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A review on genetic diversity, traditional uses, phytochemistry and nutraceutical values of red rice (*Oryza sativa* L.)

Maneesha Devi[1*], Pardeep Kumar[2]

[1] Ph.D. Research Scholar, Department of Plant Sciences, Central University of Himachal Pradesh, Shahpur, Kangra, Himachal Pradesh, India

[2] Professor, Department of Plant Sciences, Central University of Himachal Pradesh, Shahpur, Kangra, Himachal Pradesh, India

Abstract

Pigmented rice cultivars are becoming more popular because of their phenolic and nutritional qualities when compared to white rice cultivars. Rice with a red bran layer is called red rice. It is native to Asian countries and a well-known cultivar of mid and high hills of South Western Himalayas in Himachal Pradesh, Jammu and Kashmir, and some regions of Uttrakhand. Red rice is commonly used in Himachal Pradesh as Bhaat, kheer, Meetha Bhaat, Chilrhu or Lushke. In several parts of the state, it is also used for making beverages. Lugrhi, a brewed drink prepared from red rice, is famous in the Kullu district. The bran layer of red rice contain polyphenols such as phenolic acid, anthocyanin, and proanthocyanidins, and possesses antioxidant activities. Red rice is a great source of protein, zinc (Zn), and iron (Fe) than white rice. The decoction (strained liquor) made from red rice and lassi is used to cure dysentery in human beings. The rice water that is separated after cooking rice is fed to pregnant and lactating women as a nutritional food supplement. The demand for nutraceutical-rich foods is rising day by day. Keeping in view, the rising demand and shrinking area under the red rice, a concrete policy, and marketing approach is urgently required to motivate farmers and boost the cultivation of rice in its traditional areas of cultivation.

Keywords: red rice, traditional uses, phytochemicals, proanthocyanidins, antioxidant activity

Introduction

Rice (*Oryza sativa* L.) is a significant cereal crop in the developing world, and it is used as a staple food by more than half of the world's population, with Asian countries accounting for nearly all of the production [1]. White rice is the most widely utilized rice; however, there are several special cultivars of rice which are brown, black, and red in colors. The colors of the rice are caused by a significant amount of pigments which are anthocyanin or proanthocyanidins being deposited in the coat of the rice [2]. Three different types of genes regulate the color of the pericarp in rice grains that are Ra, Rc, and Rd. These three genes are thought to be monogenetically inherited. The Ra gene controls the purple color, whereas the Rc gene creates a brown pericarp in the absence of the Rd gene, and when the Rc and Rd genes are crossed, a red pericarp is formed [3]. Around the world, the most common type of rice consumed is polished rice. Rice polishing improves the physical and sensory characteristics of rice while also increasing its storage stability [4]. The rice caryopsis's bran and germ are removed using this method of processing. Proteins, vitamins, and fibers are abundant in the bran layers, whereas fat is abundant in the germ. As a result, while the polishing procedure improves the physical, sensory, and preservation aspects of rice, it reduces its nutritional value. Because pigmented rice cultivars have more phenolic compounds in their bran layers than non-pigmented rice cultivars, polishing has a negative nutritional impact on pigmented rice [5]. Rice parboiling has proven to be an efficient processing technique for increasing rice storage durability while minimizing nutritional quality change [6]. Pigmented rice types have recently gotten a lot of attention from customers because of their high bioactive chemicals, which could provide health benefits.

Red rice is rice that has a red bran layer. It is a member of the Poaceae family. Because of its unusual qualities of a red tinge of varying degrees in decorticated grains, it has been given the name "Red rice" or Laal dhaan. Red kernel color is generally a monogenic dominant feature in rice, however, in some ecotypes, two dominant genes with complementary gene activity is present [7]. The bran varies in color from pale to dark red. Red rice has been cultivated in Asia for a long period of time and utilized as an unpolished whole grain because the process of milling removes the color and bran layer, making it comparable to polished white rice. Red rice, also known as "weedy rice," is a rice variety. Weedy rice is a low-probability and nutty-flavored rice cultivar. Red rice is a Kharif season crop. The transplanting season in Himachal Pradesh runs from June to July. Sowing should take place four weeks before the transplanting date. Harvestable maturity occurs in 120-140 days, from September to October. Red rice is resistant to flood, drought, submersion, salinity, alkalinity, and pests and diseases from the viewpoint of cultivation.

