Review Article

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Pigmented Rice: From Nutritional Richness to Therapeutic Application

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Pigmented rice varieties, such as black, red, and purple, have gained increasing attention for their high content of bioactive compounds and nutritional value. Unlike white rice, these colored grains retain their bran layers, which are rich in anthocyanins, phenolic acids, flavonoids, Ɣ - Oryzanol, dietary fiber, and essential minerals. These compounds contribute to various health-supporting properties including antioxidant, anti-inflammatory, and glycemic regulation potential. This review presents recent findings on functional relevance of pigmented rice, highlighting its role in health-oriented food development. In addition to their nutritional advantages, pigmented rice varieties support clean label formulations and provide natural color enhancement in food products. However, factors such as processing-related degradation, consumer acceptance, and lower yield compared to white rice continues to pose challenges

Keywords: Pigmented rice, therapeutic potential, functional food

Introduction

Pigmented rice refers to landraces and improved cultivars of Oryza sativa L. whose bran layers contain red, purple, or black pigments formed during grain filling. These colors arise from the synthesis and deposition of flavonoid pigments principally anthocyanins and pro-anthocyanidins while the grain develops in warm, waterlogged paddies typical of south-east and north-east Asian agro-ecosystems [1]. Black 'Chak-hao' from Manipur (India), red 'Comargue' from France and purple 'Khao Kum' from Thailand, germinate and grow under the same flooded-field conditions as white rice but retain their colored bran because the outer layers are left intact after milling [2,3]. Their long history in traditional medicine, coupled with modern interest in clean-label ingredients, has moved pigmented rice steadily from regional staple towards the global function-food arena [4]. This review aims to explore the health promoting properties of pigmented rice varieties including black, red, and purple rice with a focus on their potential as functional food ingredients.

Health benefits of pigmented rice

Varieties of pigmented rice are abundant in bioactive compounds, especially anthocyanins flavonoids, phenolic acids, and γ-oryzanol. These compounds contribute significantly to the antioxidant and anti-inflammatory properties of pigmented rice.

The high anthocyanin content, especially in black and purple rice, plays crucial role in the elimination of free radicals, thereby lowering the impact of oxidative stress. These antioxidants help in protecting the cellular components by protecting cells from the effects of ROS-related damage, which are known to contribute to aging and chronic health issues, particularly those affecting the heart, neuro degeneration, and cancer [13]. Among pigmented rice types, black and purple rice are especially rich in anthocyanins, which are powerful antioxidants.

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Table 1: Summarizing notable commercial pigmented rice varieties, their origin, pigment types, and key genetic traits.

Variety Name	Origin/ Group	Pigment Type	Key Genetic Traits	Nutritional Highlights	References
Cempo lreng	Indonesia, Geng-japonica	Black (anthocyanin-rich)	Possesses anthocyanin pathway genes experimental CRISPR-Cas9 knockouts of flowering repressors (Hd2, Hd4, Hd5) yield earlier maturity	High in aromatic secondary metabolites, anthocyanins, minerals	**[5]**
Kasalath	India/Japan (Indica)	Red (proanthocyanidin)	Rc (BHLH transcriptase factor on chr.7) Rd (dihydroflavonol 4-reductase on chr. 1) produce red pericrap	Rich in iron, zinc, phenolics	**[6]**
Koshihikari	Japan (Japonica)	White (non-pigmented)	Mutant Rc allele lacks pericrap color	Good source of thiamine and manganese	**[7]**
Oryza glaberrima	West Africa	Red	Wild type Rc preicrap, unique Rc-Gl mutation in white variants	Rich in iron, fiber	**[8]**
Chinese black Rice (Heirloom types e.g., 'Heixiangnuo')	China (Geng-japonica, Xian-indica	Black (anthocyanin-rich)	Anthocyanin biosynthesis genes (MYB/BHLH/WD40; QTLs identified on chr. 1,3,4,7,8,10,11)	High in anthocyanin/antioxidant potential	**[9]**
Indian red rice (traditional landraces like 'Matta' 'Rakthashali')	India (Indica, Aus)	Red	Rc and Rd genes for red color; genetic diversity present within traditional landraces	High iron, zinc, phenolics	**[10]**
Thai Hom Mali black rice	Thailand (indica)	Black (anthocyanin-rich)	Kala 4 gene (activator of anthocyanin biosynthesis), plus MYB and other regulatory loci	High in anthocyanin, vitamins	**[9]**
Black Indonesian rice	Indonesia (Circum-Aus)	Black	QTLs and SNPs associated with pericrap pigmentation and antioxidant traits	High in minerals, antioxidants	**[11]**
Red basmati	South Asia (cricum-basmati)	Red	Rc with functional alleles for red pigmentation	High in pro-anthocyanidin, aromatic compounds	**[12]**

