

**A SCIENTIFIC REVIEW ON INDIGENOUS BLACK RICE (*KALABATI*) OF WESTERN  
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**ABSTRACT**

Nearly half of the world's population eats rice as a staple diet. Encouraging people to incorporate rice into their daily meals requires an understanding of its nutritional worth and health benefits. The anthocyanin pigments (cyanidin-3-glucoside and peonidin-3-glucoside) found in the bran give black rice its name and make it an excellent source of antioxidants among all varieties of rice available worldwide. Constipation, carcinogenesis, tumours, coronary heart disease, atherosclerosis, inflammations, nephrological disorders, type 2 diabetes, anaemia, hyperglycemia, hypertension, obesity, and other conditions are all potentially improved by consumption of black rice. Thus, our study's goal is to provide a brief understanding of black rice's beneficial effects on human health. *Kalabati* (*Oryza sativa* L.), an indigenous black rice variety from western Odisha, India, represents a unique genetic resource with exceptional nutritional and therapeutic properties. Black rice (*Kalabati*) is rich in anthocyanins, essential amino acids, and antioxidants, making it a promising functional food for combating malnutrition and preventing chronic diseases. However, current research on *Kalabati* remains fragmented, with limited biochemical characterisation, insufficient clinical validation of its health benefits, and inadequate exploration of its agronomic potential and value-added applications. Moreover, declining cultivation practices and a lack of awareness among farmers place this variety on the verge of extinction. Black rice (*Kalabati*) is gluten-free and rich in antioxidants, this paper focusses on biochemical and therapeutic potential, highlights its potential, and suggests strategies for the sustainable conservation and utilisation of this valuable genetic resource.

**KEYWORDS:** Black rice, *Kalabati*, Anthocyanins, Antioxidant.**1. INTRODUCTION**

Rice (*Oryza sativa* L.) is the primary staple food for approximately half of the world's population, with over 90% of its production concentrated in Asian nations (Tian, et al., 2024). The diversity of rice varieties encompasses numerous types based on grain characteristics, processing methods and regional adaptations. Common rice varieties include white rice (polished), brown rice (unpolished), and various specialty types distinguished by grain size, aroma, and nutritional composition (Singh et al., 2018). Beyond conventional varieties, pigmented rice represents a distinct category characterised by natural colouration in

the pericarp, aleurone layer, or endosperm. These pigmented varieties, including red, purple, and black rice, have attracted significant attention for their superior nutritional profiles and bioactive compound content (Zhao et al., 2025). Pigmented rice varieties contain elevated levels of phenolic compounds, flavonoids, and anthocyanins, which contribute to their distinctive colours and enhanced functional properties (Zhang et al., 2010).

Black rice is primarily cultivated in Asia, with China accounting for the majority of global production, estimated at approximately 62% (Chen & Wu, 2017).

Other major producers include India, Indonesia, Thailand, and Sri Lanka, where various traditional *Oryza sativa* cultivars are grown (Sreeja *et al.*, 2016). In Japan, black rice varieties such as *Oryza sativa* L. japonica are cultivated for culinary and health purposes (Maclean *et al.*, 2013). Bangladesh and Vietnam also grow diverse black rice cultivars, contributing to regional production (Sreeja *et al.*, 2016). In recent years, the United States, especially in Southern states, has introduced black rice cultivation, although production remains significantly lower than that of the other Asian countries (Chen & Wu, 2017). In India, black rice cultivation is predominantly concentrated in the northeastern states, including Manipur, Meghalaya, Assam, and Mizoram. In Manipur, four major landraces are cultivated, such as Chakhao Amubi, Chakhao Angouba, Chakhao Poireiton, and Chakhao Pungdol Ambui, with Chakhao Poireiton being the most widely grown (43% of black rice farmers) due to its superior productivity and flavour characteristics. These landraces exhibit heights ranging from 136-166 cm, with Chakhao Amubi being the tallest at 165.5 cm. In Meghalaya, *Oryza sativa* L. (Chakhao poireiton) is cultivated, while Tamil Nadu grows 'Karuppu kavuni' and 'Kavuni' rice varieties. Eastern India, particularly Odisha, is renowned for its rice landrace diversity, with approximately 10,000 documented landraces, a significant fraction of India's estimated 50,000 rice landraces (Mishra *et al.*, 2019). The tribal-dominated districts of Koraput, Rayagada, Nawarangpur, and Malkangiri are recognised as agrobiodiversity hotspots, where local communities continue in situ conservation of traditional landraces (Mishra *et al.*, 2017). Black rice varieties, such as Kalabati, are traditionally grown by tribal communities in these regions, but cultivation remains limited to small pockets and is practised mainly for local consumption rather than commercial purposes (Santhosh, 2021). The restricted spread is attributed to low public awareness, continuation of traditional agricultural practices, a lack of market linkages, and competition from higher-yielding white rice varieties (Dambale *et al.*, 2023). Significant genetic erosion has occurred due to the introduction of high-yielding white rice varieties and intensive modern agriculture, placing many traditional black rice landraces at risk of extinction (Panda *et al.*, 2021). These trends underline the importance of conservation strategies that preserve biodiversity and provide genetic resources for crop improvement, especially regarding nutritional quality (Sharma *et al.*, 2025). Globally, black rice accounts for less than 1% of rice production, though demand is increasing in developed markets due to recognised health benefits (Goswami, 2023). Fig.1 shows the Black rice production in worldwide. In northeastern India, traditional black rice yields typically range from 2–3 tons per hectare, compared to 4–6 tons per hectare for modern white rice varieties; however, with appropriate agronomic management and varietal selection, black rice yields can reach 4.8 tons per hectare while retaining superior nutritional characteristics (Santhosh, 2021).

