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UNVEILING THE SCARLET JEWEL: A COMPREHENSIVE REVIEW ON RED RICE

Vishwaradhya M. Biradar[1*], Sharanagouda Hiregoudar[1], Udaykumar Nidoni[1], Ramappa, K.T.[1], Swapna[2] and Santosh Pawar[3]

[1]Department of Processing and Food Engineering, CAE, Raichur-584101, India
[2]Department of Agricultural Microbiology, AICRP on PHT, CAE, Raichur-584101, India
[3]Department of Computer Science, CAE, Raichur-584101, India
*Corresponding author E-mail: vishwaradhyambiradar@gmail.com
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ABSTRACT

Rice (*Oryza sativa* L.) is a crucial staple food for nearly half of the global population, serving as a primary source of carbohydrates and proteins. It holds deep cultural significance across Asia, playing a vital role in social rites, rituals and festivals. The colour of rice is determined by genetic factors governing aleurone and endosperm colour, as well as starch composition. Broadly, rice comes in two colour varieties: white rice and pigmented rice. Among pigmented rice, the reddish-grain variety, known as red rice, stands out. Red rice owes its vibrant hue to phenolic compounds, particularly anthocyanin, which also act as natural pigments. The bran layer of red rice varies in colour from light to deep red and is rich in polyphenols, anthocyanin and possesses notable antioxidant properties. One remarkable aspect of red rice is its nutritional value. American scientists have even noted elevated iron content in specific Chinese red rice varieties, such as 'Bloody Sticky' and 'Dragon Eyeball.' This characteristic makes red rice a valuable ingredient for the production of gluten-free products and can contribute to addressing nutritional deficiencies. In summary, rice, often referred to as the “grain of life” is not only a staple food ingrained in Asian culture but also possesses medicinal qualities and nutritional advantages. The unique properties of red rice, with its rich anthocyanin content and elevated zinc and iron levels, highlight its potential as a valuable resource in promoting both dietary diversity and health, particularly in the context of gluten-free product development.

***Keywords*:** Anthocyanins, phenolic compounds, rice, red rice .

Introduction

Origin

The history of coloured rice is intertwined with the very origins of rice cultivation. In a Japanese myth, it is said that the rice plant initially bear no grains and it was the benevolent Goddess Kuan Yin who, through a mystical act, bestowed white grains upon the plant by sprinkling her milk. However, in the process of extracting these grains, some were inadvertently imbued with a red hue due to excessive squeezing (Sharma, 1991). Conversely, Balinese mythology tells a tale of the God shiva, who dispatched a bird carrying seeds of four distinct rice colours- yellow, black, red and white. Along its journey, the bird consumed the yellow seed, leaving only three varieties behind. Thus, the Balinese people predominantly rely on these three types of rice (red, white and black) as their primary source of sustenance (Ismani, 1985).

Historical background

Ayurveda, the science of human health, supplemented the fourth Veda, the Atharvaveda (2000 BC). Two treatises (samhitas), one by Charaka (700 BC) (Vidyalankar, 1994) and the other by Susruta (600-400 BC) (Krishnamurthy, 1991) are available today. Both these mention rice varieties in the context of their effects on human health.

Charaka writes that Raktashali (red), Mahashali (large and fragrant), Kalama (thick stem), Shakunarhita (curved), Turnaka (quick maturity), Deerghashuka

(long awned), Panduka (yellowish), Langula (tall), Sugandhika (fragrant), Lohawal (red), Shariva (pointed), Pramodaka (fragrant), Patanga (resembling grasshopper/locust), and Tapaniya (golden or maturing in hot weather) are all excellent shali (rice maturing in winter) rice. They have the properties like: refrigerant, tasty, causing slight flatulence, somewhat sticky, nourishing, semen augmenting and diuretic. Raktashali (red) was claimed to be the best. It quenched thirst and corrected humoral (three body humors: Vata, kafa, and pitta) imbalance. The next best was Mahashali and Kalama; the rest were rated lower.