Health benefits of pigmented rice

Varieties of pigmented rice are abundant in bioactive compounds, especially anthocyanins flavonoids, phenolic acids, and γ-oryzanol. These compounds contribute significantly to the antioxidant and anti-inflammatory properties of pigmented rice**.** The high anthocyanin content, especially in black and purple rice, plays crucial role in the elimination of free radicals, thereby lowering the impact of oxidative stress. These antioxidants help in protecting the cellular components by protecting cells from the effects of ROS-related damage, which are known to contribute to aging and chronic health issues, particularly those affecting the heart, neuro degeneration, and cancer **[13].** Among pigmented rice types, black and purple rice are especially rich in anthocyanins, which are powerful antioxidants.

Apart from antioxidants, pigmented rice also shows anti-inflammatory effects. Research has found that extracts from these rice types can lower the activity of certain inflammation-related substances in the body, like TNF-α and IL-6 **[14].** These effects are believed to come from the way rice compounds influence key pathways that control inflammation, such as NF-κB. Including pigmented rice in the diet may therefore help protect against chronic inflammation and support better health. These compounds are also known to offer anti-diabetic benefits, making pigmented rice a promising functional food**.** Pigmented rice can help manage blood sugar levels through several mechanisms. It slows down carbohydrate digestion and glucose absorption due to the presence of fiber and polyphenols, resulting in a lower glycemic response **[15].** Additionally, anthocyanins from pigmented rice have been shown to improve insulin sensitivity and reduce inflammation in tissues involved in glucose metabolism **[16].** Some in vitro and animal studies also report that pigmented rice extracts can inhibit key enzymes like α-amylase and α-glucosidase, which are responsible for breaking down complex carbohydrates into glucose **[17].**

Regular consumption of pigmented rice may therefore help in the prevention and management of type 2 diabetes, while also protecting cells from oxidative damage **[18].**

The cardio protective nature of pigmented rice is linked to its effectiveness in relieving oxidative stress, lessening inflammatory responses, and modulating blood lipid levels.

Scientific investigations suggest that consistent intake of pigmented rice may lower LDL (low-density lipoprotein) cholesterol, boost HDL (high-density lipoprotein) cholesterol, and decrease triglyceride values.

These enhancements play a role in reducing susceptibility to atherosclerotic conditions and elevated blood pressure **[19].** Notably, anthocyanins are known to strengthen vascular health, regulate blood pressure, and enhance overall circulatory performance **[20].** In terms of weight management, pigmented rice offers several advantages over white rice. It has a lower glycemic index, which means it causes a slower and more stable rise in blood sugar after eating. This helps reduce hunger and prevents overeating. Additionally, its high fiber content increases satiety, which can support healthy weight control. Some studies also suggest that pigmented rice may reduce fat accumulation by influencing fat metabolism and improving insulin sensitivity. Including pigmented rice in a balanced diet may therefore support both heart health and healthy weight maintenance, especially when combined with an overall healthy lifestyle **[21].**

Colored rice types, including crimson, deep black and violet-toned grains, are abundant in health-promoting constituents such as anthocyanins, proanthocyanins, phenolic compounds, plant-based flavonoids, and γ-oryzanol, which have shown significant potential in inhibiting cancer development. These compounds exhibit strong antioxidant activity, which helps to neutralize free radicals and reduce oxidative stress, a known factor in the initiation and progression of cancer **[18].** Among these, anthocyanins, responsible for the red to purple pigmentation, are particularly important. Studies have demonstrated that anthocyanin antioxidant-potential, which assists in counteracting free radicals and diminishing oxidative damage, is a recognized contributor in the onset and advancement of malignant conditions, without harming normal cells **[22].** They also inhibit cancer cell proliferation, angiogenesis, and metastasis **[23].** In addition, ferulic acid and phytic acid, present in pigmented rice bran, are known to suppress carcinogenesis by modulating gene expression, reducing inflammation, and improving detoxification enzyme activities. The synergistic effect of these phytochemicals may contribute to a protective role against carcinogen-induced DNA damage and inflammation-mediated tumor promotion **[24].**

