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# THE POTENTIAL OF RICE BRAN (*ORYZA SATIVA*) NUTRITIONAL COMPONENTS AS A FUNCTIONAL FOOD FOR HEALTHY CONSUMPTION: A REVIEW

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*KEY WORDS:*
*bioactive compounds, food systems, functional food, paddy, rice bran*

ABSTRACT
Indonesia produced 56.54 million tons of paddy (*Oryza sativa*) dried grain in 2018, with rising demand leading to increased production of by-products such as rice bran. Rice bran, a nutrient-rich by-product, contains high levels of dietary fiber and bioactive compounds with notable anti-cholesterol and anti-diabetic properties. Numerous *in vitro* and *in vivo* studies highlight the antioxidant capabilities of rice bran, mainly due to tocopherol, γ-oryzanol, and β-carotene, which function as primary and secondary antioxidants. Effective extraction and fractionation techniques can isolate these antioxidants from rice bran. Cultivation practices significantly impact the nutritional composition of rice bran. The nitrate reductase enzyme (NRA) test can assess growth conditions, which may reflect metabolic activity in paddy plants. Enhanced dietary fiber components (hemicellulose, cellulose, and lignin) and niacin levels make rice bran a promising alternative nutrient source in Indonesia, where unhealthy lifestyles are prevalent. With Indonesia's significant rice production and bran demand, processed rice bran products hold substantial potential as functional foods for routine consumption, promoting a healthier diet and aiding in prevention of degenerative diseases.

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# ПОТЕНЦИАЛ ПИТАТЕЛЬНЫХ КОМПОНЕНТОВ РИСОВЫХ ОТРУБЕЙ (*ORYZA SATIVA*) КАК ФУНКЦИОНАЛЬНОГО ПРОДУКТА ПИТАНИЯ ДЛЯ ЗДОРОВОГО ПОТРЕБЛЕНИЯ: ОБЗОР

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*КЛЮЧЕВЫЕ СЛОВА:*
*биоактивное соединение, пищевые системы, функциональные продукты питания, рис-сырец, рисовые отруби*

АННОТАЦИЯ
Производство риса-сырца (*Oryza sativa*) в Индонезии составило 56,54 млн тонн сухого зерна в 2018 году с увеличением спроса, что привело к росту производства побочных продуктов, таких как рисовые отруби. Рисовые отруби — продукт, богатый питательными веществами, содержит большое количество пищевых волокон и биоактивных соединений, которые обладают антихолестериновыми и антидиабетическими свойствами. Многие исследования *in vitro* и *in vivo* показали, что рисовые отруби обладают антиоксидантными свойствами, в основном благодаря токоферолу, γ-оризанолу и β-каротину, которые являются первичными и вторичными антиоксидантами. Эти антиоксиданты могут быть выделены из рисовых отрубей с помощью эффективной экстракции и фракционирования. Процедуры выращивания

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риса оказывают значительное влияние на состав питательных веществ рисовых отрубей. Тест NRA может использоваться для оценки условий роста растений, которые могут отражать метаболическую активность рисового растения. Повышенное содержание пищевых волокон (гемицеллюлоза, целлюлоза и лигнин) и ниацина делают рисовые отруби перспективным источником питательных веществ в Индонезии, где распространен нездоровый образ жизни. При высоком уровне производства риса и спроса на отруби в Индонезии переработанные продукты из рисовых отрубей имеют большие перспективы в качестве функциональных продуктов для регулярного употребления в пищу, стимулируя более здоровое питание и способствуя предотвращению дегенеративных заболеваний.

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## 1. Introduction

One of the main staple foods for almost half the world's population is rice made from paddy plants (*Oryza sativa*). The amount of dry grain produced by Indonesian paddy in 2018 was 56.54 million tons, while the amount of dry grain produced by rice was 32.42 million tons [1]. Paddy harvests are processed in around three batches of milling. The first batch will result in raw rice bran, the second will produce rice bran, and the third will produce rice ready to cook. The major product of the milling process is rice (endosperm), which accounts for roughly 70% of total production, as well as by-products, including crude rice bran and rice bran. Polished rice is milled rice that is less nutritionally valuable than crude and processed rice bran [2]. Rice bran, a by-product of rice milling, is a nutrient-dense layer between the rice grain and husk. Rice bran is well known for its relatively high contents of bioactive substances and nutrients, which are important in human and animal nutrition industries [3–6].