Shavak (barley-like), Hayana (golden), Panshu (dusty), Vapya (oblong), and Naishadaka (from Nishadha country, *i.e*., modern Kumaon hills) were also considered shali rice having similar but inferior properties compared to above mentioned red rice.

The Jatakas (stories of the former births of Lord Buddha -300 BC) contain references to (i) hill rice, (ii) tanks for irrigation, (iii) red husked rice (Rattasalivam), (iv) word, tandula, meaning dehusked rice, (v) scented rice, (vi) liquor from rice and (vii) medical properties (Kumar, 1988).

Since time immemorial, crimson rice have held a particular place in India. Susruta (400 BC), Charaka (700 BC) and Vagbhata (700 AD) refer to the medicinal value of shali, vrihi and shastika rice in their respective treatises, and list the rice according to their relative medicinal value, with the most useful type at the top of the list. Charaka, the author of the Charaka Samhita, and other later sources regard rakta shali or lohit shali rice (with red husk and grain) to be the greatest; this variety is thought to be the most effective in balancing the three disordered doshas (Kumar, 1988; Krishnamurthy, 1991).

The Buddhist text Milinda Panha mentions red rice, which dates back to the reign of the Greek monarch Manadros (Milinda in Sanskrit), who ruled the territory of present-day North-West India in the 1st century BC. It specifies two types of red rice, one deemed healthy and the other (Parumbhaska) not (Kumar, 1988). The Jatakas (stories of the former births of Lord Buddha-300 BC) contain references to (i) hill rice, (ii) tanks for irrigation, (iii) red husked rice (Rattasalivam), (iv) word, tandula, meaning dehusked rice, (v) scented rice, (vi) liquor from rice, and (vii) medical properties (Kumar, 1988).

Kashyapa (800 AD) describes several shali rice and the significance of collecting and conserving seeds in Kashyapiyakrishisukti, one of the early Indian agricultural treatises, and especially cites red rice of shali, kalama and sambaka varieties (Raychaudhury, 1964; Ayachit, 2002).

Since the pre-Nara era (710 AD), red rice of the japonica kind has been farmed in Japan. Later, large grained red indica type rice was brought from China during the 11th and 14th centuries, contributing significantly to the expansion of the rice acreage. Taitoumai, a high-yielding, early-ripening, drought and insect-resistant cultivar, expanded widely (Itani and Ogawa, 2004). White rice types were in high demand throughout the 18th century (1890) and red rice were subjected to eradication programmes to protect white rice from contamination. Red rice was nearly extinct in cultivation by 1930. They remained limited to a few regions, and were revered in Shinto temples (Hoshikawa *et al*., 1993).

What is red rice?

Red rice, distinguished by their distinctive red bran layer, not only stand out for their rich colour but also for their nutritional benefits. The presence of polyphenols and anthocyanin in the bran layer not only contributes to their red hue but also imparts antioxidant properties to these grains. This makes red rice a valuable addition to a balanced diet, as antioxidants play a crucial role in combating oxidative stress and reducing the risk of chronic diseases. Moreover, the inner, white portion of red and white rice is essentially identical, offering a familiar taste and texture while packing a more substantial nutritional punch. It's worth noting that red rice isn't just a visual delight; they offer a nutrient boost that can be particularly beneficial in addressing deficiencies of essential minerals like zinc and iron. With iron and zinc content two to three times higher than that of white rice, red rice is a promising source of these vital nutrients, potentially aiding in the fight against anaemia and supporting overall health. American scientists have even observed similar high iron content in Chinese red rice varieties such as 'Bloody Sticky' and 'Dragon Eyeball,' further highlighting the potential global significance of these unique grains (Rood, 2000).

Types of red rice

Red rice occurs as wild, weedy and cultivated types, and the red kernels are covered with dark or light-coloured husk.

