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Review Article

Black Rice: A Novel Ingredient in Food Processing

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ABSTRACT

Black rice (*Zizania aquatica*) is a rice variety formed by the mutation of *Kala4* gene. In the world it is mainly cultivated in Southeast Asian countries like China, Thailand and India. China accounts for 62% of black rice production in the world followed by Sri Lanka, India, Indonesia and Philippines. Thailand holds the 9th position for black rice cultivation. In India black rice is grown in North-eastern states like Manipur, Mizoram, Meghalaya, Assam and some parts of Odisha. Black rice is black in color due to the presence of the anthocyanin pigment on the outer layers (bran) of the rice kernel. Black rice is rich in tocopherols (vitamin E), iron and antioxidants. Black rice has high levels of protein, fiber, vitamins (Vitamin B1, Vitamin B2, folic acid) and minerals (iron, zinc, calcium, phosphorous and selenium) compared to that of white rice. The major essential amino acids present in black rice are lysine and tryptophan. It also possesses lot of health benefits like antioxidant activity, anti-inflammatory properties, lipid oxidation, anti-diabetic, anti-ageing and anti-cancer effects. The use of black rice as an ingredient in food processing might help in creating value added products. In this paper, an attempt has been made to highlight the application of black rice as a novel ingredient in various sectors of food processing.

Keywords: Black rice; Black rice bran; Food processing; Anthocyanin; Colorants

INTRODUCTION

Black rice is the native of the common rice species (*Oryza sativa*) and the scientific name of black rice is (*Zizania aqatica*) [1]. Other common names of black rice are purple rice, forbidden rice, heaven rice, imperial rice, king's rice and prized rice. It is known as Chak-hao Ambi in Manipur (Chak-hao means 'delicious' and ambi means 'black) and thus refers to delicious black rice. In Odisha it is known as Kalabati (kala means 'black and bati means 'rice' in oriya). In south India it is found Keelapoongudi village in karaikudi district of Tamil Nadu and it is called as 'kavuni rice'. The presence of dark purple color on the outer covering (pericarp) of the rice grain appears to be in black color and thus it became black rice. The purple color pigment is anthocyanin which is a rich antioxidant and is naturally present in many berries like blueberry, black currant and vegetables like eggplant (brinjal). Black rice is a rich source of iron, antioxidants and vitamin E, thus ensures good health and increases the overall life span of human beings (Figure 1).

HISTORY OF BLACK RICE

Black rice was initially grown in China before the Chinese dynastic period and was called as the 'luck rice' because it was believed that people consuming black rice would live longer and also it has the ability to cure most of the diseases. Black rice is a variety of rice that is formed by the mutation of *Kala4* gene that stimulates the production of the black pigment- anthocyanin [2]. Earlier people refused to consume black rice due to its black color as they

Figure 1: Black rice

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considered it to be 'dirty' because of the black color. Later it was found that the color of the grain is determined by the accumulation of colored pigments. In black rice the colored pigment accumulated is anthocyanin and in red rice it is tanin. But in case of paddy no mutation occurs and hence there is no production of colored pigment and thus it appears white in color [3]. In black rice there is production of anthocyanin pigment due to the mutation of gene controlling pro-anthocyanidin biosynthesis. Initially black rice was reserved only for the kings of China and Indonesia due to its high price and enormous medicinal properties to cure various illness, but now it is available even for local people.

PROPERTIES OF BLACK RICE

The pericarp (outer covering) of black rice is black in color due to the presence of the black color pigment called anthocyanin which is rich in antioxidants and poses a variety of health benefits such as anti-aging, anticancer, anti-diabetes, lowering the risk of obesity etc. Black rice is glutinous and contains a high level of nutrients such as vitamin B, vitamin E, iron, thiamine, magnesium, niacin, phosphorous and it is also rich in dietary fiber. Similar to normal white rice black rice is also free of gluten and cholesterol, low in sugar, salt and fat. Black rice is generally consumed along with the bran due to the presence of anthocyanin and is sold as unmilled rice. On cooking it turns into purple color with a shiny indigo finish and has a mild nutty flavor and its texture is smooth and firm (Figure 2).

