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Black rice: A review from its history to chemical makeup to health advantages, nutritional properties and dietary uses

Deepak Kumar Panda, B Jyotirmayee & Gyanranjan Mahalik*

Department of Botany, School of Applied Sciences, Centurion University of Technology and Management, Odisha, India

*Email: gyanranjan.mahalik@cutm.ac.in

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Abstract

Rice is the most popular food variety globally and is consumed as a staple food due to its high nutritional value. It is primarily black rice because of its rich anthocyanin levels, carbs, lipids, proteins, dietary fibres and minerals. Consumers are increasingly more aware of consuming healthy foods to maintain good health. Because of the strong demand from consumers, cultivars are now more interested in developing black rice due to its high anthocyanin content. The rice appears black because of the presence of anthocyanin in rice bran. Lysine, tryptophan and other essential amino acids are found in black rice. It also contains many antioxidants, the first line that protects against free radical damage and helps maintain good health. This rice type offers several health advantages and may reduce the risk of several ailments, including chronic ones. There are several health benefits associated with eating black rice. Atherosclerosis is lessened, the digestive system is strengthened, high blood pressure is stabilized, allergies are lessened, the body is cleansed, diabetes is better controlled, weight loss is more manageable and cancer development is slowed. It is now used in different food industries as a substitute for wheat due to its high nutritional profile, increasing protein digestion and decreasing starch digestion. This variety is also gluten-free and gluten-sensitive consumers can consume it. Black rice's history, chemical makeup and nutritional and functional qualities are all examined in this study. Black rice scientifically verified therapeutic benefits are the focus of this study paper.

Keywords

Anthocyanin, Aromatic compounds, Bioactive, Black rice, Phytochemicals

Introduction

Oryza sativa L., the rice species from which black rice is derived, is a very advantageous rice species (1). Rice has been a staple food worldwide. As a result, more than half of the population consumes it regularly. According to the look of rice bran, there are several sorts of rice, such as black, brown, red and white rice (2). In some cultures, forbidden rice is also known as black rice. It is also known as king, heaven, royal and valued (3). This shows different colours due to pigments in rice varieties. Black rice production has a long history in nations like India, Thailand, China and Indonesia. Black rice is produced mainly in India and China (2). Asian countries make over 90% of black rice.

Other countries have black rice after India and China, such as Thailand, Bangladesh, Indonesia, and Vietnam. According to FAO, 175 countries

and territories produce rice ranging from 100 to 200 kg per year (4). The rice contains a large number of vitamin minerals in comparison to regular rice. Black rice contains essential vitamins and minerals such as Vitamin B1 and B2, zinc, iron, calcium, selenium and phosphorous. It is a source of fibre and it contains plant-based proteins. Rice varieties are classified into several categories based on their phytochemical constituents, such as carotenoids and alkaloids and nitrogen, phenolic and organosulfur compounds. Flavonoids, phenolic acids, tannins and coumarins are all phenolic chemicals found in black rice (3).

Anthocyanin is one such flavonoid compound. Black rice contains many anthocyanins among the coloured grains. As an anti-cancer, antioxidant and anti-inflammatory chemical, anthocyanin is crucial in avoiding various illnesses, including chronic and degenerative ones. Anthocyanin is counted as an excellent dietary antioxidant. The anthocyanin in the grain's kernel layer gives the grain its dark hue, earning it the name "black rice." However, anthocyanin has a beneficial effect on human health in the fight against both chronic and non-chronic conditions (4). Pharmacological substances such as flavonoid, anthocyanin and phenolic chemicals may be found in rice bran.

Several studies have demonstrated that these substances may reduce protein synthesis and provide a well-balanced diet (3). Proteins are made up of various amino acids essential for healthy health. More protein and essential amino acids are found in black rice than in other types of rice. Protein metabolism relies heavily on amino acids in the organism. The amine group is removed from excess amino acids in the liver, resulting in ammonia formation. Controlling the risk of developing pre-diabetes is impossible without them. Asparagine is synthesized by asparagines synthetase, which is necessary to make protein in the cell. Ras sarcomas with a mutant type of asparagine availability could be treated with medications that modify asparagine availability in the body (2). Because of its many health advantages, black rice is now extensively grown and consumed worldwide. Numerous studies have shown that black rice has many more health advantages and avoids heart disease and cancer (5). It also improves the digestive system by reducing the formation of tumours and free radicals.

Further studies show that black rice is crucial in controlling and maintaining health and preventing diseases. Due to its high nutritional content and other health advantages, the production and consumption of black rice are on the rise. Black rice has more antioxidants than blueberries (6).

Black rice is also known as "long-life rice" due to its numerous health benefits. Several studies have shown that anthocyanin in black rice decreases reactive oxygen species (R.O.S.), which may cause cell damage in animals, plants and people. Nutritionists and dieticians consider black rice a nutritious food (7). Black rice's nutritional benefits, genetic diversity and phytochemical contents have made it a household name (8). Rice is one of the world's most important foods and is primarily farmed in Asian countries. People worldwide eat white rice, but many farmers cultivate black rice, brown rice and red rice. Anthocyanin rice is distinguished by the presence of anthocyanin in the pericarp, seed coat and aleurone layers. The mineral content in rice varies in cultivars and the area of cultivation. The rice contains anthocyanin, which plays a crucial role in neuroprotection by reducing oxidative stress (9, 10). India is one of the world's major producers, accounting for over 80% of domestic consumption; it is also its most enormous rice eater. Manipur, a state in India's northeast, is known for its wide variety of fragrant rice. Anthocyanin, an antioxidant in many foods, is found in black rice. Anthocyanin can protect cells from biotic and abiotic stressors and radiation as a cancer-fighting agent.

There is a kind of black rice grown in India called *Chakhao poireiton*. This rice is waxy; it has 7% protein, 2% amylose, 4% fat and 76% carbohydrate; its gelatinization temperature is between 75-92 °C. In brewing industries, rice has been used as an adjunct. A lack of starch saccharification occurs during mashing. For starch degradation, it needs Amylase activity. Incubation circumstances affect the rate of deterioration. Rice requires a minimum temperature of 10-12°C, an optimal temperature of 30–37 °C and a maximum of 40–42 °C. The ideal melting temperature for black rice in Asian countries is 30 °C close to room temperature.

Black rice plays a vital role in Manipur culture and is used in different ceremonies to prepare other dishes (11). Black rice is cultivated with the covering of endosperm. Many experts and scientists consider it a healthy diet because of its high fibre, antioxidants and anthocyanin content and nutritional value. Anti-carcinogenic effects are found in black rice. It helps in weight gain abilities to stop different diseases. Around the world, health-conscious people are growing and making the demand for black rice. The anthocyanin content in black rice is destroyed by external factors like pH, oxygen, light, enzymes, ascorbic acids, thermal treatment, sulfur dioxide and metal ions. Different studies show that the polyphenols such as anthocyanin help cure cardiovascular diseases (12). Black rice is well-known for its health advantages since it contains various anti-inflammatory chemical components. Inflammation is one of the primary immune system responses that work against infections. Histamine, bradykinin, serotonin and prostaglandins are the chemical features that promote these effects. These chemicals, which mediate cells in the immune system's ability to defend tissues from disease, unleash inflammation. As a result, treating chronic inflammation is essential to keep these life-threatening conditions, including autoimmune disorders, diabetes mellitus, cardiovascular illnesses, lung diseases and cancer at bay.

