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Fermented rice and GABA: A functional neuro-nutritional food rooted in tradition

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Abstract

Fermented rice, a staple in many Asian diets, has garnered renewed interest for its functional properties, particularly its natural enrichment with gamma-aminobutyric acid (GABA), a non-protein amino acid known for its neuro calming and immunomodulatory effects. Lactic acid bacteria such as *Lactobacillus brevis* and *Lactobacillus plantarum* significantly enhance GABA levels in fermented rice. This review explores the biochemical basis of GABA synthesis in fermented rice, its mechanisms of action in brain and nerve health, and the growing scientific evidence supporting its role in stress reduction, cognitive health, and sleep regulation. This review presents various technological strategies aimed at enhancing gamma-aminobutyric acid (GABA) content in fermented rice, focusing on the selection of appropriate rice substrates, the use of specific GABA-producing microbial starter cultures, and the optimization of key fermentation parameters such as pH, temperature, and duration.

1. Introduction

Fermentation has long been a cornerstone of traditional food processing across cultures, serving not only as a preservation method but also enhancing nutritional value through microbial activity. In the Indian subcontinent and other Asian regions, fermented rice has been consumed for centuries under various regional names: Pazhamkanji, Panta Bhat, Poita Bhat, and Chaddannam, often praised for its cooling properties, digestibility, and energizing effects (Pushkarna, 2023; Mani, 2022). Typically consumed after overnight soaking or natural fermentation, these rice forms are rich in lactic acid bacteria, organic acids, and functional compounds such as gamma-aminobutyric acid (GABA).

Recent research has spotlighted GABA, a non-proteinogenic amino acid, for its role as the chief inhibitory neurotransmitter in the mammalian central nervous system (Ngo and Vo, 2019). Dietary GABA, especially from naturally fermented sources, has been associated with stress reduction, improved sleep quality, and enhanced cognitive function (Abdou *et al.,* 2006; Yamatsu *et al*., 2015). Within fermented rice, GABA levels increase due to the activity of specific lactic acid bacteria strains such as *Lactobacillus brevis* and *L. plantarum*, which convert glutamate to GABA through the glutamate decarboxylase pathway (Dhakal *et al.,* 2012; Li and Cao, 2010).

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The growing burden of stress-related disorders, cognitive decline, and sleep disturbances has intensified interest in food-based interventions that support neurological health. Functional foods, particularly those modulating the gut-brain axis, are emerging as attractive tools in nutritional neuroscience (Auteri *et al.,* 2015). Fermented rice, with its traditional acceptability and scientifically validated bioactives, stands out as a promising candidate for next-generation neuro-nutritional solutions.

This review aims to explore the biochemical mechanisms of GABA synthesis in fermented rice, critically examine its role in supporting brain and nerve health, and present evidence-based insights into its application as a functional food in modern health contexts.

2. Fermentation of rice

Fermentation is a process in which microorganisms or enzymes cause desirable biochemical changes in food or beverages (Blandino *et al*., 2003). Fermented rice contains a rich array of health-promoting bioactive compounds including phenolics, GABA, vitamins, enzymes, phytosterols, saponins, polysaccharides, biogenic amines, isoflavones and resistant starch produced by microbial enzymatic activity (Agista *et al.,* 2022). Epidemiological studies indicate that the health benefits of rice are due to the additive/synergistic effects of several bioactive compounds. Various processing techniques including parboiling, steaming, soaking, atmospheric conditions and chemical inputs influence the bioactive present in rice (Goufo and Trindade, 2016).

3. GABA in fermented rice: Origins and Biochemistry

Gamma-aminobutyric acid (GABA) is a non-proteinogenic amino acid found in various fermented foods and is particularly abundant in fermented rice due to the action of specific lactic acid bacteria

(LAB). Traditional rice fermentation practices, widespread in India and Southeast Asia, inadvertently support the proliferation of GABA-producing microorganisms, enhancing the food's neuro-nutritional potential (Zhang *et al*., 2017).

Fermented rice preparations such as amazake in Japan and khao mak in Thailand have been traditionally consumed for their soothing and revitalizing properties, centuries before γ aminobutyric acid (GABA) were discovered. These time-honored foods highlight ancestral, intuitive recognition of beneficial fermentation effects. Modern biochemical studies confirm that koji-based amazake significantly elevates GABA content in rice-based beverages while metabolomics profiling of khao mak demonstrates complex flavor and microbial transformations consistent with traditional GABA-producing fermentation (Kim *et al*., 2019).

Figure 1: Varieties of rice used in traditional fermentation.