TYPES AND VARIETIES OF BLACK RICE

Black Japonica Rice: This type of rice is a mix of short and medium sized rice grains grown on the same field. It has an earthy flavor with a mild sweet spiciness [4].

Black Glutinous Rice: It is also known as the 'Black Sticky Rice'. This type has a short grain size and has a sticky texture. The grains are unevenly colored and generally used to make sweet dishes in Asia.

Italian Black Rice: This variety has long rice grains and has the characteristics of both Chinese black rice and Italian rice with a rich buttery aroma [4].

Thai Black Jasmine Rice: It is of a medium grain size and originated from Thailand that combines Chinese black rice with jasmine rice. Jasmine rice is native of Thailand and has a subtle floral aroma which is also observed in Thai black jasmine rice due to the combination (Figure 3).

HEALTH BENEFITS OF BLACK RICE

The main healthy component present in black rice is the colored pigment called Anthocyanin. Anthocyanins possess antioxidative and antimicrobial activities, improve visual and neurological health and also protects against non-communicable diseases. These all good health benefits are due to the antioxidant activity i.e., free radical scavenging activity which prevents the release of free radicals in the body. Anthocyanins are used to treat a wide variety of minor health issues like blood pressure, cold, urinary tract infections. It can also cure major health problems like heart attack (CVD), cancer, obesity and diabetes. Thus incorporating black rice in the normal diet can enhance the overall life span and improves the health and well-being of people.

Figure 2: Cooked Black Rice

Black Japonica rice | Glutinous Black Rice | Italian Black rice

Figure 3: Types of Black rice

Anti-inflammatory properties

Research was conducted on 2 groups of animals in which one group consumed black rice and the other brown rice. It was found that black rice suppressed dermatitis (skin inflammation) whereas brown rice did not. Therefore it was regarded that black rice "is a therapeutic agent that is capable of curing and preventing chronic diseases associated with inflammation".

Obesity

Black rice helps in weight management and reduce weight because of high fiber content on the bran. On consuming black rice it gives the feeling of fullness and the person does not feel hungry and also decreases the fatty acid synthesis thus resulting in intercellular lipid accumulation in between the tissues. Black rice also aids in detoxification.

Cardiovascular disease prevention

It is found out that anthocyanin present in black rice lowers the LDL (bad cholesterol) and increases the HDL (Good cholesterol) levels which decrease the chances for developing atherosclerosis and heart attack. Since it prevents the accumulation of LDL on the heart valves it keeps the heart healthy.

Anti-cancer effects

Anthocyanins protect the body from damage of free radicals which can prevent cancer. A research conducted on the anthocyanins extracted from black rice revealed that these anthocyanins have the potential to prevent the formation of tumors.

Anti-diabetic effect

The naturally low content of sugar and high fiber content in black rice prevents the occurrence of diabetes. Black rice does not cause

fluctuations in blood glucose levels like white rice and thus it also maintains blood pressure.

Reduces allergies

Black rice prevents the release of the amino acid histamine which is responsible for the release of allergic symptoms. Black rice soothes skin and reduces inflammation and irritation.

Prevention of constipation

As black rice contains twice the amount of fibers than brown rice it eases the bowel movement and even cures chronic constipation. The fibers also bind with toxic compounds in the colon and are easily flushed out along with the feces [5].

Anemia

Since black rice is rich in iron it is involved in the generation of new RBCs which increases the hemoglobin content and prevents anemia.

NUTRITIONAL PROFILE OF BLACK RICE IN COMPARISION WITH RED, BROWN AND WHITE RICE

It is a well-known fact that black rice has higher nutritional value than all other rice varieties. Also the nutritional property of brown rice is almost comparable with that of black rice. White rice is mostly preferred and commonly consumed by majority of the people for its taste and low cost and easy availability. Hence the nutritional value of black rice and it's amazing health benefits have made people to add more of black rice in their diet thus replacing white rice [6].

