






Review Article

Photochemistry, Functional Properties, Food Applications, and Health Prospective of Black Rice

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This review investigates black rice's photochemistry, functional properties, food applications, and health prospects. There are different varieties of black rice available in the world. The origins of this product can be traced back to Asian countries. This rice is also known as prohibited rice, emperor's rice, and royal's rice. Black rice is composed of different nutrients including fiber, protein, carbohydrates, potassium, and vitamin B complex. It contains an antioxidant called anthocyanin and tocopherols. Antioxidants are found mostly in foods that are black or dark purple. Due to its nutritious density, high fiber level, and high antioxidant content, black rice is a good alternative to white and brown rice. Utilizing black rice in various foods can enhance the nutritional value of food and be transformed into functional food items. Many noncommunicable diseases (NCDs) can be prevented by eating black rice daily, including cancer cells, atherosclerosis, hypertension, diabetes, osteoporosis, asthma, digestive health, and stroke risk. This review aim was to discuss the role of nutritional and functional properties of black rice in the formation of functional food against different noncommunicable diseases.

1. Introduction

Black rice that belongs to the *Oryza sativa* L. species, scientifically known as *Zizania aquatica*, is cultivated in Asia. They are a viscous and nutrient-dense food. Its seed appears

black due to the presence of an antioxidant pigment anthocyanin. Other popular names of black rice are forbidden rice, purple rice, heaven rice, king's rice, and prized rice. People often take it as an elixir as they are nutrient-dense and therapeutic. The food also called "long-life rice" is

known to raise the soundness and longevity of life. It has been grown in Southeast Asian countries including China, Thailand, and India for years [1]. There are 200 varieties of black rice around the world. 62% of the global production of black rice is by China alone. Around 45 modern black rice varieties are developed by China, which have high yield and multiple resistance genes [2]. Engrossment in black rice is shown by several successions that occurred in germ plasma collection, e.g., Bangladesh—24, the Philippines—25, Indonesia—42, and China—359 [3].

Black rice has minerals (Ca, P, Fe, and Zn) and dietary fiber, which are higher than brown and white rice. Being nutrient-dense, the demand for black rice is accelerating in the United States of America and European countries. Black rice is certainly a special breed that was grown in ancient times, but in modern agriculture, they are not grown on a larger scale. Black rice has both short and long grains. Black rice is openly pollinated, i.e., heirloom rice. One of its strains was called “Imperial Rice,” which was reserved for the emperor’s consumption only. The black color of rice turns royal purple when cooked. This characteristic color is due to anthocyanin; a strong antioxidant presents in the seed coat of anthocyanin. This characteristic color is typically observed in blueberries and blackberries [4].

Black rice contains about 26.3% anthocyanin, and the main functional constituents are chrysanthemum (cyanidin-3-O-glucoside) and methyl-cyanidin (peonidin-3-O-glucoside), which constitute 90% [5]. Anthocyanin present in black rice is mainly responsible for preventing DNA damage and artery endothelial degeneration and hardening [6]. Extracts of black rice have a better ability to scavenge superoxide anions than OH radicals [7]. Black rice is highly protected in Asian countries, and its intake in meals has become more common now. Black rice is particularly common among dieticians who recommend it to their clients due to its high nutritional value and therapeutic nature [8]. Black rice is usually sold with its fiber-rich black husk instead of polished rice. It is more commonly used either as savory or in dressings, and it is also a part of desserts in different parts of the world. This “Superfood” is praised and liked by people because of its rich color and nutritional value. It is often a part of fresh juices and other refreshments around the world. Once cooked, its black color converts into dark purple, which looks attractive to the consumer, and its taste is sweeter than white rice with a sticky texture. In Korea, they are consumed in combination with white rice, while in China it is part of many desserts, porridges, and bakery item. It was believed that looking at black rice in the morning is a good omen as it brings peace and happiness all day long. In ancient times, it was consumed by emperors due to its dual nature of being fluffy and good in taste first and being nutritious and curative food second. The consumption of black rice is more common among Europeans as compared to South Asians. Its antioxidant-rich nature and therapeutic effects make it a lifesaving food [9].

Black rice due to its strong antioxidant potential protects from thickening or hardening of arteries due to plaque formation by preventing the changes in low-density lipoproteins resulting from oxidative stress. Studies have shown

that the Chinese took black rice as alternative medicine due to its antioxidant potential and they also believed that it was beneficial for vital organs of the body [10]. The fractional of minerals in black rice greatly depends on the nature of the soil where it is cultivated and its strain [11].

Rice is the staple food in many countries around the globe; thus, the consumption of black rice is a great option to enhance the supply of anthocyanins to the body [12]. Another way to consume anthocyanin is in the supplemental form, which can be costly. All these aspects are contributing to giving black rice the status of novel organic food worldwide [13]. The consumption of black rice also has an antiaging, antiviral, anticancerous, and anti-inflammatory effect on its consumer [14].

Evidence-based studies have proven the physiological and pharmacological potential of black rice [15]. Harvesting and cultivation of black rice have also created many employment and career opportunities for people [16]. Excessive production of free radicals is the main cause of cancer. Breast cancer, colon cancer, and prostate cancer are greatly found to be associated with dietary choices and lifestyle. The risk of cancer can be reduced by consuming plant foods such as black rice. Many studies have suggested the role of black rice in health improvement and disease prevention. Alone anthocyanin in black rice is an undoubtedly potentially bioactive component that has come up with a great ability to improve metabolic mechanisms and conditions such as obesity, heart disease, stroke, and type 2 diabetes [17–20]. Whole seed black rice must have much more health benefits as they not only can prevent and improve conditions such as heart diseases, diabetes, and hypertension but also upgrade the quality of life.

2. Methodology

For the data collection about black rice, we used Science Direct, Google Scholar, Web of Science, and PubMed. We made the content first to make the proper design of the review and then made the conceptualization. By following the framework, we developed the partitions of the review and discussed the nutritional composition of black rice, food application of black rice foods, and the potential to combat noncommunicable diseases of black rice.

3. Classification of Black Rice

Black rice is classified into different categories according to the different shapes, sizes, nutrient contents, and colors. There are different varieties including black forbidden rice, black glutinous rice, black emperor’s rice, and black jasmine or Chak Hao rice. Black rice is classified into various varieties as described as follows and in Figure 1.

3.1. Black Forbidden Rice. Black forbidden rice is a combination of mahogany medium-sized grain rice and black short grain rice. It has a characteristic earthy flavor along with a mild sweet spicy smack [21].



FIGURE 1: Classification of black rice.

3.2. Black Glutinous Rice. Black glutinous rice is commonly known as black sticky rice, which is a short grain variety of rice with a sticky texture and sweet taste. This rice has uneven pigmentation and is mainly used as a part of desserts in Asia.

3.3. Black Emperor's Rice. Black emperor's rice is a combination of Chinese black rice and Italian rice. It is long grain rice with rich and buttery savor.

3.4. Black Jasmine or Chak Hao Rice. Thai black jasmine rice is basically of Thai origin, and they are a combination of medium grain rice with a mixture of jasmine rice and Chinese black rice. When cooked, a delicate floral aroma or fragrance can be felt [22].

4. History and Background

Black rice is a worthy grain consumed globally as a source of energy by both humans and animals. It is grown in over 100 countries in the world ranging from 45° S to 53° N latitudes [23]. Residents of at least fifteen countries in Asia, about ten countries in Latin America and the Caribbean, seven countries in Saharan Africa, and one country in North Africa consume black rice as a staple food [24]. Rice is quite a popular food among consumers as about half of the rice produced is consumed within 10 miles of where it was grown. Rice is found everywhere except Antarctica. About 95% of global rice production is from Asian countries [25]. Acknowledging the worth of another rice crop, 2004 was declared the "International Year of Rice" by the General Assembly of the United Nations. In Asia, food and rice are used synonymously. A single grain of rice can produce 3000 grains of rice, and rice is second to corn. 1/5th of human caloric intake is from rice, and when we talk about Asia, almost 60% to 70% of their caloric requirement is obtained from rice [26].