Traditional application of rice bran is frequently limited to its use as animal feed, underutilizing its potential for processing into nutritional supplements for humans and other food products [3–5,7]. The likelihood of providing more nutritional value is increased by the potential of rice bran as a dietary supplement in the national diet [6,8]. Anticholesterol, antidiabetic, and antioxidant qualities of rice bran may enhance personal health by reducing the risk of developing degenerative diseases. Based on statistics published by RISKESDAS in 2013, Indonesia's prevalence of hypertension among adults aged 18 and older was 9.5%, an increase from the data gathered in 2007 when the figure was 7.6% [9]. The data also revealed that stroke happened in 12.1 per 1000 persons, while cardiovascular disease claimed up to 1.5% of the population, and diabetes mellitus prevalence grew to 2.1% from 1.1% in 2007. Unbalanced eating habits and an unhealthy lifestyle have been discovered to be the main causes of this issue. Thus, it is better to address these issues head-on by employing the nutritional benefits of rice bran as a staple food [2,10].

Functional foods contain biologically active (bioactive) substances intended to treat or prevent health problems in consumers and help them maintain optimal health [11]. Rice bran has a high nutritional content and offers advantages such as lowering blood cholesterol and the risk of atherosclerotic disease and protecting against heart disease, kidney stones, and cancer. The bioactive components found in rice bran, including phenolic acids, flavonoids, gamma oryzanol, tocopherol, tocotrienols, β-sitosterol, and phytic acids, are thought to be responsible for the potential health benefits of the grain [12]. The content of bioactive chemicals in rice bran can be increased using various techniques, including germination with enzyme treatment, microbial fermentation, and subcritical water treatment [13]. In Indonesia, the nutritional value of active components of rice bran as a functional diet has considerable promise.

## 2. Objects and methods

This review paper systematically analyzes recent findings on the potential of rice bran (*Oryza sativa*) as a functional food. We searched several databases, including PubMed, ScienceDirect, and Google Scholar. Specific search terms, including "rice bran," "bioactive compounds," "functional food," "antioxidant properties," and "nutritional composition," were used to find relevant studies.

Inclusion criteria were studies based on the biochemical composition, bioactive properties, health benefits, or promise of rice bran in its potential application as a functional food. The following criteria were used to exclude studies: focusing only on rice cultivation techniques with no reference to nutritional or functional attributes of rice bran and the absence of empirical data (for example, opinion articles). Data sources were drawn from peer-reviewed journal publications, government reports, and scientific reviews to gather a comprehensive view of the subject.

The review is geographically focused and highlights studies done mainly in Indonesia and other rice-producing countries where rice bran is also produced due to rice cultivation, processing, and consumption systems. It covers research on rice bran bioactivity, including *in vitro* and *in vivo* (animal) studies, as well as epidemiological studies and clinical trials that have been performed on the health benefits of rice bran.

The analysis techniques in the reviewed studies were heterogeneous, ranging from biochemical assay methods for antioxidant and bioactive compound analysis to animal and human trials to assess health impacts. Thus, such methods offer a multilevel approach to characterizing rice bran and its components for nutrition applications and functional food constituents.

## 3. Rice plants

Paddy (*Oryza sativa*) is Indonesia's staple food and product. Rice is produced from paddy grain that has dropped from its panicle. Brown rice is a product of removing the husk from paddy grains. It retains the bran and germ layers, which makes it nutritionally superior to white rice. The process of milling, which transforms brown rice into white rice, removes these layers, leading to a significant loss of nutrients. Brown rice is rich in proteins, vitamins, minerals, and bioactive compounds, largely concentrated in the grain's outer layers. This makes it a valuable dietary component, especially in addressing micronutrient deficiencies and promoting health [14–16].

To increase the shelf life and enhance the beauty of rice, a technique known as winnowing involves separating rice bran from the endoderm components of the grain. The total paddy milling output comprises roughly 60% endosperm (white rice), 16–28% husk, 6–11% crude rice bran, and 2–4% rice bran. Rice bran has a light appearance and tastes slightly sweet, nutty, and bitter. It has a discernible amount of oil and, if powdered, would have a chunky flour consistency. The presence of bioactive compounds such as phenolic compounds, tocotrienols, tocopherols, and γ-oryzanol contributes to its health-promoting properties [16].

