

From grain to germination: A review of the nutritional and phytochemical changes in mature and germinated black rice

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Abstract:

Black rice is recognized as a functional food because of its rich nutritional composition and high levels of bioactive compounds, particularly anthocyanins and phenolic acids. This review compares the nutritional characteristics and health-promoting potential of black rice flour produced from mature grains with those of germinated black rice and early-stage rice sprouts. Black rice flour is generally a concentrated source of carbohydrates, dietary fibre, plant protein, minerals and grain-associated phenolic compounds, making it suitable for nutrient-dense staple foods, bakery products and functional formulations. In contrast, germination can modify the nutritional and phytochemical profile of black rice through the mobilization of storage reserves and activation of metabolic processes during early seedling development. These changes may affect the levels and profiles of selected proteins, minerals, phenolics, anthocyanins and other antioxidant compounds. The nutritional and phytochemical composition of germinated black rice can vary substantially with cultivar, germination duration, growing conditions and harvest stage. Similarly, milling and processing conditions may influence the retention of anthocyanins and antioxidant capacity in black rice flour. Overall, mature black rice flour and germinated black rice offer complementary nutritional characteristics: flour provides concentrated grain nutrients and energy, whereas germination may enhance or modify selected nutritional and functional characteristics. Further standardized comparative studies are needed to evaluate nutrient bioavailability, optimize germination and processing conditions, and support the wider application of germinated black rice in health-oriented food products.

Keywords: black rice; Germinated black rice; rice sprouts; germination; proximate composition; phenolics; anthocyanins; antioxidant activity; phytochemicals

1. Introduction

Rising interest in pigmented grains has increased attention towards germination as a simple biological process capable of modifying the nutritional and phytochemical characteristics of cereal grains. Germination involves the reactivation of metabolic processes in the seed, mobilization of stored nutrients and initiation of seedling development. During this transition, enzymatic activity increases and stored carbohydrates, proteins and other reserves may undergo biochemical transformation, potentially altering the nutritional and functional properties of the grain. Zhu et al. (2025), for example,

demonstrated that germination of black rice flour for 0–48 h altered nutritional, physicochemical and digestibility characteristics, including mineral and free amino acid contents.

Black rice is particularly relevant to germination-based functional food research because its mature grain contains substantial amounts of anthocyanins, phenolic compounds and other antioxidant constituents. Germination may modify these grain-associated compounds while simultaneously initiating the development of young rice tissues. Studies of rice sprouts have demonstrated age-dependent changes in phenolic compounds, flavonoids, anthocyanins, chlorophylls and proximate composition. Tamprasit et al. (2019) specifically investigated white and black glutinous rice sprouts harvested between 5 and 25 days and reported age-dependent changes in their phytochemical and proximate characteristics.

Unlike mature black rice grain, which primarily functions as a storage tissue for carbohydrates, proteins, lipids and minerals and contains anthocyanin-rich outer layers, germinating black rice undergoes a transition from a storage state to metabolically active seedling development. During this process, stored reserves are mobilized to support growth, while enzymatic and metabolic activities increase. As germination progresses, young shoots may subsequently develop chlorophylls and other photosynthetic pigments. Consequently, the biochemical composition of germinated black rice may differ from that of mature grain.

It is important, however, to distinguish germinated rice, rice sprouts and microgreens. Germination begins with seed activation and radicle emergence, while sprouts represent an early stage of seedling development. Microgreens generally refer to a later harvested stage in which young aerial tissues have developed. Therefore, evidence obtained from microgreen studies should not automatically be interpreted as evidence for germinated black rice. General microgreen literature can nevertheless provide useful background regarding changes in phytochemicals during early plant development.

The distinction between mature black rice and germinated black rice is important when considering rice as a source of functional food ingredients. In mature black rice, the outer grain layers are important reservoirs of anthocyanins and other phenolic compounds, whereas germination initiates physiological and biochemical processes that can alter the distribution and concentration of nutrients and phytochemicals. Although both materials originate from the same grain, differences in developmental state and metabolic activity may result in distinct nutritional and phytochemical profiles.

