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Review Article

Nutritional and functional potentials of germinated rice: A systematic review

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Abstract

The cereal food group contributes significant amounts of the major macronutrients and micronutrients, making it an essential part of a healthy diet. The primary food for nutrition, energy, and nourishment in India, especially in North Eastern India, is rice. It is rich in dietary fiber, vitamin B including niacin, riboflavin, and thiamin, in addition to minerals like phosphorus, potassium, and magnesium. Germination as a biochemical process has the ability to enhance the nutritional value of whole brown rice grains and bioactive properties of rice. It is a time-honored, cost-effective way to prepare sprouted seeds. Since, high molecular proteins break down into low molecular proteins during germination, this process impacts on product qualities including odor, bioactivity and digestibility, which is advantageous for baby nutrition. Varying steeping time or water pH causes changes in reducing sugar, free GABA, and amylase activity, however, there is a decrease in total starch content. Gamma-aminobutyric acid (GABA) inhibits leukemia cell proliferation and stimulates cancer cell Apoptosis. Therefore, the aim of this present review is to highlight the biochemical changes that occur in rice due to germination and its health benefits.

Keywords

rice, germination, nutritional properties, functional constituents, biochemical changes

Abbreviations

GABA – gamma-aminobutyric acid; PA – phytic acid;

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Introduction

One of the most significant sources of dietary proteins is cereal grains, which also contribute considerable amounts of energy, protein, carbohydrates, vitamin, and a few specific micronutrients to the diets of both animals and people (Đorđević et al. 2010). Over three billion people worldwide eat rice as a basic diet, and most of them prefer polished white rice (Park et al. 2017). The third most often grown crop worldwide is rice. More than half of the world's population eats rice as their primary staple food, with Asia, Sub-Saharan Africa, and South America being its top consumers. Global rice production is anticipated to reach 515 million tonnes by the end of 2022. The rise in world production as a result is 0.23%. India still leads the world in rice exports even though Sub-Saharan Africa is the region that imports the most (Rice production by Country 2023). In comparison to other grains, rice has higher fiber, resistant starch, and a variety of proteins and lipids when it is consumed as whole (Krishnan et al. 2021). Rice's nutritional makeup varies greatly depending on both environmental factors and variety. Due to varying soil and climatic circumstances, even the same variety of rice might exhibit compositional variances. The primary components of brown rice include 0.8-2.6% fiber, 1.5-2.1% ash, and 2.4-3.9% fat. 15.4% protein (N 5.95), 1520-1610 kJ.100g⁻¹ of calories (Bhattacharya 2017). Dietary fiber, phenolic acids, flavonoids, tocopherols, minerals, vitamins, amino acids, and oryzanol are among the phytochemicals found in brown rice (Ravichanthiran et al. 2018). In addition to lowering blood pressure and preventing cancer and heart disease, these nutritional elements also have antioxidant properties (Fukushima et al. 2020). Germination is an efficient and established method for enhancing the nutritional value of grains (Jeong et al. 2019). Numerous rice dishes have been created using diverse techniques since rice is taken in a variety of ways. Some processes that are applied directly to the grain, including parboiling, annealing and quick cooking techniques for, also include certain that promote germination (do Nascimento et al. 2022). Nutritive value as well as the level of nutrients like free amino acids, vitamins, and other

compounds present in grains alters due to all those treatments and also the sensory qualities (Chaijan and Panpipat 2020). The functional elements included in germinated brown rice (GBR) are regarded as good food sources of nutrition. GBR is preferred because it not only encourages healthy metabolic pathways for greater health but also cooks more effectively and with better digestibility than non-germinated brown rice (Cho and Lim 2016). Further, the germination of rice grains may alter the amounts of a number of nutrients, including sugar, vitamin B, total protein, and gamma-aminobutyric acid (Fukushima et al. 2020). The germination process influences by some environmental factors such as germination time, absence or presence of light (Jeong et al. 2019). Numerous varieties of rice grains upon varying parameters show different impacts and such works studied by researchers have been listed in Table 1. During the initial 0-24 h of germination, water is absorbed quickly. When germination starts and dormancy is broken, the metabolites at the embryo undergoes significant alteration (Frank et al. 2011). There is rise in metabolite concentrations within 24-48 h. For the initial germination enzymes are required and, it was the most crucial stage for accelerating metabolic reactions and mobilizing reserves. When rice grains germinate, they include proteins relating to metabolism that are engaged in many carbohydrates metabolic processes, including glycolysis, the tricarboxylic acid cycle, gluconeogenesis, and the pentose phosphate pathway. GABA levels continuously rises for another 72-96 h in germination. Important amino acids such alanine, arginine, glycine, methionine, proline, serine, and tyrosine, among others Valine and tryptophan concentrations were higher after 72-96 h compared to 0-24 h (Kamjijam et al. 2020). A few seed reserves are digested and used to respire and generate new cell components for the growing embryo during germination, which significantly alters the biochemical, dietary, and sensory properties of the cereal seed (Chen et al. 2016). The germination condition of many rice varieties, influences on dietary and biochemical constituents, and health advantages are highlighted and explained in this paper.

Table 1. Rice germination process and major changes during germination. (Δ – Increase, ∇ – Decrease)

Variety	Germination process	Major changes	Reference
PSB. Rc. 34	Washed with normal water, soaked in water for 24 h at the ratio grain and water as 1:3, at a temperature 25-35°C	Reducing and non-reducing sugar Δ	(Ayernor & Ocloo 2007)
Pusa Basmati 1	Washed with 70% ethanol and 0.05% HgCl_2 , stratified for 2 d at 4°C and further germinate at 28°C in growth germinator chamber.	Triglycerols ∇	(Sinha et al. 2020)
Xianhui 207, Heinuo	Soaked in water for 12 h at 30°C, then allowed to germinate under the condition of normoxia and moisture supplied for 72 h at 28°C	GABA Δ Lipid ∇	(Ding et al. 2016)
KDML105, Riceberry	Soaked in distilled water for 12 h and allowed to germinate for 144 h at 30°C at dark condition.	GABA Δ Protein Δ	(Kamjijam et al. 2020)
Zhengxian, Nanjing, Yannuo	120 h spent submerged in deionized water at 25°C in the dark, with water changes every 6 h	Carbohydrates ∇	(Wu et al. 2013)
Khao Niaw Dam Peuak Dam	Soaked in distilled water at a ratio 1:5 for 24 h at room temperature 30-35°C and allowed to germinate 48 h at 37°C	Carbohydrates ∇ Lipid Δ	(Owolabi et al. 2020)
Daohuaxiang	Soaked in hydrogen peroxide solution at a ratio of 1:2 for 36 h at 36°C with 100% relative humidity	Protein Δ Total antioxidant activity Δ	(Xia et al. 2017)
IET-23466, Dhan-201, IET-23448, MAS-946, IET-23445, IET-23463, IET-23455, PR-123, PR-115 e IET-23449	Steeped for 48 h at 28-30°C at 95% relative humidity in distilled water	Total phenolics Δ Total flavonoid Δ	(Kaur et al. 2017)
Ilpumbyeo	Soaked in distilled water for 3 d at a temperature 20°C and allowed to germinate for 2 d at 37°C with 80% relative humidity	Vitamin E Δ Phenolic acid content Δ	(Kim et al. 2017)

Variety	Germination process	Major changes	Reference
Sanpatong 1, Khao Jow Hawm Phitsanulok 1, KDML105, Niaw Sanpatong, Rice Department 6, Luem Pua	Soaked in distilled water for 4 d at a temperature 25-30°C	Vitamin E Δ γ -oryzanol Δ antioxidant activity Δ Total phenolics Δ	(Yodpitak et al. 2019)
OM457, TN11, Huong Dua	Soaked in deionized water (1:5 w/v) for 36 h at 30°C and allowed to germinate in darkness for 36 h at 35°C with relative humidity 90%	Total phenolics Δ flavonoids Δ	(Nguyen et al. 2020)
Qiutian Xiaoting	Immersed in de-ionized water in a ratio (3:10 w/v), followed by the incubation at 37°C for 52 h°C	GABA Δ	(Xia and Li 2018)

Germination

Soaking the grains or seeds in water is the initial step in the germination process. Water uptake by the grain through the pores and micropyle and be deposited there as a result of interactions mostly with proteins and fibers. During the second stage, when the pericarp ruptures in the vicinity of the germ and the radicle immediately appears, the water absorption index is stabilized. During the third stage, the percentage of water absorption increases once more, and the radicle cells grow more numerous (Nelson et al. 2013). According to Fukushima et al. (2020) temperature has a significant impact on germination, the coleoptile and root appeared 2 d after soaking at 30-35°C. There is no germination seen at 45°C, 50°C, and 55°C but small buds started to emerge at 40°C after steeping for 2 d, but the germ didn't extend until 10 d later. Zhang et al. (2014) studied and compared the differences in GABA production between the two-rice variety (Indica and Japonica rice), as well as the impacts of processing parameters and addition of exogenous glutamic acid or gibberellin. The greatest amount of GABA was produced by soaking in distilled water with a pH of 7.0 and germinating seeds at 35°C for 36 h. Kim et al. (2017) conducted an experiment to germinate a seed. To

start the germination process, the seed was first soaked in distilled water in a 1:5 w/v ratio at 20°C for 3 d. The water was changed every 24 h. The soaked seeds were put in trays and allowed to germinate for two days at 37°C with 80% relative humidity in a seed germinator.