In many fermentation processes (e. g., ethanol fermentation), the effects of rice bran composition on the microbial activity and accessibility of substrates are considered central factors. When using *Saccharomyces cerevisiae*, higher concentrations of rice bran will give more nutrients and fermentable substrate, resulting in a better ethanol yield. However, the high fiber composition of rice bran also brings challenges to its use as it is highly water absorbent, which can change the pH of the fermentation medium and make it a less favorable environment for some microbes. Rice bran is a complex carbohydrate substrate compared with simpler substrates. Therefore, sugars released would be more slowly available for microbial fermentation, reducing the potential for acid production and microbial growth rates.

Moreover, bran contributes as a sink for $CO_2$ by limiting the availability of fermentable sugars at high bran concentrations, affecting dough expansion in baking applications. In the case of wheat bran, optimized conditions for simultaneous saccharification and fermentation have been shown to produce significant ethanol yields, demonstrating the importance of managing fiber content and substrate distribution [17]. Rice bran, with its high cellulose and hemicellulose content, has been effectively used for ethanol production when appropriate pretreatment and fermentation strategies are employed, highlighting the potential of bran as a substrate for bioethanol production [18].

## 4. Rice bran composition

Saponins in rice bran impart a slightly bitter taste, but their sugar content can give them a slight sweetness. Reports further declare that rice bran oil has both nutritional and industrial value because its fatty acid profile is excellent. The saponifiable portion of rice bran oil is between 90 and 96%; however, rice bran oil has around 4% of the non-saponifiable fat. The saponifiable fraction constitutes the majority of energy and nutritional value with 68–71% triglycerides. It also contains 2–3% diglycerides, 2–3% waxes, 5–7% glycolipids, 5–6% monoglycerides, 2–3% free fatty acids, and 3–4% phospholipids that provide stability and functional properties. These distinctive lipid profiles prolong the shelf life and oxidative stability of rice bran oil and confirm its heart health benefits and cholesterol-lowering characteristics [19].

For health, functional foods, and ingredients in industrial applications, rice bran from Indonesian paddy hybrids possesses quite varied characteristics. The fat content varied from 16.80 to 23.75% DB in various hybrids, the best being the Sintanur hybrid. Therefore, if such hybrids show high-fat contents in some studies, they could be a good source of rice bran oil with polyunsaturated fatty acids. Another parameter of importance is the proportion of insoluble fiber, which significantly differs among hybrids with Sintanur containing maximum (30.44% DB). The content of soluble fiber in four varieties of rice was similar (4.04–4.14% DB). Menthikwangi variety was distinguished by the highest polyphenolic content (2794.28 EAG/g) and antioxidant activity of 41.28%, which are responsible for some health benefits such as anti-inflammatory and anticancer properties associated with the consumption of rice bran. Such variations highlight the need for targeted breeding and processing strategies to harness nutritional and functional properties of rice bran, which may facilitate its use in functional foods as well as obesity and cardiovascular disease control [20–22].

Rice bran serves as a functional food because it is packed with health-promoting components such as lysine-rich dietary protein indispensable for muscle integrity and body needs [23]. It is rich in carbohydrates and lipids such as palmitic, oleic, and linoleic essential fatty acids, which have been shown to improve cardiovascular and metabolic health [24]. Dietary fibers, including hemicellulose, cellulose, and starch, are beneficial for digestive health. Furthermore, rice bran is rich in bioactive compounds, such as tocotrienols and γ-oryzanol, with antioxidant activities, thus treating oxidative stress and inflammation, whereas the presence of anti-inflammatory and anticancer properties may inhibit cancer cell growth [24–26]. These elements enhance physical performance through improvements in endurance, oxidative stress regulation, and cardiovascular health support [27–29]. For various reasons, individual dietary needs, possible allergies, and health conditions precluding intake should be further studied so that a maximized application of rice bran in the continuum between optimal health status and diseases can be accomplished. Finally, bioactive compounds such as γ-oryzanol, ferulic acid, and vitamin E isoforms found in rice bran offer chemopreventive effects [30], whereby the antioxidant and anti-inflammatory effects associated with these compounds may resist some types of cancer. These features make rice bran attractive for dietary applications targeting heart disease risk factors, antioxidant status, and long-term health.

