Advances in Pharmacology and Pharmacy 11(3): 199-207, 2023 http://www.hrpub.org
DOI: 10.13189/app.2023.110303

Medicinal Benefits of Black Rice (*Oryza Sativa L. Indica*): A Review

Sakshi Bhardwaj[1], Dhanashree Javere[1], Pradnya Bagad[1], Likhit Akotkar[1], Vivekanad Chatap[2], Urmila Aswar[1,*]

[1]Department of Pharmacology, Poona College of Pharmacy, Bharati Vidyapeeth (Deemed to be University), India
[2]Department of Pharmaceutics, H. R. Patel Institute of Pharmaceutical Education and Research, North Maharashtra University, India

Received October 10, 2022; Revised December 18, 2022; Accepted January 16, 2023

Cite This Paper in the Following Citation Styles

(a): *[1] Sakshi Bhardwaj, Dhanashree Javere, Pradnya Bagad, Likhit Akotkar, Vivekanad Chatap, Urmila Aswar , "Medicinal Benefits of Black Rice (Oryza Sativa L. Indica): A Review," Advances in Pharmacology and Pharmacy, Vol. 11, No. 3, pp. 199 - 207, 2023. DOI: 10.13189/app.2023.110303.*

(b): *Sakshi Bhardwaj, Dhanashree Javere, Pradnya Bagad, Likhit Akotkar, Vivekanad Chatap, Urmila Aswar (2023). Medicinal Benefits of Black Rice (Oryza Sativa L. Indica): A Review. Advances in Pharmacology and Pharmacy, 11(3), 199 - 207. DOI: 10.13189/app.2023.110303.*

Abstract Black rice (*Oryza sativa L. indica*) is also called purple rice (gluten free rice), emperor's rice (tribute food) and king's rice. It is abundantly grown worldwide, specifically in Asian countries such as Bangladesh, China, Japan, Sri Lanka, Indonesia, and Thailand. In India, it is majorly found in north-eastern states, including Meghalaya, Assam, and Manipur, which are the cultivators of black rice. It is also considered a superfood owing to its potent antioxidant activity which mediates numerous health-beneficial effects with anticancer, anti-inflammatory, immunomodulatory and anti-allergic characteristics. Black rice has a high nutritional value due to its rich source of various vitamins (A, B, E), amino acids and lipids, dietary fibre. The presence of the flavonoid plant pigment anthocyanin contributes to its purple-black colour and strong antioxidant properties. Other components like manganese and calcium support a healthy metabolism and stronger bones. Black rice is getting popularized in recent times because of its very low toxicity and higher nutritional qualities. This review focuses on the nutritional composition, toxicity, pharmacological uses and future opportunities of black rice for better health and well-being.

Keywords Black Rice, Health, Antioxidant, Nutrition, Pharmacology, Toxicology

1. Introduction

Rice is one of the most common key regular meal food components universally engross, specifically in South Asia. Most of the population of the countries, including India, China, Japan and other southeast countries, prefer rice over wheat as their primary food source. In ancient times in China, due to its big nutritional value, black rice was restricted only to emperors and was called “Imperial Rice” [1]. In India, people have a basic predisposition for white rice, due to the percipience of the cleaner mien of the shining and cleaner grain. Black rice is aboriginal to the North-Eastern states in India, like Assam, Manipur, and Meghalaya. Other states like Odisha, West Bengal, and some parts of Jharkhand also cultivate it [2]. In the native language of Manipur, it is commonly pronounced as‘chak-hao ’, where chak means rice and ahaoba means delicious, which is majorly consumed during the traditional feasts. It comes in various forms, such as short grain and long grain. The presence of the flavonoid plant pigment anthocyanin contributes to its purple-black color and is also a potent antioxidant. Black rice is growing in popularity because it is gluten- and cholesterol-free and low in sugar, salt and fat. Black rice contains more nutrients like vitamins, minerals, and proteins. Black rice contains 18 amino acids, carotene, vitamin E, iron, zinc, and copper [1]. Apart from the anthocyanins, black rice also contains many types of flavonoids and carotenoids and more than 23 other plant

compounds which are proven to have beneficial antioxidant characteristics [3]. Comparing the nutritional value of 100 g of white rice with that of black rice, the protein content was found to be about 30% higher in black rice i.e. 9.1 g against 6.3 g of white rice. The arsenic content of black rice is much higher than that of normal white rice. Low glycaemic value makes it more suitable for consumption for diabetic patients. Black rice has also been found to help treat obesity through the secretion of leptin, which plays an important role in regulating appetite. A protective role of black rice has been reported against chronic diseases including cancer, heart attack [1]. Citing the above benefits, black rice can be considered a "Super Food" and use as an ingredient in other food products can result in very nutritious foods with natural colouring properties [4]. Since very little information is available on the medicinal value of black rice, the present review is designed by an in-depth literature survey compiling the health benefits and commercial value.

2. Black Rice Cultivation and Collection

Black rice is called by many names, such as forbidden rice, purple rice, emperor's rice, lucky rice, and king's rice. Major geographical favourable areas for black rice China, Japan, India, Sri Lanka, Thailand [2][5]. According to a study by the International Rice Research Institute in the Philippines, wild rice production spread from northern Myanmar (formerly Burma) to southern Bangladesh in the mid-1980s. It then moved south to Assam and northeast India (now part of Bhutan). Crossbreeding of wild rice, highland rice, and long-grain brown Japonica types contribute to its deep, nutty flavour with an earthy scent. Long-grain brown Japonica rice began to be cultivated on a bigger scale in various areas of north-eastern India around the same time. In India, it is mainly cultivated in Assam and grown in portions of Nepal and Burma as well as black rice is an ancient food that was domesticated at least 10,000 years ago in the Himalayas [5] (Table 1).

