and retailers to innovate and diversify product lines to include fortified, whole grain, or antioxidant-rich ingredients like black rice, appealing to health-conscious, time-sensitive consumers [16].

The growing market demand for functional and convenience foods is largely driven by shifts in consumer lifestyles, including increased participation of women in the workforce, time constraints, and rising household incomes. These factors have led to a greater reliance on foods that are quick to prepare and consume without compromising on nutritional quality. The study emphasizes that consumers are not only seeking ease and efficiency in meal preparation but are also increasingly attentive to the health benefits of the foods they consume. This has resulted in rising interest in functional convenience foods-products that offer specific health advantages, such as improved digestion, weight management, or cardiovascular benefits, alongside quick preparation features. In order to meet the demands of both convenience and nutrition, food manufacturers have responded by increasing their selection of ready-to-cook and ready-to-eat products enhanced with fibre, vitamins, antioxidants, and other health- promoting ingredients [17].

12. Future uses of black rice

The powerful antioxidants and minerals included in black rice and its bran are attracting increasing attention. In order to improve nutritional content and promote health advantages, food makers were adding black rice bran to items like cakes, cereals, cookies, and beverages, according to a 2010 study conducted by researchers at Louisiana State

University. In addition to being a grain-based cuisine, Chinese black rice is used to make black vinegar, sometimes referred to as Chekiang vinegar, particularly from the Zhejiang province. There are similarities between this vinegar and balsamic vinegar. Furthermore, Chinese black rice is used to make a variety of aromatic, delicately flavoured wines that can be used in cooking as well as for consumption.

Black waxy rice, rich in anthocyanins, yields a colorant powder with a dark purple hue and higher phytochemical content than raw bran. This powder has shown promise as a natural food colouring agent, imparting a pinkish-purple colour to yogurt while also enhancing its phytochemical content. However, further evaluations regarding quality, safety, and sensory attributes are needed before broader food applications. Black rice bran's high phenolic component content and potent antioxidant qualities have been identified. Their research suggested using ferulic acid as a natural antioxidant source and highlighted it as the main phenolic ingredient in black rice bran. The antioxidant activity of ethyl-acetate subfractions, especially subfraction 2 and its component subfraction 1, was higher than that of butylated hydroxytoluene (BHT), indicating that they could be used as food additives in cereals, snacks, bread, cakes, beverages, and cookies [32].

Additionally, compared to red and non-pigmented rice bran, black rice bran has higher concentrations of gallic, hydroxybenzoic, and protocatechuic acids. When compared to regular bread, the antioxidant and free radical scavenging properties of wheat flour were greatly increased by adding 5% black rice bran [33]. Research on the physical characteristics of various black rice types offers food processors useful reference information to maximise product quality [34].

Takju, a traditional Korean rice wine, was made better overall by adding the right amounts of black and blueberry powders. Compared to mead made from polished rice, black rice mead showed stronger prevention of lipid peroxidation and greater DPPH radical scavenging activity [35]. In addition, drinks created with raw black rice had higher anthocyanin content and more potent antioxidant properties than those made with cooked black rice [36]. As a result, black rice (*Oryza sativa*) and its derivatives are becoming more and more popular and are consumed in Southeast Asian nations like Thailand as well as China, Japan, and Korea [37].

13. Conclusion

One grain that is particularly useful and nutrient-rich is black rice, which has the potential to completely transform the use of quick food. In addition to adding to its nutritional value, its high anthocyanin, dietary fibre, essential amino acid, vitamin, and mineral content also has anti-inflammatory, anti-diabetic, and antioxidant properties. Black rice's unusual colouration and bioactive components provide it special functional features that can enhance the nutritional value and mouthfeel of fast-food products.

Advancements in processing technologies-including optimized drying, milling, and fortification techniques-have enabled better retention of these bioactive compounds, ensuring prolonged shelf life and product stability in ready-to-eat formats. The integration of black rice into instant foods like upma mix aligns well with current consumer trends favouring health-oriented, convenient, and clean-label products.

Overall, black rice offers a sustainable and promising ingredient for the development of innovative instant food products. Its inclusion not only enriches the nutrient profile but also supports the functional food industry's goal to provide convenient yet health-promoting dietary options. Future research focusing on large-scale production, cost-effective processing, and consumer acceptance will further facilitate the widespread adoption of black rice in the instant food market.

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15. Ethical Acceptance

The authors did not undertake any new research involving human or animal subjects; instead, this review is based on previously published studies. Therefore, the current investigation did not require ethical approval.

16. Conflicts of Interest

No conflicts of interest are disclosed by any of the writers.

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