Many people in Asia use rice as their primary source of nutrition. In these Asian nations, three significant forms of rice are grown: white rice, brown rice and black rice (13). In India, it was cultivated in Odisha, but nowadays mainly developed in North-eastern states of India like Manipur and Assam. There are many distinct kinds of black rice and the history of black rice is extensive. Most Asian nations,

including India, China, Thailand and others, grow black rice. There are over 200 different types of black rice on the planet. China is the world's leading producer of black rice, accounting for 62% of global output. China has also developed 54 varieties of black rice with high yielding capacity with different resistance power. Access to germplasm collection numbers, such as those for India 30, Sri Lanka 50, China 359, the Philippines 25, Bangladesh 24 and Indonesia 42, can tell us about the demand for black rice in those countries. The rice type known as black rice is very uncommon. Glutinous black rice includes amylopectin, but medium-sized non-glutinous black rice has no amylopectin. In agriculture, Nanoscience with Nanotechnology is an essential tool that helps provide more agrochemicals, which improve crop productivity. To improve the crop varieties and fulfil the necessity of food according to the human population, we need technologies that will help in crop improvement and also crop productivity; now in the world, Nanotechnology is the only advanced technology that helps in productivity in the various fields like agriculture, horticulture, viticulture etc. (14).

Black rice has been the research subject regarding its potential health benefits when regularly ingested. Black rice can be employed to develop healthy options that may benefit customers, such as functional meals and gluten-free cereals, for food and drinks. Black rice types evaluated in this research show a broad range of physical and chemical features. They might serve as a starting point for food processors that want to include black rice in their products. Studies using black rice bran extracts to isolate anti-cancer sterols and triterpenoids have shown encouraging results. It has been proved that black rice extracts protect against osteoporosis (15). The liver and kidneys benefit from black rice's anti-inflammatory and antioxidant properties. Research has shown that black rice may be used to cure alcoholism (16). As a result of research, it is safe to say that black rice may be considered a nutritious supplement with confidence.

History

Until today, the origin of black rice has remained a mystery. Black rice types have originated in China, India, Japan and Vietnam, among other Asian nations. Besides Sri Lanka and Thailand, other countries such as Bangladesh and the Philippines may also produce black rice, which has led to speculation about its origins. Black rice is the most valuable commodity in China, making it the world's most populous nation (62 %). It's not only black rice that can be found in Sri Lanka and Indonesia; it's also found in India, the Philippines, Thailand and Myanmar, among other places (Fig. 1) (17). During Chinese dynastic times, black rice was introduced. During the warring nations, a general named Sun Bin was imprisoned and had to exist only on black rice balls. This general arrived in Hangzhou. According to sure Chinese tales, they give him black rice to eat on the first summer day to commemorate him for contributing to China's Great Wall construction.

Anyone who ate black rice without sanctioning well-authorized officials risked their lives in ancient times.

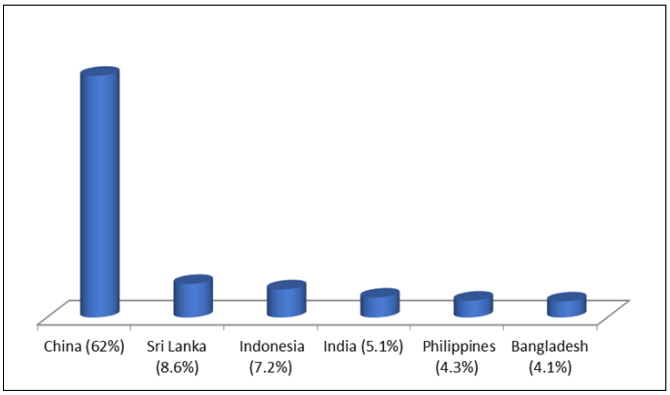

Fig. 1. Distribution of black rice.

Therefore, the rice is also known as "Forbidden Rice". In ancient times in China, the Emperor and the Royal families consumed black rice. According to some Chinese legends, the Royal families or the emperor consumed black rice because the rice varieties were rare, tasty and very nutritious. The emperor thought consuming black rice could extend their lives in ancient times, so they reserved this wonderfully. Black rice was a gift from the animals in Chinese tradition. After some time, rice sprouted from these seeds and their hunger was eradicated for good, although no one knows when or when this occurred. Neither black, brown, nor red rice kinds are seen. Black rice is also known as fortune rice in Chinese. Because this rare rice species is exclusively eaten as a tribute food, it is known as fortune rice. It was served to the emperors by the Tang dynasty and became famous as a tribute feast. This dynasty was started in 618 CE and into another dynasty known as Sung dynasty, which was created in 960 CE. During China's ruling period, the rice varieties are changed to "Forbidden rice". Growing this rice type is entirely unrestricted, yet it was only done for the emperor's benefit in ancient times. Yet, cultivating black rice is not tricky; black rice, on the other hand, has a lower production rate than brown and white rice. Emperors in China stockpiled certain rice kinds because they believed their life expectancy would grow by eating black rice and their throne would be safe for an extended time. Several myths concerning the origins of black rice have been passed down through the generations (17).

Discovery of black rice

A kind of rice that originates in Asia is known as black rice. Other emperors and Royal families consumed the black rice variety as the primary food in ancient China. The rice varieties contain various health benefits, so this rice variety is used as food in different regions of China. No one has permission to consume black rice in ancient China except the emperors or royal families. If anyone else consumes black rice without the consent of the emperor, then it will cause a life-threatening matter for the consumer; due to this type of rule and experience, the black rice is also famous as "Forbidden Rice". In Asian countries, all the varieties of different rice are important and consumed as good food for their diet. And it was cultivated from 1000 years ago. In China, black rice varieties are grown in a limited number and stored very carefully for their Emperor's consumption. The local people are not allowed to eat this rice variety.

Black rice was first released in the United States in 1995, but it has been available in other countries (17). Today, the rice varieties are used to be cultivated in different countries in small amounts compared to other rice varieties without any restrictions. In some food markets, the rice varieties are known as sweet rice, black glutinous and Indonesian black rice. This variety of rice is also broadly used as food in different Indonesian Irelands. Many Southeast Asian countries cultivate this rice variety and eat it as a good food source. Today, royal families and regular people use this as a food source without punishment. In China, people do not consume/eat black rice in their meal in daily basis, but they eat this variety on rare occasions (17-19).