Black rice, often referred to as "forbidden rice" or "emperor's rice," represents the most nutritionally dense category among pigmented varieties. The characteristic dark colouration results from high anthocyanin concentrations, particularly cyanidin-3-glucoside (C3G), which imparts potent antioxidant, anti-inflammatory, and anti-carcinogenic properties (Kong & Lee, 2010). Unlike white rice, which loses most nutrients during milling, black rice retains its nutrient-rich bran layer, providing superior levels of protein, fibre, vitamins, and minerals (Chaudhari *et al.*, 2018). There are several different types of black rice are cultivated worldwide, grown around the world, each with its own specific characteristics and regional importance. Black Japonica rice, a hybrid of black short grain and mahogany medium grain rice, is grown primarily in North America and has a mildly earthy, slightly sweet aroma (Kushwaha, 2016). Black glutinous rice, also known as sticky black rice, is widely grown in Southeast Asia, particularly in Thailand and Indonesia, and is characterised by its short grain, sticky texture and sweet, nutty flavour (Sompong *et al.*, 2011; Pengkumsri *et al.*, 2015). Italian black rice is a long-grain variety combining the genetics of Chinese black rice with Italian rice cultivars and offers a rich, buttery flavour which is ideal for risottos (Pereira-Caro *et al.*, 2013). Thai black jasmine rice, a medium-sized grain variety, combines the aromatic characteristics of jasmine rice with the nutritional benefits of black rice, providing a subtle, delicate floral aroma and a nutty taste compared to in comparison with traditional jasmine varieties (Tansawat *et al.*, 2023).

Among these varieties, Kalabati stands out due to its excellent nutritional composition and unique bioactive profile. Kalabati is a speciality black rice variety indigenous to western Odisha, India, particularly the tribal-dominated regions of southern Odisha. This traditional landrace has been cultivated for generations by tribal communities, including the Bhattada, Gond, Paroja, Bhumia, Gadaba, and Kandha peoples. Comparative nutritional analysis uncovered that Kalabati contains significantly higher protein content (8.5-9.4 g/100g) compared to white rice (6.3-7.9 g/100g), brown rice (7.54 g/100g), and red rice (9.1 g/100g). The variety also demonstrates superior iron content (1.42-1.49 mg/100 g in selected black rice landraces (Kalamalli and Kandulakathi) compared to popular Indian rice varieties such as Swarna (0.85-1.45 mg/100 g) and IR64 (1.18-1.2 mg/100 g). Kalabati also exhibits higher dietary fibre content (4.9 g/100g) than white rice (0.6-0.8 g/100g), brown rice (3.6 g/100g), and red rice (4.4 g/100g). Recent studies at Sambalpur University, located in the Sambalpur district of western Odisha, India (geographic coordinates: approximately 21.4813° N, 83.8835° E), have demonstrated the potential of this variety to address infant malnutrition through its exceptional nutritional profile (The Indian Express, 2025). The high anthocyanin content, especially cyanidin-3-glucoside (C3G), confers a distinctive black colouration and provides potent anti-inflammatory and antioxidant

properties. Black rice varieties typically contain anthocyanin concentrations ranging from 27.2 to 5045.6 µg/g, with cyanidin-3-glucoside comprising 88-100% of the total anthocyanin content. Beyond its nutritional value, Kalabati holds cultural, environmental, and economic significance for the tribal communities of western Odisha. This indigenous crop, which had nearly disappeared owing to the adoption of high-yielding varieties and modern agricultural practices, has been revitalised through the efforts of progressive farmers and conservation initiatives in the region (Panda *et al.*, 2024). However, the variety's long-term survival remains threatened by limited cultivation area and declining farmer interest, necessitating comprehensive documentation and conservation strategies.