3. Black Rice Landraces

In the villages of Manipur's Imphal East district, four landraces of black rice were identified, such as Chakhao pungdol amubi, Chakhao poireiton, Chakhao angouba, Chakhao amubi and. About 43% of farmers cultivate Chakhao poireiton because of its better productivity and delicacy. It has the longest panicle length, number of grains, and tillers. Non-black rice varieties grown at slightly less heights than black rice plants grow to a height of 136-166 cm, which is comparably higher than the other non-black rice varieties. The tallest black rice landrace is Chakhao amubi (165.5 cm). Chakhao angouba had a greater average grain weight than the other landraces. Chakhao amubi, Chakhao pungdol amubi, and Chakhao angouba had long kernels (6.57-7.45 mm) and Chakhao poireiton had medium kernels (6.57-7.45 mm). The majority of the morphological metrics investigated differed significantly across black rice landraces [5].

Table 1. Country/State wise varieties of Black rice

India/State	Varieties	References
India	Oryza sativa L. (Chakhao poireiton)	[5]
Meghalaya	Oryza sativa L. (Karuppu kavuni)	[6]
Tamil Nadu	Oryza sativa L. (Kavuni rice)	[6]
Mizoram	Oryza sativa L. (Kalabati)	[6]
Odisha	*Oryza sativa L. (*Kalabati)	[6]
Goalpara Assam	*Oryza sativa L. japonica*	[6]
West Bengal	Oryza sativa L. (Kalabhat)	[7]
America	*Oryza sativa L. japonica*	[8]
Thailand	*Oryza sativa L. japonica*	[8]
Indonesia	*Oryza sativa L. japonica*	[8]
Japan	*Oryza sativa L. japonica*	[8]
China	*Oryza sativa L. japonica*	[6]
Vietnam	*Oryza sativa*	[9]
Bangladesh	*Oryza sativa*	[9]

4. Health Benefits of Black Rice

Black rice contains many amino acids, vitamins, iron and minerals, tocopherol. The presence of high anthocyanin content (327.60 mg/100 g) plays an important role in preventing chronic and degenerative diseases [10]. It acts as a potent antioxidant, anti-inflammatory, anti-cancer, and hypoglycaemic activity. The antioxidant activity is helpful in defence against the free radical scavenging effect, inhibits lipid peroxidation and protects the liver from damage [11, 12]. Black rice constituents make bond with ROS lead to inhibit them from reacting with membrane lipids, nucleic acids, proteins and enzymes, and other small molecules, thus protecting against oxidative damage to the cell [13, 14]. It shows anti-inflammatory activity by increasing the anti-inflammatory mediators such as superoxide dismutase and protection against allergies, joint pains, atherosclerosis, ageing. Black rice contains cyanidin-3-o-glucoside (C3G), an anthocyanin compound extract reduces the glycaemic index and shows antidiabetic activity [15]. It is also observed that black rice helps in weight management owing to its high fibre content and promotes gut health with digestion. High fibre content regulates gut peristaltic movement which prevents constipation and diarrhoea and also prevents bowel illness, colitis duodenal ulcer, and haemorrhoids. It also increases the feeling of satiety and controls hunger and helps in weight loss [16, 17]. Daily consumption of black rice can protect the heart by reducing plaque formation and improving lipid profiles [18-21]. A clinical study in women demonstrated that consuming black rice daily reduced the risk of heart disease and stroke by 57%**.** It improves brain functions thus ameliorating conditions such as Alzheimer's disease, dementia, and depression. It has also been proven effective in the treatment of osteoporosis and asthma. The presence of Vit E, antioxidants and amino acids helps maintain healthy skin and hair. The high iron content of black rice can prove beneficial for the vegetarian population for maintaining healthy blood platelet levels, energy expenditure and digestion. The potential biomedical applications of black rice have motivated researchers to do more exploratory studies. The pharmacological action of black rice is shown in Figure 1.