Moongngarmand and Saetung (2010) used the procedure for the germination of rough rice, for germination, 5 kg of rough rice was steeped in tap water at room temperature for 48 h to achieve a moisture content of 40±2%. Next the rice seeds were placed over double layer of cotton cloth in plastic baskets and allowed to germinate for 48 h. For germination process (Jeong et al. 2019) steeped rough rice in tap water at room temperature for three days, with the dipping water being replaced every 24 h. The soaked rough rice was allowed to germinate for 15 to 25 mm at a temperature of 37°C and 80% relative humidity. Phytic acid content of the germinated rice flours was reduced by 75% and the starch content by 45% after 12 h of soaking and 48 hours of germination at 30°C (Chinma et al. 2015). A detailed diagrammatical flowchart explaining the germination process is shown on Fig. 1.

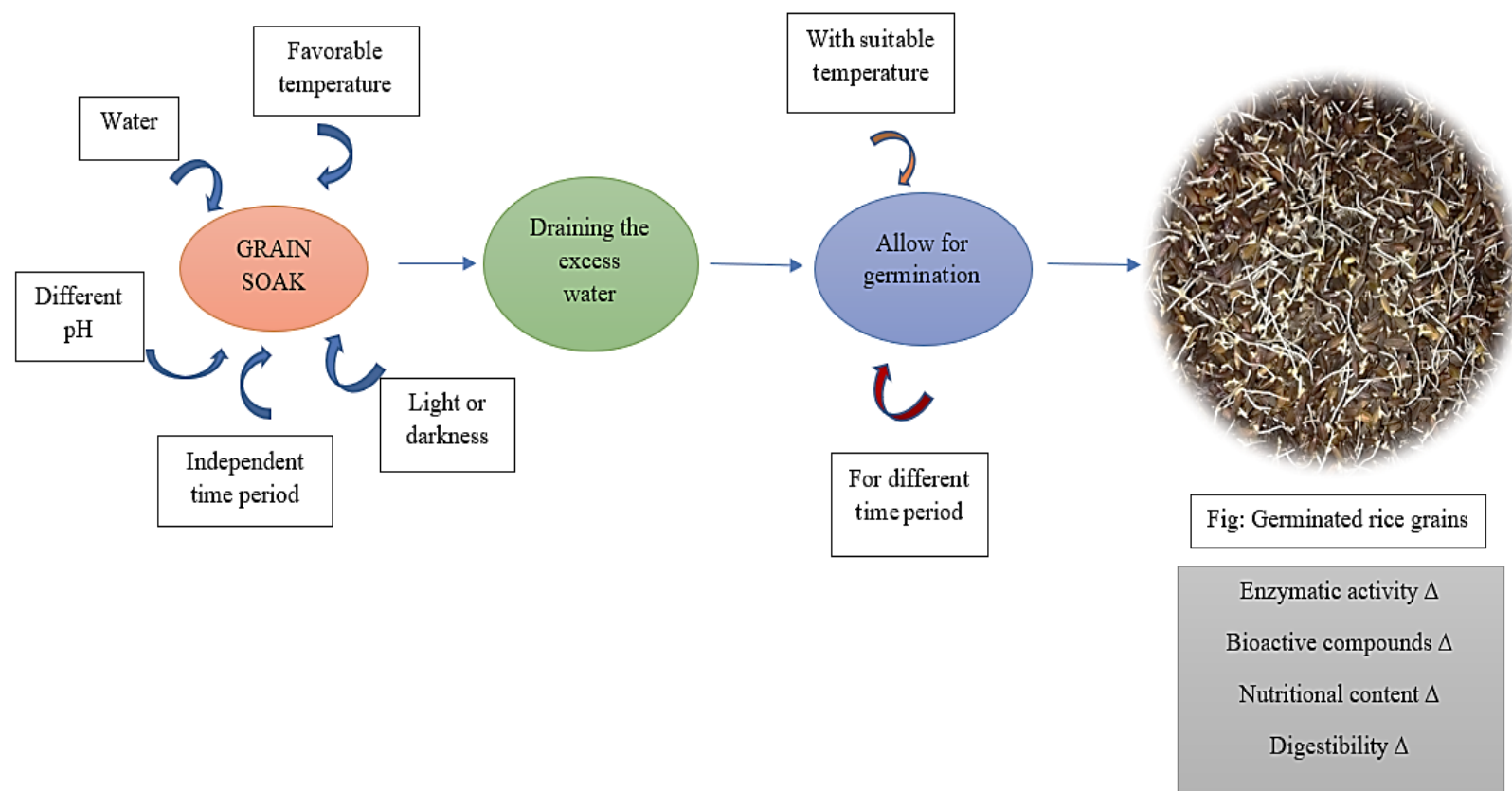


Figure 1. Diagrammatic representation of the rice germination process (Adapted by [do Nascimento et al. 2022](#))

Histological analysis showed that the root apical meristem undergoes active differentiation after the treatment of partial drying. Liao et al. (2015) found that between 14-21 d, roughly, basal callus inhibition of root growth was released in *Picea morrisonicola* Hayata; freshly formed young roots extended through the callus and then emerged into the culture media, effectively enhancing the germination process. Histological evidence and the findings of the partial-drying experiment in this study showed that a shorter partial drying time (7 d) effectively activated root meristem development, and a subsequent three-week cold storage period considerably increased germination. Liao et al. (2015) stated that their findings of the partial-drying experiment showed a shorter partial drying time (7 d) effectively activated root meristem development, and a subsequent three-week cold storage period considerably increased germination. Wu et al. (2022) found out that cadmium treatment on japonica rice restricted the root length of the rice seed but it had minimal effect on the germination rate and shoot length.

Effects of germination on various characteristics of rice

Effect on nutritional value. Since, the hydrolytic enzymes become the first to be activated due to germination conditions and act in the breakdown of starch, so carbohydrates suffer the largest alterations as a result of germination and it shows decrease in carbohydrate content (McKie and McCleary 2015). Crude protein, total sugars, reducing sugar, and total free amino acid concentrations all increased significantly at germination (Moongngarm and Saetung 2010). Chinma et al. (2015) reported that it is possible that enzymatic hydrolysis of starch to monosaccharides during germination is the cause of the decreased starch level in germinated rice flours in comparison to non-germinated rice flour. After germination, the level of protein increases. Lipid breakdown, which provided energy for the biochemical and physicochemical changes that occurred during germination, may have contributed to the decrease in fat content of rice flours on germination. Reduced total soluble solids and likely dry matter loss can be used to explain why germinated rice flour has a greater ash content than non-germinated flours.

Higher protein level and a modification in protein quality following germination could be responsible for the greater ability to absorb water of germinated rice flour (Chinma et al. 2015). The metabolism of total carbohydrates, which shown a marked reduction in quantity in each case, was attributable to this increase in the total sugar content (Sibian et al. 2017) (Table 2).

Effect on mineral content. Seed germination and PA hydrolysis are both impacted differently by different temperature ranges. At greater temperature conditions ($>50^{\circ}\text{C}$), significant PA degradation was seen (Fukushima et al. 2020). Phytic acid is one of the main barriers restricting the availability of divalent cations such Fe^{2+} , Ca^{2+} , Mg^{2+} , and Zn^{2+} . Due to stable complexes that phytic acid (inositol hexakisphosphatephosphate) groups form with these cations, they are not bioavailable (Singh et al. 2015). Magnesium, phosphorus, and potassium quantities of flour samples were enhanced by germination, whereas calcium, iron, sodium, and zinc were not significantly impacted (Chinma et al. 2015).