The nutritional superiority of Kalabati and related black rice landraces from southern Odisha is evident in comparative analyses. Protein content in these varieties (6.0–6.9 g/100g) significantly exceeds that of popular Indian rice varieties. Select landraces such as Kalamalli demonstrate exceptional mineral content, with zinc (0.49 mg/100g), iron (1.49 mg/100g), potassium (108.33 mg/100g), magnesium (78.33 mg/100g), and phosphorus (125.00 mg/100g) levels notably higher than conventional varieties. The variety Muktabali contains elevated calcium (3.88 mg/100g), while Baunsidubraj exhibits higher niacin content (4.9 mg/100g). Kalabati and related landraces demonstrate lower phytic acid content compared to many reported rice varieties, enhancing mineral bioavailability for human consumption (Panda *et al.*, 2023). The genetic and phenotypic diversity among Kalabati and associated black rice landraces presents significant opportunities for crop improvement programs. Principal component analysis of ten rice landraces from southern Odisha, including multiple Kalabati-related varieties, revealed that approximately 88% of total variation is explained by six principal components, with substantial genetic differentiation observed for traits including alkali spreading value, grain hydration capacity, moisture content, and vitamin B2 content. This genetic variability provides valuable germplasm for breeding programs aimed at developing varieties with enhanced nutritional profiles, improved agronomic characteristics, and climate resilience (Panda *et al.*, 2023). Despite these promising attributes, Kalabati faces significant conservation challenges. The cultivated area has declined dramatically due to the introduction of high-yielding white rice varieties, changing dietary preferences, lack of market infrastructure, and insufficient awareness of nutritional benefits among both farmers and consumers. The variety is maintained primarily through traditional conservation methods by tribal farming communities, with limited institutional support for germplasm conservation or varietal improvement. This precarious situation necessitates urgent intervention through comprehensive documentation, ex-situ and in-situ conservation strategies, participatory breeding programs, and market

development initiatives to ensure the long-term survival of this valuable genetic resource (Mishra *et al.*, 2017).

## 2. BOTANICAL CHARACTERISTICS AND CULTIVATION PRACTICES

### 2.1 Morphological Features

Kalabati is an indigenous black rice landrace native to western and southern Odisha, India, and displays distinctive botanical traits that set it apart from conventional rice varieties. Plants typically attain heights ranging from 5 to 7 feet, with some cultivars reaching up to 6.5 feet, making Kalabati considerably taller than most modern rice cultivars (Chanu, 2015). The leaves feature a unique mixture of green and purple pigmentation, a phenomenon caused by active anthocyanin biosynthesis throughout the vegetative tissues (Fig 2). The grains are medium-sized, elongated, and possess a dark pericarp that intensifies in color to deep purple or violet upon cooking (Fig 3). Grain morphology is marked by lengths ranging from 5.60–6.38 mm and breadths of 2.38–2.56 mm, yielding a length-to-breadth ratio of 2.21–2.68. The typical 100-kernel weight falls within 2.3–2.9 g, and grain density averages 1.25–1.66 g/cm<sup>3</sup>. Notably, Kalabati exhibits a robust tillering capacity, producing around 20–35 tillers per plant under optimum conditions, which is a trait contributing to its potential for above-average biomass and grain yield when cultivated with sound management practices (Lee *et al.*, 2013).

### 2.2 Growth Duration and Phenology

Kalabati is classified as a long-duration rice landrace, completing its full growth cycle in approximately 150 days from sowing to harvest. This extended period is conducive to comprehensive nutrient accumulation and optimal bioactive compound development (Poonia & Pandey, 2022). The plant attains its maximum vegetative growth within the initial two to three months, during which intensive tillering and stem elongation occur. In practice, Kalabati is sometimes cultivated alongside white rice varieties, leveraging its anti-foraging leaf colouration for crop protection benefits.

### 2.3 Ecological Requirements and Cultivation Practices

Kalabati has specific ecological preferences, thriving in medium-type soils (locally termed “Mal”) that offer sufficient water availability throughout the growing season. The landrace is well adapted to the tropical and subtropical climate characteristic of western Odisha, favouring warm conditions and long growing seasons of three to four months (Mohapatra, 2022). For successful germination, optimal temperatures between 20–26°C and adequate moisture are essential. When provided with proper water management and organic matter incorporation, seedlings typically emerge in one to two weeks under controlled conditions (Chanu, 2015). Farmers in the region increasingly prefer chemical-free organic cultivation methods to conserve Kalabati's unique characteristics. These practices not only support

preservation but also enhance the variety's profile for the growing organic superfood market.