Oryza sativa L. that is commonly known as Asian rice is a monocotyledonous plant and a major cereal grain making up a food source for 3 billion people around the globe. Rice was a crop from East, Southeast, and South Asia. Later, it reached the European countries and America during the colonization of the subcontinent. Rice has more than 40,000 varieties, yet we know of only a few. These varieties grow in tropical and subtropical regions and are linked to the grass

family Gramineae. It is often said that it was grown in India, China, and other Asian countries for 4,000 B.C. years ago. It is also believed that Japonica rice was first grown at a domestic level from which other types were merged including Indica [27]. *Oryza* has more than 25 varieties, and more of them are Indica, which is followed by Japonica and then Javanica. A perennial species, which is known as *Oryza glaberrima*, is grown in Africa. *Zizania aquatica*, which is also known as "wild rice," is grown in the Great Lakes region of the United States. Wild rice is closer to oats than rice. Rice is partially aquatic grasses. Rice that is grown in winter is known as Rabi rice and those that are grown in summer/spring are called Boro rice. In tropical regions, once the rice is sown, it will take about six months to harvest this crop. Using conventional methods of rice cultivation, about 2500 liters of water is needed to produce a single kg of rice, but using modern techniques of rice cultivation, the water requirement for rice cultivation has greatly reduced. During the whole plantation period, flooding according to weather conditions keeps rice plants safe from weeds and pests. Rice plants can grow from 3' to 6' vertically depending on the variety, soil nutrition, and weather conditions. The consumption of polished white rice is more common worldwide. People usually think of white or brown rice, but they are found in a broad spectrum of colors from white to brown to red and with a deep purple hue. The taste of rice consumed with their hull or seed coat is nuttier than polished rice and those with removed seed coat. An expert can distinguish between different rice varieties. Before the Chinese dynastic period, black rice was grown in China, and they were a sign of luck because of its black color. Later, it was found that color depends on the concentration of pigment. In black rice, this black pigmentation is due to anthocyanin, and in red rice, it is due to tannins. If white rice is discussed, there is no pigmentation as no mutations occur at the genetic level, while in black rice, there is a mutation in the gene controlling the biosynthesis of pro-anthocyanin. During the Hung Dynasty, black rice was cultivated and eaten in Vietnam [28]. The origin of black rice is not clearly understood; however, it is believed that it originated from Asian countries including Japan, India, China, and Vietnam [29–32]. Chaudary and Tran [33] mentioned that this superfood might be originated from the Philippines, Sri Lanka, Bangladesh, Myanmar, Thailand, and Indonesia (Table 1).

TABLE 1: Different classification of black rice consumption in the different regions of the world.

Varieties	Species and subspecies	Description	Consumption regions	References
Black rice	<i>Oryza sativa L. indica</i>	Long and nonsticky rice	People of Southern Asia and Eastern Asia	[34]
Black Japonica rice	<i>Oryza sativa L. japonica</i>	Short and sticky or mahogany rice	People of Northern China, Japan, Southern Asia, and Latin America	
Black Chak Hao Amubi rice	<i>Oryza sativa Chak Hao Amubi</i>	Medium and long nonsticky rice	People of the Indian subcontinent	[35,36]
Black Chak Hao Poireiton rice	<i>Oryza sativa Chak Hao Poireiton</i>	Medium and long nonsticky rice	People of Thailand and Iran	[37]
Black forbidden rice	<i>Oryza sativa forbidden</i>	Medium-sized grain rice and black short grain	Mostly people of China and Asian countries	[21]
Black emperor's rice	<i>Oryza sativa emperor's</i>	Long grain rice	Mostly consumed in China, South Africa and Nigeria, and Italy	[38]

5. Botanical Description of Black Rice

Black rice is formed by the ripened ovary of the flower and is between 5 and 12 mm in length and pear-shaped (Figure 2). *Oryza* is the genus belongs to the Oryzaceae of Poaceae family. Oryzaceae has twelve genera, and the genus *Oryza* has almost 22 species. Among the species, 20 are wild species and the rest of the two are cultivated: *O. sativa* and *O. glaberrima* [39]. Former is more common on a larger scale than *O. glaberrima* in different parts of the world including African, Asian, European, Middle Eastern, South, and North American countries. *O. glaberrima* is grown in West African countries. However, high-yielding hybrids of cultivating species are replacing *O. glaberrima* in African parts [40].

It is suggested by the researchers that Asian species are the ancestor of *O. sativa*. These ancestors are *O. nivara* and *O. rufipogon*, which are annual and perennial. They also added that among the developed varieties there is a similarity with wild ancestors. *O. glaberrima*, which are African cultivated rice, are the predecessors' wild ancestor species, *O. longistaminata* and *O. barthii*. The rest of the wild species belong to regions of Africa, Central and South America, Asia, and Oceania with conjoining spread. *Oryza sativa* has the smallest gene sequence and diploid genome among all food crops consisting of 430 million base pairs, and half of this genome is made up of repeated sequences. Some of the *Oryza* species are tetraploid with 48 chromosomes. Species in genus *Oryza* are classified into nine groups depending upon the similarity of the F_1 hybrids that are the first generation in meiosis [41, 42].

6. Chemical Properties

Rice comprises the hull (outside) and the caryopsis (inside). Hull makes the outer layer and consists of about 20% of the total paddy rice by weight, and it also has silica and cellulose. During the hulling process, the hull is removed and caryopsis is exposed, which is brown rice that consists of bran, endosperm, and germ [43]. Then, in another process of milling, the bran layer and germ are removed, and white rice is obtained [44]. Bran and germ are rich in minerals, proteins, fiber, oil, and phytochemicals. When it comes to black rice, the hull is removed along with a small fraction of the bran [45]. The bran makes up 6%–7% of paddy rice by weight and

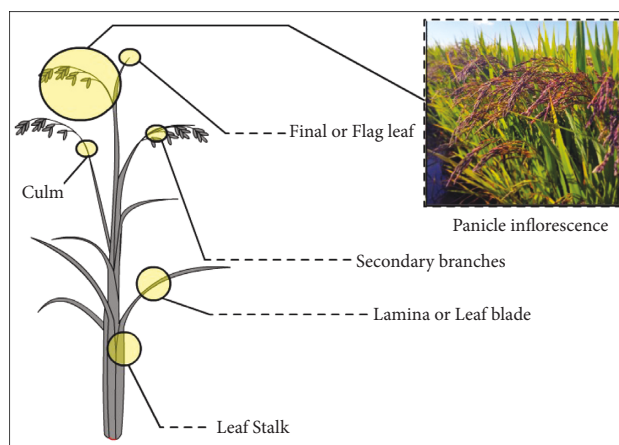


FIGURE 2: Formation of black rice.

comprises different layers [46]. Black rice is like other whole grains. The pericarp plays a protective color seed coat and has pigment, which makes rice appear brown, red, or black. Starch stores are majorly found in endosperm, which is about 75%, and proteins are found in an outer layer, which is sub-aleurone [47–49]. Mau et al. [50] believed that black rice contains lesser amounts of polysaccharides including dietary fibers (cellulose and hemicellulose, pectin, and resistant starch) and simple sugars. All these carbohydrates are mainly found in the outer layers. However, the germ of the seed has proteins and fat constituents of two to three percent (2%–3%) of the total weight of paddy rice.

Rice is a major crop that feeds more than half of the world's population. Aside from essential nutrients, black rice is a good source of phytochemicals, fiber, and minerals. In Asia, particularly in China, a variety of black rice cultivars are grown [51]. When compared to white rice, black rice has better nutritional and functional properties. This is owing to the presence of several bioactive and nutritious components in the embryo and the bran layers, such as functional lipids, essential amino acids, vitamins (A, B complex, and E), dietary fiber, minerals (Fe, K, Zn, Mg, Cu, P, and Mn), phenolic compounds, anthocyanins, γ -oryzanol, tocopherols, phytic acid, tocotrienols, and phytosterols [47–49]. Black rice's endosperm contains around 75% carbohydrates, mostly starch and a protein-rich outer layer (sub-aleurone).