Varieties of black rice (20)

Black Japonica Rice

This variety was created by combining two different rice grains. Short rice grains and medium-sized rice grains are cultivated in the same field. The flavour of this cultivar is somewhat spicy with a modest sweetness (21).

Black Glutinous Rice

Black sticky rice has a small grain size and a moist texture that distinguishes it from other types of rice. In Asia, these rice grains are frequently used to prepare delectable dishes (21).

Italian Black Rice

It's long-grain rice. This product contains both Chinese and Italian black rice. This cultivar has a strong scent.

Thai Black Jasmine Rice

This rice variety originated in Thailand. It consists of a mixture of black rice from China and jasmine rice. Medium-sized grains are seen in this rice type. The Thai jasmine black rice offers a pleasant aroma since jasmine rice is good in the aroma found in Thailand.

Characteristics of black rice

Because of the anthocyanin pigment, the pericarp, or the outer layer of rice, is black. Antioxidants are abundant in anthocyanin pigments. So due to the availability of antioxidants, black rice shows different properties such as anti-ageing, anti-cancer, anti-diabetes etc. Black rice is sticky and provides a variety of nutrients such as vitamin B, vitamin E, magnesium, niacin, iron, phosphorous, thiamine and fiber. Black rice is cholesterol-free and gluten-free (22).

Cultivation of black rice

Rice cultivation needs different mechanisms; it includes primary and highly mechanized means. Black rice varieties are significant due to their high nutritional values and essential health benefits. It requires good management to obtain a suitable type and crop with high productivity power. It is necessary to know the different techniques which help in crop management. Several practices, such as post-anthesis controlled soil drying, alternate wetting and moderate soil drying regimes during the whole growing season, and non-flooded straw mulching cultivation would maintain or even increase the grain yield of rice (23). In rice cultivation, the water requirement is high compared to other field crops, so it is necessary to manage the quantity and condition of water during rice production. The agriculture sector's future depends on a shift in emphasis from staple crops to crops with high levels of resilience. We see the possibility for increased agrobiodiversity in our meals, a decline in micronutrient shortages, and a reduction in the demand for agricultural water, fertiliser, and pesticides by encouraging the production of alternative crops (24). In India, rice biodiversity is particularly abundant in the Western Ghats, East Coastal Region, Central Highlands, and North Eastern Regions. The traditional rice varieties (TRVs) of these areas have special climatically resilient qualities, including the capacity to withstand drought-like conditions, surviving flooding during excessive rainfall, tolerance to salinity of the soil and waterlogging conditions, tolerance/resistance to pests and diseases, and having a lower cost of cultivation (25). Rice cultivation needs weed control for better productivity; herbicides should be efficacious. Pre-emergence pendimethalin herbicide application at 1.0 kg/ha, followed by post-emergence bispyribac sodium herbicide application at 25 g/ha 20 DAS, was found to effectively control weeds and boost the yield and revenue of drip-irrigated aerobic rice (26). One of the best cultural weed management techniques is proper stand establishing technique. There are many cultural weed control techniques, which are an integral aspect of integrated weed management practises, such as seed rate, line sowing, intercropping, and hoeing (27). Green manure in rice cultivation is essential in increasing productivity, such as *Sesbania* spp. And some plants are also used in green waste like Azolla and Anabaena (1, 28).

Broadcasting method

In this method, the black rice seeds are bathed in water, and after pre-germination, the seeds are distributed in the field. One of the easiest ways to spread the basis is by hand in the broadcasting method, but this distribution can reduce rice production. Pre-germination of sources requires different periods depending on the rice variety. In a hectare of land, it requires approximately 100 kg of seeds. The seeds, after pre-germination, start to germinate then the germinated seeds are distributed in the field (1).

Drilling method

This method uses drilling to sow the seeds. Two people are mainly required to drill the field in this method, and another person plants the roots. This method is primarily used in those areas where proper irrigation facilities are unavailable.

Japanese method

In this method, high-productive seeds are required. The practical high seeds are sown in a nursery bed in this method. Then the seeds are uprooted and planted by maintaining a proper distance (29).

Transplantation method

In this method, seedlings are replanted on land. For replanting, the seeds are transferred to a nursery bed, and

after some days, the germinated seeds are uprooted and transplanted into a field. In this method, labourers are required. This method is mainly used in good rainfall areas-transplantation gives better productivity than other methods (1).

Production of black rice

In all Asian countries, black rice is consumed and cultivated in more amounts. Most of India's black rice comes from Manipur and other north-eastern regions. There the rice variety is known by a different name as Chak-hao. Some other countries widely cultivate black rice include China, Indonesia, Bangladesh, Vietnam, Thailand, Burma, Philippines etc (1, 30) (Fig. 2).

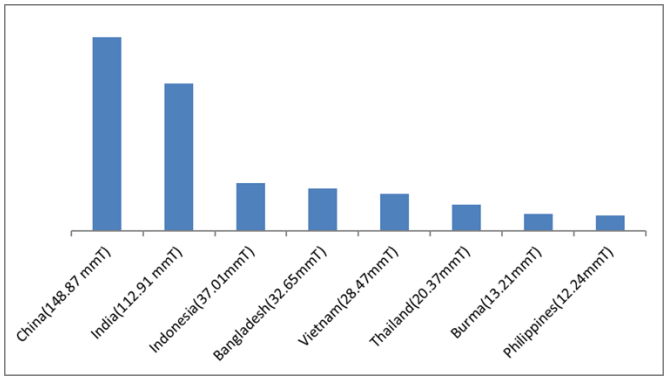

Fig. 2. Black rice production worldwide.

Nutritional composition

Black rice provides various nutrients essential for human growth and development, making it an excellent nutritional choice. Many vitamins, minerals, fibre, proteins, vital amino acids, and so on make up the list of nutrients. Vitamins, minerals and amino acids are all present in black rice; it also includes 18 different amino acids and a variety of other nutrients. Black rice is also beneficial in treating a wide range of illnesses. Iron, calcium, magnesium and potassium in black rice are high. Several studies found that black rice has the highest overall saturated and unsaturated fatty acids concentration of all rice cultivars (5.89%) (31, 32). Gluten, fat and cholesterol are absent from black rice, which is also low in fat, sugar and salt. Niacin, thiamine, antioxidants, and anthocyanins are abundant in black rice (9).

Compared with white rice, black rice contains 9.1 grams of protein per 100 g, while per 100 g, white rice has 6.3 g of protein (Fig. 3) (1). The glycemic index of black rice is low, so it is helpful for diabetic patients. It contains arsenic and this rice also helps improve adiponectin production in the body. Black rice also decreases the leptin hormone level. The leptin hormone is responsible for appetite regulation. It contains many antioxidants, which help protect our cells against oxidative stress. This rice also has different flavonoids, carotenoids and 23 different plant compounds (1) (Table 1).