### 3. NUTRITIONAL COMPOSITION AND BIOACTIVE COMPOUNDS

#### 3.1 Physio-Chemical Properties

Kalabati and other black rice variants have better nutritional profiles than traditional white rice varieties because they are unpolished, which preserves the bran layer that contains vital elements including protein, dietary fiber, vitamins, and minerals. Due to the presence of dietary fiber and resistant starch in the bran layer, kalabati has a lower glycemic index (42–45) than white rice (70–89). The carbohydrate fraction is primarily composed of amylose (18–22%) and amylopectin, which slows down digestion and improves postprandial glucose response. Kalabati contains roughly 72–76% carbohydrates on a dry weight basis. With all 18 essential amino acids present, including high amounts of lysine (3.8–4.2 g/100g protein), leucine (8.2 g/100g protein), and glutamic acid, the protein content ranges from 8.5 to 10.8 g per 100g, which is significantly higher than white rice (6.8–7.3 g/100g). Its protein digestibility-corrected amino acid score (PDCAAS) is roughly 0.7–0.8. The bran and germ layers contain the majority of the lipid content, which ranges from 2.5 to 3.4 g per 100g. The fat profile is mainly made up of unsaturated fatty acids, such as oleic acid (38–42%), linoleic acid (34–38%), and palmitic acid (16–20%). Oryzanol (10–15 mg/100g) and tocopherols enhance cardiovascular health and its high dietary fiber content, which ranges from 4.2 to 5.8 g per 100g and is 3–4 times higher than polished white rice (0.6–1.0 g/100g). It is one of its most important nutritional benefits. It contains both soluble (1.2–1.8 g/100g) and insoluble fractions (3.0–4.0 g/100g), which improve bowel regularity, promote satiety, and modulate the absorption of cholesterol (Finocchiaro *et al.*, 2007). The conservation of the mineral-rich bran layer is reflected in the ash content, which ranges from 1.8 to 2.3% in black rice and 0.5–0.8% in white rice. White rice has less than 0.2 mg/100g of vitamin E because bran is removed during polishing, but kalabati has 2.4–3.8 mg/100g, mostly in the form of  $\gamma$ -tocotrienol and  $\alpha$ -tocopherol. The forbidden rice varieties also show a more nutritious profile than white rice, featuring higher levels of B vitamins such as thiamine, riboflavin, niacin, pyridoxine, and folate, which are essential for energy metabolism, nervous system function, and the formation of red blood cells (Sompong *et al.*, 2011). Its mineral composition is significantly elevated, especially in iron, phosphorus, magnesium, calcium, and potassium, enhancing bone health, oxygen delivery, and enzymatic function. It also encompasses vital trace minerals such as zinc, manganese, copper, and selenium that aid in immune protection, antioxidant functions, and tissue healing (Goufo & Trindade, 2014). The dark colour of Kalabati rice mainly results from anthocyanins—mainly composed of cyanidin and peonidin derivatives—which, together with proanthocyanidins, flavonoids, and

phenolic acids, boost its antioxidant capacity and provide health benefits including cardioprotective, antidiabetic, and anti-inflammatory effects (Kushwaha, 2016). Table 1 shows the biochemical and antioxidant properties of different varieties of rice with comparison with black rice.

Kalabati is presented as a functional food with potential applications in addressing micronutrient deficiencies and diet-related chronic diseases that are common in South Asian populations because it retains the bran and germ layers, which results in a 3–4 fold increase in fiber, a 2–3 fold increase in minerals (especially iron, magnesium, and zinc), and a 4–6 fold increase in antioxidant capacity when compared to polished white rice (Poonia & Pandey, 2022).

#### 3.2 Anthocyanin Content and Antioxidant Properties

Kalabati black rice's deep purple colouration and health-promoting potential are attributed to its high concentrations of anthocyanins, predominantly cyanidin-3-glucoside and peonidin-3-glucoside (Bae *et al.*, 2017; Chen *et al.*, 2012). Studies confirm that the total anthocyanin content in black rice varieties consistently surpasses 100 mg/100g, reaching up to 473.7 mg/100g in some cultivars, which correlates directly with enhanced antioxidant activity compared to white rice (Chen *et al.*, 2012; Xia *et al.*, 2006). These anthocyanins efficiently neutralize reactive oxygen species (ROS), suppress NF- $\kappa$ B pathway activation, and upregulate beneficial protective genes, thus contributing to anti-inflammatory, anti-ageing, and anti-atherogenic effects demonstrated in both cellular and animal models (Sivasinprasasn *et al.*, 2024; Kopec *et al.*, 2020; Xia *et al.*, 2006). Intervention studies reveal that chronic intake of anthocyanin-rich black rice extract improves glycemic and lipid profiles, stabilizes atherosclerotic plaques, and mitigates oxidative stress induced by amyloid  $\beta$  or metabolic syndrome related conditions (Laorodphun *et al.*, 2021; Kopec *et al.*, 2020; Sivasinprasasn *et al.*, 2024). Black rice also contains additional phenolics and flavonoids, such as protocatechuic acid, vanillic acid, and ferulic acid, which work synergistically to amplify its antioxidant potential (Chen *et al.*, 2012; Hosoda *et al.*, 2018; Thepthanee *et al.*, 2015). Processing and cooking can influence anthocyanin retention, but controlled methods (such as ethanol extraction or mild cooking) can preserve over 80% of bioactive content (Bae *et al.*, 2017).