Tocopherols, γ-oryzanol, and β-carotene are bioactive ingredients that can be combined to produce functional food [30,31]. Tocopherol and γ-oryzanol are primary antioxidants, and β-carotene is a secondary antioxidant. Antioxidants work together, both primary and secondary. Each one serves as a complement and mutually strengthens the antioxidant quality. The main active component of crude bran oil, γ-oryzanol, is an antioxidant that can lower plasma cholesterol levels and treat menopausal problems [32–34]. Crude bran oil was found to be rich in tocotrienols in another study that included non-polar antioxidants [30]. Except for the distinction inside chains, tocopherols and tocotrienols have comparable bioactive chemical formulas [13]. Milling significantly reduces the protein, fat, and dietary fiber content of brown rice while increasing the starch content. This process also decreases the levels of γ-oryzanol, vitamin B1, and phenolic compounds, which are crucial for health [14].

Tocotrienols have been shown to have better antioxidant activity than tocopherols, with bran oil having a higher tocotrienol content (336 ppm) than tocopherol amount (81 ppm). By acting as lipid peroxides, singlet oxygen, oxygen-free radical scavengers, and antioxidants that prevent oxidation of oil and its carotenoids, tocopherols help to maintain the integrity of membranes. High temperatures do not affect the stability of tocopherols. Crude bran oil has a greater tocopherol and γ-oryzanol concentration than other vegetable oils [19,34,35]. Due to its chemical ability to bind singlet oxygen and inhibit radical-induced lipid peroxidation, β-carotene in rice bran plays a critical role in reducing the risk of cancer and cardiovascular disease. This powerful antioxidant acts by neutralizing free radicals, which are implicated in cellular damage and the development of chronic diseases. Notably, significant amounts of β-carotene are primarily found in colored varieties of rice bran, such as red and black rice bran, where the pigmentation indicates higher concentrations of this and other carotenoids. Pigmented rice brans contain high levels of anthocyanins responsible for their color and antioxidant activity. Black rice, for instance, is particularly rich in anthocyanins, contributing to its high antioxidant capacity. The consumption of pigmented rice brans is associated with numerous health benefits, including reducing obesity risk, anticancer properties, and improved blood sugar control [30,31,36,37].

It is necessary to consider the efficient usage of tocopherols, γ-oryzanol, and β-carotene in crude rice bran oil. In the study by Mumpuni *et al.*, the extracted rice bran oil, known as crude bran oil, underwent stabilization but no additional processing during the refining stage. As a result, it was possible to maintain the levels of three antioxidants better and prevent their loss. It is believed that high quantities of antioxidants, including tocopherol, γ-oryzanol, and β-carotene, can be obtained from this kind of crude bran oil to maximize the nutritional value of functional foods [34].

**5. Benefits of rice bran for health**

Functional foods contain biologically active (bioactive) substances intended to treat or prevent health problems in consumers and help them maintain optimal health. When used within the range of the prescribed amount, functional foods must not cause any interactions with other nutritional intake or adverse metabolic effects [33,38]. In addition, consumer-perceived sensory qualities of functional food, such as appearance, color, texture, and taste, must be acceptable. Rice bran has significant levels of vitamins, unsaturated fats, and minerals essential for human body cells' metabolic function [8].

Research advances towards understanding the nutritional quality of rice bran, especially regarding the discovery of thiamine (vitamin B1) in terms of disease prevention, including beriberi. This nutrient is required for energy metabolism and normal functioning of the nervous and cardiovascular systems. The discovery of the role of thiamine in beriberi, a disease that results from thiamine deficiency, was demonstrated by Christiaan Eijkman with his initial findings on rice bran. A lack of thiamine can result in serious complications involving neurological and cardiovascular systems resulting in the necessity of adequate thiamine [39]. His research highlighted rice bran as a vital dietary component for populations dependent on rice as a staple, underscoring its importance beyond basic nutrition. The presence of thiamine, along with other essential B vitamins in rice bran, supports a variety of metabolic processes, contributing to energy production, nervous system health, and cellular function. This recognition has paved the way for including rice bran in fortified foods and supplements to improve public health in regions where vitamin B1 deficiency is prevalent. In addition to the dietary fiber and phytosterols, which, according to nutritionists, have a hypocholesterolemic impact, stabilized rice bran contains several vital fatty acids, tocopherols, and ferulic acid derivatives. It is a good source of energy [5].