The maximum quantities of anthocyanin are found in black rice, which has a high nutritional value. The pericarp (outside part) of this rice's kernel is black due to an antioxidant pigment called anthocyanin [46]. The germ, which makes up around 2–3% of the overall mass of paddy rice, contains lipids and proteins. The inclusion of nutrients such as fiber, protein, B vitamins, minerals, vital amino acids, and others that are unique to sticky black rice is extremely helpful to human health. There is no other rice that comes close to black rice in terms of nutritional diversity. This rice is gluten-free, cholesterol-free, sugar-free, salt-free, and fat-free. Black rice is a high-fiber, antioxidant, anthocyanin, iron, vitamins B and E, thiamine, niacin, magnesium, and phosphorus whole grain rice [13].

6.1. Proteins. The germ, which makes up around 2 to 3 percent of the total weight of paddy rice, contains proteins and lipids. Although rice is primarily composed of starch, which provides energy, black rice also contains protein, which is found in the rice kernels. Rice protein can be classed based on how soluble it is. Glutelins, which are soluble in alkaline conditions and account for 60% of total protein, are accompanied by globulin (salt-water-soluble; 10%), a prolamin (alcohol-soluble; 25%), and albumin (albumin-like protein) (water-soluble; 5%) [38].

6.2. Minerals. Many vitamins and minerals, such as vitamin A, vitamin B, and iron, are found in black rice and are good for the overall prevention and health of heart diseases [52]. As compared to white rice, black rice contains more minerals, such as Zn, Fe, P, and Mn, and its mineral content is more variable, depending on the variety and soil type of the flowering location. The iron in black rice is required for healthy red blood cell synthesis, digestion, and energy expenditure, while potassium is required for muscle development [51].

6.3. Vitamins. This rice is high in fiber, vitamin E, iron, and a variety of other important minerals. A rice variety is used as both medicine and food [13]. Because of its high amounts of vitamins B and E, it is considered a “superfood” that may reduce the risk of cancer. Vitamins and minerals are beneficial for overall health and heart disease prevention [53].

6.4. Fiber. Black rice is thought to be a high-fiber food. Black rice is usually sold unmilled, which implies that the rice's fiber-rich black husks have not been removed. This rice is cholesterol-free, gluten-free, and low in salt, sugar, and fat [13]. Black rice is high-fiber whole grain rice that is extremely healthy. The most common type of fiber is insoluble fiber, which accounts for about 75% of the total. Black rice has higher fiber content than white rice, which is preferable [38]. The consumption of black rice in the diet was hypocholesterolemic. The hypocholesterolemic impact of black rice is thought to be due to a combination of dietary fiber and other bioactive components such as polyphenols [54].

6.5. Anthocyanin. Black rice is rich in anthocyanin and has a high nutritional value. Its dark purple color comes from a higher anthocyanin content than other colored grains. Anthocyanins are a collection of water-soluble reddish-purple flavonoids found on the pericarp, aleurone layer, and seed coat. Anthocyanin is one of the black rice ingredients that help protect arteries and prevent DNA damage by mopping up toxic chemicals. Anthocyanins are the flavonoid pigments found in black rice, and they are a source of antioxidants that can prevent or limit the generation of reactive cell-damaging free radicals [55].

7. Bioactive Composition of Black Rice

Preservation of pigmented rice is of prime importance for a sustainable environment and in providing a surety for food security in the future. Pigmented rice is gaining popularity due to its therapeutic potential [17]. They are also high in proteins, minerals, and vitamins [56]. They are anti-atherosclerosis, anti-allergic, and cancer-preventive. They also improve the condition of iron deficiency anemia [57]. The nutritional profile and bioactive components of this rice have gained popularity in research as well due to their ability to lower the chances of heart disease, diabetes, and inflammation. The formation of flavonoids requires phenolic compounds as their precursor [10]. The bran layer of rice has been shown to contain anthocyanin, which has antioxidant potential by scavenging free radicals. Rice is one of the most researched foods about fortified food and clinical research. Due to its antioxidant potential, pigmentary rice is gaining popularity in research studies in South America, Africa, and Europe [13]. Because of its nutritional profile, researchers and scientists have considered black rice as a superfood [58]. Black rice is a wholesome variety of rice that contains a generous amount of protein along with a high amount of fiber, vitamin B, antioxidants, iron, thiamine, vitamin E, magnesium, phosphorous, and niacin. It comprises the highest percentages of antioxidants, protein, and dietary fiber among all rice varieties [59]. Black rice has also been recognized as an excellent source of phytosterols, carotenoids, phenol carboxylic acids, bioflavonoids, and phytochemicals (Figure 3).

7.1. Phytosterols. Secondary metabolites are present in black rice grains in a wide range. An antioxidant g-oryzanol, which contains a combination of phytosterol, is present in high amounts in black rice than in white rice [60]. Campesterol ferulate, 24-methylenecycloartanyl ferulate, cycloartenol ferulate, and beta-sitosterol contribute to the nutrition. Zubair et al. [61]; Pereira-Caro et al. [62]; and Jesch and Carr [63] reported that phytosterols play important role in controlling several unwanted lipoproteins in blood inhibiting the cholesterol absorption in adipocytes.

7.2. Carotenoids. One of the important classes of nutritionally beneficial components is carotenoids [64]. About more than 90% of the carotenoids produced by rice comprise lutein and zeaxanthin. Trace amounts of lycopene and beta-

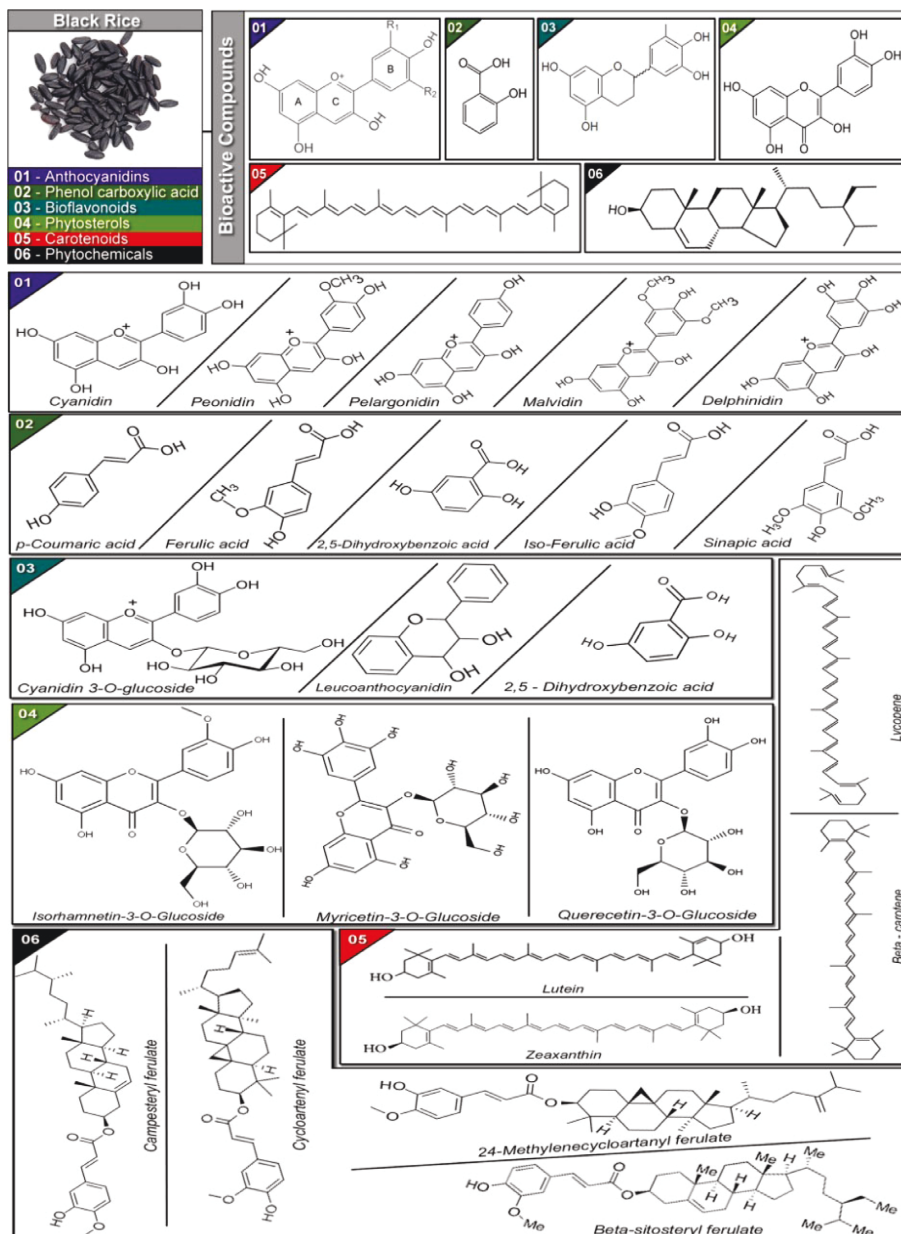


FIGURE 3: Bioactive components obtained from black rice.