Anthocyanin

The components of anthocyanin are mainly naturally occurring. Anthocyanin is a colour pigment; these come under plant pigment and are broadly found in nature. Plant

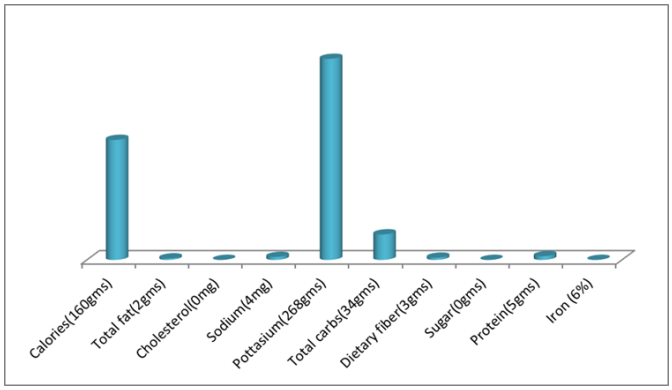

Fig. 3. Value of one cup black rice in terms of nutritional content (Cooked).

Table 1. Nutritional Composition of Black Rice

Components	Daily values
Iron	6%
Energy	356 kcl
Proteins	8.89 g
Total lipid	3.33 g
Carbohydrate	75.56 g
Fibre	4.7 g
Fatty acids	0 g
Cholesterol	0 g

parts like fruits, flowers and any other plant-based product derived from these substances show a unique, different colour due to the presence of anthocyanin. Anthocyanin comes under a sub-group of flavonoid compounds that are water-soluble and found in nature. The name anthocyanin was given by a German botanist Ludwig Marquart (33); anthocyanin comes from Greek words; in Greek, anthos indicate flower and kyanos express blue. The anthocyanin containing black rice usually has acetylated procyanidins; the acetylated procyanidins compounds show free radical scavenging activity. Anthocyanins are glycosides and acyl glycosides of anthocyanins. The anthocyanin compounds are water-soluble; much research on anthocyanin indicates that these compounds are not only shown antioxidant properties but also these compounds show different other properties; When these chemicals are present, they have detoxifying and inflammatory effects, as well as the ability to slow tumour development by preventing the establishment of new blood vessels (34, 35) (Fig. 4).

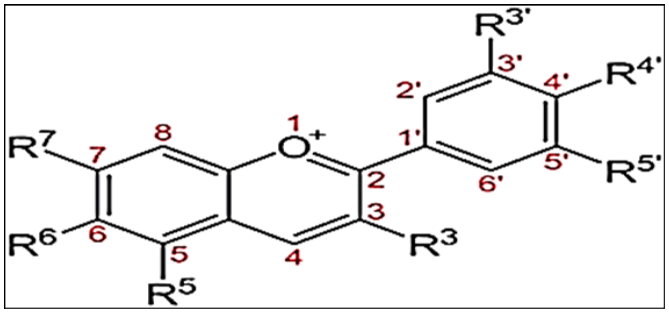

Fig. 4. The general structure of anthocyanin.

Vitamin-E

Vitamin E is fat-soluble in different forms, but in the case of human-only, alpha-tocopherol is used. Vitamin E is essential in the body because it is an antioxidant and helps pre-

vent the formation of free radicals. Vitamin E also helps to inhibit clots from forming in heart arteries. This vitamin also enhances immune function. It helps to defend from free radicals and inhibits the production of free radicals. The deficiency of Vitamin E causes nerve problems, but this deficiency is usually rare (31).

Iron

Iron plays a vital role in carrying oxygen molecules to the haemoglobin of red blood cells; by supplying oxygen to the whole body, the cell can produce energy. Iron also reduces carbon dioxide. When iron levels are low in red blood cells, they cannot carry oxygen. There is a condition in the body named anaemia that shows an iron deficiency. The shortage of iron in the body causes several problems. It leads to fatigue and weakness. It shows difficulties maintaining temperature in the body and can cause pale skin.

Dietary fiber

These are carbohydrates that are not simply digested by the enzymes in the human body. Different sources of dietary fibre include cereals, pulses, fruits, vegetables and grains (14).

Black rice's anthocyanin types

HPLC (High Performance Liquid Chromatography) analysis revealed that black rice primarily includes three different anthocyanin pigments. Cyanidin-3-glucoside (C3G), peonidin-3-glucoside, and malvidin were three anthocyanin kinds that were identified by HPLC in two Japanese black rice genotypes (Asamurasaki and Okunomurasaki), while a fourth anthocyanin (petunidin-3-glucoside) was recently found in a variety of Chinakuromai (36). Dark stains, such as the cyanidin pigments, fall within this subcategory. These anthocyanin subcomponents have an excellent uptake rate, most minor decay and good significance in the clinical field out of all anthocyanin. These are different effects on cells, a few are antidiabetic and some are effective for "metabolic syndrome" (36).

Malvidin-3-glucoside (Types of Anthocyanin Pigment)

It is an anthocyanin pigment. This pigment is a primary plant pigment; malvidin glycosides are mostly plenteous. Little acidic and neutral suspension of malvidin is shown red, but the essential rest of malvidin shows a blue colour. Black grapes and other plants contain this malvidin-3-glucoside, which may be found in the top layer of the fruit. Red wine also has malvidin-3-glucoside. Three significant anthocyanins were found in two black rice cultivars (Asamurasaki and Okunomurasaki): cyanidin-3-glucoside, peonidin-3-glucoside, and malvidin (37).

Peonidin-3-glucoside

This pigment is also the primary plant pigment and is characterized as an anthocyanin pigment. This pigment displays purplish-red colour in different flowers such as peony and the stain is named peonidin based on this flower name. Some roses and blue-hued flowers, such as morning glory, contain this pigment.

Like other anthocyanidin pigments, it is also pH sensitive. If the pH level increases, it also converts its colour from red to blue. This change occurs because these anthocyanidins are highly conjugated chromophores. The conjugation of double bonds changes when the pH level is altered (14). Black rice anthocyanin pigments were primarily made of C3G and P3G (37).

Aromatic composition of black rice

Black rice contains a good flavour due to this character; this variety is different from other rice. In rice varieties, taste plays a vital quality trait, gaining consumers' preference. This rice variety contains 35 volatile compounds (38). There are 10 aromatic compounds, 6 alcohol compounds, 4 nitrogen-containing compounds, 10 aldehydes, 2 terpenoid compounds and 3 ketones. Black rice comparatively contains more volatile compounds than white rice (39). The aromatic and nitrogen-containing compounds are more than white rice (40). White rice has more alcohol, ketones, aldehyde and terpenoids than black rice. Hexanal, 2-pentylfuran and nonanal were the only chemicals with a higher concentration of 2-acetyl-1-pyrroline. Some components, such as 2-acetyl-1-pyrroline, indole, p-xylene and guaiacol, effectively indicate the significant difference between cooked black and white rice scents. On the base of odour in black rice, there are 2 main contributors, the 2-acetyl-1-pyro line and guaiacol; the distinctiveness of black rice can't be achieved without them.