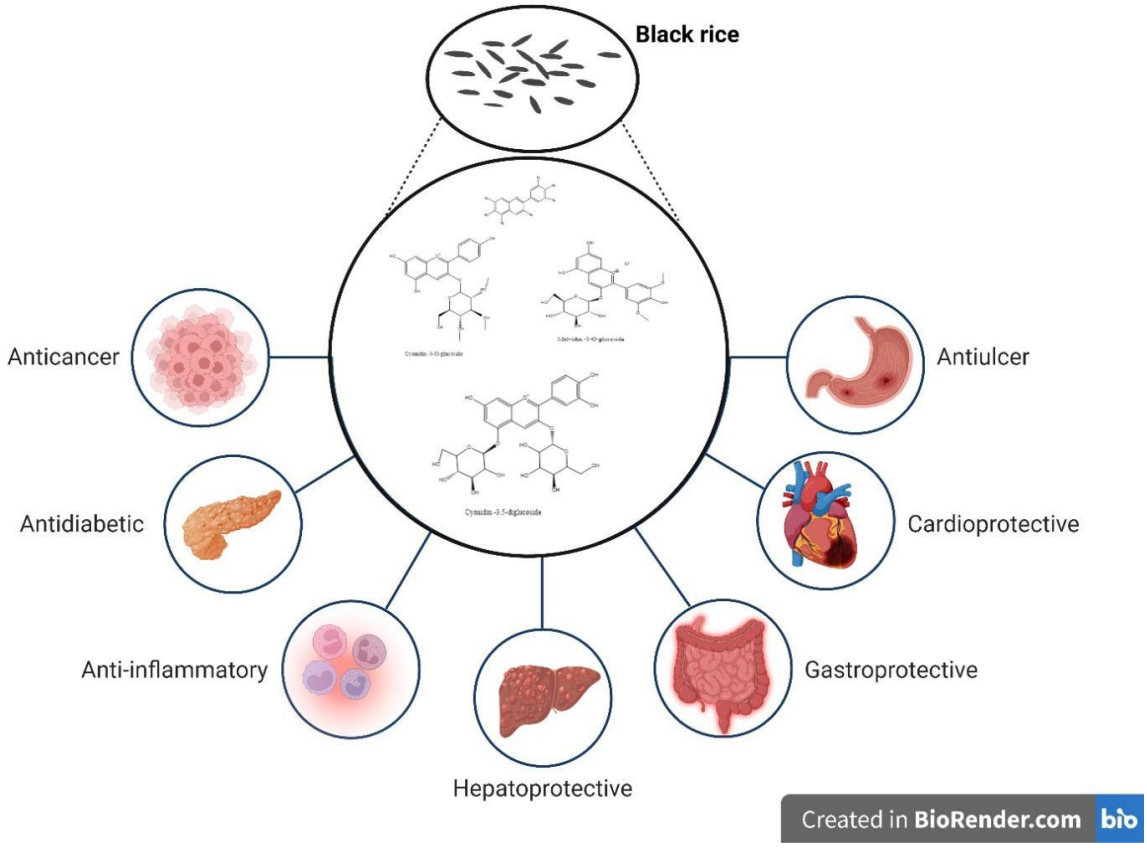

Figure 1. The therapeutic profile of black rice

5. Toxicity Profile

As per the globally harmonized system (GHS) for toxicity classification, black rice falls under class V of GHS which showed that LD_{50} values ranged between 1000-2885 mg/kg and the compound has low acute toxicity [22]. The pellets of black rice were given to the rats for 90 days as a dietary supplement. It was suggested that no significant changes were observed in body weight and biochemical parameters after 90 days of regular diet [23]. Han *et al*. Also reported a toxicity study of anthocyanins as a potent constituent of black rice. Anthocyanins in male and female mice showed a non-significant effect on body weight as well LD_{50} was found to be above 10 g/kg body weight of mice [24].

6. Chemical Constituents of Black Rice

Rice contains the hull that is the outer layer and incorporates silica and cellulose. After the elimination of the hull, the rice received which includes bran endosperm and germ [25, 26]. The endosperm contains 75% of carbohydrates in the form of starch and the outer layer contains protein [27]. In low concentration, polysaccharides are present in the formed cellulose, hemicellulose, pectins and simple sugars (glucose, fructose and saccharose) [28]. The germ portion is rich in protein and lipids and constitutes 2-3% of the total paddy weight. Overall, black rice is wealthy in bioactive additives which play an essential function in diverse pharmacological features of the human body. This consists of vital amino acids, lipids, nutritional fiber, phytosterols, minerals (K, Fe, Zn, Cu, Mg, Mn, and P), vitamins (A and E), anthocyanins, phenolic compounds, γ-oryzanols, tocopherols, tocotrienols, and phytic acid. The phenolic compounds might either be free phenolic acids or phenolic acids that are bound. Cinnamic, protocatechuic, and gallic acids, which are free or soluble phenolic acids, can be extracted using a solvolytic solution and an 80 percent methanol solution. The covalently bonded phenolic acids (ferulic, coumaric, and caffeic acids) to cellulose, hemicellulose, lignin, and pectin are insoluble [29] (Figure 2).