Table 2: Therapeutic evidence from recent studies

Discovery/Health effect	Functional component	Target health outcome	Model	Reference
Black rice bran reduces hyperlipidaemia, fatty liver (hepatic steatosis), and oxidative stress in obese mice	Anthocyanins, fibre, SCFA modulators	Lipid profile, liver function, oxidative stress	Mouse (in vivo)	**[25]**
12-week human clinical trial showed fat loss in obese postmenopausal women with anthocyanin supplementation	Purified black rice anthocyanins	Obesity and fat mass reduction	Human (clinical)	**[26]**
Systematic review of 17 RCTs: Chronic intake of pigmented rice lowers fasting glucose, body weight, and DBP.	Whole-grain polyphenols, complex carbs	Cardio metabolic risk factors	Human	**[27]**
Acute pigmented-rice meals reduce post-prandial glycaemia and insulin, anaemia hypertension activity.	Anthocyanins. Low GI Starch, polyphenols	Glycemic control (short term)	Human(clinical)	**[27]**
Supplemented pigmented rice shows ACE inhibition (anti hypertension activity.	Rice bran, protein hydrolysates, peptides	Blood pressure regulation	In vitro	**[22]**

Table 3: Functional foods made from pigmented rice and their health effects

Functional food product	Pigmented rice used	Reported functional benefit	Reference
Rice berry yogurt	Black-purple rice	Reduced postprandial glucose and increased antioxidant capacity	**[28]**
100% black rice crackers (gluten-free)	Whole black rice flour	+37% fibre, +58% polyphenols, +95% proanthocyanidins; post-prandial glycaemia <30mg dl	**[29]**
Anthocyanin-fortified Bread	Black rice extract	Inhibited lipases, reduced starch digestibility and postprandial glycaemia and lipaemia	**[30]**
Black rice beverage	Black rice Anthocyanin extract	Improved post-meal glycemic and lipid profiles in overweight /obese adults	**[31]**
Germinated & roasted red rice	Red rice	Increased total phenolic, flavonoids, and antioxidant activity (DPPH, ABTS); safe microbiologically	**[32]**
Functional idli with pigmented rice	Black & red rice	Improved nutritional and sensory quality compared to white rice	**[33]**
Pigmented rice flour muffins/ cakes	Mixed pigmented rice Red black brown	Higher total phenolic and flavonoid content, healthy snacking option	**[34]**
Pigmented brown rice flour	Brown rice	Exhibited high water/oil absorption, antioxidant activity, suitable for gluten free or health-oriented food products	**[35]**

Limitation and consideration

Despite its strong nutritional and therapeutic potential, wider adoption of pigmented rice in functional food systems faces key challenges. Anthocyanins and other bioactives are unstable and can lose 30–50% of their content during cooking and processing, reducing antioxidant activity **[36, 32].** Agronomically, most pigmented cultivars are traditional, lower-yielding, and slower-growing than commercial white hybrids, making them less viable for large-scale farming without supportive policy or premium pricing, while susceptibility to stress adds further constraints **[3, 37].** Consumer acceptance is another barrier, as the dark color and bitter or nutty taste can deter those accustomed to white rice, with sensory studies showing lower overall acceptability outside health-conscious groups **[29].** Clinical evidence, though promising, remains limited in scale, duration, and population diversity, restricting broad health claims **[27].** Post-harvest practices like de-husking and minimal polishing must be optimized to retain functional compounds, and emerging approaches such as encapsulation, co-pigmentation, and fermentation could improve anthocyanin stability and bioavailability, though scalable solutions are still under research **[22].** Overall, unlocking the potential of pigmented rice requires coordinated agronomic, technological, economic, and sensory innovations supported by interdisciplinary research and policy.

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