Kalabati's aromatic profile is characterised by a rich spectrum of volatile compounds and a notably high concentration of 2-acetyl-1-pyrroline (2-AP) compared to typical white rice. These compounds, comprising aldehydes, ketones, alcohols, terpenoids, and nitrogen-based aromatics, collectively define its distinct sensory characteristics and contribute to its superior culinary appeal (Sukhonthara *et al.*, 2009; Kim *et al.*, 2024). The presence of 2-AP is particularly responsible for the signature aroma favoured in aromatic rice varieties and

noted in traditional black rice cultivars (Kim *et al.*, 2024; Sukhonthara *et al.*, 2009).

#### 4. HEALTH BENEFITS AND THERAPEUTIC PROPERTIES

##### 4.1 Cardiovascular Health Protection

The cardiovascular benefits of Kalabati primarily stem from its high anthocyanin content, which demonstrates significant cardioprotective effects. Regular consumption of black rice varieties has been associated with reduced cholesterol levels, decreased risk of atherosclerosis, and improved blood pressure regulation (Kong & Lee, 2010). The antioxidant properties of anthocyanins help prevent oxidative damage to cardiovascular tissues while promoting healthy circulation.

##### 4.2 Anti-inflammatory and Anti-cancer Properties

Kalabati exhibits potent anti-inflammatory properties attributed to the presence of C3G and other bioactive compounds. Research has demonstrated that anthocyanin biosynthesis significantly affects the nutritional value and anti-inflammatory effects of black rice (Poonia & Pandey, 2022). These compounds help suppress chronic inflammatory conditions and may reduce the risk of cancer development through multiple mechanisms, including DNA damage prevention and tumour metastasis inhibition. The anti-carcinogenic properties of Kalabati are particularly notable in breast cancer prevention, where anthocyanins demonstrate specific protective effects against cellular damage and malignant transformation (Chaudhari *et al.*, 2018).

##### 4.3 Diabetes Management and Glycaemic Control

The high fiber content and complex carbohydrate structure of Kalabati contribute to superior glycemic control compared to conventional rice varieties. The slower digestion rate and reduced glycemic index make it particularly suitable for individuals with diabetes or prediabetes (Zhang *et al.*, 2010). Studies have shown that black rice consumption provides viable options for consuming lower-digestibility starch-containing foods, supporting better postprandial glucose management.

#### 5. VALUE ADDITION OF BLACK RICE

The growing recognition of black rice as a functional ingredient has catalysed considerable interest in developing value-added food products across multiple sectors of the food industry (Kumar & Murali, 2020). The remarkable nutritional profile and bioactive compound content of black rice varieties present substantial opportunities for product diversity and market expansion, particularly in sectors that address health-conscious consumers seeking alternatives to conventional refined grain products (Rahim *et al.*, 2022). Value addition through strategic incorporation of black rice and its bioactive fractions into processed foods represents both an economically viable approach for farmers and a functional opportunity for food manufacturers to create nutritionally enhanced offerings (Loukrakpam *et al.*, 2025). The application of black rice

in value-added product development aligns with sustainable food system objectives by maximizing utilization of agricultural byproducts and enhancing nutritional quality of conventional staple foods (Loukrakpam *et al.*, 2025).