Effect on bioactive compounds. The overall vitamin E content was increased by adding α -tocopherol, α -tocotrienol, and germination α -tocotrienol (Kim et al. 2017). According to Yodpitak et al. (2019) Vitamin E content rises throughout the germination process, and amounts might change greatly based on the variety and germination duration. In their study on the viability of getting a germinated extract of native Thai rice (Chaijan and Panpipat 2020) noted a significant rise in GABA at 35°C in the dark, during germination from the 36-th to the 48-th h, going up from 1.5 to 55.0 mg.kg^{-1} , a range that did not exceed changes up until the procedure' conclusion 96 h (Jeong et al. 2019) before germination, the total polyphenol and flavonoid content was $4.11 \text{ mg GAE.g}^{-1}$ and $2.14 \text{ mg CE.g}^{-1}$, respectively. After germination, these values rise to $9.82 \text{ mg GAE.g}^{-1}$ and $3.85 \text{ mg CE.g}^{-1}$. The synthesis of phenolic compounds brought on by enzyme hydrolysis during germination is greater in germinated rice (He et al. 2011; Jeong et al. 2019). DPPH and ABTS radicals scavenging activity improved from $3.75 \text{ mg TE.g}^{-1}$ and $18.58 \text{ mg AE.g}^{-1}$ to $6.54 \text{ mg TE.g}^{-1}$ and $28.73 \text{ mg AE.g}^{-1}$ after germination (Jeong et al. 2019).

Table 2. Effect on nutritional value during germination

Nutritional value	Effect	Changes	References
Carbohydrates	Decrease	The increased enzymatic activity that led to the breakdown of carbohydrates into less complex components like simple sugars and oligosaccharides could be linked to changes in the usage of food reserve carbohydrates. The amount of carbohydrates per kg of wheat, triticale, and brown rice all reduced from 756.4 to 684.6, 688.8 to 601.5, and 764.6 to 689.4 respectively.	(Sibian et al. 2017)
Total sugar	Increase	The utilisation of total carbohydrates, which decreased significantly in quantity in each case, was responsible for this increase in the total sugar content. Triticale, wheat, and brown rice all showed an increase in total sugars of 43.28%, 58.01%, and 44.09%, respectively.	(Sibian et al. 2017)
Reducing sugar	Increase	With longer germination times, the decreasing sugar content gradually rose. It was less than 10% at the beginning of germination and could reach 25% by the end of the germination phase. This might be as a result of rice consuming sugar in numerous biochemical processes at a rate that exceeds the rate at which it is produced during germination.	(Lekjing and Venkatachalam 2020)
Starch	Decrease	Initially in the germination process, the enzyme α -amylase hydrolyzes starch, releasing simple sugars like fructose and glucose that will be utilized to create cell structural polymers like hemicellulose, lignin, and cellulose.	(Nkhata et al. 2018)
Protein	Increase	The activation of protease enzymes during germination causes biochemical changes that result in protein degradation and hydrolysis into free amino acids, which can be quickly converted into new protein compounds. As a result, germination increased the protein content in the germinated brown rice flour from 7.92% to 7.99%.	(Bolarinwa et al. 2019)
Dietary fibres	Increase	After 72 hours of soaking, the Koshihikari cultivar showed a 1.5 times increase in dietary fibre. Indica and japonica cultivars saw a rise in total dietary fibre of 28.2% and 40%, respectively. Additionally, the levels of soluble dietary fibre increased by 61.0% and 79.0%, respectively.	(Ohtsubo et al. 2005; Mohan et al. 2010)
Lipid	Increase	After germination, crude lipid was highest in the sprout i.e. ($6 \pm 0.18\%$) rose in the hull from $0.6 \pm 0.12\%$ to $1.1 \pm 0.06\%$ but decreased in brown rice on comparison.	(Kim et al. 2012)

GABA contents of germinated rice increased marginally over the first 36 h, significantly up to 48 h later, tended to rise somewhat up to 72 h later, and stayed steady till germination was complete. The altered glutamate decarboxylase (GAD) activities throughout germination were presumably the cause of this. Between 36 and 48 h, a substantial improvement in GABA content was noticed (Chaijan and Panpipat 2020). After 5 h of steeping, 50 h of germination, 30°C germination temperature, and relative humidity of 80%, the highest GABA concentration of 51.9 mg.100 g⁻¹ was discovered and the minimum GABA level was recorded after 5 h of steeping period, 10 h germination time, at 30°C and at relative humidity of 70% (Hussain et al. 2020). Kaur et al. (2017) studied on ten variety of rice and they found in increase in reduced ascorbate content, tannin, tocopherol, GABA content and also antioxidant activity (Table 3).

Effect on enzymatic activity. The activation time of enzyme varies based on the type of cereal, germination, and growth conditions, and also due to presence of hormones such gibberellins, which are created in the embryos of the grains and encourage the development and manufacturing of enzymes, specifically those that are involved in the digestion of carbohydrates α -amylases. High enzymatic activity permits breakdown of macromolecules, which can make them more digestible and can produce bioactive substances, increasing functional characteristics. Typically, the addition of enzymes such amylases, proteases, and xylanases modifies the elastic properties of the dough, gas retention, and smoothness of the particle (Miransari and Smith 2014). Some plant hormones like Gibberellic acid, abscisic acid, and ethylene are produces and/or releases during the germination process which serve as indicators for the stimulation and production of enzymes such amylases, lipases, and proteases (do Nascimento et al. 2022). One of most prevalent protease that works on the degradation of storage protein during the germination of seeds is cysteine protease (Szewińska et al. 2016). Amylase enzyme is generated during germination because endosperm needs to activate stored macromolecules in order to supply nutrients for the seed during germination (Kondhare et al. 2015).

The content of amylase activity is higher in germinated rice than non germinated rice (Guzmán-Ortiz et al. 2019). Increase in amylase enzyme begins at 8 h of imbibition, with a larger increase occurring after 20 h. On the other hand, brown and rough rice that germinate at 28-30°C displayed a gradual rise in α -amylase activity, reaching a peak after four days of germination. In comparison to ungerminated grain and germinated rice, amylase activity increases up to 143-fold more after 24 h germination (Moongngarm et al. 2014). Guzmán-Ortiz et al. (2019) reported that longer the steeping period, higher the percentage of water absorption which in turn encourages for enhancement of amylase activity. α amylase greatly increases up to 86.97 u.g⁻¹ after steeping the rough rice cultivar RD-6 for 2 d and 48 h germination period. Amylase-induced starch hydrolysis results in the production of sugars and changes the shape of the granule. Enzymes have the ability to hydrolyze and enter granules, producing porous surfaces, erosion along the surface in the form of sponges, and degraded granules (Lu et al. 2016) (Table 4).

Comparison with other germinated cereals

It has been noticed how germination has various positive effects on rice such as improved or increased amounts of functional compounds. However, change in nutrient profile for other germinated cereals have also been tracked in Table 5 to get a more comprehensive idea on the effects of germination overall.

Future scopes and new trends

The idea of germination is to increase the overall nutritional profile of the grains and improve its cooking behavior by soaking at various temperatures. Already, a number of ways have been identified wherein the germination rate was hugely impacted. The main aim behind improving germination is to provide better nutrients to the consumers since it has been found to elevate the essential properties of the grains (wheat, cereal, brown rice, white rice). All recent research has been tabulated in the Table 6 given below.

Table 3. Changes of bioactive compounds after germination in different varieties of rice

Rice variety	Effect on bioactive compounds	References
Xianhui 207, Heinuo	GABA increased	(Ding et al. 2016)
Daohuaxiang	Antioxidant activity increased	(Xia et al. 2017)
Purple rice	Anthocyanin content decreased	(Veeradittakit et al. 2021)
Purple rice	Polyphenol increased	(Owolabi et al. 2018)
Purple rice	Flavonoid increased	(Owolabi et al. 2018)
KDML105, Riceberry	GABA increased	(Kamijam et al. 2020)
IET-23466, Dhan-201, IET-23448, MAS-946, IET-23445, IET-23463, IET-23455, PR-123, PR-115 e IET-23449	Total phenolics and flavonoids increased	(Kaur et al. 2017)
Pusa Basmati 1	TAG decreased	(Sinha et al. 2020)
Sanpatong 1, Khao Jow Hawm Phitsanulok 1, KDML105, Niaw Sanpatong, Rice Department 6, Luem Pua	Vitamin E, γ -oryzanol, antioxidant activity, total phenolics increased	(Yodpitak et al. 2019)
Hom Mali 105, Hom Deang Sukhothai 1, Hom Dam Sukhothai 2	GABA, γ -oryzanol, total phenolics increased	(Pramai et al. 2018)
Sanqiuding, SZ	GABA increased	(Xia & Li 2018)
Ilpumbyeo	Vitamin E increased	(Kim et al. 2017)
KDML105	GABA, γ -oryzanol, phenolic acids increased	(Tuntipopipat et al. 2015)

Health benefits

In various pieces of literature, germinated rice has been found to have numerous beneficial properties (Fig. 2). Germination encourages the enzymatic alterations of carbohydrates, particularly, interactions between starch and polyphenol that may be used to manage blood sugar levels (Oliveira et al. 2022). Pramai et al. (2018) investigated the characteristics of germinated black, red, and white rice and came to the conclusion that the germinated black rice had higher content of organic acids, phenolic compounds, and amino acids. According to Karau (2014), Kovanda (2020) and González-Burgos (2021) amino acids, organic acids and phenolic compounds are beneficial for human

health by contributing in hemoglobin production, improving disease resistance, growth promotion and treat obesity by inhibiting adipogenesis. Tian et al. (2004) studied and found that germinated brown rice had higher insoluble phenolic acids which includes hydroxycinnamates.