From the Table 1 it is found that black rice has the highest amount of protein, fat, iron, tocopherols, vitamin B (Thiamin and riboflavin), zinc. Thus we can understand that application of black rice in various food processing sectors will contribute to the overall increase in the nutritional profile of traditional food products.

BLACK RICE AS AN INGREDIENT IN FOOD PROCESSING

The various positive health benefits of black rice and the presence of the black pigment-"Anthocyanin" makes black rice a wonder ingredient in food processing. The use of black rice in food processing can increase the nutritional profile of the food products being created with black rice and can also be converted into a functional food targeting a particular group of people (eg., diabetic patients, obese people or people with high blood pressure and cardiac ailments). As black rice is not well known among the common people, its use in food processing will be novel as well as a healthy alternative to other common foods for the future generation.

APPLICATION OF BLACK RICE IN BAKERY PRODUCTS

Bakery products are increasingly becoming popular in India as indicated over 250% increase in their production. Baked products have a great demand throughout the world due to its ease of availability, ready to eat, convenience, unique taste and reasonable cost even in rural areas. Baked products include a wide range of products such as biscuits, cakes, cookies, puffs, pastries, bun, bread etc. At present, consumers are demanding newer options for existing baked goods, and the industry has been trying on new ingredients for fortification, enrichment or value added bakery products in order to satisfy the appetite of health conscious people.

Black rice powder in cakes

Cakes are important bakery products in which wheat is the main ingredient to provide structure to the cakes due to the presence of gluten. Black rice is also rich in protein content and can be used as a substitute for wheat flour in the preparation of cakes. Black rice is milled to flour/powder and incorporated at different levels 0,10,20,30,40,50,60,70,80,90 and 100% (W/W) of wheat flour in chiffon cakes [7]. The proximate composition of the black glutinous flour was 8.0% protein, 0.4% fat, 1.5% ash, 0.9% crude fiber and 89% carbohydrates on dry basis [8]. It was observed that the specific gravity of cake batter increased but the batter viscosity decreased on substitution of black rice powder [8]. On evaluating the properties of black rice powder incorporated baked cakes, it was found that the crumb hardness, crust and crumb color, chewiness increased. The cakes also observed a dense crumb structure instead of airy porous nature. The moisture content, cake volume, springiness and resilience decreased in baked cakes. Further there was a positive increase in antioxidant activity of the cakes. The sensory scores showed good results for incorporation levels of black rice powder between 10-60%, but replacement level between 70-100% reported less sensory scores [7]. The high protein content of black rice flour increases the overall nutritional profile of cakes and makes it an healthy alternative to traditional cakes made from refined wheat flour.

Black rice powder in bread

Bread is a fermented bakery product produced by yeast fermentation (*saccharomyces cervisiae*). The major ingredients used in the preparation of bread are refined wheat flour, salt, water and yeast. During fermentation, yeast acts upon the carbohydrates

Table 1: This table represents the nutritional profile of different rice varieties in per 100 g serving [6].

RICE VARIETY	Carbohydraes (g)	Protein (g)	Fat (g)	Fiber (g)	Iron (mg)	Tocopherol (mg)	Thiamin (mg)	Riboflavin (mg)	Zinc (mg)
Black rice	34 ± 0.05	8.5 ± 0.5	2 ± 0.06	4.9 ± 0.3	3.5 ± 0.15	12.54 ± 0.34	0.46 ± 0.032	0.403 ± 0.04	3.16 ± 0.05
Red rice	23 ± 0.04	7 ± 0.05	0.8 ± 0.01	2 ± 0.6	5.5 ± 0.14	10.77 ± 0.24	0.33 ± 0.15	0.105 ± 0.03	1.91 ± 0.036
Brown rice	24 ± 0.07	7.9 ± 0.07	0.8 ± 0.02	1.8 ± 0.5	2.2 ± 0.07	2.2 ± 0.76	0.54 ± 0.07	0.1 ± 0.2	1.8 ± 0.05
White rice	28 ± 0.03	2.7 ± 0.04	0.3 ± 0.01	0.6 ± 0.1	1.2 ± 0.19	0.1 ± 0.14	0.7 ± 0.06	0.03 ± 0.33	1.41 ± 0.039