Among various domains of value addition, the applications of black rice extracts in cereal-based products, particularly in bakery applications, have emerged as one of the most extensively investigated (Pal *et al.*, 2019). The bakery sector, characterized by high global demand and established distribution networks, provides strategic opportunities for integrating functional ingredients through relatively straightforward formulation modifications (Pratiwi & Purwestri, 2017). Cakes formulated with black rice flour demonstrated substantially elevated levels of bioactive compounds, with progressive increases in phenolic content, anthocyanin concentration, and free radical scavenging capacity as substitution levels increase (Mau *et al.*, 2016). In another study, chiffon cake production by incremental substitution of wheat flour with black rice powder (from 10% to 100% w/w) showed that while total phenolic content and antioxidant properties increased progressively, optimal sensory acceptability was attained between 10 and 60% substitution levels, with higher concentrations yielding less favorable textural and organoleptic properties due to increased cake density and darker pigmentation (Mau *et al.*, 2016). Consumer preference evaluations have demonstrated that black rice-incorporated baked products are favorably accepted when formulation ratios are optimized, with acceptability declining when pigmentation intensity becomes excessive (Pal *et al.*, 2019). Incorporation of black rice bran at 5-25% levels in pasta formulations similarly demonstrated enhanced nutritional profiles, with statistically significant increases in protein, fiber, anthocyanin, and mineral content, though optimal acceptance was attained at 15% supplementation levels where palatability remained satisfactory (Sethi *et al.*, 2020). Black rice incorporation in bread products, particularly through fortification with 2-4% anthocyanin-rich black rice extract powder, has yielded functional breads with reduced *in vitro* digestibility rates, with 2% fortification decreasing the digestion rate by 14.1% while 4% fortification reduces it by 20.5%, thus offering a scope for application in blood glucose management and dietary interventions for diabetes (Sui *et al.*, 2016). Beyond traditional bakery applications, emerging research has demonstrated the utility of black rice extracts as functional ingredients in diverse food matrices (Kumar & Murali, 2020). Black rice bran flour substitutes (2-15% levels) in noodle products increase protein, fat, and mineral content, with the enrichment in anthocyanin being capable of offering advantages from a nutritional point of view comparable to classic whole grain alternatives (Kong *et al.*, 2012). Texture profile analysis showed that when the percentage of black rice bran extract increased in noodles, hardness increased while cohesiveness decreased (Kong *et al.*, 2012). Black

rice application in beverage formulation, as exemplified by the production of mead (honey-fermented alcoholic beverages), yielded products with elevated concentrations of phenolic compounds and enhanced antioxidant capacity, specifically 200-300 µg/mL GAE and 800-870 µM Trolox equivalent DPPH activity, while fermentation of unpolished black rice grains demonstrated superior bioactive retention compared to polished grain varieties (Koguchi *et al.*, 2009). Black rice anthocyanin extracts have also demonstrated potential as natural food colorants in yoghurt and other dairy products, with up to 0.6% anthocyanin incorporation rendering a purplish-pink color while maintaining a good color stability and an improved phytochemical content with maintenance of sensory acceptance (Nontasan *et al.*, 2012)

Black rice's anthocyanin components have been recognized as a significant means of dealing with postprandial glycemic and lipid dysregulation. The research also indicates that the inhibition of enzymes  $\alpha$ -glucosidase and  $\alpha$ -amylase results in lower glucose absorption rates (Thilavech *et al.*, 2025). These regulatory properties of black rice on metabolism have, therefore, led to a broader scientific study of its use in the formulation of functional foods specifically aimed at the management of carbohydrate metabolism disorders (Thilavech *et al.*, 2025). Judging the success of value addition interventions largely depends on the choice of processing methods, as various industrial operations such as drying, storage, extrusion, cooking, and conventional thermal processing can dramatically reduce the anthocyanin and phenolic content (Obadi *et al.*, 2023). To sustain the phytochemical benefits that constitute the basis for the commercial development of black rice value-added products, there needs to be a focus on the optimization of extraction and preservation technologies (Navale *et al.*, 2015). The use of new techniques like fermentation, sprouting, and targeted extraction methods has, in fact, been able to retain or raise the level of bioactive compounds as compared to the traditional ones (Rahim *et al.*, 2022). The concerted effort in R&D and the subsequent implementation of value-added black rice products in the market thus requires not only the careful consideration of formulation aspects but also the processing conditions so that the functional properties that result in health claims and product differentiation can be retained during the manufacturing and distributing stages (Sethi *et al.*, 2020). The great promise of utilizing black rice value addition to enhance the nutritional security of the consumers and, at the same time, increase the economic returns of the farming communities is, indeed, worthy of continued research focus on the optimization of product formulations and processing technologies (Kumar & Murali, 2020).

## 6. CONSERVATION STATUS AND CHALLENGES

### 6.1 Genetic Erosion and Extinction Risk

Kalabati is currently facing critical conservation challenges that threaten its survival as a genetic resource.

The variety is teetering on the edge of extinction, representing a significant loss to agricultural biodiversity in Odisha (Mohanty *et al.*, 2011). The decline in cultivation has resulted from multiple factors, including farmer preference for high-yielding modern varieties, limited market awareness, and a lack of technical knowledge regarding optimal cultivation practices. Of the 30 landraces of black rice available in India, Odisha possesses 6 black rice varieties (Kalabati, Kalajeera, Bhaludhan, Surubadi, Chakhao) in its indigenous seed germplasm of Bargarh district, highlighting both the region's genetic diversity and the urgent need for conservation efforts (Mohanty *et al.*, 2011).