The rich phenolic and flavonoid content in rice bran contributes to its ability to inhibit HMG-CoA reductase, an enzyme involved in cholesterol biosynthesis, thus imparting both anti-hypercholesterolemic and antioxidant effects. Studies show that a blend of rice bran and red yeast rice extracts, particularly in a 3:1 ratio, achieves optimal cholesterol-lowering effects by effectively inhibiting HMG-CoA reductase activity. This combination maximizes the health benefits of rice bran bioactive compounds, such as gamma oryzanol, tocopherol, and tocotrienol, all known to support cardiovascular health by reducing cholesterol levels. These compounds synergize to enhance antioxidant and anti-inflammatory responses, further contributing to lipid-lowering. A mixture of rice bran and red yeast rice (RYR) in a ratio of 3:1, which reduced cholesterol synthesis and increased antioxidant activity, might be useful for hypercholesterolemia patients, improving their medication adherence, reducing side effects compared to commercial RYR products, and providing heart health benefits. The highest phenolic content was found at a ratio of rice bran extract and red yeast rice extract of 2:2, and the highest flavonoid content was found at a ratio of 1:3. The overall amount of phenolic compounds in rice bran was found to be 14.54 mg GAE/g, while the total amount of rice bran flavonoids was only 4.26 mg QE/g. The phenolic compound content in rice bran influences its antioxidant activity [40]. Red yeast rice (RYR) is a natural product obtained from the fermentation of specific strains of white rice with *Monascus purpureus*. It has monacolin K, an active compound identified as being structurally similar to lovastatin. Effects of RYR on cholesterol and cardiometabolic health are well-known [41,42].

A specific functional food that was made as an antihypercholesterolemic snack by mixing 0.8 grams of red yeast rice with 30 grams of rice bran and 7 grams of gelatin has been shown to have the ability to bind cholesterol. The cholesterol-binding ability of this functional food is 60.11% higher than that of commercial gelatin products without the rice bran component, according to *in vitro* test results. Additionally, rice bran increased dietary fiber content by 8.92% [43]. Rice bran suggests possible hypocholesterolemic effects, as it may modulate lipid metabolism and increase bile acid excretion, interrupting the enterohepatic circulation of bile acids, and leading to decreased circulating levels of cholesterol. These effects have been reported in both animal and human studies, indicating the role of rice bran in improving lipid profile and metabolic health [44].

Rice bran oil contains antioxidant compounds such as tocopherol, tocotrienol, and oryzanol. Depending on the bran type, bran oil can range in color from dark green to bright yellow. Pigments and the existence of the Maillard reaction products are two elements that influence the color of rice bran oil. The primary pigments of bran oil are beta-carotene and chlorophyll. Rice bran oil turns brown due to the Maillard reaction [45]. The dietary fiber and antioxidant compounds in rice bran are recognized for their health benefits, including hypocholesterolemic and hypolipidemic effects and potential anticancer properties. Microencapsulated rice bran (MRB) has been shown to reduce serum lipid levels and hepatic lipid accumulation in hyperlipidemic mice. This is achieved by decreasing the expression of genes related to lipogenesis and increasing those related to lipid catabolism and oxidation [46]. Because rice bran is high in antioxidants, it has the potential as a free radical scavenger. Experiments on mice have shown that rice bran oil can lower total blood cholesterol by lowering low-density lipoprotein (LDL) and very low-density lipoprotein (VLDL) levels [47]. The cholesterol-lowering effect of rice bran was demonstrated in an experiment with hamsters, where including rice bran in the diet significantly reduced plasma cholesterol levels compared to a cellulose control diet. The reduction was dose-dependent: the greater the amount of rice bran consumed, the more pronounced the decrease in cholesterol levels. Clinical studies have also shown notable reductions in both liver and plasma cholesterol levels when rice bran is processed or fermented. While rice bran is recognized as a potent lipid-lowering dietary modifier, the claim that high-temperature processing (stabilization) enhances its hypocholesterolemic properties is not supported by the information found in [48].