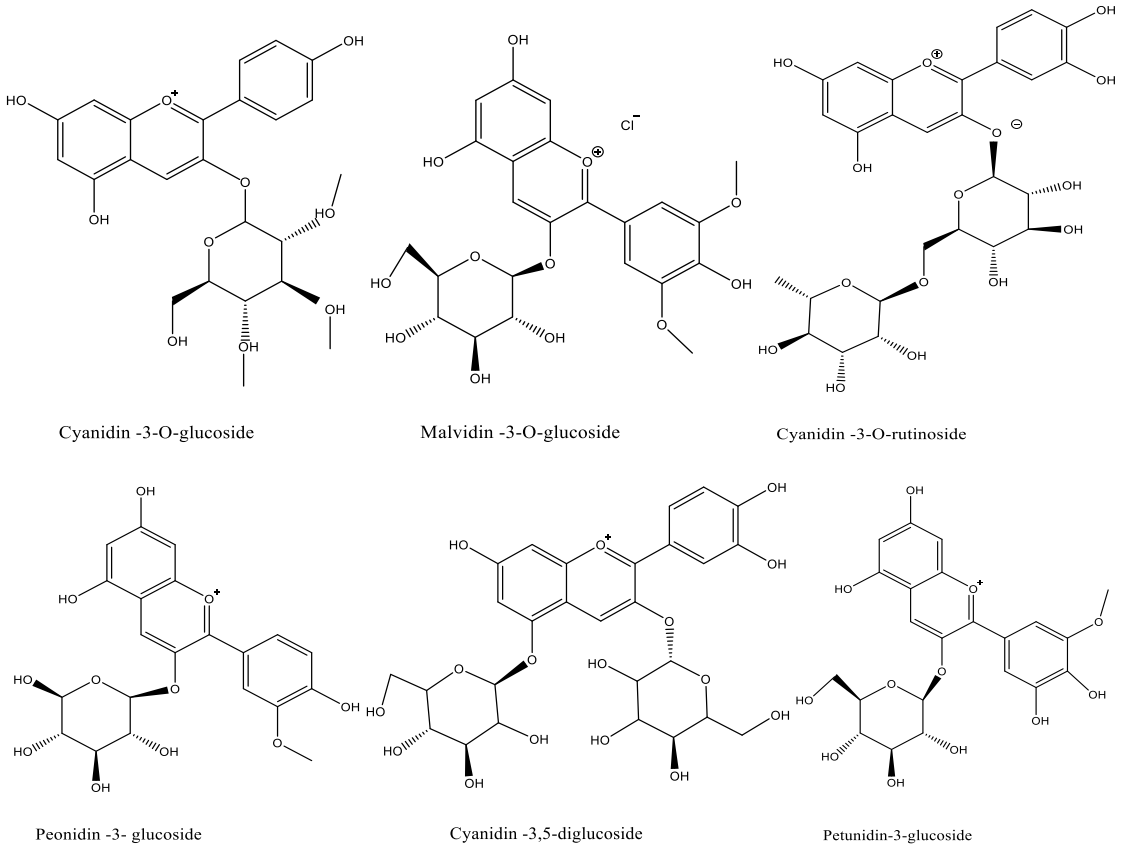

Figure 2. The various phytoconstituents present in black rice

7. Phytochemical Profile

Anthocyanins are a coloured bioflavonoid phytochemical, present in vegetables, nuts and cereals (Figure 3). Anthocyanins are phenolic group pigments that are glycosylated and water soluble and are found in the outer layer of black rice. Anthocyanins are structurally 2-phenyl benzopyrilium or polyhydroxylated and/or methoxylated heterosides produced from the flavylium ion [30]. Phenolics can donate hydrogen and act as a reducing agent. Phenolics donate hydrogen and attenuate the oxidative stress generated by free radicals. They exhibit a protective effect by donation of the hydroxy group to the free radicals and act as singlet oxygen quenchers [31]. The colour pigment gives the black rice its purple-black colour. It plays an important role in free radical scavenging and antioxidant property. Other prime roles include providing DNA protection from cleavage, estrogenic activity, enzyme inhibition and regulation of immune response. It also attenuates liver dysfunction, hypertension, visual disorder, microbial infection, diarrhoea and tumour formation. The important components of anthocyanin are cyanidin, pelargonidin, quercetin etc. C3G ameliorates oxidative damage and controls diabetic cardiomyopathy inflammation, metabolic dysfunction, and also modulates apoptosis pathways [32]. In chronic gut inflammatory disease, C3G effectively reduces symptoms associated with inflammation that appears in the intestinal cell lines [33]. The measure of anthocyanin present in dark rice is higher than in some other grains such as earthly-coloured rice, red rice, or other hued grains. Even the spoonful of black rice bran accommodates more health-promoting anthocyanin antioxidants. C3G contains more than 75 – 80% of the anthocyanin content of black rice. There are types of anthocyanins, The major one is C3G, cyanidin-3, 5-diglucoside, petunidin-3-glucoside, malvidin-3-O-glucoside, cyanidin-3-O-rutinoside, peonidin-3-glucoside. In addition to anthocyanin, black rice contains several types of flavonoids and carotenoids and over 23 plant compounds with beneficial antioxidant properties along with tocopherols, tocotrienols, phytosterols and phytic acid [34].

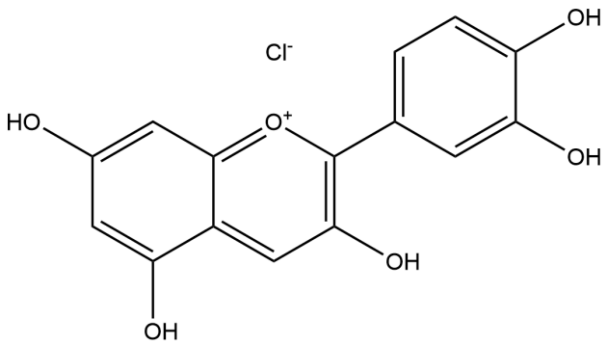

Figure 3. Chemical structure of anthocyanin

8. Pharmacological Activities of Black Rice Extract and Isolated Constituents

8.1. Hepatoprotective Activity

Acute or chronic cellular injury resulting from a variety of factors, including toxic chemicals, viral hepatitis B or C, alcohol abuse and non-alcoholic steatohepatitis causes liver injury, which is currently a common disease. When an injury is left untreated, the liver's pathological growth may modify the hepatic architecture and cause portal hypertension, which leads to liver fibrosis and liver failure [35]. A preclinical study performed by Hou et al. suggested that anthocyanin-rich extract of black rice (AEBR) demonstrated to be protective against the liver damage caused by ethanol and carbon tetrachloride in male Wistar rats and mice, respectively. The liver enzymes alanine transaminase (ALT), aspartate transaminase (AST), gamma-glutamyl transferase (GGT) in serum and hepatic malondialdehyde (MDA) level were increased when ethanol (3.7/kg/day) is consumed orally for 45 days. Treatment with AEBR 125,250, and 500 mg/kg for 45 days decreased the activity of liver enzymes. The higher dose of AEBR had a more prolonged effect on lipid profile. There is a meagre evidence of the hepatoprotective activity of black rice, hence much more research is warranted [36, 37].

8.2. Antidiabetic Activity

Wahyuni *et al.* studied the antidiabetic activity of ethanol extract of black rice bran (EEBRB) on alloxan-induced rat model. Treatment with EEBRB at dosages of 50,100 and 200 mg/kg has been shown to enhance pancreatic beta cell regeneration and lower blood sugar levels. In comparison to the 50, 100 mg/kg dosage group, a dose of 200 mg/kg of EEBRB boosted insulin levels. EEBRB has the ability to inhibit the enzyme α-glucosidase causing insulin and glycogen levels to rise [15]. The work carried out by Alin *et al.* indicated retention of total phenolic content, total antioxidant activity (TAA) and inhibitory effect against lipase and glycation. A different study on the Thai variety of black rice as well the extract of its germinated form was studied on STZ induced diabetes. It was observed that their content was able to reduce plasma glucose, cholesterol, triglycerides, as well as insulin resistance [38]. Moreover, germinated black rice shows an equivalent effect as metformin and helps to improve the consequences of diabetes mellites [39]. The black rice bran is reported to inhibit α-amylase and α-glucosidase enzymes, thus favouring antidiabetic activity [40]. The molecule docking study was carried out by extraction of 6 bioactive from black rice C3G, 6 -o-feruloyl sucrose, p- coumaric acid, syringic acid, symphonic acid, protocatechuic acid and their interaction

with glutamine fructose 6 phosphate aminotransferase (GFAT) enzyme. This enzyme is a rate-limiting enzyme in glucose metabolism. Also, it is getting considerable attention as a therapeutic target for Type 2 diabetes. The present study demonstrated C3G and 6-o-feruloyl sucrose exhibit significant binding affinity with GFAT. Thus, postulating the effectiveness of black rice in overcoming diabetes and diabetic complications [41]. It is observed that there is considerable research on different varieties of black rice while Indian variety for the metabolic disease is desired.