### 6.2 Socioeconomic Factors

The limited cultivation of Kalabati reflects broader socioeconomic challenges affecting indigenous crop varieties. Farmers often prioritise immediate economic returns over long-term sustainability, leading to abandonment of traditional varieties in favour of commercially promoted high-yielding cultivars (Singh *et al.*, 2018). The lack of organised marketing channels and price premiums for speciality rice varieties further discourages farmers from maintaining indigenous varieties. Additionally, limited awareness regarding the nutritional and therapeutic benefits of Kalabati among both farmers and consumers contributes to its declining cultivation.

## 7. CONSERVATION STRATEGIES AND FUTURE PROSPECTS

### 7.1. In-situ Conservation

In-situ conservation refers to the preservation of crop varieties within their native habitats, allowing them to continue evolving in response to natural and human-influenced environmental pressures. This approach is essential for maintaining the dynamic relationship between crops and their ecosystems. In the case of Kalabati, an indigenous rice variety from western Odisha, in-situ conservation emphasises supporting local farmers who cultivate it within traditional agroecosystems. According to Bellon *et al.* (2004), such practices sustain on-farm genetic diversity and strengthen agroecological resilience. Farmer participatory conservation plays a key role in this process, engaging cultivators as active stewards through the provision of technical assistance, training, and financial incentives. Exemplary initiatives by conservationists such as Dr. Ashok Kumar Panigrahi and his wife Kusum of Balasore, demonstrate how local seed banks and the free distribution of native seeds can promote community-based conservation ([www.newindianexpress.com](http://www.newindianexpress.com)).

Another crucial component of in-situ conservation is the establishment of community seed banks, which serve as localised repositories where farmers can store, exchange, and select high-quality seeds to maintain genetic diversity across generations (Vernooy *et al.*, 2015). Additionally, documenting traditional knowledge related

to cultivation practices, selection criteria, and utilisation methods ensures the preservation of indigenous wisdom that underpins local agricultural systems. Habitat preservation also forms an integral part of in-situ strategies, ensuring that the ecological conditions favourable for traditional varieties like Kalabati continue to support their cultivation and evolution. By protecting natural landscapes and maintaining sustainable farming systems, in-situ conservation helps safeguard the genetic integrity and cultural heritage of indigenous crop varieties.

## 7.2. Ex-situ Conservation

Ex-situ conservation complements in-situ efforts by preserving genetic resources outside their natural habitat. This approach provides a safeguard against genetic erosion, allowing for the systematic characterization and utilization of diverse germplasm. For the Kalabati rice variety, ex-situ methods are particularly valuable in ensuring long-term genetic security. Seed and gene banks play a central role in these conservation efforts, as they allow seeds to be stored under controlled conditions, typically at  $-20^{\circ}\text{C}$  for orthodox seeds and ensuring their

viability for several decades (Rao *et al.*, 2006). The National Bureau of Plant Genetic Resources (NBPGR) in India, along with state agricultural universities, manages extensive collections that include indigenous and improved genotypes, thus supporting ongoing breeding and research programs. Field gene banks further complement these efforts by maintaining living collections of rice varieties for continuous evaluation, genetic characterization, and breeding utility. Advanced methods such as cryopreservation have also gained attention for enabling ultra-low temperature storage of seeds, pollen, or tissues, providing the longest-term conservation option for plant genetic resources, although this technology remains under development for certain rice genotypes (Li & Pritchard, 2009). Moreover, the emerging use of DNA banks allows researchers to store genetic material in the form of extracted DNA, facilitating future molecular studies and supporting advanced biotechnological conservation strategies. Together, these ex-situ approaches build a robust backup system that ensures the enduring preservation and accessibility of genetic resources like Kalabati for present and future generations.