Table 1: Various types of rice and their percentage concentration of GABA

Type of rice	Treatment/fermentation condition	GABA content (mg/100 g)	References
White rice	Germinated (24 h, soaked at 30°C)	18.7	Karladee *et al.,* 2012
Brown rice	Germinated (48 h, aerobic conditions)	32.1*	Karladee *et al.,* 2012
Black rice	Fermented with *Lactobacillus plantarum*	42.6*	Chittrakhani *et al.*, 2022
Germinated brown rice	Soaking/germination (12-120 h, Thai/Indonesian varieties)	75-100	Sitanggang *et al.,* 2021
Brown rice (untreated)	Control (soaking, no incubation)	10.1	Komatsuzaki *et al.,* 2005
Brown rice (large-germ)	Soak 3 h + gaseous CO, incubation 21 h at 35°C	24.9	Komatsuzaki *et al.,* 2005

3.1 Microbial pathways of GABA synthesis

The primary mechanism of GABA synthesis in fermented rice involves the microbial decarboxylation of glutamate *via* the glutamate decarboxylase (GAD) system. This system is particularly active under mildly acidic conditions, which are characteristic of lactic acid fermentation. LAB strains such as *Lactobacillus brevis*, *L. plantarum*, and *L. buchneri* have been widely studied for their high GABA-yielding capacities during rice fermentation (Dhakal *et al.,* 2012; Li and Cao, 2010). The GAD system not only serves a metabolic function but also helps bacteria withstand acidic stress by consuming intracellular protons during GABA synthesis (Siragusa *et al.,* 2007).

3.2 Substrate and rice variety influences

The concentration of glutamic acid in the rice substrate is a limiting factor for GABA biosynthesis. Brown and black rice varieties retain higher levels of glutamate precursors due to their intact bran layers and thus offer better substrates for microbial fermentation (Zhang *et al.,* 2017). Pre-treatment steps such as soaking or mild germination prior to fermentation have also been shown to increase free glutamate levels, leading to a significantly enhanced GABA yield (Komatsuzaki *et al.,* 2007).

3.3 Fermentation conditions

The fermentation of rice is shaped by multiple intrinsic and extrinsic factors that influence microbial activity, metabolite production, and ultimately GABA synthesis. Among these, pH, temperature, and time are crucial. Optimal GABA accumulation typically occurs within a pH range of 4.0-5.5 and temperatures between 30-37°C, which support the maximal activity of glutamate decarboxylase enzymes and microbial metabolism (Siragusa *et al.,*2007). Fermentation periods of 24 to 48 h are ideal; extended durations may lead to GABA degradation due to proteolysis or shifts in microbial communities (Li and Cao, 2010).

The oxygen availability during fermentation can steer microbial succession and metaboliteoutput. Aerobic conditions favor molds like A. oryzae, while anaerobic settings support LAB and enhanced GABA yield. The microbial strains used such as *Lactobacillus plantarum, Lactobacillus brevis, or Aspergillus oryzae,* vary in their ability to produce GABA through glutamate decarboxylation, affecting bothyield and flavor (Wang *et al.,* 2023).

Pre-fermentation steps like soaking can significantly impact outcomes. Soaking rice in warm, slightly acidic water improves substrate availability, activates endogenous enzymes, and enhances microbial colonization. Additionally, exogenous addition of MSG has been shown to markedly boost GABA production (Karladee and Suriyong, 2012).

4. Nutritional role of GABA in brain and nerve health

4.1 Stress and anxiety modulation

GABA is the principal inhibitory neurotransmitter in the central nervous system, helping to regulate neuronal excitability and reduce overstimulation. Dietary GABA from fermented foods has been linked to reduced cortisol levels, lower heart rate, and improved stress resilience (Abdou *et al.,* 2006). GABA-enriched rice or fermented drinks may support calmness and mental clarity by modulating the hypothalamic-pituitary-adrenal (HPA) axis (Yamatsu *et al.,* 2015).

4.2 Sleep quality enhancement

Several human studies have shown that oral GABA intake promotes faster sleep onset and better sleep quality. GABA may increase melatonin and serotonin synthesis, both of which are essential for circadian rhythm regulation (Yamatsu *et al.,* 2015). Fermented rice beverages consumed traditionally at night in cultures like Bali have long been associated with improved rest and relaxation (Bair, 2023).

4.3 Mood regulation and cognitive clarity

GABA functions as a neuroactive compound within this gut-brain communication loop. Emerging evidence suggests that fermented foods can improve mood and focus by elevating GABA ergic signaling and reducing systemic inflammation (Auteri *et al.,* 2015). Regular dietary intake of GABA-rich foods may assist in modulating depression and anxiety symptoms by influencing GABA and serotonin pathways (Shabel *et al.,* 2014).