It is an Asian native that has long been grown in Philippines, Sri Lanka, China, Japan, Korea, India, and other rice-growing countries. Red rice types are grown in Bihar, Bengal, Karnataka, Kerala, Tamil Nadu, Madhya Pradesh, Orissa, and other North-eastern Indian states with unfavorable environmental conditions such as deep water, dryness, and sandy soil [1]. Uttarakhand, Himachal Pradesh, and Jammu and Kashmir, all in the Northwest Himalayas, have a wide range of traditional rice genotypes [8]. The major growing regions in Himachal Pradesh include

Dodrakwar, Chiragaon, Rohru, Jubbal, and Chopal in district Shimla; Naggar and Nirmand areas in district Kullu; Jogindernagar and Jhanjheli areas of district Mandi; low lands along with Giri, Tons rivers and their tributaries in Sirmaur; Bhanghal area of district Kangra; and mid and high hills of Chamba [9].

Pigmented rice has a distinct color, and flavor therefore it is used as an ingredient in many dishes. When compared to regular rice, red rice provides a variety of nutritional advantages. Red rice has two to three Times higher zinc and iron content than white rice, while the iron content varies by cultivar and manufacturing area. The rice bran fraction is high in fiber and bioactive phytochemicals such as oryzanols, tocotrienols, tocopherols, vitamins, dietary fibers, and phenolic compounds, all of which are good for human health [10]. Red rice is quite popular in Brazil because it is gluten-free, and one of the most common raw materials used in flour manufacture.

Red rice has been shown to have anti-fungal, anti-bacterial, anti-viral, anti-diarrheal, anti-inflammatory, anti-oxidant, anti-tumor, anti-thyroid, and anti-hypercholesterolemic properties in pharmacological and clinical trials. Aside from having radical scavenging properties, it also stimulates protein secretion [11]. Because of its high polyphenol and anthocyanin content, red rice has become popular in Japan as a functional meal. Red rice may also aid in the prevention or treatment of disorders caused by the deficiency of vitamin A and B.

This review is mainly based on genetic diversity, traditional uses, phyto chemistry, and nutraceutical values of red rice.

Origin of Red Rice

Red rice disappeared from commercial production in the early 1990s and remained confined to a few areas. There are records of red rice in ancient scripts believed to be as old as 7000BC. An ancient Japanese myth has a description of the origin of white rice and red rice as well. The rice used to be vegetative and produce no grains, according to this inscription. White grains appeared after the Goddess Kuan Yin poured her milk over the plant but repeated squeezing caused blood to leak out, and some grains turned reddish [12]. According to *Catur Bumi's* Balinese mythology, it is believed that the God Ciwa assigned the job of descending the seeds of rice on the earth. He gave seeds of four colors: yellow, black, red, and white. However, the seeds of white, red, and black could only reach the earth as the yellow colored seeds were eaten by a passing bird. As a result, it is believed that red rice is originated as early as the rice itself.

Types of Red Rice

Red rice may be divided into three groups based on their habitat: wild, weedy, and cultivated.

Wild Red Rice

Oryza nivara, O. granulate, O. officinalis, and *O. rufipogon* are all wild red rice species. These species, particularly *O. nivara*, have numerous nutraceutical benefits such as body elements enrichment, toxin reduction or exclusion, body strengthening, regeneration and energization, blood pressure regulation, skin health improvement, and premature aging prevention [13]. In crop development programme, wild rice also acts as a genetic resource for a variety of qualities. Male sterility (*O. rufipogon*), resistance to bacterial leaf blight (Xa 21 gene), tolerance to acid sulfate, grassy stunt virus resistance (*O. nivara*), and resistance to various diseases and pests are among the wild rice features exploited in crop improvement [14].