present in flour along with sugar to release carbon dioxide which is trapped in the protein network (gluten) causing the dough to raise. The viscoelastic nature of gluten is responsible for good texture and quality of bread. Till now many ingredients like hydrocolloids (xanthum gum), transglutaminase and proteases are being substituted in wheat flour to get the same viscoelastic properties [9]. Recently attempts were made to substitute black rice flour in small quantities in wheat flour for bread preparation as it also has high protein content. Black rice flour has Nutraceutical properties and can be used for fortification of bread. In a study black rice flour was replaced at 2% level substitution in wheat flour and was found that there was no significant difference from control bread (0% black rice flour). At 4% level of substitution, it was observed that baked bread had a dense crumb structure and less elasticity [10]. Further in this study a mathematical model was designed to examine the digestion rates of black rice flour substituted bread. The results showed that the digestion rates were lowered in both the cases (2% and 4% substitution level). Thus it was concluded that replacing black rice flour in wheat flour can increase the health benefits and can serve as a functional food especially for diabetic patients as it lowered the starch digestion rates and maintains the blood glucose levels.

Black rice powder in cookies/biscuits

The term cookies and biscuits mean the same, the difference lies only in the places where they are known. In American countries it is referred as cookies and in British countries it is referred as biscuits. Technically, cookies are thick and soft having slightly higher moisture content whereas the latter are thin and crispy and with slightly low moisture content. On the whole, cookies and biscuits are one and the same. Cookies or biscuits are prime bakery products and are cherished as an all-time snack by everyone. A study was conducted to analyze the quality characteristics of black rice powder incorporated cookies. Wheat flour was substituted with 20% black rice powder and the cookies were prepared using the standard procedure [11]. Certain properties of the dough were evaluated and it was observed that the pH of cookie dough increased on addition of black rice powder. Also it was found that the moisture content of the dough was high because black rice powder has a tendency to absorb more water due to its sticky nature and so the cookies also had high moisture content due to high fiber content in the black rice flour [12]. The cookies were baked and were tested for color, spreadability and textural properties. The dough had a darker color due to substitution of black rice powder and on baking the color increased further [12]. There was no change on the texture of cookies even after addition of black rice powder [11]. Addition of black rice powder increased the spread ratio [13]. The sensory scores revealed that 20% substitution of black rice flour in cookies was greatly accepted by the panelists. Substitution beyond 20% had a very strong flavor and also had texture and poor sensory scores [11]. In another study purple rice flour was incorporated in biscuits at 25%, 50% and 100% substitution levels and found that the protein digestibility increased with an increase in addition of purple rice flour and decreased the starch digestion rates [13]. It was observed that 100% purple flour biscuits had very low levels of glycemic index. 25 and 50% substitution levels showed good overall acceptability in sensory analysis [13]. Thus it was concluded that addition of purple rice flour in cookies or biscuits could serve as a functional food for diabetic patients as it lowered the starch digestion rates and maintain the blood glucose levels.

SUPPLEMENTATION OF BLACK RICE IN EXTRUDED PRODUCTS

Extruded snacks are most commercially successful products due to their different variety of products, easy availability, ready to cook, convenience and long shelf life. Some examples of extruded products are pasta, noodles, breakfast cereals, modified starches etc. They are made from cereal flour with high starch content because starch has the ability to gelatinize during extrusion cooking and convert into a plasticized mass and forced into die to get desired shape products. Extruded products can be made out of raw materials with high protein too. Some examples include texturised vegetable protein, meat mince, pet foods etc. Since black rice has high protein and high starch content researches tried to use black rice in extrusion process to create highly nutritious products.