Bioactive compounds

These chemicals have a significant impact on human health. In black rice, some phytochemicals are identified, such as γ-oryzanol, zeaxanthin and lutein, flavonoids, and phenolic compounds (41). Flavonoids are critical in demonstrating strong antioxidant qualities with additional health advantages in bioactive substances. It has been determined that the high antioxidant properties of foods like black rice, other dark fruits and vegetables, and other such bioactive chemicals reduce the risk of many illnesses (41).

Phytosterols

Black rice varieties also contain different secondary metabolites. Black rice includes a high amount of γ-oryzanol compared to regular white rice. Phytosteryl-ferulates, such as cycloartenyl-ferulate, 24-methylenecycloartanyl ferulate, campesteryl ferulate and β-sitosteryl ferulate are discovered in γ-oryzanol, which is found in these black rice grains. Phytosterols are essential in preventing cholesterol absorption and the management of undesirable lipoproteins in circulation (42).

Carotenoids

The carotenoid compounds found in rice serve an essential function in nutrition, accounting for 90 % of the total carotenoids found in rice. Lycopene and β-carotene are found in fewer amounts in rice. These compounds are primarily found in rice bran. On the other hand, Milled rice showed a lower level of carotenoids. The carotenoid content in rice cultivars varies genetically. Compared to conventional white rice, black rice has a higher carotenoid content.

Phenolic acids

Black rice has a greater phenolic acid concentration than white rice. P-coumaric acid, isoferulic acid, sinapic acid, 2,5-diphenylbenzoic acid and ferric acid are precursors to synthesizing many phenolic acids, including cinnamic acid. Syringic acid may be found in various rice varieties, including red, black and brown rice. Rice, both red and white, contains pinellic acid. Hydroxybenzoic acid is present in black rice (43).

Flavonoids

In black rice, the main flavonoids are anthocyanins. Anthocyanin synthetase of leucoanthocyanidin catalyzes an oxidation process that produces delphinidin, cyanidin and pelargonidin components. Flavonoids, particularly anthocyanin pigments are responsible for purple and black rice's blue and purple colours. In flavonoids, there are some essential compounds such as peonidin-3-O-glucoside and cyanidin-3-O-glucoside. It also includes cyanidin-3-O-arabidoside, pelargonidin-3-O-glucoside and cyanidin-3-5-diglucoside (44).

Phytochemicals

Numerous investigations and research have established that phytochemicals and other valuable components are abundant in black rice (45, 46). In black rice, there are twenty-three other secondary metabolites found and it also includes anthocyanins, carotenoids, γ-oryzanols, flavonoids glycosides, flavones and vitamin-E; these compounds provide different health benefits and help in curing various diseases and also promote the consumption of this rice varieties as a functional food. About 26.3% of the anthocyanin pigment is found in black rice. Nearly 90% comprises 2 primary practical chemicals, cyanidin-3-O-glucoside and peonidin-3-O-glucoside. The principal component of black rice is anthocyanins. Flavonoids, such as anthocyanin pigments, are a rich source of antioxidants that may help treat free radical cancer and other illnesses. Improved memory and coordination are two of its many benefits. Microbial characteristics in antioxidants are essential in promoting eye and brain health. Non-communicable diseases may also benefit from the use of these chemicals. Besides lowering blood pressure, urinary tract infections and inflammation, anthocyanin pigments also play a crucial role in treating these conditions. According to a study presented in 2010 at the American Chemical Society by Dr ZhiminXu, black rice has more anthocyanin pigments per tablespoon than blueberries (47, 48).

Role of different nutrients

Antioxidants

Black rice has anti-oxidant properties. The pigments help in memory function and coordination (49, 50).

Anthocyanins

The pigments help in different conditions like improving memory-enhancing vision and it also exhibits anti-inflammatory properties.

Proteins

One plate of black rice gives 10% of the daily required value of protein (31).

Fibre

Black rice provides 8% of the daily required fibre. Soluble fibre helps in managing weight. To prevent constipation, insoluble fibres play a crucial role (31).

Iron

One plate of black rice gives 4% of the daily required iron (31). Iron is an essential mineral that helps to keep blood healthy and robust. The oxygen supply is carried out by blood to different body parts. Still, if the oxygen concentration becomes low, our body becomes fatigued, affecting brain function and a weak immune system (9).

Health benefits

Non-communicable diseases are thwarted by anthocyanin pigments, which aid in creating visual and neurological problems. The high antioxidant qualities of anthocyanin pigments make them excellent and effective for protecting the body from free radical damage. Many minor ailments, such as high blood pressure and a cold or urinary tract infection, may be treated with these pigments and more severe health issues like cancer, heart attack, and diabetes (51). Consumption of black rice is highly nutritious for the body and it is suitable for health and increases the immune system (28, 52, 53). Plants are being utilized as an elective hotspot to advance protected, compelling, and appropriate new medications to treat and forestall illnesses. Ongoing examinations have shown that dark rice is a significant wellspring of supplements and has comprehensive pharmacological exercises. Pharmacological investigations show that the dark rice has potential antiarthritic, mitigating, antidiabetic, anticancerous, β - glucosidase and tyrosine restraint exercises and affirms that the black rice groups are significant in vitro enemy of ligament against inflammatory, anticancerous, antidiabetic, hepato defensive activities, β - glucosidase restraint and tyrosine hindrance examine (52). Black rice extricates essentially hinders the multiplication of Hela malignant growth cells and may decrease the high sugar levels (54). The outcomes approved the ayurvedic plans referenced in the old Telugu palm-leaf composition to treat jaundice, wounds, fibroids and disease. Notwithstanding, a definite examination is expected to distinguish and portray the unadulterated dynamic synthetic standards liable for noticed natural exercises (55).

Anti-inflammatory properties

Black rice is an effective treatment for chronic disorders accompanied by inflammation. In RAW 264.7 cells, black rice, C3G and its metabolites decreased the expression of the genes for nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2) as well as the production of the proinflammatory cytokines TNF-α and IL-1β (56). The greatest anti-inflammatory effect has been found in black rice aqueous extract, as shown by increased Treg cells, decreased nuclear factor kappa B activity on CD4+ and CD8+ T cells, decreased production of TNF-α by CD4+ T cells, and decreased production of IL-6 and IFN-γ by macrophages (57).

Obesity

The high fibre content in this rice's bran helps regulate weight and reduce weight. This rice type promotes a feeling of fullness and inhibits the creation of fatty acids when consumed. This causes a build-up of lipids in the spaces between cells in the tissues (58).