Wild red rice

In India, wild rice species include *Oryza granulata*, *Oryza officinalis*, *Oryza rufipogon*, and *Oryza nivara*. Red grains are found in *Oryza rufipogon* and *O. nivara*, which are both utilised as food and

medicine. *Nivara* comes from the Sanskrit word Niv., which meaning fattening or feeding.

Nivara rice has the unusual medicinal quality of redressing any imbalances in the tridosha, according to ancient Indian Ayurvedic scriptures. This rice is frequently utilised in Ayurvedic medicine because of its unique ability to enrich the body's elements, exclude poisonous metabolites, strengthen, rejuvenate and energise the body, control blood pressure, and prevent skin problems. Although *Oryza nivara* has been utilised as a donor for a variety of diseases, it is the unique source of resistance to grassy stunt virus (Khush, 1977).

Cultivated red rice

Red rice was common in India's South, East and mountainous regions of the North-East and West. Red rice cultivars demonstrated strong endurance to adverse situations such as infertile soils, deep water and mountainous terrain. A few red variants have been documented from Haryana, Punjab, Rajasthan, Western Uttar Pradesh and Gujarat. Several red-grained cultivars were grown in Kerala, Tamil Nadu, Karnataka, Bihar, Orissa, Bengal, Madhya Pradesh and the North-Eastern states in places with adverse conditions such as deep water, dryness, sandy soils, salinity and freezing temperatures. Some well-known red types include Matta from Kerala, Patni from Maharashtra and Jatu and Matali from Himachal Pradesh's Kulu valley.

Weedy rice

Weedy rice typically drops seeds; they are hardy, more prolific in nature, and have genes for tolerance to a variety of harsh environments. Scientists believe this rice arose as a result of hybridization between wild and cultivated rice. In Korea, short-grained red rice of the japonica kind is occasionally mated with long-grained indica varieties to develop hybrids that can withstand the frigid winters (Oka, 1988). Weedy rice is mostly consumed by the impoverished in India. The little red weedy rice, dania/rana, is picked in the Haryana district of Sonipat for the preparation of kheer, a rice-based sweet confection.

Uses of red rice in India

In some parts of India, red rice is considered highly nutritive and medicinal. The rice is eaten as whole grain and red gunja is preferred for making bread and chapati (Rani and Krishnaiah, 2001).

In South India Glutinous red rice is used for making puttu and in Himachal Pradesh, Jatu red rice is prized for its aroma and taste. Matali and Lal dhan of red rice are used for curing blood pressure and fever.

Kafalya, a Himachal Pradesh and Uttar Pradesh hill herb, is used to treat leucorrhea and abortion problems. Kari kagga and Atikaya are used for cooling and tonic purposes in Karnataka, whilst Neelam samba is utilised for breastfeeding mothers in Tamil Nadu. (Arumugasamy *et al*., 2001).

Tradition and heritage of rice

Rice was used for a variety of religious purposes during the Puranic period. The use of red, black, and wild nivara rice is mentioned in the Agni Purana (900 AD) and the Vishnu Purana (200 AD). The Garuda Purana describes the medical applications of red shali as a destroyer of the three doshas; it delays thirst and stops perspiration. Mahashali is thought to be extremely restorative (Kumar, 1988; Sensarma, 1989). Different types of rice produced world-wide is presented in Table1.

The red rice has been used widely for its nutraceutical values rather than as food. However, in the Asian rice growing regions, it has been used as food in region specific diverse dishes and preparations since ancient times. Table 2 and 3, provides a comprehensive comparison of the proximate composition, physical properties, mineral and antioxidant properties of white rice and red rice.

Traditional uses of red rice in India

The prime use of red rice is staple food. It is consumed as whole grain, bread or chapati (Rani and Krishnaiah, 2001). It was the main kharif season crop of low and irrigated areas of mid and high hills. Red rice is commonly used as Bhaat (cooked in water), Kheer (cooked in milk), Meetha Bhaat (cooked in water with added jiggery or sugar), Chilrhu or Lushke (a preparation like dosa, served with jiggery and ghee). Chilrhu or Lushke has special significance as it is prepared on the festivals like Makar sakranti (Lohri) and Beeshu (Baisakhi) in Shimla, Solan and Sirmaur districts.