Mature black rice and germinated black rice have largely been investigated as separate food resources. Research on mature black rice has predominantly focused on grain, bran, germ, anthocyanins, phenolic compounds and antioxidant activity, whereas germination studies have examined changes in proximate composition, minerals, free amino acids, starch characteristics, phenolic compounds and other phytochemicals. Consequently, direct comparisons of mature black rice flour and germinated black rice using a common analytical framework remain limited. A germination-based comparison therefore provides an appropriate framework for integrating evidence from mature black rice, germinated black rice flour and early rice sprouts.

2. Black Rice and Germination

2.1 Black rice: characteristics and bioactive composition

Black rice (*Oryza sativa* L.) is a pigmented rice type distinguished by its dark purple to black colour and its abundance of nutritionally and biologically important compounds. The characteristic pigmentation is primarily associated with anthocyanins concentrated in the outer layers of the grain. In addition to anthocyanins, black rice contains phenolic acids, flavonoids, proanthocyanidins, tocopherols,

tocotrienols, γ -oryzanol and other antioxidant constituents. The distribution and concentration of these compounds can vary according to rice genotype, cultivar and grain fraction, resulting in differences in the antioxidant potential of individual black-rice varieties [6].

The functional characteristics of black rice are closely related to its phytochemical composition. Anthocyanins contribute to the characteristic colour and antioxidant properties of pigmented rice. However, their concentration, together with that of other phenolic constituents, is not uniform across black-rice genotypes. Differences among cultivars have been reported in phenolic content, flavonoid concentration, anthocyanin levels and antioxidant activity, emphasizing the importance of genetic background when evaluating black rice as a functional food material [8]. This cultivar-dependent variation is particularly relevant when the same rice genotype is evaluated before and after germination.

2.2 Germination and early development of black rice

Germination begins with the rehydration and metabolic reactivation of the rice grain, followed by enzymatic activity, mobilization of storage reserves and emergence of the developing seedling. During germination, α -amylase and other hydrolytic enzymes become active and contribute to the breakdown and mobilization of stored nutrients. In black rice, recent evidence demonstrates that germination can alter starch characteristics, reducing sugars, free amino acids, minerals and GABA content. Zhu et al. (2025) reported that germination of black rice flour for 0–48 h increased α -amylase activity and reducing sugars and markedly enhanced free amino acids and mineral contents.

As germination progresses beyond the initial stage, the developing rice seedling forms young shoots and eventually green tissues. Tamprasit et al. (2019) investigated black glutinous rice sprouts harvested from 5 to 25 days and found age-dependent changes in proximate composition, phenolic compounds, flavonoids, anthocyanins and chlorophylls.

A clear distinction should therefore be maintained between germinated grain, sprouts and microgreens. Germinated grain refers to grain undergoing germination; sprouts represent young developing seedlings; and microgreens generally represent a later harvested stage of young aerial plant tissues. These materials should not be treated as interchangeable because their biochemical composition changes with developmental stage. General microgreen literature may be used to provide background on early plant development, but black-rice-specific germination and sprout studies should form the primary evidence base of this review.

2.3 Nutritional and phytochemical changes during germination

As black rice seeds undergo germination, stored reserves are mobilized to support seedling growth. This transition involves changes in the relative proportions of macronutrients, minerals and phytochemicals. The magnitude and direction of these changes depend on genotype, germination duration and developmental stage.

Germination activates hydrolytic enzymes and can alter starch, reducing sugars, free amino acids and other nutritional components. In black rice flour, Zhu et al. (2025) reported increased α -amylase activity, reducing sugar formation and marked changes in free amino acids and minerals during 0–48 h of germination.

Phytochemical composition can also change during early development. Studies of black glutinous rice sprouts have reported age-dependent changes in total phenolics, flavonoids, anthocyanins and

chlorophylls, demonstrating that the developmental stage at harvest is an important determinant of composition.

For black rice, this transition is particularly relevant because the mature grain and developing seedling perform different biological functions. The mature grain contains storage reserves and grain-associated phytochemicals, whereas germination initiates active metabolic processes that support seedling development and may modify the composition and accessibility of these constituents. Thus, germinated black rice should not be interpreted simply as a reduced or immature form of black rice flour. Rather, it represents a biologically transformed form of the grain whose nutritional and phytochemical characteristics depend on the duration and conditions of germination.