Hydroxycinnamates contain antimutagenic capabilities, and this physiological activity may be important in the cancer-prevention effect of dietary fiber. (Ferguson 2003). Brown rice that has been germinated has been shown to have a variety of physiological effects, such as cardiovascular disease (CVD), antihyperlipidemia, antihypertension, and a lower risk of cancer, diabetes, and Alzheimer's disease thereby, it can be categorized as a functional food (Wu et al. 2013).

Table 4. Enzymatic activity observed after germination

Enzyme	Treatment	References
Diastase	The mean diastase activity of brown rice was 456 mg of maltose per 10 g after 12 h of germination and increased to 757 mg after 48 h. The average diastase activity was 543 mg maltose per 10 g when germination took place at 25°C, and it rose to 796 mg maltose per 10 g at 35°C	(Singh et al. 2018)
α-amylase	The alpha amylase concentration of germinated brown rice rose from 0.17 to 21.00 U.g ⁻¹ after being treated for 96 h at 28-30°C in comparison to unaffected brown rice	(Guzmán-Ortiz et al. 2019)
Cysteine protease	Cysteine protease, which is in charge of breaking down and mobilizing storage proteins, was observed to be present in rice in greater quantities	(Szewińska et al. 2016)
α-amylase and β-amylase	After germination was complete, all glutinous brown rice's - amylase activity rapidly rose and steeping proceeded for another 24-48 h	(Charoenthaikij et al. 2009)
Proteases	Rice's protease activity increased from 0 to 0.12 (U.g ⁻¹ DM) during the course of 5 d after being subjected to the germination process.	(Veluppillai et al. 2009)
Diastase, Alpha Amylase, protease	After being germinated for 4 d in the dark, diastase activity grew from 0.007 to 0.061 Units.min ⁻¹ , -amylase activity increased from 0.004 to 0.056 Units.min ⁻¹ , and protease activity increased from 0.84 to 3.89 Units.min ⁻¹	(Van Hung et al. 2020)

Food products

Germinated rice can be incorporated into various food products and pose as a potential ingredient for obtaining various health benefits. Numerous attempts have been made by researchers with successful results in incorporating germinated rice in food products. Recent relevant researches have been listed below in Table 7.

Conclusions

Notable alterations in a number of chemical compositions, bioactive substances, and amino acids occur during rice germination. It also reworks the starch digestibility and displays an increase in GABA content. All of these modifications aim to raise the rice's quality and increase its healthbenefits. It is noteworthy to mention that all

these significant properties contribute in claiming germinated rice as a potential functional food. Various researches need to be conducted in the future for a clear understanding on germination conditions to find out the best conditions for various types or cultivars. This would create a valuable opportunity for the functional food sector, and consumers would gain health advantages from using these products.

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Table 5. Comparison of the effects of germinations on rice and other germinated cereals

Compound	Other germinated cereal	Germinated rice
GABA (γ-Amino- butyric acid)	Germinated sorghum (<i>Sorghum bicolor</i> L. Moench) had increased GABA content up to 0.336 mg.g⁻¹ (Elbaloula et al. 2022) Germinated chickpea increased GABA content from 6.42 to 245.76 mg.100 g⁻¹ (Ferreira et al. 2019) Germinated soybeans were found to have a 10-fold increase compared to non-germinated soybeans from 0.216 mg.ml⁻¹ and 0.302 mg.ml⁻¹ to 1.343 mg.ml⁻¹ and 1.506 mg.ml⁻¹ respectively (Shabbir et al. 2022) Germinated barley showed an increase in GABA content from 6 mg.100 g⁻¹ to an overall content of 11.9 mg.100 g⁻¹ (Waleed et al. 2020)	Germinated brown rice had increased GABA content from 16.43 mg.100 g⁻¹ up to 50.54 mg.100 g⁻¹ (Chen et al. 2023) Germinated red rice after being treated to germination revealed that the GABA content increased from 91.44 μg.g⁻¹ to 122.87 μg.g⁻¹ (Kang et al. 2022)
Phenolic content (<i>p</i>-coumaric acid)	Adlay seed (<i>Coixlachryma-jobi</i> L.) when germinated for 4.5 d increased <i>p</i>-coumaric acid (soluble free phenolic content) content from 3.11 μg.g⁻¹ to 63.86 μg.g⁻¹ (Xu et al. 2017). Black soybean (<i>Glycine max</i> L.) when germinated for 4 d showed a decrease in <i>p</i>-coumaric acid content from 2.96 μg.g⁻¹ to 0.39 μg.g⁻¹ (Kim et al. 2016). Buckwheat (<i>Fagopyrum esculentum</i> Moench) when germinated for 3 d the <i>p</i>-coumaric acid content increased from 1.74 μg.g⁻¹ to 6.13 μg.g⁻¹ (Zhang et al. 2015). Flaxseed (<i>Linum usitatissimum</i> L.) underwent germination for 10 days and had an optimum <i>p</i>-coumaric content of 4.33 mg.100 g⁻¹ from an initial 0.26 mg.100 g⁻¹ (Wang et al. 2015). Quinoa seeds (<i>Chenopodium quinoa</i> Willd.) germinated for 3 d and had an optimum <i>p</i>-coumaric acid content 1.96 mg.100 g⁻¹ from an initial 0.09 mg.100 g⁻¹ (Carciochi et al. 2016).	Chinese wild rice (<i>Zizania latifolia</i>) underwent germination for 120 h to receive the optimum <i>p</i>-coumaric acid content from 14 μg.g⁻¹ to 105 μg.g⁻¹ approximately (Chu et al. 2020)
Vitamins	In sorghum (<i>Sorghum bicolor</i> L.), after 72 h of germination the vitamin B2 content increased (riboflavin) but showed decreased levels of vitamin E (Pinheiro et al. 2021) Germinated pea flour after undergoing germination for (24-72 h) was seen to have increased levels of vitamins B and vitamin C (Chinma et al. 2022)	High performance liquid chromatography (HPLC) analysis of germinated brown rice showed the presence of vitamin E and its five isomers α-tocopherol/ tocotrienol, γ-tocopherol/ tocotrienol, and β-tocopherol, δ-tocopherol/ tocotrienol, β-tocotrienol (Kong et al. 2022)

Table 6. New trends and research in the field of germination

New Trends	Treatment	References
Slightly acidic electrolyzed water (SAEW)	SAEW pH - 5.5, and available chlorine concentration (ACC) - 10 ppm, germination was performed in a CO ₂ incubator with a moisture content of 20-30% at 35.1°C. The germination increased the GABA level by almost three times, from 1.8 mg.L ⁻¹ to 7.35 mg.L ⁻¹ .	(Tyagi et al. 2022)
Nanoprimering	Nano-priming is a revolutionary seed priming technology that improves seed germination, seed growth, and yield by giving resilience to various stresses in plants. There are several different types of nanoprimering, including bioprimering, hydropriming, haloprimering, osmoprimering, and solid matrix priming, which enhance seed germination, plant development, and performance.	(Nile et al.2022)
Hydropriming	The initial seed water content of rice seeds was obtained by priming them in tap water at 30°C for 12 h. During the early germination period, priming increased germination rate but did not enhance water intake (0-24 h after imbibition).	(Matsunami et al. 2022)
Static magnetic field (SMF)	After being subjected to SMF (10 mT, 60 min, 25°C), brown rice underwent 0-72 h of 30°C germination. The amylase activity was increased (15.2%) by the SMF treatment, which caused the starch to be hydrolyzed into reducing sugar (8.2%) and raised the germination rate from 9.7% to 158.8%.	(Luo et al. 2022)
Melatonin	According to the findings, the key melatonin concentration is 100µM, and the crucial interaction treatment is germination at 38°C followed by recuperation at 26°C for a day + 100 µM. When seeds were exposed to various high-temperature settings while being soaked in melatonin (100µM), the effect of the high temperatures on the germination rate was dramatically reduced by 18.2%, 3.2%, 3.9%, and 10.6%, respectively.	(Yu et al. 2022)
Priming with rhizobacteria	According to the results, bioprimering using rhizobacteria can significantly boost rice grain germination over hydropriming in just 4 d. The increase in germination is related to the improvement in amylase enzyme temperature and pH range.	(Al- Hazmi and Naguib 2022)
Nitrogen (N) and Zinc(Zn)	When nitrogen(N) and zinc(Zn) were employed to treat the grain, the yield increased by 28.5% and 32.5%, respectively. Additionally, the largest gains of 37.9% grain were obtained with foliar application of combined N and Zn.	(Tuiwong et al. 2022)
Hydrogen peroxide	The grains considerably outperformed antioxidant-conjugated redox buffering at both high and low H ₂ O ₂ doses (20 mM and 500 µM H ₂ O ₂).	(Bhattacharjee et al. 2022)