8.3. Anticancer Activity

Using SKHep-1 cells and Huh-7 cell lines from hepatocellular carcinoma, HeLa cell lines for cervical cancer, SCC-4 from a human tongue squamous cell carcinoma, and Chang liver cells from a human non-malignant liver tissue myeloma, the major anthocyanins obtained from Black rice (Oryza sativa L. Indica) were evaluated for cell invasion, motility, and adhesion. An attempt was also made to study the expressions of matrix metalloproteinase (MPP's) and urokinase type plasminogen activator (u-PA). These enzymes are responsible for cell invasion, migration, inflammation and most importantly, degradation of the extracellular matrix. It was observed that these anthocyanins inhibited cell invasion at a higher dose of 200 μg/ml and reduced the invasion motility of cells as well as inhibited expressions of MPP-9 and u-PA. The author also found a reduction in AP-1 to DNA. Thus, this study strongly suggests that anthocyanins from black rice inhibit tumour growth and metastasis [42]. Breast cancer cell lines MCF-7, MDA-MB-231, and MDA-MB-H53 have less viability after being exposed to an anthocyanin-rich extract (AEBR) from black rice. By cleaving poly ADP ribose polymorphism (PARD), activating caspase, and causing mitochondrial damage, it also caused apoptosis. AEBR suppresses angiogenesis *in vivo* research showed, hence reducing tumour growth [42]. A study on the Indian black rice variety showed black rice flour to be effective against colon cancer cell lines (HCT 116) indicating its potent cytotoxic and anticancer potential [43]. The docking study on campesterol, an important bioactive present in black rice, is found to exhibit anticancer activity by binding to mortalin p53 and inhibiting it. The black rice anthocyanins show an antimetastatic effect when used on human epidermal growths factor receptor -2-(HER-2) positive human breast cancer cells by inhibiting CSRC/FAK/P130 Cas pathway [44].

8.4. Anti-inflammatory Activity

The anti-inflammatory mechanism of black rice was reported by Min *et al.*, Inflammation was studied by carrageenan induced air pouches model of inflammation. It consisted of development of air pouches followed by carrageenan injection, 7 days of air pouch formation. These animals were treated with BR (100 mg/kg) C3G (5 and 25 mg/kg) and cyanidin (5 and 25 mg/kg) were given for 3 days once daily, prior to carrageenan injection. Post 24 hrs of injection these animals were sacrificed, the pouches and exudates were analysed for anti-inflammatory mediators and cox2 enzyme. Interestingly, it was found that BR, C3G and its metabolites inhibited TNF-α, IL-1β, PGE2 as well as INOS and COX-2. The possible mechanism reported is regulation of NF-kβ and activation of MAPK. Thus, the study indicated BR and its component exhibit potent anti-inflammatory effect. In the second model of LPS induced inflammation, BR, C3G and cyanidin treated RAW-264.7 cells were exposed to LPS followed by measurement of pro- inflammatory cytokines (TNF-α and IL-1β). The results indicated that the BR and its component inhibited LPS induced expression of inflammatory mediators [45]. Rahman *et al*. discussed the *in vitro* anti-inflammatory effect of Oryza sativa Var. Joha rice (EEOS-JR) on human red blood cells (HRBC) indicated protection of HRBC 51, 59, 64% against hypotonic solutions by 100, 250, and 500 mg/ml, respectively. These doses demonstrated 39, 53, 60% anti denaturation of Bovine serum demonstrated antiarthritic type of effect. It also demonstrated 75, 80, and 84% inhibition of albumin denaturation. Thus it can be concluded EES-JR exhibits potential anti-inflammatory, antiarthritic activity [46].

8.5. Gastroprotective Activity

The black rice bran extract was also highly explored for its gastroprotective actions. Black rice bran ethanol extract (BRB) studied for gastric ulceration induced by different methods in rats. These methods were acidophile ethanol, indomethacin and restrain water emerging stressed test. Pre-treatment with 400 and 800 ml/kg of BRB inhibited all types of ulcers as measured by ulcer index and percentage inhibition. Moreover, BRB demonstrated reduced MDA levels. The effects of BRB (800 mg/kg) were comparable to that of omeprazole (10 mg/kg). The DPPH assay used in this investigation showed that BRB has a powerful free radical exchange study. However, the pyloric ligation procedure had little impact on gastric pH and overall acidity. The high concentration of phenols, flavonoids, and anthocyanins is responsible for the gastroprotective action. The essential ones are α-oryzanol, α-tocopherol, phenolic acid, gallic acid, β carotene, astaxanthin, and capsanthin [47].

8.6. Cardioprotective Activity

It is demonstrated that in adult male Wistar rats suffering from hypercholesterolemia, after administration of a diet containing 20% black rice showed lipid lowering activity by reducing LDL, triglycerides while HDL were increased. Hence, diet with black rice improves dyslipidaemia [48]. Introduction of black rice pigmented fraction (BRF) (30

gm BRF that contains black rice pigment fraction, 12 gm starch, 8 gm sucrose). 60 patients with coronary heart disease (CHD) for 6 months exhibited improved antioxidant status reduced vascular cell adhesion molecule, soluble CD-40 ligand and highly sensitive C-Reactive Protein. They reported phytochemicals such as anthocyanins are responsible for these favourable effects. Previously, anthocyanins have been reported to exhibit antioxidant activity as well as hypolipidemic effects. Thus, in CHD patients, the black rice pigment fraction can lower the risk factors for cardiovascular disease [28, 49]. Supplementation of anthocyanin extract from black rice (AEBR) stabilises platelet, reduces triglycerides in the blood, and maintains body weight, thus proposing the importance of a black rice diet in reducing cardiovascular disease [50]. Again, there are many studies reporting benefits of black rice and its extracts in reducing hyperlipidaemia, insulin resistance and obesity. Black rice anthocyanin fed along with HFD to C57BL16J mice for 14 weeks showed reduced body weight gain, triglycerides, total cholesterol as compared to HFD group [51]. This recent study also influenced gut microbiota thereby correcting obesity and related consequences.

8.7. Antiulcer Activity

Black rice anthocyanins (5, 25 and 50 mg/kg) significantly reduced the risk of ulcers caused by naproxen and slowed the oxidation of lipids in the stomach mucosa by controlling MMP2 activity, anthocyanin treatment thus exhibits strong antiulcer action as well as strong antioxidant characteristics [52].

9. Conclusions

Black rice exhibits many health benefits. Considering the rich vitamin and mineral content, and huge antioxidants such as tocopherol and anthocyanins. It can emerge as a super functional food. In recent years, black rice is gaining popularity and has become a functional food from the staple diet due to its rich content of bioactive and medicinal properties. Many *in vitro* and *in vivo* studies suggest the rice itself, its extracts, anthocyanins-rich extract, and some of its bioactive such as C3G exhibit significant anti-inflammatory, antioxidant and anticancer potential. Moreover, the adoption of black rice in the diet can also take care of metabolic diseases such as obesity, hyperlipidaemia, high blood glucose, and heart disease. However, we feel that most of the scientific studies that have been performed are devoid of pharmacological investigation. Thus, there is an urgent need to perform more scientific, preclinical and clinical studies on black rice.