2.4 Factors affecting the composition of germinated black rice

The composition of germinated black rice is influenced by genetic, environmental and processing variables, including cultivar, seed quality, moisture availability, temperature, germination duration and harvest stage. Because germination involves rapid biochemical changes, differences in germination time and analytical procedures can introduce substantial variability among studies. The developmental stage at which germinated rice is harvested is particularly important because early germination and later sprout development represent different physiological states.

Evidence from black rice leaf studies can provide supportive information regarding the phytochemical potential of later-developed rice tissues; however, mature leaves are not equivalent to germinated grain or young sprouts. Such studies should therefore be interpreted as complementary evidence rather than direct measurements of germination-induced changes.

3. Nutritional and Phytochemical Composition of Mature and Germinated Black Rice

3.1 Proximate composition

The proximate composition of mature black rice flour and germinated/young black rice provides a basis for comparing their major nutritional components. The parameters commonly evaluated include moisture, protein, fat, ash, dietary fibre, carbohydrate and energy. Mature black rice grain contains concentrated nutrient reserves, whereas germination and subsequent sprout development alter water content and nutrient distribution as metabolic activity increases.

The reported proximate composition showed differences between mature black rice flour and young black rice sprouts. Mature flour contained higher reported protein (10.98–11.16 g/100 g), fat (3.42–4.01 g/100 g), carbohydrate (78.54 g/100 g) and energy (404.39 kcal/100 g). In contrast, young black rice sprouts reported in the literature showed higher moisture (64.72–76.73 g/100 g) and ash (3.31–5.78 g/100 g). Dietary/crude fibre in young sprouts ranged from 16.92–17.81 g/100 g, compared with 4.75–5.11 g/100 g in mature black rice flour. Carbohydrate and energy values were comparatively lower in young sprouts, ranging from 15.09–24.54 g/100 g and 80.90–124.00 kcal/100 g, respectively. Tamprasit et al. (2019)

3.2 Mineral composition

Mineral	Mature black rice flour	Germinated black rice flour	Researcher(s), year	Method
Potassium (mg/kg)	4044.93 ± 93.16	3148.07–3727.83	Zhu et al. (2025)	ICP-MS
Magnesium (mg/kg)	1231.07 ± 43.72	1272.07–1435.63	Zhu et al. (2025)	ICP-MS

Mineral	Mature black rice flour	Germinated black rice flour	Researcher(s), year	Method
Calcium (mg/kg)	45.90 ± 4.25	81.30–91.47	Zhu et al. (2025)	ICP-MS
Iron (mg/kg)	11.83 ± 0.65	11.90–13.03	Zhu et al. (2025)	ICP-MS
Zinc (mg/kg)	13.77 ± 0.85	14.60–17.37	Zhu et al. (2025)	ICP-MS
Copper (mg/kg)	0.28 ± 0.03	0.38–0.41	Zhu et al. (2025)	ICP-MS
Sodium (mg/kg)	12.33 ± 0.71	29.13–32.93	Zhu et al. (2025)	ICP-MS

ICP-MS: Inductively Coupled Plasma–Mass Spectrometry.

The mineral composition data indicate that mature black rice flour contained particularly high levels of potassium (4044.93 ± 93.16 mg/kg) and magnesium (1231.07 ± 43.72 mg/kg). Following germination, potassium decreased to 3148.07–3727.83 mg/kg, whereas magnesium increased to 1272.07–1435.63 mg/kg. Germinated black rice flour also showed higher reported concentrations of calcium (81.30–91.47 mg/kg), iron (11.90–13.03 mg/kg), zinc (14.60–17.37 mg/kg), copper (0.38–0.41 mg/kg) and sodium (29.13–32.93 mg/kg). These findings indicate that germination can modify the measured mineral profile of black rice flour. Zhu et al. (2025) reported that mineral contents were markedly affected during germination. Such changes should not, however, be interpreted directly as increases in mineral bioavailability without specific bioavailability measurements. Overall, germination appears to alter the relative distribution of several minerals, with potassium showing a decrease and several other measured minerals showing increases.