New Trends	Treatment	References
Infrared radiation (IR)	According to the results, it is proper to treat rice that will be used as seed grain with an IR intensity of 10.84 kW.m ⁻² for 7 s to obtain a temperature of 60°C; lesser IR intensities seem more appropriate.	(Hampton et al. 2022)
Salicylic acid (SA)	Treatment with 0.1 mM SA significantly reduced amylase activity inhibition and accelerated the conversion of starch to soluble sugars.	(Liu et al. 2022)
Pulsed light	After being exposed to pulsed light for 18 h, the glutamic acid concentration peaked, and the GABA content peaked after 24 h. Additionally, increased levels of free amino acids were found.	(Zhang et al. 2022)
Ergothioneine (ESH) extract from <i>Aspergillus oryzae</i>	The findings showed that when 4% of ESH was applied, total lipid was steady and that in germinated brown rice, there were higher quantities of GABA and γ -oryzanol.	(Ha et al. 2022)
Combined Calcium and Aeration treatment	The breakdown of protein increased the overall concentration of free amino acids after aeration and a calcium ion-based pretreatment. Brown rice that had been germinated and cooked showed excellent pasting qualities and thermal stability, which helped it have the right edible attributes.	(Zhang et al. 2022)
Smoke induced germination	The smoke water caused an early, partial increase in seed germination rates, indicating that seeds that ingested it may use the majority of the nutrients to begin metabolic processes earlier than seeds that received other treatments.	(Jamil et al. 2020)
Lactobacillus acidophilus and Bifidobacterium animalis subsp. lactis	Combining probiotics L. acidophilus and/or B. animalis subsp. lactis with germinated brown rice prevented the development of colorectal cancer in rats by suppressing the colonic preneoplastic lesions caused by 1,2-dimethylhydrazine (DMH) or Dextran sulfate sodium (DSS).	(Lin et al. 2019)



Figure 2. Health benefits of germinated rice

Table 7. Food products made from germinated rice

Product	Findings	References
Dumplings	The storage and textural quality of the glutinous rice flour-based dumplings with the appropriate germinated brown rice flour addition (5-15%) were improved, with lower water loss and cracking rates as well as greater hardness and adhesiveness. Additionally, it also increased the digestibility of the food product.	(Wang et al. 2022)
Tea	The formation of free amino acids and reducing sugars during germination promoted the non-enzymatic browning reaction and the development of aroma compounds during subsequent roasting for tea preparation; additionally, the rise in total phenolic content caused by roasting boosted antioxidant properties.	(Kim et al. 2021)
Cookies	In comparison to non-germinated brown rice flour, germinated brown rice flour comprised more protein, ash, dietary fiber, and fat. Inclusion of this flour to make cookies had a good overall acceptability.	(Bolarinwa et al. 2019)
Yoghurt	The proximal composition of brown rice formulations was somewhat altered by fermentation, which also increased the overall number of bioactive substances (phenolic compounds and GABA), ACE-inhibitory action, consistency index, and density. The product displayed the best biological, technological, and acceptance characteristics.	(Cáceres et al. 2019)
Bread	In comparison to the control, germinated brown rice bread displayed higher specific volume (4% to 10%), decreased hardness (34% to 90%), and lower starch retrogradation (66% to 90%).	(Wunthunyarat et al. 2020)
Rice cake	Germinated black glutinous rice was used to make fermented rice cake with the probiotic yeast <i>saccharomyces boulardii</i> . The created product contains antioxidants like anthocyanins, flavonoids, and GABA, each not less than 30%, according to all the results of tested analysis.	(Cheirsilp et al. 2023)
Cupcake	After germination for around 40 hours, the red rice flour portrayed increased phenolic acid and flavonoid content which was then utilized to prepare cupcake with an overall acceptability of 90% approximately.	(Müller et al. 2021)

References

- Al-Hazmi N.E., Naguib D.M. Amylase properties and its metal tolerance during rice germination improved by priming with rhizobacteria. *Rhizosphere*, 2022, 22(6): 100518.
<https://doi.org/10.1016/j.rhisph.2022.100518>
- Ayernor G., Ocloo F. Physico-chemical changes and diastatic activity associated with germinating paddy rice (PSB. Rc 34). *African Journal of Food Science*, 2007, 1(3): 037-041.
<https://doi.org/10.5897/AJFS.9000227>
<https://academicjournals.org/journal/AJFS/article-abstract/88F3E9211186>
- Bhattacharjee S., Chakrabarty A., Kora D., Roy U.K. Hydrogen peroxide induced antioxidant-coupled redox regulation of germination in rice: redox metabolic, transcriptomic and proteomic evidences. *Journal of Plant Growth Regulation*, 2023, 42(3): 1084-1106.
<https://doi.org/10.1007/s00344-022-10615-3>
- Bhattacharya S. Chemical and Nutritional Properties of Brown Rice. In: *Brown Rice* (A. Manickavasagan, C. Santhakumar, N. Venkatachalapathy Eds.). Springer, Cham. 2017, pp. 93-110. Print ISBN: 978-3-319-59010-3, Online ISBN: 978-3-319-59011-0
https://doi.org/10.1007/978-3-319-59011-0_6