The total antioxidant activities of rice bran were discovered to be greater than those of tomatoes. Total antioxidant activities measured were 60.74% in tomato juice and 83.89% in the rice bran extract, indicating that rice bran has a higher ability to reduce harmful oxidative processes. One hundred grams of tomato juice can reduce DPPH free radicals equivalent to vitamin C by up to 1.87 times, while rice bran can reduce DPPH free radicals equivalent to vitamin C by 28.74 times. The antioxidant capacity of a beverage based on rice bran extract has been shown to cause a significant reduction in oxidative stress markers measured in the blood serum of women with breast cysts, suggesting its potential therapeutic benefits in managing oxidative stress-related conditions [26].

Oryzanol is a valuable compound derived from rice bran. Oryzanol has a higher antioxidant activity than tocopherol (vitamin E) and can stimulate human growth, improve blood circulation, and facilitate hormone secretion. Recently, $\gamma$-oryzanol, a powerful antioxidant mainly found in rice bran oil, has been recognized for its ability to treat many human diseases as it can scavenge free radicals and inhibit cholesterol synthesis. Cyclopentenyl ferulate has the highest antioxidant activity among its constituents after other ferulate esters [49].

Through progressive extraction and fractionation methods, rice bran yields significant antioxidants, enhancing its potential as a functional food ingredient. Compounds such as tricin and $\beta$-sitosterol, which can be effectively isolated from rice bran, demonstrate powerful antioxidant properties, specifically in scavenging superoxide radicals. This activity is essential in mitigating oxidative stress, as superoxide radicals are highly reactive and can contribute to cellular damage if not neutralized. The efficacy of these compounds can vary based on the extraction solvents and times used, suggesting that optimizing these conditions is critical for maximizing the antioxidant yield and activity of rice bran extracts. Refining extraction techniques can enhance the concentration of beneficial antioxidants in rice bran, making it a valuable source for nutraceuticals to reduce oxidative stress and support overall health [49–52].

The total phenolic content and ferulic acid content in rice bran are mostly responsible for this action [52]. In chemical tests and mammalian cells (human leukemia HL-60, lymphoblastoid B95–8 B marmoset B, and Chinese hamster lung cells V79), the rice bran extract has been found to have antioxidant, antimutagenic, and anticarcinogenic substances. The following tests were used to evaluate the antioxidant, antimutagenic, and anticarcinogenic activities of rice bran extracts: inhibition of 4-nitroquinoline N-oxide-induced mutagenesis; inhibition of xanthine oxidase activity; chelation of ferrous ions; reduction of potassium ferricyanide; scavenging of superoxide anions, hydroxyl radicals, and intracellular peroxides; and inhibition of tumor promotion induced by phorbol esters. The results demonstrated that bran from pigmented rice varieties can produce antioxidants and anti-carcinogens [53]. To combat oxidative cell damage, natural plant-based antioxidant supplements are crucial. The antioxidant and antiproliferative properties of bran from several rice varieties have been described by Rao *et al.* [54]. $IC_{50}$ values for scavenging DPPH and nitric oxide ranged from 30.85 to 87.72 µg/ml and 52.25 to 107.18 µg/ml, respectively. The total phenolic and flavonoid content range in rice bran was 3.2–12.4 mg GAE/g bran and 1.68–8.5 mg QEE/g bran, respectively. $IC_{50}$ values in the MTT assay were 17.53–57.78 µg/ml. Rice bran from the Njavara variety had high amounts of polyphenolic compounds showing superior antioxidant activity. It demonstrated the highest reducing power activity and antiproliferative properties in C6 glioma cells.

A highly substantial association was found between total antioxidant and free radical reduction levels. The significant levels of polyphenolic components with exceptional antioxidant activity were demonstrated in rice bran extracts [47]. The dietary fiber of rice bran, with a relatively high level in it (25.3%) has an important function in controlling blood glucose levels. This largely happens because of its ability to bind with glucose and pull off water, making less glucose and carbohydrates available for absorption into the body. Several studies have shown that this trait contributes to keeping blood glucose levels lower [55]. Rice varieties, such as black rice, have a high anthocyanin content in the pericarp layer, imparting a dark purple appearance. Anthocyanin functions as an antioxidant that regulates blood cholesterol levels, prevents anemia, may increase the body's resistance to disease, lessens liver cell damage from hepatitis and cirrhosis, prevents impaired kidney function, has anticancer/tumor and anti-aging activities, and prevents the development of atherosclerosis and cardiovascular disease. Anthocyanins present in rice bran play a protective role in vascular health by supporting the integrity of endothelial cells, which line blood vessel walls, and preventing cellular damage due to oxidative stress [56]. Additionally, rice bran extract has demonstrated cholesterol-lowering effects *in vitro*, with its ability to bind cholesterol increasing as the extract concentration rises. At a concentration of 20 ppm, rice bran extract achieved a notable reduction in free cholesterol, binding up to 47.46% of available cholesterol. This cholesterol-binding capacity of rice bran extract suggests its potential as a natural supplement for managing cholesterol levels, which could be particularly beneficial for cardiovascular health. The efficacy of rice bran in binding cholesterol appears to be dose-dependent, highlighting the importance of optimizing extract concentrations to maximize its hypocholesterolemic benefits [20,57].