Weedy red rice

In the cultivated field, weedy red rice often appears as weed or off-type. It generally possesses a high level of cross-pollination, seed shedding, seed dormancy, earliness, and hardiness enabling it to survive in adverse environments [15]. Weedy red rice is sometimes referred to as "fat beggars" and "red menace"due to its hardiness and obnoxious nature. However, weedy/wild red rice is consumed in various Asian regions.

Cultivated red rice

Before the development of improved white rice cultivars, many landraces and cultivars of red rice were in cultivation in the majority of the Asian countries including Philippines, Sri Lanka, Korea, Bhutan, Japan, China, Japan,and India [16].

Genetic Diversity of Red Rice

In different rice-growing locations across the world, there is a wide variety of wild, weedy, and cultivated red rice. A few types of research are summarized below to have a better understanding of the degree of variety in red rice and its link to farmed rice. Red rice, white rice, and their hybrids were identified using microsatellite markers. KHP-10 is a novel red rice cultivar with tall non-loding plants and blast endurance [17]. Dodiga, Sharavathi, Akkalu, Bettasali, IRLON/90/39, and KHRS-17 red rice genotypes were found as prospective donors for crop enhancement in terms of grain production [18]. Using 15 STMS primer pairs, the intra- and inter-population molecular diversity of red rice landraces were determined to be moderate to low, with polymorphism ranging from 26.67 to 66.67. A study of 137 red rice accessions utilizing 27 microsatellite primers spread across 12 chromosomes revealed that 25% of red rice accessions share alleles with farmed rice types [19].

Traditional Uses of Red Rice

Red rice has been used widely for its nutraceutical values rather than as food. It is eaten as whole grain, chapatti or bread [20]. Red rice is commonly used as Bhaat (cooked in water), kheer (cooked in milk), Meetha Bhaat (cooked in water with added sugar), Chilrhu (a preparation like dosa, served with jaggry and ghee) in Himachal Pradesh. Chilrhu has special significance as it is prepared on the festivals like Makar sakranti (Lohri) and Beeshu (Baisakhi) in Shimla, Solan and Sirmaur districts. Jatu (red rice from Himachal Pradesh) is valued for its taste and aroma. In Kerala and Tamil Nadu, parboiled red rice is widely consumed.

Red rice, as a traditional crop, is deeply knitted with traditional rituals and is utilized in various folk dishes and snacks. Phooli Moorhi is a traditional snack produced by boiling husked red rice followed by dehusking and then roasting in sand or oil, Sookhi Moorhi is a roasted dehusked red rice mixed with marijuana seeds, Hari Moorhi (roasting of green filled panicles followed by drying, grinding, and sieving to separate husk), Shakli or Sanse (made from dehusked red rice by washing, shade drying, grinding to make flour, bartered with water, a thin layer of barter is spread on the lid of utensil having boiling water, after solidification dried in shade, then roasted in oil) and the flour of red rice is also used to make Sidhku (steam-cooked

balls of red rice flour stuffed with pulse flour and spices) are some of the most common uses.

Moorhi has special significance in rituals of hill folks as it is gifted to married daughters and sisters at festivals. Red rice is used in religious ceremonies as a tilak and hawan samagri. In various parts of the state, red rice is also used to make beverages. In the kullu district, lugrhi, a brewed drink made from red rice, is well-known.