Conflict of Interest Statement

Authors declared no conflict of interest in the manuscript.

Acknowledgements

The authors would like to acknowledge Dr A. P. Pawar, Principal, Poona College of Pharmacy, Bharati Vidyapeeth (Deemed to be University), Erandwane, Pune-411038, for suggestions and motivation to write this manuscript.

REFERENCES

[1] Banerjee R., Chakraborty A., Chowdhury S., Ganguly S., "Mediconutritional value and profitability of black rice-the new black gold of indian agriculture," Science for Agriculture and Allied Sector, vol. 3, no. 6, pp. 11-16, 2019. DOI:https://agriallis.com/wpcontent/uploads/2021/06/medico-nutritional-value-and-profitability-of-black-rice-the-new-black-gold-of-indian-agriculture.pdf

[2] Sangma H., Parameshwari S., "Health benefits of black rice (Zizania aqatica)-a review," Materials Today: Proceedings, vol. 45, no. 6, pp. 4377-5834, 2021. DOI: 10.1016/j.matpr.2021.07.257

[3] Agrawal A., "Black Rice the New black gold of India," Food and Agriculture Spectrum Journal, vol. 2, no. 03, pp. 237-240, 2021. DOI: https://fasj.org/index.php/fasj/article/view/52

[4] Kushwaha U., "Black rice," in *Black Rice*, Springer, 2016. pp. 21-47.

[5] Borah N., Athokpam F. D., Semwal R., Garkoti S., "Chakhao (Black Rice; Oryza sativa L.): A culturally important and stress tolerant traditional rice variety of Manipur," Indian Journal of Traditional Knowledge, vol. 17, no. 4, pp. 789-794, 2018. DOI: nopr.niscpr.res.in/handle/123456789/45052

[6] Dhull S., Punia S., Kumar M., Singh S., Singh P., "Effect of different modifications (physical and chemical) on morphological, pasting, and rheological properties of black rice (Oryza sativa L. Indica) starch: A comparative study," Starch - Stärke, vol. 73, no. 1-2, pp. 2000098, 2021. DOI: 10.1002/star.202000098

[7] Bhattacharyya S., Roy S., "Qualitative and quantitative assessment of bioactive phytochemicals in gobindobhog and black Rice, cultivated in West Bengal, India," International Journal of Pharmaceutical Sciences and Research, vol. 9, no. 9, pp. 3845-3851, 2018. DOI: 10.13040/IJPSR.0975-8232.9(9).3845-51

[8] Fatchiyah F., Sari D., Safitri A., Cairns J.R., "Phytochemical compound and nutritional value in black rice from Java Island, Indonesia," Systematic Reviews in Pharmacy vol. 11, no. 7, pp. 414-421, 2020. DOI: 10.31838/srp.2020.7.61

[9] Roy P., Deb D., Pradeep T., Talai-Mukhopadhyay S., Sinha A. K., Saha T., "Comparative analyses of the nutraceutical potentialities of selected Indian traditional black rice (Oryza sativa L.) landraces," ORYZA-An International Journal of Rice, vol. 58, no. 2, pp. 295-309, 2021. DOI:

10.35709/ory.2021.58.2.6

[10] Thanuja B., Parimalavalli R., "Role of black rice in health and diseases," International Journal of Health Science and Research, vol. 8, no. 2, pp. 241-248, 2018. DOI: https://www.ijhsr.org/IJHSR_Vol.8_Issue.2_Feb2018/IJHSR_Abstract.031.html

[11] Abdel‐Aal S., Akhtar H., Rabalski I., Bryan M., "Accelerated, microwave‐assisted, and conventional solvent extraction methods affect anthocyanin composition from colored grains," Journal of Food Science, vol. 79, no. 2, pp. C138-C146, 2014. DOI: 10.1111/1750-3841.12346

[12] Ichikawa H., Ichiyanagi T., Xu B., Yoshii Y., Nakajima M., Konishi T., "Antioxidant activity of anthocyanin extract from purple black rice," Journal of medicinal food, vol. 4, no. 4, pp. 211-218, 2001. DOI: 10.1089/10966200152744481

[13] Zulfafamy K., Ardiansyah A., Budijanto S., "Antioxidative properties and cytotoxic activity against colon cancer cell WiDr of Rhizopus oryzae and Rhizopus oligosporus-fermented black rice bran extract," Current Research in Nutrition and Food Science, vol. 6, no. 01, pp. 23-34, 2018. DOI: 10.12944/CRNFSJ.6.1.03

[14] Budijanto S., Nuraida L., Priosoeryanto B. P., Saepuloh U., Marya S. S., Shirakawa H., "Fermented black rice bran extract inhibit colon cancer proliferation in WiDr cell lines," Food Science and Technology, vol. 42, no. pp. 2022. DOI: 10.1590/fst.14422

[15] Wahyuni A., Munawaroh R., Da'i M., "Antidiabetic mechanism of ethanol extract of black rice bran on diabetic rats," National Journal of Physiology, Pharmacy and Pharmacology, vol. 6, no. 2, pp. 106, 2016. DOI: 10.5455/njppp.2015.5.1111201590

[16] Zhao L., Zhang Y., Liu G., Hao S., Wang C., Wang Y., "Black rice anthocyanin-rich extract and rosmarinic acid, alone and in combination, protect against DSS-induced colitis in mice," Food & function, vol. 9, no. 5, pp. 2796-2808, 2018. DOI: 10.1039/C7FO01490B

[17] Zawistowski J., Kopec A., Kitts D. D., "Effects of a black rice extract (Oryza sativa L. indica) on cholesterol levels and plasma lipid parameters in Wistar Kyoto rats," Journal of Functional Foods, vol. 1, no. 1, pp. 50-56, 2009. DOI: 10.1016/j.jff.2008.09.008