- Bolarinwa I.F., Lim P.T., Muhammad K. Quality of gluten-free cookies from germinated brown rice flour. *Food Research*, 2019, 3(3): 199-207. [https://doi.org/10.26656/fr.2017.3\(3\).228](https://doi.org/10.26656/fr.2017.3(3).228)
- Cáceres P.J., Peñas E., Martínez-Villaluenga C., García-Mora P., Frías J. Development of a multifunctional yogurt-like product from germinated brown rice. *LWT*, 2019, 99(1): 306-312. <https://doi.org/10.1016/j.lwt.2018.10.008>
- Carciocchi R.A., Dimitrov K., Galván D' Alessandro L. Effect of malting conditions on phenolic content, Maillard reaction products formation, and antioxidant activity of quinoa seeds. *Journal of Food Science and Technology*, 2016, 53(11): 3978-3985. <https://doi.org/10.1007/s13197-016-2393-7>
- Chaijan M., Panpipat W. Nutritional composition and bioactivity of germinated Thai indigenous rice extracts: A feasibility study. *Plos ONE*, 2020, 15(8): e0237844. <https://doi.org/10.1371/journal.pone.0237844>
- Charoenthakij P., Jangchud K., Jangchud A., Piyachomkwan K., Tungtrakul P., Prinyawiwatkul W. Germination conditions affect physicochemical properties of germinated brown rice flour. *Journal of Food Science*, 2009, 74(9): C658-C665. <https://doi.org/10.1111/j.1750-3841.2009.01345.x>
- Cheirsilp B., Mekpan W., Sae-ear N., Billateh A., Boukaew S. Enhancing functional properties of fermented rice cake by using germinated black glutinous rice, probiotic yeast, and enzyme technology. *Food and Bioprocess Technology*, 2023, 16(5): 1116-1127. <https://doi.org/10.1007/s11947-022-02985-z>
- Chen C., Tao Y., Han Y., Ding Y., Jian X., Li D. Preparation of germinated brown rice with high γ -aminobutyric acid content and short root by magnetic field treatment. *Journal of Cereal Science*, 2023, 112(7): 103720. <https://doi.org/10.1016/j.jcs.2023.103720>
- Chen H.H., Chang H.C., Chen Y.K., Hung C.L., Lin S.Y., Chen Y.S. An improved process for high nutrition of germinated brown rice production: Low-pressure plasma. *Food Chemistry*, 2016, 191(1): 120-127. <https://doi.org/10.1016/j.foodchem.2015.01.083>
- Chinma C.E., Abu J.O., Adediji O.E., Aburime L.C., Joseph D.G., Agunloye G.F., Adebo O.A. Nutritional composition, bioactivity, starch characteristics, thermal and microstructural properties of germinated pigeon pea flour. *Food Bioscience*, 2022, 49(10): 101900. <https://doi.org/10.1016/j.fbio.2022.101900>
- Chinma C.E., Anuonye J.C., Simon O.C., Ohiare R.O., Danbaba N. Effect of germination on the physicochemical and antioxidant characteristics of rice flour from three rice varieties from Nigeria. *Food Chemistry*, 2015, 185(10): 454-458. <https://doi.org/10.1016/j.foodchem.2015.04.010>
- Cho D.-H., Lim S.-T. Germinated brown rice and its bio-functional compounds. *Food Chemistry*, 2016, 196(4): 259-271. <https://doi.org/10.1016/j.foodchem.2015.09.025>
- Chu C., Du Y., Yu X., Shi J., Yuan X., Liu X., Yan N. Dynamics of antioxidant activities, metabolites, phenolic acids, flavonoids, and phenolic biosynthetic genes in germinating Chinese wild rice (*Zizania latifolia*). *Food Chemistry*, 2020, 318(7): 126483. <https://doi.org/10.1016/j.foodchem.2020.126483>
- Ding J., Yang T., Feng H., Dong M., Slavin M., Xiong S., Zhao S. Enhancing contents of γ -aminobutyric acid (GABA) and other micronutrients in dehulled rice during germination under normoxic and hypoxic conditions. *Journal of Agricultural and Food Chemistry*, 2016, 64(5): 1094-1102. <https://doi.org/10.1021/acs.jafc.5b04859>
- do Nascimento L.Á., Abhilasha A., Singh J., Elias M.C., Colussi R. Rice germination and its impact on technological and nutritional properties: A review. *Rice Science*, 2022, 29(3): 201-215. <https://doi.org/10.1016/j.rsci.2022.01.009>
- Đorđević T.M., Šiler-Marinković S.S., Dimitrijević-Branković S.I. Effect of fermentation on antioxidant properties of some cereals and pseudo cereals. *Food Chemistry*, 2010, 119(3): 957-963. <https://doi.org/10.1016/j.foodchem.2009.07.049>
- Elbaloula M.F., Hassan A.B. Effect of different salt concentrations on the gamma- aminobutyric- acid content and glutamate decarboxylase activity in germinated sorghum (*Sorghum bicolor* L. Moench) grain. *Food Science & Nutrition*, 2022, 10(6): 2050-2056. <https://doi.org/10.1002/fsn3.2821>
- Ferreira C.D., Bubolz V.K., da Silva J., Dittgen C.L., Ziegler V., de Oliveira Raphaelli C., de Oliveira M. Changes in the chemical composition and bioactive compounds of chickpea (*Cicer arietinum* L.) fortified by germination. *LWT*, 2019, 111(8): 363-369. <https://doi.org/10.1016/j.lwt.2019.05.049>
- Frank T., Scholz B., Peter S., Engel K.-H. Metabolite profiling of barley: Influence of the malting process. *Food Chemistry*, 2011, 124(3): 948-957. <https://doi.org/10.1016/j.foodchem.2010.07.034>
- Fukushima A., Uchino G., Akabane T., Aiseki A., Perera I., Hirotsu N. Phytic acid in brown rice can be reduced by increasing soaking temperature. *Foods*, 2020, 10(1): 23. <https://doi.org/10.3390/foods10010023>
- Guzmán-Ortiz F.A., Castro-Rosas J., Gómez-Aldapa C.A., Mora-Escobedo R., Rojas-León A., Rodríguez-Marín, M.L., Falfán-Cortés R.N., Román-Gutiérrez A.D. Enzyme activity during germination of different cereals: A review. *Food Reviews International*, 2019, 35(3): 177-200. <https://doi.org/10.1080/87559129.2018.1514623>
- Ha N.C., Thao D.L.P., Ngoc N.T.L. Ergothioneine extract from *Aspergillus oryzae* prevents lipid

- oxidation and increases bioactive compounds during the processing of germinated brown rice. *Journal of Food Processing and Preservation*, 2022, 46(1): e16211. <https://doi.org/10.1111/jfpp.16211>
- Hampton R.M., Atungulu G., Rolland V., Wilson S.A., McKay T. Effects of infrared radiation on germination of long grain rice. *Applied Engineering in Agriculture*, 2022, 38(1): 129-133. <https://doi.org/10.13031/aea.14774>
- He D., Han C., Yao J., Shen S., Yang P. Constructing the metabolic and regulatory pathways in germinating rice seeds through proteomic approach. *Proteomics*, 2011, 11(13): 2693-2713. <https://doi.org/10.1002/pmic.201000598>
- Hussain S.Z., Jabeen R., Naseer B., Shikari A.B. Effect of soaking and germination conditions on γ -aminobutyric acid and gene expression in germinated brown rice. *Food Biotechnology*, 2020, 34(2): 132-150. <https://doi.org/10.1080/08905436.2020.1744448>
- Jamil M., Jahangir M., Rehman S.U. Smoke induced physiological, biochemical and molecular changes in germinating rice seeds. *Pakistan Journal of Botany*, 2020, 52(3): 865-871. [https://doi.org/10.30848/PJB2020-3\(37\)](https://doi.org/10.30848/PJB2020-3(37))
- Jeong H.S., Lee Y.R., Lee S.H., Jang G.Y., Lee Y.J., Kim M.Y., Kim Y.-B., Lee J. Antioxidative and antidiabetic effects of germinated rough rice extract in 3T3-L1 adipocytes and C57BLKS/J-db/db mice. *Food & Nutrition Research*, 2019, 63(11): 3603. <https://doi.org/10.29219/fnr.v63.3603>
- Kamijiam B., Bednarz H., Suwannaporn P., Jom K.N., Niehaus K. Localization of amino acids in germinated rice grain: Gamma-aminobutyric acid and essential amino acids production approach. *Journal of Cereal Science*, 2020, 93(1): 102958. <https://doi.org/10.1016/j.jcs.2020.102958>
- Kang S.J., Jeong S.Y., Islam M.Z., Shin B.K., Park Y.J., Kim J.K., Lee J.H. Bioactive compounds and quality evaluation of red-pigmented rice processed by germination and roasting. *Foods*, 2022, 11(18): 2735. <https://doi.org/10.3390/foods11182735>
- Kaur, M., Asthir, B., Mahajan, G.. Variation in antioxidants, bioactive compounds and antioxidant capacity in germinated and ungerminated grains of ten rice cultivars. *Rice Science*, 2017, 24(6): 349-359. <https://doi.org/10.1016/j.rsci.2017.08.002>
- Kim, H. J., Han, J. A., Lim, S. T., Cho, D. H. Effects of germination and roasting on physicochemical and sensory characteristics of brown rice for tea infusion. *Food Chemistry*, 2021, 350(7): 129240. <https://doi.org/10.1016/j.foodchem.2021.129240>
- Kim H.Y., Hwang I.G., Kim T.M., Woo K.S., Park D.S., Kim J.H., Kim D.J., Lee J., Lee Y.R., Jeong H.S. Chemical and functional components in different parts of rough rice (*Oryza sativa* L.) before and after germination. *Food Chemistry*, 2012, 134(1): 288-293. <https://doi.org/10.1016/j.foodchem.2012.02.138>
- Kim M.Y., Jang G.Y., Lee Y., Li M., Ji Y.M., Yoon N., Lee S.H., Kim K.M., Lee J., Jeong H.S. Free and bound form bioactive compound profiles in germinated black soybean (*Glycine max* L.). *Food Science and Biotechnology*, 2016, 25(8): 1551-1559. <https://doi.org/10.1007/s10068-016-0240-2>
- Kim M.Y., Lee S.H., Jang G.Y., Li M., Lee Y.R., Lee J., Jeong H.S. Changes of phenolic-acids and vitamin E profiles on germinated rough rice (*Oryza sativa* L.) treated by high hydrostatic pressure. *Food Chemistry*, 2017, 217(2): 106-111. <https://doi.org/10.1016/j.foodchem.2016.08.069>
- Kondhare K., Farrell A., Kettlewell P., Hedden P., Monaghan J. Pre-maturity α -amylase in wheat: The role of abscisic acid and gibberellins. *Journal of Cereal Science*, 2015, 63(5): 95-108. <https://doi.org/10.1016/j.jcs.2015.03.004>
- Kong L., Lin Y., Liang J., Hu X., Ashraf U., Guo X., Bai S. Dynamic changes in vitamin E biosynthesis during germination in brown rice (*Oryza sativa* L.). *Foods*, 2022, 11(20): 3200. <https://doi.org/10.3390/foods11203200>
- Krishnan V., Rani R., Awana M., Pitale D., Kulshreshta A., Sharma S., Bollinedi H., Singh A., Singh B., Singh A.K., Praveen S. Role of nutraceutical starch and proanthocyanidins of pigmented rice in regulating hyperglycemia: Enzyme inhibition, enhanced glucose uptake and hepatic glucose homeostasis using in vitro model. *Food Chemistry*, 2021, 335(1): 127505. <https://doi.org/10.1016/j.foodchem.2020.127505>
- Lekjing S., Venkatachalam K. Effects of germination time and kilning temperature on the malting characteristics, biochemical and structural properties of HomChaiya rice. *RSC advances*, 2020, 10(28): 16254-16265. <https://doi.org/10.1039/D0RA01165G>
- Liao Y.K., Juan I.P. Improving the germination of somatic embryos of *Picea morrisonicola* Hayata: Effects of cold storage and partial drying. *Journal of forest research*, 2015, 20(1): 114-124. <https://doi.org/10.1007/s10310-014-0445-2>
- Lin P.Y., Li S.C., Lin H.P., Shih C.K. Germinated brown rice combined with *Lactobacillus acidophilus* and *Bifidobacterium animalis* subsp. *lactis* inhibits colorectal carcinogenesis in rats. *Food Science & Nutrition*, 2019, 7(1): 216-224. <https://doi.org/10.1002/fsn.3.864>
- Liu Z., Ma C., Hou L., Wu X., Wang D., Zhang L., Liu P. Exogenous SA affects rice seed germination under salt stress by regulating Na^+/K^+ balance and endogenous GAs and ABA homeostasis. *International Journal of Molecular Sciences*, 2022, 23(6): 3293. <https://doi.org/10.3390/ijms23063293>