3.3 Bioactive compounds and antioxidant activity

Black rice contains a diverse range of bioactive compounds, including phenolic acids, flavonoids, anthocyanins, proanthocyanidins, tocopherols, tocotrienols and γ -oryzanol. Among these, anthocyanins are particularly characteristic of black rice and contribute to its pigmentation and antioxidant potential [6]. Their concentration, along with that of other phenolic constituents, varies considerably with genotype, grain fraction and processing conditions [6, 8].

Germination may modify the phytochemical profile of black rice through metabolic activation and seedling development. Studies of black glutinous rice sprouts have reported age-dependent changes in total phenolic, flavonoid, anthocyanin and chlorophyll contents, together with the identification of protocatechuic acid, vanillic acid and rutin in rice sprouts [16].

The development of green tissues during later seedling growth can additionally be associated with the appearance or accumulation of photosynthetic pigments such as chlorophylls. However, these later-stage characteristics should not be assumed to represent all stages of germination. Consequently, the phytochemical profile of germinated black rice depends strongly on germination duration and developmental stage.

Antioxidant activity has been reported in mature black rice and in young rice tissues. Black rice is particularly rich in antioxidant compounds, with phenolic compounds, flavonoids and anthocyanins contributing to its antioxidant potential [6, 8]. Similarly, rice sprouts have demonstrated the presence of several phytochemical constituents, including phenolic compounds, flavonoids and anthocyanins, although their concentrations vary with harvest age [16].

However, quantitative comparison of antioxidant activity between mature black rice and germinated or young rice remains difficult because published results vary in genotype, germination duration,

developmental stage, extraction procedure, assay type and expression of results. Therefore, reported differences in antioxidant activity should be interpreted as evidence of compositional change rather than as proof that germination universally increases antioxidant capacity.

Overall, mature and germinated black rice provide complementary phytochemical characteristics. Mature black rice is distinguished by anthocyanin-rich grain-associated phytochemicals, whereas germination initiates metabolic changes that can modify phenolic compounds, anthocyanins and other bioactive constituents; at later seedling stages, chlorophyll-containing tissues may also develop. Direct same-genotype comparisons are required to determine the extent and nutritional significance of these changes.

3.4 Research gap and future perspectives

Although mature black rice has been extensively investigated for its nutritional and phytochemical profile, studies examining the effects of germination on black rice remain comparatively limited. What is particularly needed is a direct, same-genotype comparison between mature black rice flour and the corresponding germinated black rice material under standardized germination and analytical conditions. Shifting from a mature grain to a germinated state triggers physiological and biochemical transformations. Evaluating these stages side by side using standardized methods could clarify changes in proximate composition, minerals, phenolics, flavonoids, anthocyanins, chlorophylls, carotenoids and antioxidant capacity. Such studies should also distinguish between early germination, sprouting and later seedling development because these stages are physiologically different.

Future investigations should therefore use the same black-rice genotype, clearly defined germination durations, standardized drying and extraction procedures, and comparable analytical methods. This approach would help distinguish true germination-associated changes from differences caused by cultivar, developmental stage or analytical methodology.

4. Conclusion

The present review indicates that black rice is a nutritionally and phytochemically valuable cereal and that germination represents an important biological process capable of modifying its nutritional and functional characteristics. Mature black rice flour is characterized by concentrated macronutrients, energy and grain-associated phytochemicals, particularly anthocyanins, whereas germinated black rice undergoes metabolic changes associated with reserve mobilization, enzymatic activation and early seedling development. Studies of black rice sprouts further demonstrate that proximate composition and phytochemical characteristics can vary with harvest age.

Germination can modify the mineral profile of black rice flour, while studies of later-stage rice sprouts demonstrate age-dependent changes in phenolics, flavonoids, anthocyanins and chlorophylls. A major limitation of the current literature is the scarcity of standardized, same-genotype comparisons between mature black rice and its germinated forms. Future research should therefore examine clearly defined stages of germination under controlled conditions using comparable analytical methods. Such investigations may clarify nutritional and phytochemical changes associated with germination and help establish germinated black rice as a functional ingredient for value-added food applications.

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