4.4 Neuroprotection and cognitive aging

Oxidative stress, neuroinflammation, and excitotoxicity are key drivers of neurodegenerative diseases. GABA has demonstrated neuroprotective properties by limiting excitatory glutamate-induced damage and regulating calcium influx into neurons (Czapski and Strosznajder, 2021). Though most data are from animal models, fermented rice rich in GABA and polyphenols holds promise for supporting cognitive function and delaying age-related decline.

4.5 Antispasmodic and muscle relaxation effects

Beyond the brain, GABA influences peripheral nervous system activity. Studies on rodent models show that GABA-rich fermented products can relax intestinal smooth muscle, possibly offering relief in stress-induced gut disorders. These antispasmodic properties may also relate to its traditional use in post-labor recovery and convalescence diets in various Indian communities (Filho *et al.,* 2022).

5. Scientific evidence: GABA from fermented rice in human and animal studies

Despite the widespread consumption of fermented rice in traditional diets, systematic scientific validation of its GABA content and neuro functional benefits is still in early stages. However, growing research on both fermented rice products and isolated dietary GABA provides encouraging data on its physiological relevance.

5.1 Evidence from animal studies

Several animal studies have demonstrated that GABA-enriched fermented rice improves neurological and metabolic functions. For instance, GABA-enriched brown rice fermented with *Lactobacillus reuteri* significantly reduced oxidative stress markers and improved behavioral outcomes in mice models subjected to fatigue and anxiety stress (Tyagi *et al.,* 2021).

In rodent models, dietary GABA exerts substantial antiobesity and hepatoprotective effects. In high-fat diet (HFD)induced obese mice, GABA supplementation significantly reduced body weight gain and adiposity, improved serum lipid profiles, and activated lipolytic pathways including PKA-UCP1-mediated browning of white adipose tissue (Jin *et al*., 2024).

Separately, GABA or GABA enriched fermented *Curcuma longa* extract enhanced AMPK/SIRT1 signaling, attenuated hepatic steatosis, and suppressed inflammation-related pathways in obese mice (Chen *et al.,* 2022).

In avian models, GABA supplementation in broiler chickens fed a high fat diet reduced liver and serum triglyceride accumulation, upregulated β oxidation gene expression, enhanced antioxidant capacity, and modulated gut microbiota composition (Chen *et al.,* 2022).

5.2 Evidence from human studies

Direct studies on GABA-rich fermented rice in humans remain limited. However, trials using GABA-enriched functional foods have shown measurable effects on stress reduction, sleep quality, and immune modulation:

Abdou *et al.* (2006) showed that 100 mg/day of GABA significantly decreased anxiety and increased alpha brain waves within an hour of oral administration.

Yamatsu *et al*. (2015) reported improved sleep onset and duration in participants consuming GABA combined with *Apocynum venetum* extract.

In a small-scale clinical study from Japan, fermented brown rice with naturally elevated GABA levels improved subjective sleep quality scores over four weeks. While these studies affirm GABA's functional potential, they are often conducted with isolated GABA or non-rice sources, limiting their direct application to fermented rice beverages. The lack of standardization, variation in GABA content, and limited bioavailability data remain key limitations (Shin *et al*., 2018).

Although, GABA has shown promising effects on stress, sleep, and cognitive functions, most human studies are based on isolated GABA supplements or non-rice-based formulations. Direct clinical trials involving fermented rice remain scarce, and the GABA content across different preparations varies significantly. As a result, drawing strong conclusions about its functional benefits from current evidence may lead to overstatements. More controlled human studies using standardized, fermented rice products are essential to validate its efficacy (Shin *et al.,* 2018).

5.3 GABA bioavailability and dose-response

The effectiveness of dietary GABA depends not only on its concentration in food but also on its absorption and physiological action. While GABA's ability to cross the blood–brain barrier remains limited, it may still exert benefits through peripheral mechanisms such as gut-brain signaling and autonomic modulation. Reported functional doses in humans typically range from 10 mg to 100 mg per day, but the actual bioavailable fraction from fermented rice is yet to be clearly quantified. These gaps highlight the importance of bioavailability studies and dose-response trials to support functional claims and guide formulation of GABA-enriched rice products (Czapski and Strosznajder, 2021).

6. Technological strategies to enhance GABA in fermented rice

6.1 Starter cultures over spontaneous fermentation

Targeted use of GABA-producing LAB like *Lactobacillus brevis*, *L. plantarum*, and *L. buchneri* significantly increases GABA yield compared to traditional wild fermentations (Dhakal *et al.,* 2012; Li and Cao, 2010).

6.2 Substrate optimization

Germinated or pigmented rice varieties such as black and red rice possess higher levels of glutamate, improving microbial conversion to GABA (Zhang *et al.,* 2017). Addition of glutamate-rich substrates, such as seaweed extract, also boosts GABA synthesis (Siragusa *et al.*, 2007).