Being a traditional crop of Himachal Pradesh red rice is deeply knitted with traditional rituals and used in various folk dishes and snacks. The key uses include, Phooli Moorhi (a traditional snacks made by boiling of husked red rice followed by dehusking and then roasting in sand or oil), Sookhi Moorhi (roasted dehusked red rice mixed with marijuana seeds), Chewrhi or 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, 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).

Moorhi has special significance in rituals of hill folks as it is gifted to married daughters and sisters on festivals. The religious uses of red rice include as tilak and in hawan sama

In Maharashtra, three festivals/rituals called Hal shashti, Rishi panchami, and Shirawundevasdasee are celebrated during the months of August and September, during which people are required to abstain from food grown with the help of animals; instead, they are advised to take wild rice (*O. nivara*) and other self-grown plants (Watt, 1896; Ahuja *et al*., 2001; Ghate and Sane, 2004). In Himachal Pradesh, the growing of Jatu rice is a religious ceremony. Seed soaking and ground preparation for transplanting are accompanied by worship of the family god Ishtadeo.

Table 1 : Types of rice produced worldwide

Type	Where grown	Percent of global trade
Indica	Tropical and sub-tropical regions such as southeast Asia and south Asia	75 %
Aromatic (Jasmine and basmati)	Thailand, Vietnam, Cambodia, India, Pakistan	16-18 %
Japonica	Japan, Korea, some parts of China, California, Europe and Australia	5-6 %
Glutinous and speciality rice	South east Asia	2-3 %

(**Source:** USDA, Economic Research Service Calculations)

Table 2 : Proximate composition and physical properties of white rice and red rice

Nutritional parameters	White rice	Red rice
Moisture Content (g/100 gram)z	12.75±0.15	12.7±0.13
Crude Fat Content (g/100 gram)	0.62±0.015	1.81±0.011
Crude Fibre Content (g/100 gram)	0.23±0.02	2.71±0.1
Crude Protein Content (g/100 gram)	7.6±0.23	10.49±0.43
Total Ash Content (g/100 gram)	0.46±0.04	1.53±0.01
Carbohydrate Content (g/100 gram)	78.34±1.5	70.19±1.0
Energy Content (kcal/100 gram)	349.34±2.5	341±1.2
Total phenolic content (mg GAE/100g of phenol)	24.26±1.05	143.38 ±1.5
DPPH scavenging activity (%)	20%	25%
Thousand kernel weight (g)	14.2±0.51	18.3±0.83
Seed weight (g)	1.42±0.02	1.827±0.02
Seed volume (mL)	1.16±0.05	1.1±0.05
Seed density (g/mL)	1.22±0.072	1.59±0.083
Hydration capacity (g/100 seeds)	0.179±0.03	0.347±0.02
Hydration index	0.125±0.02	0.19±0.009
Swelling capacity (mL/100seeds)	0.85±0.35	1.6±0.1
Swelling index	0.72±0.34	1.41±0.11
Length of grain(cm)	0.7±0.1	0.56±0.057
Bulk density of 1g of sample(g/L)	0.703± 0.005	0.82±0.017
Kernel elongation	1.28 cm± 0.127	1.32cm± 0.096
Gelatinization Temp (Alkali spread value)	1-5scale point	High (1-2 scale point)
Cooking quality	30- 40 min	more than 60 min

(**Source:** Raghuvanshi *et al*., 2017)

Table 3 : Mineral and antioxidant properties of white rice and red rice

Minerals and Antioxidant properties	White rice	Red rice
Calcium Content (mg/100g)	7.94±0.17	8.71±0.65
Iron Content(mg/100g)	7.65±0.22	13.45±0.60
Magnesium Content (mg/100g)	46.45±0.649	192.27±5.98
Zinc content(mg/100g)	1.49±0.039	1.91±0.036
Total flavonoid content (mg R.E./100 g of flavonoid)	166.23±0.25	120.0 ±0.38