**Table 1: Biochemical and antioxidant properties of different varieties of rice.**

S.No	Nutrients	Black Rice (General)	Red Rice (Mali Red)	Brown Rice (Suphanburi-1)	White Rice (Polished)	Reference
1	Protein	Higher*	10.49%	10.5-14.6 g/100g	6.8-7.3 g/100g	Singh Raghuvanshi (2017)
2	Fat	Moderate	Moderate	Moderate	Lower	Baptista <i>et al.</i> (2024)
3	Ash	Moderate	Higher	1.53%	Lower	Singh Raghuvanshi (2017)
4	Crude Fiber	Higher	2.71%	2.7%	0.2-0.4%	Singh Raghuvanshi (2017)
5	Carbohydrates	Moderate	Higher	70.19%	80.13 g/100g	Chen <i>et al.</i> (2019)
6	B-Vitamin (Niacin)	-	-	-	1.5-1.9 mg/100g	Sompong <i>et al.</i> (2011)
7	Iron	-	13.45 ± 0.60 mg/100g	-	0.7-1.2 mg/100g	Sompong <i>et al.</i> (2011); Singh Raghuvanshi (2017)
8	Magnesium	-	192.27 mg/100g	-	25-35 mg/100g	Sompong <i>et al.</i> (2011); Singh Raghuvanshi (2017)
9	Calcium	-	Higher than white	-	7.94 ± 0.17 mg/100g	Singh Raghuvanshi (2017)
10	Zinc	-	1.91 mg/100g	-	1.49 mg/100g	Singh Raghuvanshi (2017)
11	Total Anthocyanins	19.4-140.8 mg/100g DM (Cy3G)	-	-	-	Pengkumsri <i>et al.</i> (2015); Sompong <i>et al.</i> (2011)
12	Total Phenolics	305.30 mg GAE/g	36.14 mg GAE/g	118.33 mg/kg	-	Sompong <i>et al.</i> (2011)
13	DPPH Radical Scavenging	62-76.4%	-	52.30%	-	Sompong <i>et al.</i> (2011); Pengkumsri <i>et al.</i> (2015)
14	Glycemic Index	42± 0.72	-	-	71.7 ± 0.91 (HIGHEST)	Singh Raghuvanshi (2017)

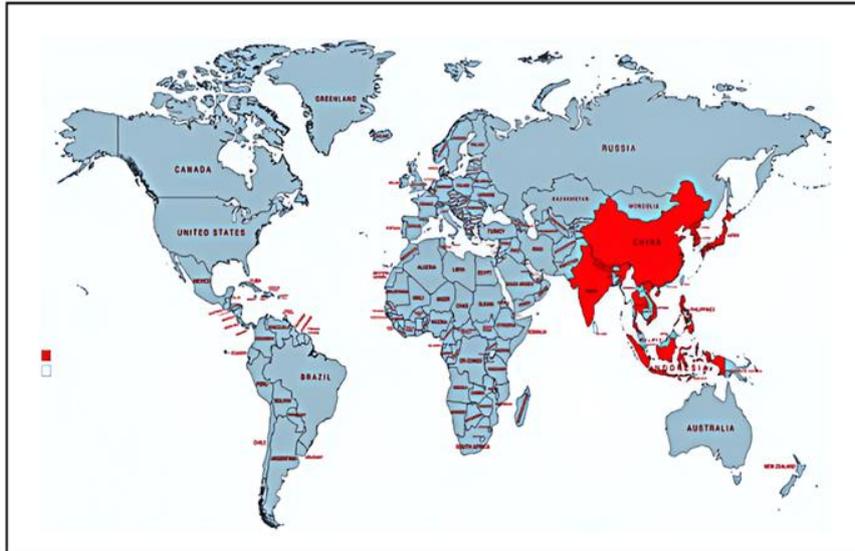


Fig. 1: Countries showing black rice production in the world map.



(a) (b)

Fig 2: (a) Black rice (*Kalabati*) paddy field; (b) Black rice (*Kalabati*) panicle.

Source: Villamart Pvt.Ltd; www.indiamart.com



Fig 3: (a) Black rice (*Kalabati*) paddy and (b) Black rice (*Kalabati*) de-husked grain.

**8. CONCLUSIONS**

Kalabati represents a valuable genetic resource that integrates exceptional nutritional qualities with notable therapeutic benefits. Its proven effectiveness in addressing malnutrition highlights its critical role in

enhancing nutritional security among vulnerable populations. However, the current status of Kalabati cultivation is precarious, with risks of genetic erosion and potential loss looming. Reviving this variety necessitates collaborative efforts among farmers,

researchers, policymakers, and market stakeholders. Success depends on establishing economic incentives that make cultivating indigenous varieties financially sustainable while conserving their unique traits. Capitalising on growing markets for functional and organic foods offers an avenue to transform Kalabati from an endangered heritage crop into a commercially viable product. Future research should prioritise thorough genetic characterisation, optimise agronomic practices, develop scalable processing technologies, and rigorously validate health claims through clinical trials. These approaches will not only aid in conservation but also foster sustainable agricultural systems that respect traditional knowledge and bolster rural livelihoods. The revival and conservation of Kalabati thus serve as a vital example of balancing biodiversity preservation with socio-economic development, contributing meaningfully to sustainable food systems, cultural heritage, and public health goals.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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