6.3 Fermentation control

Controlled fermentation conditions, pH 4.0-5.5, 30-37°C, and 24-48 h, are shown to optimize GABA biosynthesis in multiple studies (Siragusa *et al.,* 2007; Komatsuzaki *et al.,* 2007).

6.4 Co-fermentation approaches

Combining rice with legumes such as soyabean or prebiotic-rich components like rice bran or fruit peel has demonstrated synergistic increases in bioactive yield and probiotic activity (Agista *et al.,* 2022).

6.5 Post-fermentation processing

Low-temperature drying and freeze-drying techniques help retain GABA post-fermentation, while microencapsulation using maltodextrin or alginate can preserve functionality during shelf-life (Li and Cao, 2010).

7. Future applications of GABA-enriched fermented rice

7.1 Functional beverages

Japan and South Korea already market GABA-labeled drinks for stress and relaxation. India has a significant opportunity to innovate culturally rooted, science-backed fermented rice beverages for similar markets. (Food Navigator Asia, 2022).

7.2 Clinical and personalized nutrition

Given GABA's role in neuroinflammation and stress modulation, fermented rice could be incorporated into medical nutrition therapy for conditions like anxiety, insomnia, and neurodegeneration (Czapski and Strosznajder, 2021).

7.3 Fortified everyday foods

Instant porridges or meal replacers made from fermented rice could provide daily neurological support with minimal dietary disruption, especially for working professionals and students (Auteri *et al.,* 2015).

7.4 Elderly nutrition

A germinated brown rice-based beverage enriched with GABA (42.12 mg/100/ g) was specifically designed to be elderly-friendly in texture, digestibility, and flavor. It demonstrated strong antioxidant properties and sensory acceptability, highlighting its suitability for cognitive and immune support in older individuals (Jabeen *et al*., 2024).

7.5 Global commercialization potential

Global commercialization of GABA-enriched rice has expanded significantly, particularly in Japan where the Foods with Function Claims (FFC) policy has accelerated the development of functional grain products. Clinical evidence supports this trend: A randomized trial demonstrated that GABA-enriched white rice delivering approximately 11.2 mg GABA 100 g significantly reduced morning systolic blood pressure in mildly hypertensive individuals after 8 weeks of consumption (Mabunga *et al.,* 2015). The natural accumulation of GABA during rice germination has been well-documented, with soaking conditions optimized to enhance GABA levels (Saikusa *et al.,* 1994).

From a nutraceutical and supplement perspective, enzymatically extracted GABA from rice germ such as in ORYZA's GABA GERMs, achieves extremely high concentrations (300-400 mg 100/ g), making it suitable for formulation into capsules and functional beverages (Kawakami *et al.,* 2018). These developments highlight how GABA-rich rice has moved from experimental settings to real-world applications, supported by both functional food regulations and robust scientific validation.By combining indigenous knowledge and fermentation technology, fermented rice can enter the global stage as an ethno-functional product with real health benefits, if backed by clinical trials and standardization (Jane, 2022).

8. Comparative perspective with other GABA-enriched functional foods

Beyond fermented rice, several functional foods such as natto, yogurt, kimchi, and germinated grains like barley and buckwheat have also been identified as rich sources of dietary GABA. While soy-based or dairy-based fermented products often exhibit higher GABA concentrations, rice-based substrates offer unique advantages in terms of digestibility, hypo allergenicity, and cultural acceptance, particularly across South and Southeast Asia. In contrast to legume or milk-based carriers, fermented rice is vegan-friendly, gluten-free, and suitable for diverse age groups. Its mild taste and versatility make it ideal for incorporation into porridges, beverages, and nutraceutical formulations. These features position fermented rice as a promising, scalable GABA-delivery platform in both traditional diets and modern functional food markets (Ngo and Vo, 2019; Agista *et al.,* 2022).

9. Conclusion

Fermented rice, deeply rooted in Indian and Southeast Asian culinary traditions, is emerging as a powerful neuro-nutritional food through its enrichment with gamma-aminobutyric acid (GABA) and other bioactive compounds. Its ability to modulate stress, support sleep, and promote cognitive resilience positions it uniquely in the landscape of functional foods targeting the gut-brain axis. Advances in microbial fermentation, starter culture development, and substrate engineering now allow for the controlled enhancement of GABA content in fermented rice, bridging traditional knowledge with modern scientific validation.

Despite promising findings from both animal and early human studies, clinical trials specifically involving fermented rice products are still limited. Addressing standardization, bioavailability, and long-term safety will be essential for its translational success. With increasing consumer demand for clean-label, natural, and culturally relevant wellness foods, GABA-enriched fermented rice holds untapped potential as a scalable, sustainable solution for mental and neurological well-being.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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