[18] Ling W., Cheng Q., Ma J., Wang T., "Red and black rice decrease atherosclerotic plaque formation and increase antioxidant status in rabbits," The Journal of nutrition, vol. 131, no. 5, pp. 1421-1426, 2001. DOI: 10.1093/jn/131.5.1421

[19] Ling W., Wang L., Ma J., "Supplementation of the black rice outer layer fraction to rabbits decreases atherosclerotic plaque formation and increases antioxidant status," The Journal of nutrition, vol. 132, no. 1, pp. 20-26, 2002. DOI: 10.1093/jn/132.1.20

[20] Xia M., Ling W. H., Ma J., Kitts D. D., Zawistowski J., "Supplementation of diets with the black rice pigment fraction attenuates atherosclerotic plaque formation in apolipoprotein E deficient mice," The Journal of Nutrition, vol. 133, no. 3, pp. 744-751, 2003. DOI: 10.1093/jn/133.3.744

[21] Xia X., Ling W., Ma J., Xia M., Hou M., Wang Q., Zhu H., Tang Z., "An anthocyanin-rich extract from black rice enhances atherosclerotic plaque stabilization in apolipoprotein E–deficient mice," The Journal of Nutrition, vol. 136, no. 8, pp. 2220-2225, 2006. DOI: 10.1093/jn/136.8.2220

[22] Hartati F., Djauhari A., Kharisma V., "Evaluation of Pharmacokinetic properties, toxicity, and bioactive cytotoxic activity of black rice (Oryza sativa L.) as candidates for diabetes mellitus drugs by in silico," Biointerface Research in Applied Chemistry, vol. 11, no. 4, pp. 12301-12311, 2021. DOI: 10.33263/BRIAC114.1230112311

[23] Xia Y., Zuo S., Zheng Y., Liu J., Yang W., Tang X., Ke X., Zhuo Q., Yang X., Li Y., "Subchronic Oral Toxicity Study of Genetically Modified Rice Rich in β-Carotene in Wistar Rats," International Journal of Environmental Research and Public Health, vol. 18, no. 11, pp. 5526, 2021. DOI: 10.3390/ijerph18115526

[24] Han H., Choi S., Shin J., Chung H., "A study on single oral dose toxicity of highly-developed anthocyanin-pigmented rice varieties," Journal of the Korean Society of Food Science and Nutrition, vol. 36, no. 5, pp. 527-533, 2007. DOI: 10.3746/jkfn.2007.36.5.527

[25] Juliano B. O., "Rice properties and processing," Food Reviews International, vol. 1, no. 3, pp. 423-445, 1985. DOI: 10.1080/87559128509540778

[26] Juliano B., Hicks A., "Rice functional properties and rice food products," Food Reviews International, vol. 12, no. 1, pp. 71-103, 1996. DOI: 10.1080/87559129609541068

[27] Ito V. C., Schnitzler E., Demiate I. M., Eusébio M. E. S., Lacerda L. G., Castro R. A., "Physicochemical, thermal, crystallographic, and morphological properties of biodynamic black rice starch, and of residual fractions from aqueous extraction," Starch‐Stärke, vol. 70, no. 11-12, pp. 1700348, 2018. DOI: 10.1002/star.201700348

[28] Burlando B., Cornara L., "Therapeutic properties of rice constituents and derivatives (Oryza sativa L.): A review update," Trends in food science & technology, vol. 40, no. 1, pp. 82-98, 2014. DOI: 10.1016/j.tifs.2014.08.002

[29] Min B., Gu L., McClung A. M., Bergman C. J., Chen M.-H., "Free and bound total phenolic concentrations, antioxidant capacities, and profiles of proanthocyanidins and anthocyanins in whole grain rice (Oryza sativa L.) of different bran colours," Food Chemistry, vol. 133, no. 3, pp. 715-722, 2012. DOI: 10.1016/j.foodchem.2012.01.079

[30] Pedro A. C., Granato D., Rosso N. D., "Extraction of anthocyanins and polyphenols from black rice (Oryza sativa L.) by modeling and assessing their reversibility and stability," Food Chemistry, vol. 191, no. 07, pp. 12-20, 2016. DOI: 10.1016/j.foodchem.2015.02.045

[31] Pal S., Bagchi T. B., Dhali K., Kar A., Sanghamitra P., Sarkar S., Samaddar M., Majumder J., "Evaluation of sensory, physicochemical properties and Consumer preference of black rice and their products," Journal of Food Science and Technology, vol. 56, no. 3, pp. 1484-1494, 2019. DOI: 10.1016/j.foodchem.2014.11.025

[32] Liu X., Li S., Yang W., Mu B., Jiao Y., Zhou X., Zhang C., Fan Y., Chen R., "Synthesis of seed-specific bidirectional

promoters for metabolic engineering of anthocyanin-rich maize," Plant and Cell Physiology, vol. 59, no. 10, pp. 1942-1955, 2018. DOI: 10.1093/pcp/pcy110

[33] Ferrari D., Cimino F., Fratantonio D., Molonia M. S., Bashllari R., Bus à R., Saija A., Speciale A., "Cyanidin-3-O-glucoside modulates the in vitro inflammatory crosstalk between intestinal epithelial and endothelial cells," Mediators of Inflammation, vol. 2017, no. 02, pp. 2017. DOI: 10.1155/2017/3454023

[34] Kang M.-Y., Kim J.-H., Rico C. W., Nam S.-H., "A comparative study on the physicochemical characteristics of black rice varieties," International Journal of Food Properties, vol. 14, no. 6, pp. 1241-1254, 2011. DOI: 10.1080/10942911003637350

[35] Wynn T. A., Ramalingam T. R., "Mechanisms of fibrosis: therapeutic translation for fibrotic disease," Nature Medicine, vol. 18, no. 7, pp. 1028-1040, 2012. DOI: 10.1038/nm.2807

[36] Hou F., Zhang R., Zhang M., Su D., Wei Z., Deng Y., Zhang Y., Chi J., Tang X., "Hepatoprotective and antioxidant activity of anthocyanins in black rice bran on carbon tetrachloride-induced liver injury in mice," Journal of Functional Foods, vol. 5, no. 4, pp. 1705-1713, 2013. DOI: 10.1016/j.jff.2013.07.015