(Source: Raghuvanshi *et al*., 2017)

Special features of red rice

Red rice has several unique properties aside from their nutritional and therapeutic benefits. Red and black-husked rice are shown to be more resistant to storage and insect problems than brown-husked rice. In Japan, it has been stated that red rice grains held since 1905 have remained intact and have retained their original status, as opposed to white rice grains, which have been severely damaged. The Maharashtra Patni rice and Himachal Pradesh Jatu rice are widely recognised for their toughness and resistance (Kitano *et al*., 1993).

Red rice types are commonly cultivated in a variety of agro-climatic settings, in addition to their storage capacity. Agronomically, from a cultivation standpoint, such rice is resistant to drought, flood, submergence, alkalinity, salt and pests and diseases (Chaudhary and Tran, 2001).

Red rice cultivation boost in Karnataka

The Mangalore Taluk of coastal Karnataka (Dakshina Kannada and Udupi) has 300 ha of paddy land inundating with the flood for long duration creating unfavourable situation for paddy cultivation and resulting in low production. Hence, the suitable paddy variety for low lying flood situation of the region is the need of the hour. To solve the problem, the Zonal Agricultural and Horticultural Research Station (ZAHRS), Brahmavar, Udupi District, Karnataka State released the flood-resistant Red Rice variety - Sahyadri Panchmukhi (under ICAR-All India Coordinated Research Project on Rice Project) during 2019.

The variety has high yielding potential with cultivation period of 130 to 135 days, can withstand the flood for 8 to 12 days with tolerance to blast disease, gall midge insect pest, biotic and abiotic stress. It also has high consumer preference due to better taste and aroma.

In multi-location trials organized by the ZAHRS, Brahmavar, the variety recorded 14% increase in yield and the trials organized by Karnataka State Agricultural Department recorded 26% increase in the yield compared to MO_4 paddy variety. *(**Source**: Krishi Vigyan Kendra, Dakshina Kannada, Kankanady, Mangalore, Karnataka)*

Efforts on to secure GI tag for 'Royal rice'

Rajamudi, a traditional red rice variety of old Mysore region, which was patronised by the "Royals" (and hence the nomenclature), will now join the league of Basmati and get a Geographical Indication (GI) tag in recognition for its unique qualities. The best quality of Rajamudi is cultivated in Mysuru-Hassan-Mandya belt.

This is the first case of an agricultural crop from the State being promoted for GI status, though fruits such as Kodagu orange or Nanjangud rasabale have been accorded GI tags for their distinctive nature. There are various strains within Rajamudi which have to be identified and classified and hence farmers, experts from the Department of Agricultural Science, Bengaluru, Agricultural Price Commission and paddy researchers are participated in the work shop, which is the first step in the long journey to procure the GI tag. (**Source:** https://www.thehindu.com/news/national/ karnataka /efforts-on-to-secure-gi-tag-for-royal-rice/ article 26197329.ece)

Registered GI tags of different varieties of red rice in India

Navara rice

Navara is also known as "Sastika rice." The word "Sashti" in Sanskrit means sixty, which is the maturing period of Sastika rice, *i.e*., sixty days. It is known in Dravidian languages as Njavara, and it is considered a medicinal miracle due to its unique therapeutic capabilities. Njavara rice from Kerala is an unpolished type that is widely utilized in many Ayurvedic therapies. It is described in Ayurvedic texts as being sweet in flavour, cool in potency, easily digestible, stimulating and offering stability. Farmers frequently compare Navara to gold because it is so valuable. It was given the GI tag in 2007 and indication details are represented in Table 4.