carotene are found in carotenes [65]. The bran layer of black rice has a generous amount of these compounds. However, negligible amounts of carotenoids are found in milled rice [66]. Carotenoids are associated with pigmentation and genetic makeup, so they are mostly present in black rice [67]. A comparatively higher concentration of carotenoid is present in black and red rice as compared to white rice [66].

7.3. Phenol Carboxylic Acids. Zhang et al. [68] and Gunaratne et al. [69] reported that higher levels of phenolic carboxylic acids are found in black rice as compared to white rice. Cinnamic acid is a precursor for the making of several phenolic acids, including major p-coumaric acid, ferulic acid, 2, 5-dihydroxybenzoic acid, isoferulic acid, and sinapic acid [70]. Syringic acid is found in the extract of black,

brown, and red rice [71], while pinellinic acid is found in red and white rice and hydroxybenzoic acid is present in black rice [72, 73].

7.4. Bioflavonoids. The main flavonoids found in black rice are anthocyanins, and Galland et al. [74] reported that the synthesis of delphinidin, pelargonidin, and cyanidin is done by oxidation reaction and is catalyzed by anthocyanin synthase of leucoanthocyanidin. Flavonoids and particularly anthocyanins cause purple and blue color pigmentation in purple and black rice. The most prominent compounds are cyanidin-3-O-glucoside, peonidin-3-O-glucoside, cyanidin-3, 5-glucoside, pelargonidin-3-O-glucoside, peonidin-3-O-(600-O-p-coumaroyl) glucoside, cyanidin-3-O-(600-O-p-coumaroyl) glucoside, and cyanidin-3-O-arabidoside [62, 68].

7.5. Phytochemicals. Black rice is a vital and abundant source of phytochemicals, and the dehulled seeds of Japanese black-purple rice have twenty-three secondary metabolites, comprising anthocyanins, flavones, isorhamnetin-3-O-glucoside, and myricetin-7-O-glucoside, and flavonoid glycosides, quercetin-3-O-glucoside, vitamin E (tocopherols and tocotrienols), carotenoids, and γ -oryzanol have been characterized both qualitatively and quantitatively, and they provide health benefits. They also make black rice a functional food [75, 76]. Anthocyanins are responsible for the dark color of the rice. 90% of anthocyanin components in black rice are about 26.3%, and cyanidin-3-O-glucoside and peonidin-3-O-glucoside are the main effective components. Anthocyanins are flavonoid pigments with antioxidant potential that protect the body against free radicals, thus slowing down aging and preventing cancer and other chronic diseases including cardiovascular diseases and diabetes. Improvement in memory and brain function and coordination is also reported by black rice [6]. Its antioxidant potential improves visual and neurological functions. It also shows antimicrobial properties. Anthocyanins are also used to treat a wide variety of other health problems such as blood pressure and urinary tract infections. Black rice has been reported to be the rival of blueberries in terms of its antioxidant power. Kushwaha [13] carried out a study at the American Chemical Society, and he reported that one spoonful of black rice bran contains more anthocyanin when compared with fresh blueberries.

8. Utilization of Black Rice and Its Components in the Food Industry

It is now clear that how black rice has a superior level of quality over the other varieties of rice regarding appearance and nutrition. It is rich in protein, fat, riboflavin, thiamine, zinc, tocopherols, and iron. Because of its health and nutritional advantages, black rice is becoming more common in the food choices of people and replacing white rice slowly. Utilizing black rice in various foods can enhance the nutritional value of food and be transformed into functional food items [4]. Functional foods may help with diverse health problems such as diabetes, obesity, high blood pressure, and heart diseases [20]. The black rice variety is not very well-known among the general population and can be thought of as a novel and healthier alternative to various food items for generations to come. The use of black rice in various food processing industries can enhance the nutritional value of traditional food items [13].

9. Applications and Quality Attributes of Black Rice

Due to numerous health-promoting and disease-preventing effects, black rice cultivars have been the subject of exploratory research regarding their potential applications and processing technologies to improve quality attributes and provide beneficial health properties. Black rice is utilized as a primary or small ingredient in paella, rice cakes, cooked rice, pancakes, and cereals [77]. Because of its unique functions, it has become a

major ingredient in a variety of new foods such as drinks, puddings, children's meal porridge, desserts, classic Chinese white rice cake bread, pasta, and bread. The studies in Table 2 have inspired research into the physicochemical and functional characteristics of starches and flours derived from black rice along with other kinds. This is because various factors can impact the quality of these flours and starches, such as size and structure of the grain's composition, gelatinization type, crystal polymorph, ratios of amylose and amylopectin, and the amylose-lipid complex, and that of a noncarbohydrate portion of the starch [95]. For instance, the external amylopectin, as well as amylose chains, could create double helices and join to form crystal domains, but in most starches, these are restricted to the amylopectin portion. Amylopectin-rich starches are the cause of crystallinity because of the creation of double helices between the chains that are external to amylopectin's molecules. Amylose does not affect the amount of crystallinity that occurs in glutinous and normal black rice starches, but it can contribute to crystallinity in starches with high amylose [96]. Amylose is among the most important factors in the rice's quality, particularly when it comes to the properties of cooking and pasting. The rice that has a low amylose content will be dry and sticky when cooked, while black rice that has a moderate amount of amylose can be dry and airy after being cooked, and it retains its soft texture even after cooling as well. Black rice that has a high amount of amylose will also become dry and fluffy after being cooked, but it becomes harder as it cools because of the retrogradation of amylose molecules [97]. Starches from black rice that have more amylose typically have a higher temperature for pasting, a lower peak viscosity, and greater setback viscosity. In contrast, those with lower levels of amylose tend to have less retrogradation and a higher swelling capacity [98]. The black rice starch has distinct characteristics. It is a mild taste and smells odorless in addition to being white in color, nonallergenic, and digestible in the tiny granular form [47]. Starch granules made of black rice are comparable to other varieties of rice and are the smallest among cereal grains, having an average size of between 3 and 8 μ m. They are polyhedral and with irregular shapes, sharp edges, and sharp angles [48], which makes them perfect for use as a cosmetic dusting powder, a fabric stiffener, and fat mimetics in food [99].

10. Processing Technologies of Black Rice

While rice starch is extensively used in its original form, its use is limited by factors such as high viscosity, insufficient solubility, high-temperature degradation, and the high likelihood of retrogradation. Therefore, both conventional and nonconventional sources of starch are altered by treatment (enzymatically and chemically) to meet the particular requirements of industries, by adjusting their functional and physicochemical properties. The methods for enzyme modification are complicated and time-consuming, which is why they are not widely used in the industry of food. Chemical modification is often employed because it is quicker, but there are risks with the presence of chemicals in the product [100]. There is a rising trend to modify the physical properties of black rice with green technology [101]. As per Zhu [102], the bioactive substances that are found in black rice may react with the starch in

TABLE 2: Food applications of black rice and their components.