[37] Hou Z., Qin P., Ren G., "Effect of anthocyanin-rich extract from black rice (Oryza sativa L. Japonica) on chronically alcohol-induced liver damage in rats," Journal of agricultural and food chemistry, vol. 58, no. 5, pp. 3191-3196, 2010. DOI: 10.1021/jf904407x

[38] Muntana N., Prasong S., "Study on total phenolic contents and their antioxidant activities of Thai white, red and black rice bran extracts," Pakistan Journal of Biological Sciences: PJBS, vol. 13, no. 4, pp. 170-174, 2010. DOI: 10.3923/pjbs.2010.170.174

[39] Chaiyasut C., Sivamaruthi B. S., Pengkumsri N., Keapai W., Kesika P., Saelee M., Tojing P., Sirilun S., Chaiyasut K., Peerajan S., "Germinated Thai black rice extract protects experimental diabetic rats from oxidative stress and other diabetes-related consequences," Pharmaceuticals, vol. 10, no. 1, pp. 3, 2016. DOI: 10.3390/ph10010003

[40] Noviasari S., Kusnandar F., Setiyono A., Budijanto S., "Antioxidant activity and inhibition of α-amylase and α-glucosidase in fermented black rice bran-based analog rice," AIMS Agriculture and Food, vol. 7, no. 1, pp. 61-72, 2022. DOI: 10.3934/agrfood.2022004

[41] Bhuyan P., Sarma S., Ganguly M., Hazarika J., Mahanta R., "Glutamine: Fructose-6-phosphate aminotransferase (GFAT) inhibitory activity of the anthocyanins present in black rice bran: a probable mechanism for the anti diabetic effect," Journal of Molecular Structure, vol. 1222, no. 01, pp. 128957, 2020. DOI: 10.1016/j.molstruc.2020.128957

[42] Hui C., Bin Y., Xiaoping Y., Long Y., Chunye C., Mantian M., Wenhua L., "Anticancer activities of an anthocyanin-rich extract from black rice against breast cancer cells in vitro and in vivo," Nutrition and cancer, vol. 62, no. 8, pp. 1128-1136, 2010. DOI: 10.1080/01635581.2010.494821

[43] Thanuja B., Parimalavalli R., Vijayanand S., Alharbi R. M., Abdel-Raouf N., Ibraheem I. B. M., Sholkamy E. N., Durairaj K., Meansbo Hadish K., "Anticancer and Cytotoxicity Activity of Native and Modified Black Rice Flour on Colon Cancer Cell Lines," Evidence-Based Complementary and Alternative Medicine, vol. 2022, no. 01, pp. 2022. DOI: 10.1155/2022/8575026

[44] Zhou J., Zhu Y.-F., Chen X.-Y., Han B., Li F., Chen J.-Y., Peng X.-L., Luo L.-P., Chen W., Yu X.-P., "Black rice-derived anthocyanins inhibit HER-2-positive breast cancer epithelial-mesenchymal transition-mediated metastasis in vitro by suppressing FAK signaling," International Journal of Molecular Medicine, vol. 40, no. 6, pp. 1649-1656, 2017. DOI: 10.3892/ijmm.2017.3183

[45] Min S.-W., Ryu S.-N., Kim D.-H., "Anti-inflammatory effects of black rice, cyanidin-3-O-β-D-glycoside, and its metabolites, cyanidin and protocatechuic acid," International immunopharmacology, vol. 10, no. 8, pp. 959-966, 2010. DOI: 10.1016/j.intimp.2010.05.009

[46] Rahman H., Eswaraiah M. C., Dutta A., "In-vitro anti-inflammatory and anti-arthritic activity of Oryza Sativa Var. joha rice (an aromatic indigenous rice of Assam)," American Eurasian Journal of Agriculture and. Environment Sciences, vol. 15, no. 1, pp. 115-121, 2015. DOI: 10.5829/idosi.aejaes.2015.115.121

[47] Tonchaiyaphum P., Arpornchayanon W., Khonsung P., Chiranthanut N., Pitchakarn P., Kunanusorn P., "Gastroprotective activities of ethanol extract of black rice bran (Oryza sativa L.) in rats," Molecules, vol. 26, no. 13, pp. 3812, 2021. DOI: doi.org/10.3390/molecules26133812

[48] Salgado J. M., de Oliveira A. G. C., Mansi D. N., Donado-Pestana C. M., Bastos C. R., Marcondes F. K., "The role of black rice (Oryza sativa L.) in the control of hypercholesterolemia in rats," Journal of Medicinal Food, vol. 13, no. 6, pp. 1355-1362, 2010. DOI: 10.1089/jmf.2009.0246

[49] Zhang S., Ma Q., Dong L., Jia X., Liu L., Huang F., Liu G., Sun Z., Chi J., Zhang M., "Phenolic profiles and bioactivities of different milling fractions of rice bran from black rice," Food Chemistry, vol. 378, no. pp. 132035, 2022. DOI: 10.1016/j.foodchem.2021.132035

[50] Yang Y., Andrews M. C., Hu Y., Wang D., Qin Y., Zhu Y., Ni H., Ling W., "Anthocyanin extract from black rice significantly ameliorates platelet hyperactivity and hypertriglyceridemia in dyslipidemic rats induced by high fat diets," Journal of Agricultural and Food Chemistry, vol. 59, no. 12, pp. 6759-6764, 2011. DOI: 10.1021/jf201079h

[51] Song H., Shen X., Zhou Y., Zheng X., "Black rice anthocyanins alleviate hyperlipidemia, liver steatosis and insulin resistance by regulating lipid metabolism and gut microbiota in obese mice," Food & Function, vol. 12, no. 20, pp. 10160-10170, 2021. DOI: 10.1039/D1FO01394G

[52] Kim S., Park Y. S., Paik H., Chang H. I., "Effect of anthocyanins on expression of matrix metalloproteinase-2 in naproxen-induced gastric ulcers," British Journal of Nutrition, vol. 106, no. 12, pp. 1792-1801, 2011. DOI: 10.1017/S000711451100242X