Cardiovascular disease prevention

In black rice, anthocyanin pigments are present due to their antioxidant properties. Anthocyanin reduces the risk of heart attack and atherosclerosis by lowering harmful cholesterol levels and increasing good cholesterol levels in the body. Anthocyanin decreases bad cholesterols and retains good heart condition (59). Black rice contains a high amount of dietary fibre, which helps control cardiovascular health and blood pressure. It also decreases lipid levels, improves glucose metabolism, and maintains body weight.

Anti-cancer property

In black rice, the pigment anthocyanin plays a vital role in preventing the body from damaging free radicals; it can control cancer by avoiding the damage. Anthocyanin pigment extracted from black rice could potentially suppress the growth of tumours (42).

Antidiabetic properties

Black rice constitutes low sugar and high fibre, so it helps inhibit diabetes. This rice variety does not create fluctuations in sugar levels in the blood; thus, it sustains blood pressure (60).

Reduce allergies

The histamine deficiency causes allergic reactions; thus, black rice hinders the body from producing this amino acid. Black rice also decreases inflammation and irritation in the skin (3).

Constipation prevention

Because black rice has twice the amount of fibre as brown rice, it helps relieve intestinal discomfort and cure chronic constipation. Black rice fibre binds to the colon's harmful components and is easily flushed with faeces (3). The high fibre content of black rice aids digestion by reducing gas, bloating and guarding against constipation. This rice also aids gastrointestinal issues, including gastric reflux illness, duodenal ulcer, diverticulitis, and haemorrhoids.

Anaemia

Anaemia may be avoided by eating a diet rich in iron-rich foods like black rice, which aids in the formation of new red blood cells (R.B.C.s) (22).

Helps in liver detoxification

Liver disease occurs due to the high-fat deposition in the liver. An experiment was conducted on mice to know the curing properties of black rice. In this experiment, the result concluded that the rice variety has high antioxidant properties. It manages the metabolism of fatty acids, decreases triglycerides and lowers the cholesterol level; These effects can potentially reduce the risk of fatty liver disease (61).

Aids healthy brain function

Many scientists feel that oxidative stress is detrimental to mental health. As a result, like other antioxidant pigments, anthocyanin might reduce oxidative stress and preserve the brain's outstanding performance. Anthocyanin pigment helps to improve memory functioning and the learning capacity of the rat suffering from estrogen deficit (2).

Natural gluten-free

Many foods contain gluten, including wheat, rye, barley, etc. One person in every seven persons is sensitive to gluten. Prodromos caused by gluten protein includes diarrhoea, bloating, and constipation. It also increases the chance of a leaky gut. Unlike white rice, black rice is naturally devoid of gluten. Those acute to this protein can consume black rice daily to fulfil their diet.

Treat asthma

Black rice contains anthocyanin pigments, and these pigments help in the curing of asthma. Korea did a study, and according to this study, anthocyanin helps cure asthma by decreasing inflammation in airways and hyper mucus secretion in mice suffering from a respiratory disorder (3).

Good for eyes

The anthocyanin pigment found in black rice is beneficial for improving eye power. An experiment conducted on rats and the study found that these pigments inhibit the damage to the retina, which is caused due to fluorescent light (62).

Applications of black rice

Black rice as a dietary source

There are several health benefits of eating black rice. Rice is a good source of nourishment of this kind. The food items processed using black rice will be novel and a good healthy alternative for the consumers.

Black rice in bakery products

Bakery items are becoming increasingly popular in India, with daily demand. In the world, bakery food products have an outstanding order because these products are readily available in the market, have different tastes, and have reasonable prices. Bakery products mean various food items like cakes, biscuits, bread, bun, pastries, etc. Consumers demand new and different bakery items, and industries try other ingredients to fulfil customers' demands.

Cakes with black rice powder

Baking without cakes would be impossible because wheat's gluten helps shape cakes (63). Black rice also contains different types of proteins and can be used in cake preparation as a substitute for wheat. Using black rice in cake products will increase its nutrition due to its antioxidant activity. The black rice contains different proteins and raises the cakes' nutritional profile (63).

Black rice powder in bread

In bakery industries, pieces of bread are prepared by fermentation using yeast. Bread uses various components, including wheat flour, salt, yeast, and water. In the fermen-

tation process, yeast interacts with the carbohydrates in wheat flour and sugar, releasing carbon dioxide, which helps bind the protein network and aids in digestion. In bread, good texture obtains due to the presence of gluten. The gluten protein is viscoelastic. Other ingredients, such as hydrocolloids, transglutaminase, and protease, substitute wheat flour to find the exact viscoelastic nature. Still, black rice flour has recently been used in small amounts of wheat flour to make bread (63). Because of its high nutraceutical activity, black rice flour may be used to fortify bread. Black rice has a low digestion rate and can be used as black rice flour as a substitute for wheat flour. Anyone, even diabetics, may benefit from consuming it.

Black rice powder in cookies/biscuits

Several investigations investigate the quality of black rice powder in cookie making (63). Addition of black rice powder to cookies seems to boost the cookie's moisture content. Because of its sticky nature, it will absorb more water, but the texture of the cookies remains the same when black rice powder is added. The purple rice powder also boosts the rate at which protein is digested. Purple rice powder has been shown to reduce the pace at which starch is outlined so that diabetic individual may eat the cookies.

Extruded products with black rice supplementation

These meals are more popular because they are simple to prepare and come in various flavours. The food products are made from cereal flour and use high starch, and these food products are also made from other raw materials with high protein, such as vegetable protein, pet foods, etc. Researchers use black rice to produce highly nutritious food because black rice contains high proteins (64).

Pasta

Pasta is widely accepted and eaten across the globe because of its simple preparation, distinctive flavour, and several health benefits. The primary ingredient in most pasta is durum wheat, which has a higher protein level than other wheat kinds. When some black rice flour was added to durum wheat flour during pasta preparation, the water absorption capacity of the pasta was improved. According to this research, black rice pasta's antioxidant and phenolic compound characteristics degraded due to anthocyanin pigment degradation at high temperatures.

Noodles

Extrusion is the procedure through which noodles are formed by combining several components, such as wheat flour, salt, oil and water. Noodles are always ready to prepare because it requires only water for preparation. Due to the wheat's refining process, several nutrients, including protein, fibre and vitamins are lost during the manufacture of noodles; this significantly impacts the dish's nutritional content. Many studies explored the use of black rice powder in the preparation of noodles because of the growing global population and the resulting need for functional foods (22).