Table 4 : Geographical Indication details for Navara rice

Application Number	17
Geographical Indications	Navara Rice
Status	Registered
Applicant Name	Navara Rice Farmers Society
Applicant Address	Karukamanikalam, Chittur College, Palakkad ,678104, Palakkad, Kerala, INDIA, 678 104
Date of Filing	25/11/2004
Class	30
Goods	Agriculture
Geographical Area	Kerala
Priority Country	India
Journal Number	17
Availability Date	20/06/2007
Certificate Number	40
Certificate Date	23/11/2007
Registration Valid Up to	24/11/2024
GI Logo	**Navara rice** 

(**Source:** https://ipindia.gov.in/the-registration-process-gi.htm)

Palakkadan matta rice

It is also known as Rose Matta rice. Matta rice is an indigenous rice variety grown in Kerala's Palakkad area. It is renowned for its coarseness as well as its health advantages. Its popular in Kerala and coastal Karnataka in India, as well as Sri Lanka, where it is used for Idli, Appams and plain rice regularly. Red Matta has a strong and earthy flavour that pairs well with lamb, cattle, and game meats. The presence of enhanced nutrition and fibre content is ensured by bold grains with crimson per carp. This rice that has been parboiled retains much more nutrients. It was awarded the GI tag in 2007 and indication details are represented in Table 5.

Table 5 : Geographical Indication details for palakkadan matta rice

Application Number	36
Geographical Indications	Palakkadan Matta Rice
Status	Registered
Applicant Name	Palakkadan Matta Farmers Producer Company Limited
Applicant Address	Palakkadan Matta Farmers Producer Company Limited, Karukamanikalam, Chittur College P.O., Palakkad - 678104
Date of Filing	18/04/2005
Class	30
Goods	Agriculture
Geographical Area	Kerala
Priority Country	India
Journal Number	17
Availability Date	20/06/2007

Certificate Number	41
Certificate Date	24/09/2007
Registration Valid Up to	17/04/2025
GI Logo	 Palakkadan Matta Rice

(Source: https://ipindia.gov.in/the-registration-process-gi.htm)

Pokkali rice

The Pokkali rice type is notable for its saltwater resilience and thrives in the rice terraces of Kerala's coastal districts of Alappuzha, Ernakulam, and Thrissur. This single-season paddy is grown in saltwater fields, followed by a fish-farming season. Pokkali's gene pools have been studied by several foreign research institutes, and a segment of DNA on one of its chromosomes has been discovered as necessary for salt tolerance. It can aid in the promotion of climate-resilient agriculture due to its ability to survive in adverse climatic conditions and provide high yields. Pokkali has therapeutic effects, and those on a reduced sugar diet will like its higher antioxidant level and low carbohydrate content and indication details are represented in table 6.

Table 6 : Geographical Indication details for pokkali rice

Application Number	81
Geographical Indications	Pokkali Rice
Status	Registered
Applicant Name	Kerala Agricultural University,
Applicant Address	(i) Kerala Agricultural University, K.A.U. P.O. Thrissur District, Kerala - 680 656 (ii) Pokkali Land Development Agency, N. Paravur, Ernakulam District, Kerala - 683 513.
Date of Filing	29/01/2007
Class	30
Goods	Agriculture
Geographical Area	Kerala
Priority Country	India
Journal Number	Supplementary 2
Availability Date	26/05/2008
Certificate Number	86
Certificate Date	09/09/2008
Registration Valid Up to	28/01/2027
GI Logo	 **Pokkali rice**

(Source: https://ipindia.gov.in/the-registration-process-gi.htm)

Value added products of red rice

1. Red rice flour cake

Red rice cakes are prepared using refined wheat flour, 15.9% sugar powder, 12.0% sunflower oil, 31.7% whole eggs, 15.9% milk and 0.7% baking powder. Using a domestic mixer, the dry ingredients (flour, sugar powder, and baking powder) were mixed for 5 minutes. Using the same mixing tool, the liquid whole egg, milk, and sunflower oil were each combined separately for 5 minutes. The liquid mixture was then added to the dry mixture, which was stirred for 10 minutes. The prepared batter was placed into moulds for baking that were 10 cm in diameter. The moulds were put in a domestic oven and maintained temperature up to 190°C and baked for 30 minutes to get our required product (Das *et al*., 2019).