Procurement	Black rice product	Mixing	Quantity and ratios	Phytochemicals	Conclusion	References
Rural Development Administration, Korea	Noodles	Bran powder: wheat flour	98 : 2; 95 : 5; 90 : 10, and 85 : 15 (w/w)	Polyphenolics, flavonoids, phytic acid, and anthocyanins	Improved the antioxidant activities when compared to the control noodles	[78]
Local Market of Manipur, India	Pasta	Black rice + Joha rice	30%, 55.32%, and 14.68%	Anthocyanin, total phenolic content, and DPPH scavenging activity	Conventional pretreatment method showed less degradation of anthocyanin and phenolic compound than sous vide and microwave processes	[79]
Chiang Mai, Thailand	Vinegar	Steamed rice	100 g	Total phenolic compounds, total acid, and acetic acid	Work as an antioxidant, anticancer, and antibacterial agent against various disorders	[80]
Zibo, Shandong Province, China	Beer	Black rice flour + malt	6.80 kg + 15.20 kg	Total polyphenol contents, Cyperus japonicus -3-O-glucoside (C3G), and paeoniflorin-3-0-glucoside (P3G)	The polyphenol content that influences the antioxidant ability and foam stability of extruded rice adjunct beer	[81]
Research Institute of Korea	Wine	Rice: black rice	1 kg: 0 + 800 g: 200 g + 600 g: 400 g + 400 : 600 g	Citric acid, malic acid, succinic acid, lactic acid, and acetic acid	The concentration of antioxidant was significantly increased with increasing amount of black rice. As a result of sensory evaluation, overall preference was high in rice wine made with less than 20% of black rice	[82]
Maha Sarakham Province, Thailand	Punch	Flavored yogurt	0.2, 0.4, and 0.6% by weight	γ -Oryzanol, total phenolics, and anthocyanins	A good stability of color and increasing phytochemicals contributed by black waxy rice bran	[83]
Nong Don District, Saraburi, Thailand	Milk chocolate	Anthocyanin powder + cocoa powder	3, 5, and 7 g	Antioxidant	Milk chocolate with 42% anthocyanin powder was selected as the most desirable health product with overall acceptance	[84]
Yogyakarta, Indonesia	Kefir	Black rice extract	Goat milk + inulin; goat milk and black rice extract (1 : 1); and goat milk + black rice extract (1 : 1) + inulin. Inulin was added in GM + IN and GM + BRE + IN as much as 0.5 g/ 100 ml	Total phenolic contents	Kefir can be used to treat diabetics as it acts as an antidiabetic agent	[85]

TABLE 2: Continued.

Procurement	Black rice product	Mixing	Quantity and ratios	Phytochemicals	Conclusion	References
Imphal, Manipur, India	Chicken nuggets	Rice flour + other ingredients	1, 3, and 5%	Antioxidants	The higher the nutritional value, the greater the textural properties of the final product and the better antioxidant activity	[86]
Chiang Mai Province, Thailand	Mayonnaise	Fish oil: black glutinous rice flour: soybean oil: vinegar: egg yolk: salt: potassium sorbate: mustard	Oil mixture (3:1 weight ratio of soybean oil to fish oil), 9.5 g, 8.9 g, 1.3 g, 1.0 g, and 0.7 g	Tocopherols, carotenoids, and antioxidants	The synergistic impact of all antioxidants can improve the oxidative stability of mayonnaise	[87]
Shaanxi Taiji Huaqing Technology, China	Bread	Black rice extract powder: bread flour	0%, 1%, 2%, and 4%	Anthocyanin	The experimental product may be an alternative to making active bread with the lower digestive rate and additional health benefits	[88]
Taichung, Central Taiwan	Chiffon cake	Black rice and wheat flour	0%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% (w/w)	Total phenols, total anthocyanins, and antioxidant property	Black rice significantly enhanced the bioactive components in the experimental product than the control. Therefore, it can be incorporated into bakery products with more bioactive components and more effective antioxidant activity	[50]
Gimpo, Korea	Cookies	Powder	Control and 7%	Antioxidant	Significantly improve the total phenol content and DPPH radical scavenging ability in the product	[89]
Thailand	Crackers	Brown Brown oyster Brown mussels Black rice Black oyster Black mussels	100% 80% + 20% 80% + 20% 100% 80% + 20% 80% + 20%	Antioxidant properties and total phenolic content	Significantly improved the antioxidant activity and total phenolic content in both cracker types due to the addition of functional ingredients	[90]
Zlín, Czech Republic	Muesli mixture	Kamut, einkorn, red and black quinoa, or rice flakes together with hibiscus, mallow, rose	60–70% of nontraditional flakes and 30–40% of lyophilized fruits and edible flowers	Anthocyanins, cyanidin-3-glucoside, delphinidin-3-glucoside, quercetin, epigallocatechin, flavonoids, sinapic and protocatechuic acids	Nontraditional muesli blends can be a valuable source of nutrients and biological components	[91]

TABLE 2: Continued.

Procurement	Black rice product	Mixing	Quantity and ratios	Phytochemicals	Conclusion	References
Guilin, Guangxi Province, China	Porridge	Waxy and non-waxy black rice	40 g	Total phenolic content, total flavonoid content, condensed tannin content, monomeric anthocyanin content, cyanidin-3-glucoside, and peonidin-3-glucoside	Heat treatment in black rice porridge has significantly reduced these biological compounds. It can retain a lot of antioxidants (such as phenolics) and maintain the stability of the functional substances. Therefore, rice porridge in the form of cooking black rice can have more health-promoting effects	[58]
Kanpur, India	Soup	Black rice, okra, and barley	(50:10:40), (50:15:35), and (50:20:30)	Anthocyanin and antioxidants	The soup can be easily swallowed by patients, who cannot chew and keep human health away from any inflammatory conditions such as allergies, cancer, asthma, atherosclerosis, and arthritis	[92]
Assam, India	Kheer	Black rice and xylooligosaccharides	5%, 8%, and 10%	Antioxidants	It can be used against various noncommunicable diseases	[93]
Kuta Selatan, Indonesia	Skin cream	Bran and powder	35%	Antioxidant	It increased the expression of matrix metalloproteinase-1 and density of dermal collagen in the skin to UV rays	[94]

gelatinization, affecting its pasting, thermal, and digestibility characteristics. The principal methods employed to examine the various analysis of quality in the black rice include scanning electron microscopy (SEM) and differential scanning calorimetry (DSC) within the flour and X-ray diffractometry, rapid visco analysis (RVA) high-performance liquid chromatography (HPLC)-photodiode array (HPLC-PDA), mass spectrometry (LC-MS), liquid chromatography (LC-MS), ultraviolet/visible (HPLC-UV/Vis), a fluorescent detector (HPLC-FLD) and texture profile analysis within the grain [47], and polarized light microscopy (PLTM) and Fourier transform infrared (FTIR) spectrum within the starch [48, 101, 103, 104].

The applications for the development of new goods are generally treated by steaming, boiling pan-frying, or roasting. These techniques can affect the bioactive components such as anthocyanins and phenolic acids, which can cause an increase in antioxidant activity [77]. Ryu and Koh [105] examined their thermal stability for phenolic acids. They discovered that all cooking techniques resulted in

significant increases in the total amount of phenolic acids. However, no significant change was observed in the quantity of inbound phenolic acids. The protocatechuic acid content free increased eleven-fold for cooked white rice as compared to raw rice. The acid showed a negative correlation with the total content of anthocyanins, which suggest that it is produced by the thermal breakdown of anthocyanins. Additionally, Melini et al. [106] reported that the main pigmented rice varieties have been recognized as a good source of carotenoids, total phenolic compounds, and anthocyanins. In this study, various cooking methods was used to investigate the impact of cooking methods on these ingredients. The results reveal that the main carotenoid (lutein), free anthocyanin, and phenolic compounds were reduced in all samples, while anthocyanins were observed only in black genotypes. On the other hand, it was observed that insoluble phenolics increased in some samples. Anthocyanins are potent natural colorants because of their high content of pigment and low toxicity. This means they could be utilized

within the industry of food as replacements for synthetic dyes. For instance, He et al. [107] created an easy method of removal and separation of the anthocyanins extracted from black rice, using water for extraction and membrane separation and resin adsorption to purify. However, using anthocyanins in food formulations, particularly in aqueous systems, is difficult because they can be reactive and are prone to degradation to brown or colorless compounds. Anthocyanins are believed to be affected by a variety of aspects, such as temperatures of heat treatment, storage temperature addition to exposure to UV and light pH value's chemical structure [108]. Therefore, the food industry is always looking for efficient and cost-effective methods to produce colorants that are powdered and condition-sensitive. A few studies have been conducted on the degradation of pH and thermal bioactive compounds' kinetics, particularly anthocyanins derived made from black rice [109].