Pasta

Pasta is one of the common foods consumed throughout the world due to its easy cooking methods, convenience, taste and nutritional properties. Traditionally pasta is manufactured from a special variety of wheat called durum wheat because of its high protein content among all other wheat varieties, thus giving the end product a good texture. As black rice also has appreciable amount of protein content, studies were conducted to use black rice as a bioactive compound in the manufacturing of pasta [14]. Durum wheat flour along with some quantity of black rice flour was used for pasta making and certain quality attributes were studied. It was observed that the water absorption index and water solubility index of black rice pasta was increased due to the swelling power of black rice flour. It was also found that there was a decrease in antioxidant activity and phenolic content of black rice pasta as there was degradation of anthocyanins at high temperature extrusion cooking [14].

Noodles

Noodles are ready to cook instant foods which are made from wheat flour, salt, oil and water through the process of extrusion. Noodles can be prepared anywhere at any time as it needs only water for cooking. Though noodles have lot of advantages among the customers, it also has some disadvantages because most of the nutrients such as protein, dietary fiber and vitamins are lost during refining process of wheat. With increasing concerns for healthy and functional foods, researchers examined the possibility of supplementing Black rice bran powder as an ingredient in noodles. In this study noodles were prepared using Black rice bran powder at 0, 2, 5, 10 and 15% substitution levels in wheat flour and the chemical and functional properties were evaluated [15]. The proximate analysis of Black rice bran powder incorporated noodles revealed that the protein, fat and ash contents increased. Also the moisture content increased with increasing the level of addition of Black rice bran powder. The color and texture analysis showed that the lightness of noodles with black rice bran powder decreased on increasing the levels of black rice bran powder. The texture of noodles also became harder on increasing the concentration of black rice bran powder and it also decreased the cohesiveness [15]. The cooking characteristics of noodles were tested and found that the optimum cooking time for black rice bran noodles was 7minutes. Studies also revealed that the antioxidant activities

were increased in an ascending manner in raw noodles with 15% substitution level showing the highest antioxidant activity. But the antioxidant activity subsequently decreased in cooked noodles [15]. The reason for this may be explained because of leaching of phenolic compounds into the cooking medium. The overall nutritional profile of black rice bran noodles was improved as black rice bran has high amount of anthocyanin antioxidants fiber content. It is also found that black rice bran has preventive effect against cancer and prevents oxidative damage thus improving the overall health [5]. Therefore black rice bran is an excellent ingredient to be used in noodles.

APPLICATION OF BLACK PIGMENT-"ANTHOCYANIN" IN FOOD PROCESSING

Anthocyanins are a class of organic compounds belonging to the group of flavanoids, formed by the phenyl propanoid pathway. Anthocyanins are water soluble pigments and generally appear in dark blue or purple color. Depending on the pH the color may vary from red, purple, blue etc., Food plants that are rich in anthocyanins are blueberry, raspberry, black rice, black soybean. Black rice contains the highest amount of anthocyanins (327.60 mg/100 g) than any other fruit or vegetable [5]. Anthocyanins in black rice are present in higher concentrations in the outer pericarp (bran) of the rice kernel. It is also found in variety of colors like red, purple, blue in the petals of flowers. The major anthocyanins present in black rice include cyanidin-3-o-glucoside, peonidin-3-o-glucoside, malvidin-3-o-glucoside, pelagonidin-3-o-glucoside and delphinidin-3-o-glucoside [16]. Anthocyanins have high antioxidant activity and wide variety of health benefits such as reducing the risk of developing cardiac diseases, obesity, diabetes, cancer and also used in the treatment of skin cancer or other skin related issues. Use of anthocyanin for food application can increase the nutritional profile and bioavailability of nutrients and also used for the development of functional foods (Figure 4) [17].