Triglycerides and serum cholesterol have a positive or unidirectional association. Triglycerides rise along with cholesterol when cholesterol levels rise [2]. After giving white rats nata de coco mixed with rice bran for two weeks of treatment, it was found that the fiber content of the nata de coco mixture can lower the triglyceride level to 23.09 mg/dl [2]. Oryzanol, a bioactive component of rice bran, can bind with insoluble cholesterol to form complex molecules. Through its ability to absorb peroxyl radicals, tocopherol inhibits lipid peroxidation. The most effective isomer of fat-soluble vitamin E, $\alpha$-tocopherol, is a formidable free radical scavenger [22]. Additionally, as demonstrated in animal research, tocotrienols block cholesterol synthesis, lower serum cholesterol levels, and decrease the growth of tumor cells [2,5].

Furthermore, lipid peroxidation in rats was reduced when red yeast rice (angkak) and rice bran were combined. The combination of these two ingredients also helped prevent and improve histopathological conditions in the pancreatic, liver, and renal tissues. The study by Hasim *et al.* demonstrated that the formation of malondialdehyde (MDA) and the activity of alanine/aspartate aminotransferase (ALT/AST) enzymes in the rat blood serum were inhibited. These medicinal properties provide compelling evidence that rice bran and angkak have significant potential as functional foods [10].

Due to its relatively high fiber content (25–35%), rice bran is an important source of dietary fiber and can be considered a functional food ingredient. Although the relative proportions of soluble and insoluble dietary fiber vary, rice bran typically contains a significant amount of insoluble dietary fiber, which assists in bowel health by facilitating fecal bulk, increasing fecal water content, and eliminating intestinal wastes. Soluble fiber contained in rice bran helps control cholesterol and contributes to heart health. The main monosaccharides in rice bran fibers include xylose, glucose, arabinose, and galactose, contributing to their functional properties [15,55,57]. Compared to wheat bran, highland barley bran, and tartary buckwheat bran, rice bran exhibits a unique rugged microscopic structure that contributes to its functional properties. While highland barley and tartary buckwheat brans show higher glucose and cholesterol adsorption capacities, overall functional profile of rice bran, including its antioxidant and metal ion binding capabilities, is nevertheless noteworthy [55,58].

Rice bran, a by-product of the rice milling process, is a versatile ingredient utilized across various industries, including fuel, fertilizer, medication and soap production, as well as the food and beverage sector. Its inclusion in food products is particularly notable, as it offers both nutritional value and functionality. Rice bran is widely used in products such as snack bars, breakfast cereals, fiber drinks, cakes, cookies, bread, and other foods, due to its unique combination of bioactive phytochemicals and health benefits [5,31,35]. Consumer acceptance studies have shown optimal results when rice bran was incorporated into food products at a substitution level of 10–15% of wheat flour, particularly in items like cookies and sweetbreads. This substitution significantly enhances the nutritional profile of the final product by increasing levels of essential nutrients such as niacin and dietary fiber fractions, including hemicellulose, cellulose, and lignin. Additionally, the high fiber content of rice bran influences texture characteristics, often improving the mouthfeel and overall sensory appeal of the product. Beyond its functional contributions, rice bran offers substantial health benefits, making it an attractive ingredient for health-conscious consumers. It is linked to improved digestive health due to its high fiber content and has been associated with lowering cholesterol levels and reducing the risk of chronic diseases, such as cardiovascular disease and type 2 diabetes. Its rich profile of antioxidants, including tocopherols, tocotrienols, and γ-oryzanol, further enhances its appeal in food formulations targeting wellness and preventive healthcare. The incorporation of rice bran into various food formulations not only provides a cost-effective way to utilize this nutrient-dense by-product but also aligns with the growing consumer demand for functional and health-promoting foods. As research advances, the potential applications of rice bran are expanding, offering exciting opportunities for innovation in the food industry [59–61]. Recent research has highlighted the unique properties of rice bran, emphasizing its potential in preventing and managing chronic diseases. The synergy of its bioactive compounds contributes significantly to its therapeutic effects, including modulation of metabolic pathways, enhancement of gut microbiota, and regulation of immune responses. Moreover, its application in functional food formulations has expanded due to its affordability, sustainability, and versatility, making it an attractive option for both researchers and the food industry [20,62–65].