A previous study assessed the effects of gamma radiation (0, 1, 2, and 3 kGy) on the thermal degradation and stability of anthocyanins and the stability of the total phenolic compound and antioxidant activity at various temperatures in the black rice flour [38]. The results revealed that combining radiation at different temperatures could enhance the shelf-life of black rice flour. According to Norkaew et al. [104], there is evidence to suggest that the stability of bioactive substances in rice may be affected by certain post-harvest treatment methods, such as temperature and time of drying, storage, and packaging. Numerous studies have attempted to limit the depletion of bioactive substances in addition to improving the qualities of black rice, such as through the creation and selection of high-potential phytochemical genotypes [2, 110] and the high-temperature fluidization method [111]. Papillo et al. [112] have discovered polyphenolic anthocyanin-rich extracts made from Italian black rice. The rice was processed using spray drying and freezing to get ingredients that could remain more stable in baking and storage. The extracts in powdered form were tested as ingredients that could be used in a model food baked (biscuit). The biscuits with enriched ingredients had a greater number of polyphenols, anthocyanins, and antioxidants when compared to the unenriched biscuit. The researchers found that bioactive substances can be dried by spray to produce powders that are more stable components for nutraceuticals and functional foods.

11. Future Uses

More attention is being paid to the essential antioxidants and nutrients in black rice and bran. Research conducted by researchers from Louisiana State University in 2010 indicated that food manufacturers were adding black rice bran into certain food items such as cakes, cereals, cookies, and beverages to improve nutrition and make health improvements. Apart from its role as a diet or staple of grains, Chinese black rice is utilized to create vinegar that is black, specifically from the Zhejiang variety that comes from this area of China. Vinegar, when not transcribed into pinyin, is written with the correct spelling as Chekiang. This kind of vinegar is as balsamic vinegar. Chinese black rice can also be

used to produce different types of wine. Most of them are fragrant and delicately scented. They are excellent for drinking and for cooking purposes. Black waxy rice is among the sources of plants with anthocyanins with a dark purple hue. The colorant powder has more phytochemicals than the untreated bran. The efficacy of using colorant powder has been realized by giving a pinkish-purplish color to yogurt, which results in the best durability of color, as well as the increase in phytochemicals produced by the rice bran that is black and waxy. This makes the powder a possibility to use in food products to act as an effective food colorant, but to make further use of this colorant for food use to other food products additional quality assessments are needed including safety and sensory evaluation. Jun et al. [113] discovered that black rice bran is a source of phenolic compounds with a high antioxidant capacity. Jun and others identified ferulic acid as the principal phenolic compound found in the bran of black rice and suggested the utilization of the bran of black rice as an organic source of antioxidants. Particularly, the ethyl-acetate subfraction 2 and its subfraction 1 are able to be utilized as food additives that can be used in cereals, breakfasts, snack foods, bread, cakes, beverages, cookies, and many other food items because they possess greater antioxidant power than butylated toluene (BHT). The black rice bran is a source of gallic, hydroxybenzoic, and protocatechuic acids with higher amounts than regular and red rice bran. In addition, adding 5% bran from black rice to wheat flour for bread making resulted in a significant increase in antioxidant and free radical scavenging activity, compared with regular bread [114]. The diverse physical properties of varieties of black rice have been studied, and the results can be used as baseline information for food processors to check the quality of black rice for special processing of food [115]. Kim et al. [5] claimed that adding the right amount of black and blueberry powders improved the general quality of Korean traditionally brewed rice wine Takju. It was found that the DPPH radical scavenging capability of the mead derived from black rice grains was greater than beverages made of polished rice. The inhibitory effect of lipid peroxidation from mead made of black rice grains was greater [116]. The anthocyanin content of beverages made with raw black rice was higher than the content of beverages prepared from the cooking of the black rice. The antioxidative capacity of alcohol drinks made from raw black rice was superior to drinks made from prepared black rice [117]. Therefore, the black rice (*Oryza sativa*) along with its derivatives is becoming increasingly sought-after and is consumed extensively throughout China, Japan, Korea, and other East Asian countries such as Thailand [62, 118].

12. Health Benefits of Black Rice

The health benefits of colorful black rice are numerous. The deep color of the grain is one of the most noticeable. Amino acids, fatty acids, antioxidants, flavonoids, anthocyanins, and other phenolic compounds are abundant in black rice. Black rice contains 18 amino acids, with an essential and nonessential type. Amino acids are essential for a variety of

TABLE 3: Role of black rice against various disorders.

Diseases	Animals	Duration	Analysis	<i>In vitro/ in vivo</i>	Results	References
Hypercholesterolemia disorder	48 Wistar male rats	30 days	Biological analysis	<i>In vivo</i>	Black rice significantly reduced the level of plasma cholesterol, triglycerides, and low-density lipoprotein levels in rats compared with rats fed with whole rice diet	[54]
Diabetic nephropathy	Sprague Dawley rats	8 weeks	Blood metabolites	<i>In vivo</i>	Supplementation of black rice significantly decreased blood glucose and serum insulin, improved the renal function, and relieved renal glomerular sclerosis and interstitial fibrosis of diabetic nephropathy rats	[119]
Breast cancer	Female immunodeficient BALB/c nude mice	28 days	Cell viability	<i>In vitro and in vivo</i>	The anticancer impact of anthocyanin-rich extract from black rice significantly works against human breast cancer cells <i>in vitro</i> and <i>in vivo</i> by affecting apoptosis and suppressing angiogenesis	[120]
Obesity	Sixty male-specific pathogen-free mice	12 weeks	Biochemical analysis	<i>In vivo</i>	Whole grain black rice significantly reduced lipid accumulation and normalized levels of protein or gene expression related to liver and intestinal lipid metabolism in treated mice	[121]
Osteoclastogenesis and osteoporosis	Female Sprague Dawley	16 weeks	Histomorphometric and biochemical analysis	<i>In vitro and in vivo</i>	Fermented black rice with <i>Lactobacillus casei</i> extract can inhibit the production of reactive oxygen species and the activation of mitogen-activated protein kinase and nuclear factor-kappa, thereby reducing the c-Fos and nuclear factor of activated T cells. Lastly, oral administration of <i>Lactobacillus casei</i> extract modified bone microarchitectural parameters and characteristics associated with ovariectomy-induced osteoporosis in rats	[122]
Liver damage	Male mice	12 weeks	Biochemical and gene expression analysis	<i>In vivo</i>	The complementary diet had significantly decreased serum triglycerides and LDL cholesterol levels in the liver and nonsignificant effect on serum and liver total cholesterol in mice	[123]

TABLE 3: Continued.