Rice intensification system can help with climate-smart agriculture

Most rice has been grown for a long time on perennially overflowing soils, with genuinely mature seedlings transplanted in clusters of three or (at least 4) plants at high thickness. Higher-yielding varieties (H.Y.V.s) with more prominent use of mineral composts, developed water systems and herbicides and pesticides to control different weeds, bug vermin and microorganisms were created and presented during the Green Revolution to increase rice and other grain crop yields (65). The relocation of rice growing areas and the adoption of superior rice cultivars may have been made possible by adaptation to climate change, which may have contributed to the observed increase in rice yield. One way to improve the future food supply is to transition to an agriculture that more intelligently takes use of climate benefits (66). The idea that more results could be accomplished by downsizing farming data sources and unexpectedly using them is disparate from the latest practices and arrangements. This departure warrants additional investigation because using more water, seed and synthetic manure to expand rice production can be detrimental, as evidenced by research conducted at the China National Rice Research Institute. In comparison to how super-rice is generally planted under SRM, yield optimization under SRI was accomplished with significantly less plant densities. With concurrent increases in output, N fertiliser applications can also be successfully decreased. The crop performance was found to be negatively impacted by increasing plant densities associated with SRM since the increase in yield per unit of input (seeds, water, and N fertiliser) was marginally negative. The intake of N ha-1 with SRI was larger with lower plant density and was not linearly affected by N applications, in contrast to the SRM studies where N uptake was boosted by higher N application and by greater plant density. At all levels of application, N productivity with SRI was higher than with SRM. With the super-rice varieties created in China, it seems that these two techniques of managing rice could have advantages beyond agronomy, such as economic and environmental gains. The outcomes of the trials suggest that changing the management procedures can have a positive impact on the outputs of the rice crop (67). Rice reproducers at the International Rice Research Institute (IRRI) have noticed that their preliminary yields haven't increased significantly in 30 years (65). The worldview which directs the latest horticultural innovative work (Research and development) should be available to audit, mainly since agribusiness is the area generally touchy and defenceless against unfavourable climatic impacts. Rice farming expertise, media availability, training, and a reported drop in rainfall all have a beneficial impact on how aggressively farmers adopt climate-smart agricultural technologies. On the other hand, factors such as farm size, location, and the reported rise in temperature had a negative impact on farmers' intensity of technology adoption. In light of this, it is clear how crucial it is for the government to support farmer education programmes and campaigns to raise public understanding of the need to em-

brace climate-smart farming practises (68). To assess the effects of layering key technologies, practises, and services in various combinations and compare them with business as usual (farmer's practise) for productivity (crop, water, and energy), profitability, and global warming potential (GWP) in a RW system, a multi-location farmer's participatory strategic research was conducted. With the addition of a broader range of activities to farmers' routines, yield, income, water and energy use efficiency, and the reduction of greenhouse gases all improved. This aids in determining the technological approaches from the CSAP portfolio that should be prioritised in order to increase agricultural output, profitability, and input usage efficiency while enhancing adaptability and minimising environmental impacts (69).

Principles for more climate-resilient rice production

Rice seedlings planted separately grow more extended roots and absorb more plant compounds, or cytokinins, than at least three seedlings of a similar variety planted together on one slope, according to research (70). Furthermore, establishing more early seedlings is beneficial to the development of rice plants since there is less competition in the nursery and less shock from relocating (71, 72). More extensive dispersing between plants advances the bountiful development of roots and turners by working with plants' admittance to supplements, water and light (73). Utilizing natural excrements and keeping paddy fields unflooded further develops soil well-being, supplements take -up and the climate of the rhizosphere (74, 75). These practices, by implication, improve roots' expansion, working and life span, coming about in further developed shoot development and working (76). Shifting seedlings grown in unflooded nurseries into unflooded fundamental fields rather than overflowing areas has advantages for the model and relocating them early has even more significant benefits (77). The essential standards for S.R.I. (System of Rice Intensification) agronomy is appropriate for rice and different yields (78, 79).

Establishing healthy plants early, carefully and quickly

Young rice seedlings transplanted during a few leaf stages maintain a more significant proportion of their genetic capacity for tillering, panicle development and grain filling than older seedlings (73, 77). Relocating seedlings before the start of their fourth phyllochron of product, in a few leaf stages, as a rule before 15 days later planting is referred to as "youthful" (76). For the best outcomes, seedlings should be relocated rapidly, tenderly and shallow, with only 1 to 2 cm profundity, into very much evened out, sloppy soil without standing water. These boundaries relocate shock, allowing seedlings to resume development sooner (71). Local factors, such as encompassing temperature, field water depth, job accessibility and so on, must modify the ideal age for transplanting "youthful seedlings". The guideline for using young seedlings optimally has broad importance, despite its limitations in application.

Improved soil environment for root growth

Mineral manures provide supplements to plants in general for their short-term benefit. However, it also involves long-term natural contamination issues, like eutrophication, GHG (Greenhouse gas) outflows and soil fermentation. Traditional overflowed rice has deficient compost use effectiveness because of misfortunes from fields and decreased take-up from declined root foundations (73).

Root growth and microbiological mobilization improve morphological and physiological features

Most harvest improvement projects have emphasized changing and expanding the hereditary possibilities of plants through plant rearing, combined with more prominent or improved utilization of various acquired inputs, mainly growing synthetic manures, since the Green Revolution. Arrangement of rice increases insight and exploration appears.

Soil biota

S.R.I. rehearses huge impacts on advantageous microbial populaces inside plant rhizospheres (78). These populaces incorporate the cooperative microorganisms that live around, on and inside plants, which have begun to get consideration and exploration.

Root system

The construction and physiology of rice plants under the S.R.I. board have demonstrated significant architectural and physiological differences, with more critical, profound and longer-lived root systems.

Effects of phenotypes

According to morphological and physiological assessments of S.R.I. plants, rice genotypes can be made more valuable by modifying the circumstances under which they are formed. Bhubaneswar executives found that rice plants cultivated with S.R.I. procedures vastly improve in different morphological and physiological parameters under similar soil, climatic and environmental conditions.

Crop adaptation to climate change

Water productivity increased with higher yield and water conservation

Water usefulness and water reserve money are essential considerations when water for agricultural production becomes increasingly limited and unreliable. However, when S.R.I. crop management techniques are combined with alternative wetting and drying (AWD), less water is wasted, but paddy yields are increased, making water-saving strategies valuable to ranchers or farms (73). Water is vital for rice development. Adequate water supply is one of the main variables in rice creation. In Asia, the rice crop experiences either too little water (dry spell) or a lot of it (flooding). Most investigations on limitations to high rice yield show water as the primary element for yield holes and inconstancy from try stations to ranches. The development rate in the advancement of the water system has proactively declined. With the developing shortage and rivalry for water, there is an expanded interest for examination to distinguish likely regions for increasing water efficiency in rice-based frameworks. Improvement of on-ranch water repositories for water collecting, determina-

tion of dry spell open-minded assortments, land evening out, dirt compaction and need-based water system planning might assume a significant part in expanding water use proficiency and declining yield holes (80).

Drought resistance

Because they have deeper roots and don't senesce as much or as soon as rice plant roots under hypoxic, overflowing conditions, S.R.I. rice plants are better prepared to withstand water pressure (73). When the soil biota is abundant, the impact of dry season opposition is enhanced because soil microbial consortia address a never-ending reservoir of water in the soil and increase the ground's organization and absorbency to more readily swallow and hold water.