Anthocyanin in fermented Thai pork sausage

The fermented Thai pork sausage is one of the popular varieties of sausage in Thailand. It is made from pork meat, cooked rice along with salt and other spices. Some food additives like nitrates and nitrites are also added to give the sausage an intense pink color to attract the consumers with its appearance. This color is developed by the formation of nitrosomyoglobin [18]. Nitrates are also used to prevent the microbial growth and prevent spoilage of sausages. But nitrates when consumed along with sausages have adverse effects on health and proved to be carcinogenic. Thus the addition of nitrates/nitrites in meat products is currently restricted by European Commission. Therefore research was carried out to introduce a new natural pigment which fulfills the function of nitrates like color development, prevention of lipid oxidation, preventing spoilage. The colorant powder was obtained from black rice bran through ohmic heating-assisted solvent extraction method. The Thai sausage was prepared by replacing nitrate salts with different concentrations of colorant powder. The sausages were prepare with six different concentrations of colorant powder (0, 0.2, 0.4, 0.6, 0.8 and 1g per 100 g of sample) compared with commercial sausage (containing 120 mg/kg of sodium nitrate) [19]. It was found that 0.8 and 1 g levels of colorant powder had developed a scarlet red color on sausages similar to that of commercial sausage. Further it also retarded the lipid oxidation. Sensory scores showed more acceptability of 0.8 and 1% colorant powder sausages. Thus the colorant powder extracted from black rice bran has the potential to be added as a natural coloring agent and antioxidant in fermented meat sausages.

Anthocyanin as natural colorant in yogurt

Yogurt is a fermented dairy product obtained by bacterial fermentation of *Lactobacillus bulgaricus* and *streptococcus thermophillus* cultures. Yogurts are generally available as flavored yogurt which has gained popularity worldwide. Flavored yogurts are developed using artificial flavors and colors which may have some adverse health effects if consumed in long run. Yogurt has become an important part of the human diet. Researches were conducted to eliminate the use of artificial colors and replacing it with natural colors. Attempts were made to make use of the natural pigment anthocyanin obtained from glutinous rice (black rice) in yogurt. Anthocyanin has a bright purple color and antioxidant activity. An experiment was conducted to investigate the use of black rice bran colorant in yogurt and the potential use as a functional ingredient. The black rice bran colorant powder was obtained through enzymatic extraction and flavored yogurt was prepared by adding 3 different levels of black rice bran colorant powder (0.2, 0.4, 0.6 per 100 g of sample) by weight to raw milk [20]. The yogurt was then prepared by standard yogurt manufacturing process and the samples were stored at 4°C for 21 days to check the color stability of the colorant powder. The samples were evaluated at every 3