Diseases	Animals	Duration	Analysis	<i>In vitro/ in vivo</i>	Results	References
Atherosclerosis	Male Sprague Dawley rats	12 weeks	Hematological parameters	<i>In vivo</i>	The thrombogenic ratio of thromboxane A ₂ , prostacyclin, serum calmodulin and triglyceride, platelet hyperactivity, hypertriglyceridemia, optimal platelet function, and soluble P-selectin was significantly decreased, while raised in body weight, hepatic CPT-1 mRNA expression in rats fed a high-fat diet supplemented with anthocyanin extract from black rice	[124]
Diabetes mellitus	Adult male Wistar rats	12 weeks	Biochemical analysis	<i>In vivo</i>	The plasma glucose, cholesterol, triglyceride levels, insulin resistance, and glucose tolerance were reduced, while the degree of insulin secretion in rat plasma was significantly increased upon germinated black rice extract treatment	[125]
Hippocampal neuronal damage	Male mice	21 day	Histological analysis	<i>In vivo</i>	Black rice extract profoundly attenuated neuronal cell death, inhibited reactive astrogliosis, and prevented loss of glutathione peroxidase expression in the hippocampus when compared to vehicle treatment	[126]
Digestive disease	—	—	Glycemic index and hydrolysis	<i>In vitro</i>	Black rice extract significantly improved the gastrointestinal health and glycemic index of the prepared gels. Additionally, starch hydrolysis has been suppressed by inhibiting digestive enzymes	[127]
Hyperlipidemia	Male Sprague Dawley rats	8 weeks	Biochemical analysis and oxidative stress	<i>In vivo</i>	Black rice is significantly preventing and ameliorating the hyperlipidemia in rats fed with a high-fructose diet	[18]
Photoaging of the skin	—	—	Cell viability and proteomic analysis	<i>In vitro</i>	The black rice extract could be modulating mitogen-activated protein kinase, the inhibition of reactive oxygen species generation, and activator protein-1 signaling in prepared solution	[128]

bodily activities, including skin and tissue regeneration, energy production, and digestion (Table 3).

Anthocyanins are pigments that can be found in a variety of blue and purple foods and serve to protect your cells from harm. These pigments have also been linked to a reduction in inflammation and a lower risk of cardiovascular disease. Consuming black rice can help you improve your heart health and general fitness [129]. Tocopherol in combination

with anthocyanins present in black rice shares a role towards health and reduces noncommunicable diseases (NCDs) [130]. They also show anticancerous potential by scavenging free radicals. Meals added with black rice can prevent and ameliorate conditions of diabetes, atherosclerosis, obesity, asthma, digestive health, stroke, and cancer. Anthocyanins of black rice also provide neurological protection, visual improvement, and antimicrobial potential. They are also

used to treat minute health issues including UTI, cold, and blood pressure. Black rice when added to meals is known to improve life span and quality of life [14]. Antioxidants were claimed to be abundant in black fragrant rice (Hom Nil variety). It contains 186.20 mg GAE/100 g of total phenolics and 24.55 mg/100 g of anthocyanins, respectively. When milling for 10 seconds ($p < 0.05$), phenolic content dropped abruptly to 127.82 mg GAE/100 g and then progressively dropped to 61.01 mg GAE/100 g after 100 seconds. Changes in anthocyanin content during milling followed a similar pattern. Anthocyanin levels in raw black rice dropped to 7.46 mg/100 g after 10 seconds of milling ($p < 0.05$), followed by minor changes for the next 30–60 seconds. Finally, grinding the black rice kernel for 100 seconds fully removed the anthocyanin pigments. During milling, antioxidants were lost. As a result, the DPPH scavenging activity of raw black rice (227 mg AAE/100 g) was demonstrably lowered to 175 mg AAE/100 g after only 10 seconds of milling ($p < 0.05$). Additional milling (30–100 s) resulted in a small decrease in DPPH activity, which dropped to 118 mg AAE/100 g. Polyphenolics, flavonoids, vitamin E, phytic acid, and oryzanol are all antioxidants found in black rice. Other researchers such as Zhou et al. [131] and Walter et al. [132] found that the light brown pericarp (70–90%) and black pericarp (92–97%) had higher levels of phenolic chemicals. After milling, antioxidant activity decreased due to a decrease in antioxidants. Milling black grains had an effect on antioxidant activity that was similar to that of polyphenols. When black rice was polished, it decreased by about 88 percent. When all was confidently eliminated, only 35% of antioxidant activity was seen in this study. Black rice milled for 10 seconds showed 77% of the antioxidant activity of black rice [133].

Today, one of the most prevalent diseases is systematic inflammation. This inflammation can be regarded as the key factor contributing towards chronic diseases including asthma, Alzheimer's disease, cardiac disorders, and cancer. Inflammations at the cellular level are reduced due to the consumption of black rice. Reduction in cellular inflammation results in a reduction in systematic inflammations. It also improves the cell health and overall health [134]. Anti-inflammatory mediators including superoxide dismutase increase when black rice is consumed. Hence, it provides a shield from allergic reaction, joint pains due to inflammations, and aging [135]. Black rice bran when added to meals has shown to improve conditions such as dermatitis by reducing inflammation of dermal and epidermal cells [136]. An extract of black rice was discovered to help minimize edema and greatly suppress allergic contact dermatitis on the skin of mice in the study. This is a strong indication of black rice's ability to heal disorders related to chronic inflammation [137].

Gut health and digestion improve when food contains a high amount of fiber. Black rice contains a generous amount of fiber. Studies have shown that black rice contains double the fiber as compared to brown rice. Fiber promotes satiety as it passes through the gastrointestinal tract, results in reduced energy intake, and promotes weight loss [138]. Black rice also adds bulk to the stool and aids the easy release of stool from

rectum, preventing the constipation. It also takes away toxic compounds by binding them with fiber, thus helps detoxifying the body. Black rice is low in calories, low in carbohydrates, and high in dietary fiber, all of which are important for weight control and weight loss. As a result, it makes you feel full and prevents hunger pangs. In fact, a study conducted in Korea compared the weight loss caused by white rice to a combination of brown and black rice in 40 overweight women over the course of six weeks. They discovered that the brown/black rice group lost considerably more weight and had a lower body mass index (BMI) and body fat percentage than the white rice group at the end of the trial. This merely goes to prove that both brown rice and black rice can be effective in obese women's diet therapy [139].

Black rice is reported to prevent cardiovascular health by preventing the formation of plaque in arteries. Plaque formation in arteries can cause blockage, which reduces or stops the flow of blood, thus leading to a condition called hypertension [140]. The addition of black rice to meals can reduce the levels of triglycerides (TGs) and low-density lipoproteins (LDLs). By lowering these parameters, heart health can be improved. Anthocyanins of black rice have the potential to reduce the risk of heart attack by preventing atherosclerosis. Recent research has shown that black rice can improve the high-density lipoprotein (HDL) levels. Black rice has also shown an ameliorative effect on hardening of arteries walls [141]. Research has shown that black rice has improved HDL and reduced the TGs and LDL level in rats when given in diet. A black rice-containing diet can improve the condition of hyperlipidemia. Black rice is proven to reduce the risk of heart disease and stroke by 57% [142]. White rice is replaced with black rice in your regular diet to protect your heart's health. High cholesterol, as we all know, is a leading cause of a variety of cardiovascular problems. However, several research investigations have indicated that the anthocyanin content of black rice has a substantial effect on lowering cholesterol in rats [143]. Atherosclerosis is a cardiovascular condition in which plaque builds up in the arteries, causing them to become clogged. This could lead to coronary artery disease, stroke, peripheral artery disease, or kidney problems, among other major issues. However, there is some good news! In rabbits, black rice consumption was reported to lower atherosclerotic plaque build-up by 50 percent [140].