2. Prebiotic gluten-free bread with red rice flour

The breads were made using 50% red rice flour and 50% cassava starch, yielding a total of 100% farinaceous foundation. Concentrations of water (45%), canola oil (7.5%), egg (1.0%), inulin (3.0%), dry yeast (3.0%), sugar (5.8%) and salt (1.15%), powdered milk (11.5%), anti mould (0.3%), flour improver (1.15%) and apple vinegar (3.8%). Rice samples were ground in a batch procedure (10 g) in a laboratory mill (Tecnal, Brazil) with blades set to 1 mm and a 10 Mesh sieve. After grinding, rice flour with a moisture content of 11 g 100 g^{-1} (wet basis) was packed in polyethylene airtight packaging and stored at room temperature of 25°C ±3.0°C. The ingredients were chosen depending on their starch and flour composition. The enzyme MTgase was added to the dry flour (red rice flour and cassava starch) for 2 minutes before the other ingredients were combined in an industrial mixer on medium speed for 10 minutes until dough was formed. They were weighed in bread tins (170 mm, 7 mm, 6 mm) after dough creation. Tins were placed in a chamber at 30°C and 80% relative humidity for 60, 80 and 100 minutes, respectively. After fermentation, the doughs were baked for 40 minutes at 190°C in an electric modular oven. After 60 minutes of cooling, the breads were removed from the moulds and weighed. They were then packed in polyethylene plastic bags and kept at 20°C until they were analysed. The volume and texture of the bread were measured 24 hours after baking. (Gusmao *et al*., 2019).

3. Development of GABA-Enriched yogurt from germinated red Rice (Munpu rice)

The main ingredients used for yogurt production are Milk (100 g), Skim milk powder (4 g), Sucrose (5 g), Starter culture (*S. thermophilus* and *L. bulgaricus*) (17 g). Milk is heated at 92°C for 5 min. Skim milk powder and sucrose were then added. The mixture was cooled down to 45°C, inoculated with the starter (*S. thermophilus* and *L. bulgaricus*) and fermented at room temperature. The fermentation is stopped when the pH of the yogurt reached 4.4-4.6 and the yogurt was stored at 4°C. Commercial yogurt was used as a control in this experiment. The yogurt with enhanced levels of GABA was produced by substituting milk in the formula with 30, 35 and 40% (w/w) germinated red rice paste (Anawachkul *et al*., 2009).

4. Flakes production from red rice and orange sweet potato

Red rice samples are washed, drained, and blended (Philips food processor). The OSP samples are chopped into small pieces. All samples were then freeze-dried, refined, and sieved (30 mesh). Finally, the powdered samples were placed in dark bottles and stored in a refrigerator (4℃) for further usage. Then RR is cooked with tap water (1:1.8; w/w) in a rice cooker (Panasonic) for approximately 45 min. After, the cooked rice was cooled for 10 min. Meanwhile, known g of OSP was boiled in an aluminium pot using tap water for 20 min, cooled for 10 min, and then mashed. Both samples were freeze-dried, refined, sieved (30 mesh), and stored (4℃) in a refrigerator. RR was placed in a cabinet dryer (60℃) for 1 h. The OSP was peeled, sliced and placed in a cabinet dryer (60℃) for 6 h. The dried OSP and RR were mashed using a blender. The flour was passed through an 80 mesh. Flakes were produced using six different proportions of OSP and RR, namely 100:0, 80:20, 60:40, 40:60, 20:80 and 0:100. Salt (3% w/w), sugar (30% w/w) and water (150% w/w) were mixed in as additional ingredients. The mixture was heated at 75℃ for 1 min and pressed at 170℃ for 1 min using a customized flake pressing tool. The pressed flakes were cut into 2 × 2 cm and dried using an oven at 125℃ for 5 min (Jati *et al*., 2022).