- Lu S., Wu J., Gao Y., Han G., Ding W., Huang X. MicroRNA-4262 activates the NF- κ B and enhances the proliferation of hepatocellular carcinoma cells. *International Journal of Biological Macromolecules*, 2016, 86(5): 43-49. <https://doi.org/10.1016/j.ijbiomac.2016.01.019>
- Luo X., Li D., Tao Y., Wang P., Yang R., Han Y. Effect of static magnetic field treatment on the germination of brown rice: changes in α -amylase activity and structural and functional properties in starch. *Food Chemistry*, 2022, 383(7): 132392. <https://doi.org/10.1016/j.foodchem.2022.132392>
- Matsunami M., Hayashi H., Murai-Hatano M., Ishikawa-Sakurai J. Effect of hydropriming on germination and aquaporin gene expression in rice. *Plant Growth Regulation*, 2022, 97(2): 263-270. <https://doi.org/10.1007/s10725-021-00725-5>
- McKie V.A., McCleary B.V. A rapid, automated method for measuring α -amylase in pre-harvest sprouted (sprout damaged) wheat. *Journal of Cereal Science*, 2015, 64(7): 70-75. <https://doi.org/10.1016/j.jcs.2015.04.009>
- Miransari M., Smith D. Plant hormones and seed germination. *Environmental and Experimental Botany*, 2014, 99(3): 110-121. <https://doi.org/10.1016/j.envexpbot.2013.11.005>
- Mohan B.H., Malleshi N.G., Koseki T. Physico-chemical characteristics and nonstarch polysaccharide contents of Indica and Japonica brown rice and their malts. *LWT-Food Science and Technology*, 2010, 42(5): 784-791. <https://doi.org/10.1016/j.lwt.2010.01.002>
- Moongngarm A., Saetung N. Comparison of chemical compositions and bioactive compounds of germinated rough rice and brown rice. *Food Chemistry*, 2010, 122(3): 782-788. <https://doi.org/10.1016/j.foodchem.2010.03.053>
- Moongngarm A., Moontree T., Deedpinrum P., Padtong K. Functional properties of brown rice flour as affected by germination. *APCBEE procedia*, 2014, 8(1): 41-46. <https://doi.org/10.1016/j.apcbee.2014.01.077>
- Müller C.P., Hoffmann J.F., Ferreira C.D., Diehl G.W., Rossi R.C., Ziegler V. Effect of germination on nutritional and bioactive properties of red rice grains and its application in cupcake production. *International Journal of Gastronomy and Food Science*, 2021, 25(10): 100379. <https://doi.org/10.1016/j.ijgfs.2021.100379>
- Nelson K., Stojanovska L., Vasiljevic T., Mathai M. Germinated grains: a superior whole grain functional food? *Canadian Journal of Physiology and Pharmacology*, 2013, 91(6): 429-441. <https://doi.org/10.1139/cjpp-2012-0351>
- Nguyen B.C.Q., Shahinozzaman M., Tien N.T.K., Thach T.N., Tawata S. Effect of sucrose on antioxidant activities and other health-related micronutrients in gamma-aminobutyric acid (GABA)-enriched sprouting Southern Vietnam brown rice. *Journal of Cereal Science*, 2020, 93(5): 102985. <https://doi.org/10.1016/j.jcs.2020.102985>
- Nile S.H., Thiruvengadam M., Wang Y., Samynathan R., Shariati M.A., Rebezov M., Nile A., Sun M., Venkidasamy B., Xiao J., Kai G. Nano-priming as emerging seed priming technology for sustainable agriculture - recent developments and future perspectives. *Journal of Nanobiotechnology*, 2022, 20(1): 1-31. <https://doi.org/10.1186/s12951-022-01423-8>
- Nkhata S.G., Ayua E., Kamau E.H., Shingiro J.B. Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes. *Food Science & Nutrition*, 2018, 6(8): 2446-2458. <https://doi.org/10.1002/fsn3.846>
- Ohtsubo K., Suzuki K., Yasui Y., Kasumi K. Bio-functional components in the processed pre-germinated brown rice by a twin-screw extruder. *Journal of Food Composition and Analysis*, 2005, 18(4): 303-316. <https://doi.org/10.1016/j.jfca.2004.10.003>
- Owolabi I.O., Dat-arun P., Yupanqui C.T., Wichienchot S. Gut microbiota metabolism of functional carbohydrates and phenolic compounds from soaked and germinated purple rice. *Journal of Functional Foods*, 2020, 66(3): 103787. <https://doi.org/10.1016/j.jff.2020.103787>
- Owolabi I.O., Saibandith B., Wichienchot S., Yupanqui C.T. Nutritional compositions, polyphenolic profiles and antioxidant properties of pigmented rice varieties and adlay seeds enhanced by soaking and germination conditions. *Functional Foods in Health and Disease*, 2018, 8(12): 561-578. <https://doi.org/10.31989/ffhd.v8i12.564>
- Park H.-Y., Lee K.-W., Choi H.-D. Rice bran constituents: Immunomodulatory and therapeutic activities. *Food & Function*, 2017, 8(3): 935-943. <https://doi.org/10.1039/C6FO01763K>
- Pinheiro S.S., Anunciação P.C., de Moraes Cardoso L., Della Lucia C.M., de Carvalho C.W.P., Queiroz V.A.V., Sant'Ana H.M.P. Stability of B vitamins, vitamin E, xanthophylls and flavonoids during germination and maceration of sorghum (*Sorghum bicolor* L.). *Food Chemistry*, 2021, 345(5): 128775. <https://doi.org/10.1016/j.foodchem.2020.128775>
- Pramai P., Hamid N.A.A., Mediani A., Maulidiani M., Abas F., Jiamyangyuen S. Metabolite profiling, antioxidant, and α -glucosidase inhibitory activities of germinated rice: Nuclear-magnetic-resonance-based metabolomics study. *Journal of Food and Drug Analysis*, 2018, 26(1): 47-57. <https://doi.org/10.1016/j.jfda.2016.11.023>