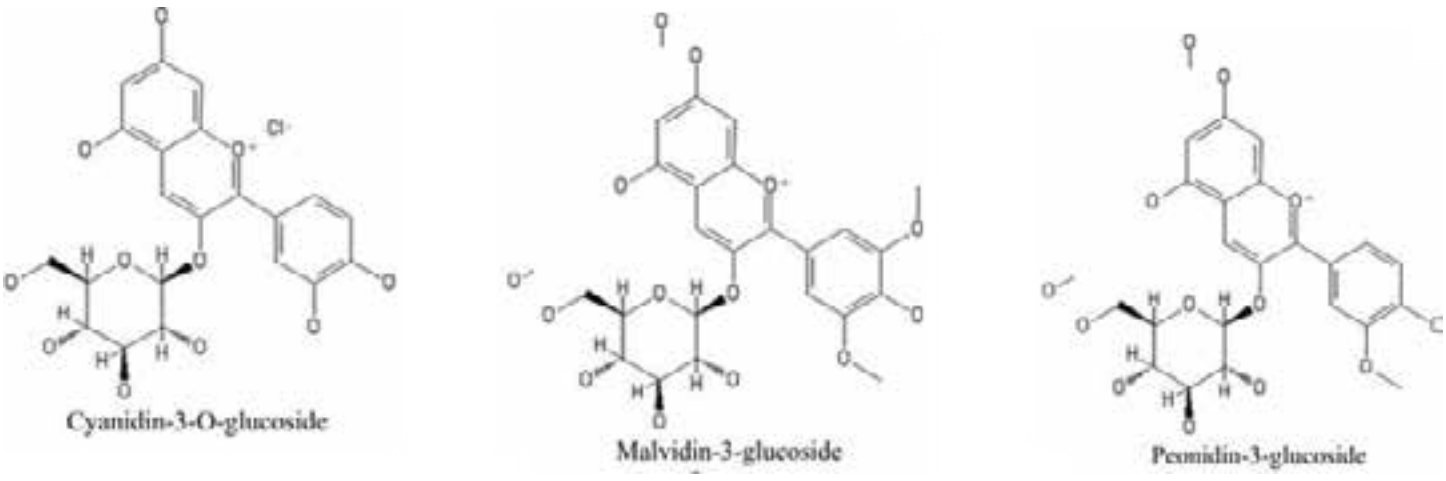

Figure 4: Major anthocyanins in black rice (Source: Balasubramaniam et al. 2019)

days for 21 days and found that yogurt added with 0.6% black rice bran colorant powder ha a pleasant purplish pink color [20]. The phytochemical content was also increased and it can be made into a functional food. The color was stable at 4°C for 21 days which proves that application of black rice bran colorant powder as a natural coloring agent to yogurt was successful.

Black rice bran oil

Rice bran oil is extracted from the outer layers (Bran) of the Rice kernels. Rice bran oil is an edible vegetable oil obtained only from the plant sources packed with high amount of bioactive compounds. Rice bran oil is rich in antioxidants and has a balanced fatty acid profile. Rice bran oil has a longer shelf life than any edible vegetable oil due to its own antioxidant properties and is regarded as the most "healthiest" of all edible vegetable oils. Rice bran oil is rich in Oryzanol which is a more powerful antioxidant than vitamin E. It lowers the LDL (Bad cholesterol) levels in the body and fights against free radicals. The general composition of Rice bran oil is 81-84% triglycerides, 2-3% diglycerides, 5-6% monoglycerides, 2-3% fatty acids, 0.3% wax, 0.8% glycolipids, 1.6% phospholipids and 4% unsaponifiables [21]. Rice bran oil can be extracted from the bran using different extraction methods like solvent extraction, cold extraction, hot extraction, supercritical fluid extraction etc. Rice bran oil is extracted from all rice types (white rice, red rice, brown rice and black rice). A comparative study was done to understand the physicochemical and antioxidant properties of rice bran oil extracted from the colored bran. The oil was extracted using 3 different extraction methods namely-solvent extraction, supercritical fluid extraction and cold press extraction and the physicochemical and antioxidant activities were compared. It was found that the antioxidant activities and oryzanol and tocopherol contents were higher for oil extracted from the bran of brown rice and black rice than white rice bran [22]. The fatty acid profile also revealed that the amount of unsaturated fatty acids are more than saturated fatty acids for brown and black rice bran oil. For Black Rice Bran Oil, the supercritical CO_2 extraction method gave high yield of oil along with high antioxidant and physicochemical properties [23]. Thus it is advisable to replace other edible oils with Black Rice Bran Oil for cooing purposes or incorporate small amounts of Black Rice Bran Oil in the daily human diet to gain a healthy lifestyle.

CONCLUSION

Black rice is a variety of rice which has several promising health benefits. The high antioxidant activity of black rice makes it a super food and its application as an ingredient in other food products can create highly nutritious foods. Anthocyanin, the main pigment of black rice has gained attraction among the researchers due to its high antioxidant activity, health benefits and natural coloring properties for use in other food applications. Black rice is rich source of tocopherols (vitamin E), iron, antioxidants and the overall nutritional profile of black rice has made it a functional and novel ingredient in food processing. Consumption of black rice by individuals those who show allergic symptoms to other cereal grains has proved to be beneficial and also helps in reducing the risk of developing cardiovascular diseases, diabetes and obesity. There is a dire need to include black rice as a novel ingredient in food processing to explore its complete benefits.

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