Furthermore, rice bran oil (RBO), which is rich in γ-oryzanol, tocopherols, and unsaturated fatty acids, is also suggested for better cardiovascular health due to the regulation of the level of LDL and HDL cholesterol, and it has been used in formulations of functional food [63]. Comparative studies on diverse Thai rice bran varieties highlight a range of nutrient profiles, including some with high levels of anthocyanins and γ-oryzanol, which are implicated in chronic disease prevention and mitigation of metabolic complications [64,65]. A comprehensive metabolomic profiling study identified more than 450 metabolites, including rare amino acids, cofactors, and secondary metabolites that support immunity, lower oxidative stress, and offer protection against cardiovascular diseases [66]. These studies highlight and support various health benefits of rice bran and its versatility as a functional food ingredient that can be marketed to promote human health through many different food applications. This body of evidence supports the restorative capacity of rice bran and facilitates changes in its perception as low-value rubbish to a high-value preventive health functional food.

However, rice bran is highly susceptible to rancidity due to lipase and lipoxygenase activity. This problem can be overcome with the help of processing techniques such as microwave stabilization and enzymatic extraction, which lead to a marked improvement in the stability and functionalities of stabilized rice bran compared to raw rice bran. Microwave treatment effectively stabilizes rice bran by inactivating lipase enzymes, reducing free fatty acid (FFA) content, and improving oxidative stability. This method has been shown to maintain high levels of total phenolic content and γ-oryzanol, which are crucial for antioxidant activity [16,62,67].

The rice variety and cultivation practices affect metabolic processes occurring within the plant and also lead to variation in compositions of bioactive substances due to the activity of nitrate reductase enzyme (NRA), which plays a key role in nitrogen metabolism that ultimately impacts amino acids and proteins generated in the seed thus affecting the nutrient profile of rice bran [68]. The activity of this enzyme differs among rice varieties, leading to differences in nitrogen assimilation efficiency and affecting the final nutrient composition in rice bran. The concentration and types of metabolites, such as amino acids, considerably vary between different rice cultivars, which critically determine the nutritional quality of rice bran [69]. Methods of cultivation and the application of fertilizers can play a significant role in improving the bioactive components, fatty acids, and volatile oils of rice grains. While some studies suggest potential benefits of nanomaterials in agricultural applications, the effect of cerium oxide nanoparticles ($nCeO_2$) on rice quality, as reported by Rico *et al*. [70], raises concerns. Their findings indicate that $nCeO_2$ may compromise the quality of rice grains.

Rice bran is rich in proteins, fibers, lipids, and contains minerals; however, the compositions depend upon rice cultivars and processing techniques [59]. Bioactive components like γ-oryzanol and tocopherols benefit human health due to their antioxidant and anti-inflammatory properties [60,61]. Although the composition of bioactive compounds, including flavonoids, phenolic acids, and ferulic acid in rice bran depends largely upon the activity of nitrate reductase enzyme, other factors such as cultivation practices, environmental conditions, and post-harvest processing have a significant influence on it eventually affecting prospectively functional aspects of rice-bran in food/ pharmaceutical applications.

## 6. Conclusion

Rice bran has the potential to be used as a functional food to improve national health. To prevent damage caused by rancid hydrolysis or oxidation, effective processing methods, such as stabilizing the rice bran, must be employed. Consumer acceptance should be prioritized during the stabilization and processing of rice bran. As a result, it is recommended that researchers develop functional food products from rice bran with long-lasting stability and high quality. Rice bran represents a significant market opportunity for the paddy milling industry in terms of providing healthy food to consumers.

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