- Ravichanthiran K., Ma Z.F., Zhang H., Cao Y., Wang C.W., Muhammad S., Aglago E.K., Zhang Y., Jin Y., Pan B. Phytochemical profile of brown rice and its nutrigenomic implications. *Antioxidants*, 2018, 7(6): 71. <https://doi.org/10.3390/antiox7060071>
- Rice production by Country 2023. Available at: <https://worldpopulationreview.com/country-rankings/rice-production-by-country>
- Shabbir U., Tyagi A., Ham H.J., Oh D.H. Comprehensive profiling of bioactive compounds in germinated black soybeans via UHPLC-ESI-QTOF-MS/MS and their anti-Alzheimer's activity. *Plos ONE*, 2022, 17(1): e0263274. <https://doi.org/10.1371/journal.pone.0263274>
- Sibian M.S., Saxena D.C., Riar C.S. Effect of germination on chemical, functional and nutritional characteristics of wheat, brown rice and triticale: a comparative study. *Journal of the Science of Food and Agriculture*, 2017, 97(13): 4643-4651. <https://doi.org/10.1002/jsfa.8336>
- Singh A.K., Rehal J., Kaur A., Jyot G. Enhancement of attributes of cereals by germination and fermentation: a review. *Critical Reviews in Food Science and Nutrition*, 2015, 55(11): 1575-1589. <https://doi.org/10.1080/10408398.2012.706661>
- Singh A., Sharma S., Singh B. Germination behaviour, physico-nutritional properties, and diastase activity of brown rice influenced by germination time and temperature. *Acta Alimentaria*, 2018, 47(1): 70-79. <https://doi.org/10.1556/066.2018.47.1.9>
- Sinha K., Kaur R., Singh N., Kaur S., Rishi V., Bhunia R.K. Mobilization of storage lipid reserve and expression analysis of lipase and lipoxigenase genes in rice (*Oryza sativa* var. *Pusa Basmati 1*) bran during germination. *Phytochemistry*, 2020, 180(12): 112538. <https://doi.org/10.1016/j.phytochem.2020.112538>
- Szewińska J., Simińska J., Bielawski W. The roles of cysteine proteases and phytocystatins in development and germination of cereal seeds. *Journal of Plant Physiology*, 2016, 207(12): 10-21. <https://doi.org/10.1016/j.jplph.2016.09.008>
- Tuiwong P., Lordkaew S., Veeradittakit J., Jamjod S., Prom-u-thai C. Seed Priming and foliar application with nitrogen and zinc improve seedling growth, yield, and zinc accumulation in rice. *Agriculture*, 2022, 12(2): 144. <https://doi.org/10.3390/agriculture12020144>
- Tuntipopipat S., Muangnoi C., Thiyajai P., Srichamnong W., Charoenkiatkul S., Praengam K. A bioaccessible fraction of parboiled germinated brown rice exhibits a higher anti-inflammatory activity than that of brown rice. *Food & Function*, 2015, 6(5): 1480-1488. <https://doi.org/10.1039/C4FO01194E>
- Tyagi A., Chen X., Shabbir U., Chelliah R., Oh D.H. Effect of slightly acidic electrolyzed water on amino acid and phenolic profiling of germinated brown rice sprouts and their antioxidant potential. *LWT*, 2022, 157(3): 113119. <https://doi.org/10.1016/j.lwt.2022.113119>
- Van Hung P., Yen N.T.H., Phi N.T.L., Tien N.P.H., Trung N.T.T. Nutritional composition, enzyme activities and bioactive compounds of mung bean (*Vigna radiata* L.) germinated under dark and light conditions. *LWT*, 2020, 133(11): 110100. <https://doi.org/10.1016/j.lwt.2020.110100>
- Veeradittakit J., Jumrus S., Sringarm K., Prom-u-thai C. Improving nutritional values in purple rice through germination and parboiling processes. *Journal of Food Processing and Preservation*, 2021, 45(2): e14979. <https://doi.org/10.1111/jfpp.14979>
- Veluppillai S., Nithyanantharajah K., Vasantharuba S., Balakumar S., Arasaratnam V. Biochemical changes associated with germinating rice grains and germination improvement. *Rice Science*, 2009, 16(3): 240-242. [https://doi.org/10.1016/S1672-6308\(08\)60085-2](https://doi.org/10.1016/S1672-6308(08)60085-2)
- Waleed A.A., Mahdi A.A., Al-Maqtari Q.A., Mushtaq B.S., Ahmed A., Karrar E., Mohammed J.K., Fan M., Li Y., Qian H., Wang L. The potential improvements of naked barley pretreatments on GABA, β -glucan, and antioxidant properties. *LWT*, 2020, 130(8): 109698. <https://doi.org/10.1016/j.lwt.2020.109698>
- Wang H., Qiu C., Abbasi A.M., Chen G., You L., Li T., Fu X., Wang Y., Guo X., Liu R.H. Effect of germination on vitamin C, phenolic compounds and antioxidant activity in flaxseed (*Linum usitatissimum* L.). *International Journal of Food Science & Technology*, 2015, 50(12): 2545-2553. <https://doi.org/10.1111/ijfs.12922>
- Wang Y., Liu S., Yang X., Zhang J., Zhang Y., Liu X., Zhang H., Wang H. Effect of germination on nutritional properties and quality attributes of glutinous rice flour and dumplings. *Journal of Food Composition and Analysis*, 2022, 108(5): 104440. <https://doi.org/10.1016/j.jfca.2022.104440>
- Wu F., Chen H., Yang N., Wang J., Duan X., Jin Z., Xu X. Effect of germination time on physicochemical properties of brown rice flour and starch from different rice cultivars. *Journal of Cereal Science*, 2013, 58(2): 263-271. <https://doi.org/10.1016/j.jcs.2013.06.008>
- Wu B., Zeng Z., Wu X., Li Y., Wang F., Yang J., Li X. Jasmonic acid negatively regulation of root growth in Japonica rice (*Oryza sativa* L.) under cadmium treatment. *Plant Growth Regulation*, 2022, 98(3): 651-667. <https://doi.org/10.1007/s10725-022-00897-8>
- Wunthunyarat W., Seo H.S., Wang Y.J. Effects of germination conditions on enzyme activities and starch hydrolysis of long-grain brown rice in relation to flour properties and bread qualities. *Journal of*

- Food Science*, 2020, 85(2): 349-357.
<https://doi.org/10.1111/1750-3841.15008>
- Xia Q., Li Y. Mild high hydrostatic pressure pretreatments applied before soaking process to modulate wholegrain brown rice germination: An examination on embryo growth and physicochemical properties. *Food Research International*, 2018, 106(4): 817-824.
<https://doi.org/10.1016/j.foodres.2018.01.052>
- Xia Q., Wang L., Xu C., Mei J., Li Y. Effects of germination and high hydrostatic pressure processing on mineral elements, amino acids and antioxidants in vitro bioaccessibility, as well as starch digestibility in brown rice (*Oryza sativa* L.). *Food Chemistry*, 2017, 214(1): 533-542.
<https://doi.org/10.1016/j.foodchem.2016.07.114>
- Xu L., Wang P., Ali B., Yang N., Chen Y., Wu F., Xu X. Changes of the phenolic compounds and antioxidant activities in germinated adlay seeds. *Journal of the Science of Food and Agriculture*, 2017, 97(12): 4227-4234. <https://doi.org/10.1002/jsfa.8298>
- Yodpitak S., Mahatheeranont S., Boonyawan D., Sookwong P., Roytrakul S., Norkaew O. Cold plasma treatment to improve germination and enhance the bioactive phytochemical content of germinated brown rice. *Food Chemistry*, 2019, 289(8): 328-339.
<https://doi.org/10.1016/j.foodchem.2019.03.061>
- Yu Y., Deng L., Zhou L., Chen G., Wang Y. Exogenous melatonin activates antioxidant systems to increase the ability of Rice seeds to germinate under high temperature conditions. *Plants*, 2022, 11(7): 886.
<https://doi.org/10.3390/plants11070886>
- Zhang G., Xu Z., Gao Y., Huang X., Zou Y., Yang T. Effects of germination on the nutritional properties, phenolic profiles, and antioxidant activities of buckwheat. *Journal of Food Science*, 2015, 80(5): H1111-H1119.
<https://doi.org/10.1111/1750-3841.12830>
- Zhang H., Zhang Y., Wang T., Wang R., Feng W. Effect of coercion germination through combined calcium and aeration treatment on the edible and physicochemical characteristics of brown rice. *Food Biophysics*, 2022, 17(4): 612-620.
<https://doi.org/10.1007/s11483-022-09739-6>
- Zhang L., Du L., Shi T., Xie M., Liu X., Yu M. Effects of pulsed light on germination and gamma-aminobutyric acid synthesis in brown rice. *Journal of Food Science*, 2022, 87(4): 1601-1609.
<https://doi.org/10.1111/1750-3841.16087>
- Zhang Q., Xiang J., Zhang L., Zhu X., Evers J., van der Werf W., Duan L. Optimizing soaking and germination conditions to improve gamma-aminobutyric acid content in japonica and indica germinated brown rice. *Journal of Functional Foods*, 2014, 10(9): 283-291.
<https://doi.org/10.1016/j.jff.2014.06.009>