5. Fermenting fusion: Dairy drinks with red rice for vibrant living

Whole, pasteurised, homogenised milk, natural yoghurt containing Streptococcus thermophilus and Lactobacillus bulgaricus (Nestle, Brazil), sugar, and stabiliser (GFG of brand RICANATA, Brazil), and red rice were obtained at the Morrinhos (GO, Brazil) local market. Milk coagulation was used to get the whey (Furtado and Neto 1994). Microwave cooking was used to create the red rice extract. The rice was first ground in an industrial blender at a ratio of five parts water to one part rice (5:1 v/w), then heated in a

microwave (Eletrolux, MEF41, Brazil) at high power (1000 W) until the sample reached 85°C, as measured with a handheld thermometer. The cooked extract was blended for two minutes in a blender until it achieved a creamy consistency. The fermented dairy beverages were made with red rice extract as the base and milk replaced with whey (Boeno *et al*., 2020).

Health benefits of red rice

a. Red rice contains proanthocyanidins, which protect against type 2 diabetes. (Chen *et al.,* 2016) and also red rice contains proanthocyanins, which control the inflammatory response and protect against some malignancies. Similarly, epidemiological and in vivo animal and human research show that anthocyanins, which are plentiful in black rice, have anti-carcinogenic characteristics. (Pojer *et al*., 2013, Chen *et al.,* 2016).

b. The magnesium in red rice lowers the chance of heart attacks. Red rice extracts strong in anthocyanins have been shown to mitigate a number of cardiovascular disease risk factors caused by a high-fat diet (Dietary Reference Intakes, 1997).

c. Proanthocyanidins in red rice protect against cardiovascular disease by modulating inflammatory responses. According to these research, whole grains can reduce the odds of arterial plaque buildup, lowering the chances of acquiring heart disease (Chen *et al*., 2016).

d. Rice varieties such as brown, red and black rice are rich in fibre and have the ability to keep healthy bowel function and metabolic function. Anthocyanins present in red rice have properties that can help in weight management (Dietary Reference Intakes, 1997).

e. Rice protein is hypoallergenic; products from other plant sources such as soy and peanut and animal sources like eggs and milk are a good source of proteins, yet they may cause allergy when consumed. Rice protein provides a solution to this problem because it is hypoallergenic. Furthermore, the anthocyanins present in red rice also have the property to reduce allergy (Dietary Reference Intakes, 1997).

f. Red rice has been proven in pharmacological and clinical experiments to have antifungal, antibacterial, antiviral, anti-diarrheal, anti-inflammatory, antioxidant, anticancer, anti-thyroid and anti-hypercholesterolemic properties. It also increases protein production in addition to having radical scavenging properties (Oki *et al*., 2005).

g. Red rice extract is applied as a regenerative medicine and antiaging treatment for ageing skin, addressing both the intrinsic and hormonal causes of ageing, which are related to human hormones, diet and lifestyle (Limtrakul *et al*., 2016).

h. Compared to white rice, red rice is higher in calcium, iron, and zinc; as a result, it helps to lower weight, preserve bone health and enhance blood circulation (Rathna *et al*., 2019).

Conclusion and future persepectives

Although the scientific community is totally aware of its wonders as a source of minerals, protein and antioxidants, yet alone they cannot make a significant mark without an immense market demand. Since its evident that red rice is having very low glycaemic index, low fat, high iron and zinc content. So, this can be a healthier alternative to white or polished rice and can reduce lifestyle-related health issues and diseases such as diabetes, cancer and heart problems. Looking onto its health properties, it will be desirable to have processed food items such as puffed and flaked rice, coloured noodles and snack items prepared from red rice adding to its popularization and commercialization as an important food grain. There has been lack of studies on red rice and its processing techniques, so this creates ample scope in creating new ways to explore health benefits with good palatability. The red rice must evolve onto its journey as a gift of nature rather than ending as weedy and wild rice.

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