Storm damage resistance

Rice plants (Black, red, basmati, jasmine, brown rice etc.) with more extensive, deeper, non-senescing underground roots and more grounded, thicker shoots anchored to a single root base are better prepared to withstand the beating of rain and wind during storms, which are becoming more frequent and severe as a result of environmental change (73).

Resistance to colder temperature

The all-around created root foundations of rice plants developed with S.R.I. techniques likewise better assist them with enduring virus spells. Surprisingly, this was evident during the 2006 storm season at the Andhra Pradesh state rural college in India, where synchronized bug the board (I.P.M.) preliminaries were held. When the preliminary plots were hit by a severe but short cold period, whenever evening air temperatures dipped below 10 °C for five consecutive days, the preliminaries, intended to survey potential contrasts in bug opposition, produced spontaneous information on extraordinary obstruction. Because of the frost, plots under standard rice crop control had almost no harvestable grain, whereas adjoining S.R.I. plots yielded.

Insect pest and disease resistance

Reduced helplessness to invasion and injury by bug pests and illnesses are other phenotypical benefits of SRI-developed rice crops. Changes in precipitation and temperature due to environmental change may exacerbate this constraint on rural development. Most studies have found that S.R.I. plants are less vulnerable to insect pests and bacterial and infectious illnesses than other plants, though not all (78).

Taste quality and improvement technology of black rice

Black rice skin is complex and contains a ton of cellulose and gelatin, prompting troublesome cooking and unfortunate taste quality, restricting the turn of events and usage of dark rice generally. Pregelatinizing black rice and handling it with pregelatinized dark rice is one way to develop the cooking quality further and eating nature of dark rice. Drying is a vital connection in the creation cycle of pregelatinized black rice. The drying attributes of pregelatinized black rice and the inner dampness change law of black rice straightforwardly influence the drying effectiveness and item nature of pregelatinized black rice. The reduction of bond is connected with the draining of low sub-atomic weight mixtures, for example, amylose and amylopectin, which are the primary pieces of starch drained during cooking. While making nourishment porridge with black rice, the expansion of black rice essentially affects the nature of sustenance porridge. With the increment of dark rice, the tangible of sustenance porridge expanded first and afterwards diminished. Starch is the leading supplement for black rice and all rice, incorporating straight amylose with low sub-atomic weight and amylopectin with high sub-atomic weight. The amylose content in waxy black rice is under 2%, which can further develop the alcohol yield as a natural substance for alcohol making. Low amylose causes the gelatinized result of dark rice to have a better consistency (81).

Prospects of Black Rice Research

Even though there are some explores of the nourishing parts, wholesome quality, cooking and eating quality, handling quality, appearance quality, clinical treatment and food medical care of black rice, there are still a few issues in the examination of black rice, particularly the anthocyanins which assume a significant part in the dietary nature of black rice. For instance: (1) the conventional black rice anthocyanins extraction, detachment and filtration time is extended, significant expense, low yield, the significant expense of wastewater treatment. (2) Due to the trouble in cleansing and readiness of black rice anthocyanin standard, significant expense, costly norm and high gear prerequisites, it is hard to get a solitary part of anthocyanin (3). Black rice anthocyanins have the impacts of antioxidation, liver security against lipid, hostile to growth, insusceptible guideline, weight reduction etc. Be that as it may, there are many examinations on the physiological impacts of black rice in vitro climate recreation and somewhat a couple of concentrates on creature tests and clinical application, particularly in the construction movement relationship, portion impact relationship and atomic and physiological system of black rice anthocyanins (82).

Black rice vs Brown rice

Both brown and white forms of rice are better for you than white rice (83). These rice types also have a few notable distinctions; for example, Raw brown rice has 226 calories per third cup, but uncooked black rice has 200 calories per third cup (84). Black rice is better and healthier than brown rice in terms of carbohydrates, fibre, protein and fat since it has a lower quantity of carbs and a higher level of protein and fibre. There is a significant difference in iron concentration between these rice kinds, although they possess the same amount of zinc and phosphorus (62, 85, 86).

Conclusion

There are several health advantages of eating black rice, a kind of rice. This variety is used as a super food due to its high antioxidant properties. In this rice variety, anthocyanin is the primary pigment that attracted many researchers' attention due to its high antioxidant properties. Among the many nutrients in black rice are vitamins E and

B, anthocyanin and iron, fibre, proteins and a wide range of vital amino acids. While white rice includes gluten and harmful cholesterols, black rice does not. It also has reduced sugar, salt and fat levels compared to white rice. Secondary metabolites are also found in black rice. According to further research, eating black rice may reduce various ailments, including diabetes, cancer, heart disease, Alzheimer's and more. This rice type is tasty, affordable and quick to cook and it also has a pleasant scent because of the vital aromatic ingredient. So social awareness should be created and allow people to learn about the nutritional properties of black rice and their other benefits so that consumers can discover more about this variety and consume it to increase their life and maintain good health. Recent discoveries into the possible biological impacts of black rice and its derivatives have made significant progress in our knowledge. One of the most promising sources of health-enhancing functional foods for various non-infectious conditions has been discovered. It is necessary to conduct more clinical studies to verify this study's findings. Discussion of novel food and beverage applications and processing technologies to enhance their quality should also be focused on. Its primary goal should be to review and discuss new advancements in black rice bioactivities. In order to reverse the current slowdown in rice production increase and improve food supply, climate-smart agriculture could boost the biophysical potential ceiling. Under stress-free crop management, the incremental yield growth from rice cultivars with climate intelligence could range from 20 to 50%. One way to increase food supply is to change agriculture to be "climate-smart." Modifying crop, soil, water, and nutrient management practises can result in more resilient and fruitful crop phenotypes. SRI qualifies as CSA because the crops it produces enable farmers to adjust their operations to the biotic and abiotic pressures of climate change while minimising the warming effect of rice paddies. Compared to traditional approaches, climate smart agriculture has been found to be better suited to climatic hazards. In order to achieve high and stable productivity and profitability while enhancing natural resources (water and energy) and reducing environmental footprints, layering different CSA practises (portfolio) offers opportunities to address the issues of crop adaptability with projected climate change in RW (Rice Wheat) rotation. Adoption of CSATs increases rice productivity over the long term. In order to properly direct and educate their climate change programmes and actions, policymakers should be aware of the factors affecting rice farmers' adoption of CSATs. Farmers should be made aware of the importance of implementing CSATs as a whole as opposed to picking individual technologies. Additionally, agricultural extension staff should train rice farmers on CSATs on a regular basis to increase their understanding of the advantages of CSATs and encourage their adoption.

Authors contributions

G.M.: Conceptualization and design of this work; †D.K.P. and †B.J. (†Equal contribution to both authors): Writing, collection, interpretation and arrangement of data; G.M.: Critically revised the manuscript; All the authors read and approved the final manuscript.

Compliance with ethical standards

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