Phyto chemistry of Red Rice

Phytochemicals are naturally occurring molecules produced by plants and herbs that have health benefits for human beings. Phytochemical study of rice bran is rich in tocotrienols, tocopherol, ϒ-oryzanol, carotenoids, octacosanol, aminobutyric acid, phytosterols, unsaturated fatty acids, squalene, and phenolic compounds [10]. These phytochemicals can be found in two forms (free, and bound) in the bran fractions and endosperm of the rice grain. Phenolic compounds of rice are mostly found in the pericarp, which makes up around 3% of the rice caryopsis, and may be divided into different groups that are flavonoids, phenolic acid, hydroxycinnamic acids and lignans. One of the most common phytochemical groups present in whole grain are phenolics, which are natural antioxidants that function as radical scavengers to prevent oxidative stress-induced damage to major biological components including DNA, lipids and proteins [21]. 1, 1-diphenyl-2-picryl-hydrazyl (DPPH) and Nitric oxide (NO) scavenging tests were used to assess the antioxidative characteristics of the free and bound fractions [22].

Iron, zinc, and manganese are abundant in red rice. The manganese concentration of red rice bran contributes significantly to antioxidative effects [23]. The free and bound fractions of red rice bran are showing to include five phenolic compounds (Syringic acid, protocatechuic acid, cinnamic acid, ferulic acid, and *p*-coumaric acid) and five flavonoids compounds (catechin, apigenin, quercetin, myrecitin, and luteolin) [22]. The most prevalent phenolic components in the extract of red rice bran are *p*-coumaric acid and ferulic acid, whereas catechin and myrecitin are the most abundant flavonoids compounds [24]. Some biochemicals found in red rice extracts, such as chlorogenic, syringic, sinapic, vanillic, 4-hydroxybenzoic, *p*-coumaric, ferulic, and isoferulic acids, have scavenging properties and suppress LPS-stimulated IL-1b, IL-6, AND COX-2 mRNA expression in laboratory experiments, suggesting that they could be useful in human health [25,26]. Parboiling of germinated seeds of red rice for 5 minutes increases the quality in terms of total free phenol, free *p*-coumaric acid, bound vanillic and *p*-coumaric acid, and antioxidant activity [27].

When compared to white rice, red rice has more ash, protein, fat, total phenol, total anthocyanin, antioxidant activity, and a lower glycemic index [28]. Red rice has a higher concentration of peonidin-3-O-β-glucoside and cyanidin-3-O-β-glucoside [29]. A recent study showed that the concentration of anthocyanin in colored rice is greatly influenced by the grain color.

Proanthocyanidins: The main phenolic constituent of red rice grains have been identified as proanthocyanidins (PAs), also known as condensed tannins [30]. These are a group of polyphenolic secondary metabolites produced by plants as oligomers or polymers of flavan-3-ol molecules through the flavonoids pathway. Catechin, epicatcehin, gallocatechin, and epigallocatechin are the primary proanthocyanidins found in rice germ and bran, especially in pigmented rice.

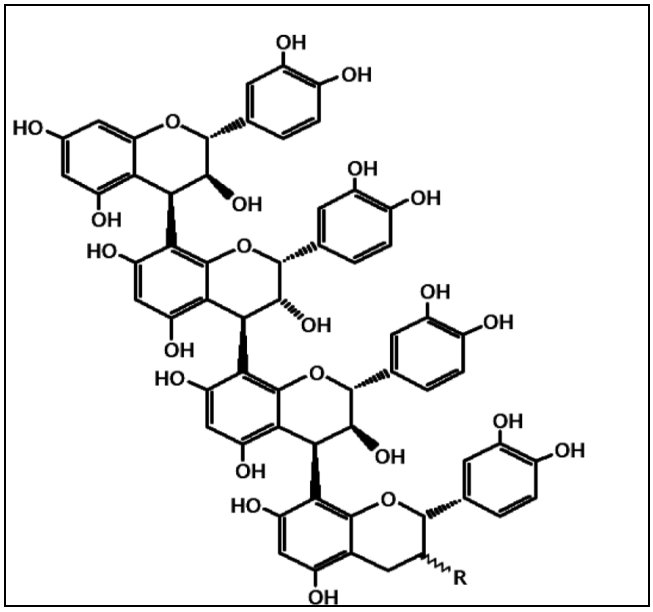

Fig: General Structure of Proanthocyanidins [31].