Mutation in genes can cause uncontrolled cell division leading to a condition called cancer. Cancer formation that is also known as carcinogenesis consists of the following steps: initiation, promotion, and progression by uncontrolled cell division. Any damage to DNA of the cell leads to malignancy in the cells [144]. This damage to DNA can be due to any physiological or physical factor. These factors may be an error during cell division, toxins, environmental factors, stress, inflammation, or reactive oxygen species (ROS). These ROS can be formed by both exogenous and endogenous factors [145]. The body tries to maintain a balance by neutralizing these ROS with the help of defense mechanisms including glutathione, catalase, and superoxide dismutase. Excessive production of these free radicals or ROS can damage DNA and initiate cancer [142]. Excessive production of ROS is caused by the contribution and combination of factors such as

dietary choices, genetic factors, and environmental factors. Breast cancer, colon cancer, and prostate cancer are greatly found to be associated with dietary choices and lifestyle. Many studies have proven the association of colon cancer risk with increased consumption of red meat and saturated fats, and this risk can be reduced by consuming fibrous foods. In recent years, dietary choices have gained great attention in reducing the risk of cancer [132]. In vitro studies, active food components have been used to treat cancer, along with chemotherapy and radiotherapy, with chemo being unpropitious to healthy cells. Dietary components have shown great potential as an antioxidant, thus suppressing cancer development [146]. Protecting DNA from damage prevents the carcinogenesis by modulating initiation through phytochemicals. It also stops the proliferation of cancer cell and promotes cell death in cancer cells. Antioxidants prevent the onset of cancer development by the prevention of the formation of free radicals. Moreover, black rice has shown the potential to slow down metastasis. Black rice extract has also shown a cancer-preventive effect [147]. Terpenes, isothiocyanates, carotenoids, and flavonoids, which are widely present in fruits and vegetables, have cancer-preventive effect. Mode of actions of biological value such as anticancerous and antioxidative is shown by the secondary metabolites, i.e., flavonoids and its class anthocyanins. Peonidin, peonidin-3-glucoside, cyanidin-3-glucoside, and other major anthocyanins of black rice have been reported to show a shield from cancer cell invasion [4]. In the past few years, studies have proven that anthocyanins have an exceptional ability to suppress oxidative stress and initiation of apoptosis in cancerous cells, which shows the anticarcinogenic potential of anthocyanins. Cyanidin and peonidin-3-glucoside, which are present in the extract of black rice, have proven to show cancer inhibition potential and protective effect on endothelial cells from free radicals [12]. The anticancer properties of black rice are due to the anthocyanin concentration. An anthocyanin-rich extract of black rice successfully inhibited tumor growth and spread of breast cancer cells in mice, according to an experimental study done by China's Third Military University [120].

Phytosterols, carotenoids, polyphenols, and fatty acids have been studied in in vitro and in vivo studies as worthy alternative in the management of hepatotoxicity and associated complications. They have shown anti-inflammatory and liver protective potential [12]. Black rice has a direct influence on liver health, and it also shows the reduction in risk factors that lead to fatty liver. A healthy liver can protect the body from many other illnesses. Black rice mounts up liver functionality and detoxifies liver. Condition of increased blood glucose level and blood cholesterol level also improves as black rice enhances the metabolism of fatty acids [148]. Fatty liver disease is characterized by an accumulation of fat deposits in the liver, as the name implies. Mice were used to investigate the efficiency of black rice in treating this illness. The antioxidant activity of the black rice extract was found to control fatty acid metabolism and lower triglyceride and total cholesterol levels, lowering the risk of fatty liver disease [149].

Type II diabetes is one of the most widely found diseases around the globe that leads to insulin resistance

and other complications associated with metabolism. Anthocyanins are found in fruits and vegetables. Black rice is also a good source of anthocyanins. Research based upon animal models, using cell lines and clinical trials including human subjects, has suggested that anthocyanins of black rice possess antidiabetic properties. Literature shows that anthocyanin has a role in improving the insulin resistance, protecting β cells, enhancing insulin output from cells, and decreasing absorption of sugar in intestine cells [150].

The bran, which is a repository of nutritional fiber, is intact in whole grain black rice. Because the fiber takes longer to digest, it ensures that the sugar in the grain is absorbed over a longer period, allowing blood sugar levels to remain stable. As a result, it can help prevent type 2 diabetes by preventing insulin levels from rising too high. In fact, in mouse research, the extract of germinated Thai black rice behaved similarly to the diabetic medicine metformin, preventing and managing diabetes mellitus complications. Anthocyanins, a type of flavonoid, affect blood sugar levels and diabetes control. Phytochemicals have a good impact on your body, boosting insulin sensitivity and allowing you to use glucose more effectively. They also aid in lowering blood sugar levels by slowing sugar digestion in the small intestine [125].

Clinical studies also showed that anthocyanins helped to improve learning capacity and reduce symptoms of depression. By adding black rice in the diet help to boost memory and prevent premature cognitive aging. Anthocyanins have antioxidant potential that imposes a positive impact on brain cells and their function. Age-related conditions such as dementia, Alzheimer's disease, and depression are prevented or reduced due to these anthocyanins of black rice. They also found to improve memory-related issues and improve cognition and learning abilities [149]. Many scientists feel that oxidative stress has a negative impact on cognitive performance. As a result, antioxidants such as anthocyanins (found in black rice) may help to minimize oxidative stress and protect brain health. Anthocyanins were discovered to increase learning and memory function in rats suffering from estrogen deficiency in a study conducted by the Medical University of Bulgaria. [151] Another six-year study of 16,000 adults found that eating anthocyanin-rich foods for a long time delayed the rate of cognitive deterioration by up to 2.5 years [152].

Atherosclerosis is a condition characterized by the formation of plaque in the walls of arteries, thus causing blockage to blood flow. This condition can lead to cardiovascular complications. The consumption of black rice can improve such condition and reduce the risk of death due to these conditions. Active components of black rice extract including anthocyanins and tocopherols are proven to lower down total cholesterol, LDL, and TGs. They also prevent the accumulation of fat and hypertension. The dietary fiber included in black rice (or any whole grain in general) has been shown to promote cardiovascular health by lowering cholesterol levels, regulating body weight, enhancing glucose metabolism, and reducing chronic inflammation, among other things [153, 154].

Black rice is loaded with fiber, behaves friendly to digestive system ecosystem, and improves bowel movements. It also prevents those conditions associated with gastrointestinal tract such as diverticulitis, irritable bowel syndrome, duodenal cancers, hemorrhoids, and constipation. Being high in fiber, it induces satiety and helps in weight loss. Black rice, as we saw in the nutrition profile, is a high-fiber food. This dietary fiber promotes regular bowel motions and helps to avoid bloating and constipation. It can also help with gastric reflux disease, duodenal ulcers, diverticulitis, constipation, and hemorrhoids, among other gastrointestinal issues [147, 155].

The anthocyanins in black rice have been shown to be useful in the treatment of asthma. In a study conducted in Korea, anthocyanins were found to be effective in treating (and even preventing) asthma in mice by lowering airway inflammation and mucus hypersecretion [156].

Black rice is high in lutein and zeaxanthin, two carotenoids renowned for their role in eye health, in addition to protective anthocyanins. These antioxidants aid in the protection of eye cells and the reduction in the harmful effects of ultraviolet (UV) radiation. Anthocyanins, which can be found in black rice, have long been known to help with vision. Anthocyanidins isolated from black rice were found to be significantly effective in preventing and decreasing retinal damage caused by fluorescent light in rats in a study [157, 158].

Flavonoid groups (anthocyanins, proanthocyanidins, flavonoids, flavones, flavanones, flavan-3-ols) control anthocyanins, which are most notably linked to hypertension prevention. The role of anthocyanin and tocopherol extracts from black rice bran has been studied, and it was discovered that the anthocyanin extract plays a significant role in cholesterol maintenance but not in fatty acid oxidation inhibition [159].

It is linked to age-related skeletal illness, which shows an increase in adipogenesis as osteogenesis expands from common osteoporotic bone marrow cells. Incorporating BRE (black rice extract) into our diet can help prevent the onset of osteoporosis [160].

Collagen is an extracellular matrix protein produced by fibroblasts in the dermis layer of the skin, and the regulation of collagen synthesis and degradation is critical for wound healing and skin rejuvenation. In comparison with the controls, the wound healing benefits of the KRB extract were expressed as percent migration and percent collagen production in the NHDF. The wound healing effects of the KRB extract were evident on day 1 and day 2, as evidenced by increased NHDF proliferation [161–164].

13. Conclusion

It is concluded that black rice is composed of different nutritional and bioactive compounds. Because of its high nutritional value, black rice is one of the most potent rice in our diet. It is essential for the promotion of health benefits. It is high in fiber, protein, iron, vitamins, and minerals, which help to balance out the effects of other foods in our bodies. Antioxidants known as anthocyanin and tocopherol are

found in black rice. Black rice is also used as a functional ingredient in different foods. Individuals who consume black rice have shown that it has numerous health benefits, including the prevention of diabetes, atherosclerosis, obesity, and cancer.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this study.

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