Red rices have stronger DPPH radical scavenging activity than white and black rices, and this activity is linked to polyphenol and proanthocyanidin concentration [11].

Total phenolics in red rice are dominated by insoluble bound phenolics [32]. The concentration of free phenolics in harvested red rice increases after one month of storage and then drops sharply during the second month. Soluble esterified phenolics, on the other hand, show a reversal of trend, decreasing after the first month and gradually increasing after the second month of storage. However, total and bound phenolics rapidly decrease during storage [33].

Extrusion-cooked flour of red rice is a potential ingredient for the preparation of gluten-free cakes [34]. The color of red rice deepens as the chemical characteristics of proanthocyanidins change during storage. The antioxidant content in red rice decreases with storage length and temperature [35]. In terms of carbs, protein, fiber, fat, iron, and zinc composition, the landraces of red rice have higher nutraceutical qualities than varieties.

Nutraceutical Values and Uses

The composition of major constituents of red rice is detailed below:

Table: Nutritional values of red rice [37]

Constituents	Value (g 100 g^{-1})
Moisture	12.51
Total fibre	1.19
Proteins	10.53
Fats	1.49
Phosphorus (P)	0.21
Zinc (Zn)	0.005
Iron (Fe)	0.004
Calcium (Ca)	0.02
Carbohydrates	74.40
Energy	1425 KJ

Red rice possesses two or three times higher zinc and iron than white rice. It contains magnesium which lowers the risk of heart attacks and plays a critical function in blood pressure regulation. Manganese and calcium are present in abundance that helps in strengthening metabolism, and bones. Selenium is also a part of the nutritional package of red rice and helps the body fight against infection.

One of the prominent red rice nutrition advantages is the presence of vitamin B6. Vitamin B6 helps to enhance the production of serotonin and red blood cells in the body. Red rice's low glycemic index makes it suitable for several conditions, including diabetes. This is the only cereal that is ingested as a whole grain, making it easier to digest. Anthocyanin pigments are quite effective in lowering cholesterol levels in humans and can also be helpful in weight management. Proanthocyanins, which are found in red rice, help to control inflammation, protect against cancer, [36] and provide protection against type II diabetes. Other nutraceutical constituents include oligomeric procyanidins, carotenoids, ϒ- oryzanol, flavones, and flavonols are present in red rice [37].

Rakthasali (red rice from Karnataka) is effective in relaxing the body's humor and is beneficial for fever and ulcers. It also improves eyesight, voice, and skin health, as well as increasing fertility. In Himachal Pradesh, Lal dhan and Matali are used to treat fever and high blood pressure. Another red rice cultivar from Uttar Pradesh and Himachal Pradesh called Kafalya is used to cure leucorrhoea and abortion problems [38]. Maappillai Samba, a type of red rice native to Tamil Nadu, heal colon cancer, lowers cholesterol and boosts fertility. Furthermore, stigmasterol (unsaturated phytosterol) which is abundant in this genotype is a precursor to semi-synthetic progesterone production [39]. In humans, a decoction made from red rice and lassi is used to treat diarrhoea. Because of its strong antioxidant capacity and lack of cytotoxicity, ferulic acid, a bioactive phenolic acid molecule found in red rice bran extract, has a neuroprotective impact [40].

Conclusion

Red rice has many important consequences on human health not only in terms of food but also has a variety of unique characteristics such as drought, flood, insect illness, salinity, and alkalinity tolerance. Red rice production is decreasing due to the development of high-value commercial crops such as apples, vegetables, and other high-yielding rice varieties and hybrids. Currently, however, with increased awareness of food and health, demand for nutraceutical-rich foods is increasing. Keeping in view, the increased demand and shrinking area under the red rice, a concrete policy, and marketing approach is urgently required to motivate farmers and boost the cultivation of rice in its traditional areas of cultivation.

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