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Exploring the gut–brain axis: Fermented foods as a nutritional strategy for mental health

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Abstract
Mental health disorders, including depression, anxiety, and stress-related illnesses, have emerged as significant global public health concerns. Recent advances in neuroscience, microbiology, and nutritional science have highlighted the importance of the gut–brain axis (GBA), a bidirectional communication network connecting the gastrointestinal tract and the central nervous system. The gut microbiota plays a crucial role in regulating neurological function through neural, endocrine, immune, and metabolic pathways. Alterations in gut microbial composition (dysbiosis) have been associated with several psychiatric and neurodegenerative disorders. Fermented foods, naturally enriched with probiotics, prebiotics, bioactive peptides, vitamins, short-chain fatty acids (SCFAs), and antioxidants, have gained considerable attention as dietary interventions capable of modulating gut microbiota and improving mental health outcomes. Traditional fermented foods such as yogurt, kefir, kimchi, sauerkraut, miso, tempeh, kombucha, fermented vegetables, and fermented dairy products contain beneficial microorganisms that enhance intestinal microbial diversity, reduce inflammation, strengthen gut barrier integrity, and influence neurotransmitter synthesis including serotonin, dopamine, and gamma-aminobutyric acid (GABA). This review summarizes current knowledge regarding the gut–brain axis, mechanisms linking gut microbiota with mental health, the composition and functional properties of fermented foods, clinical evidence supporting their psychological benefits, and future prospects for psychobiotic nutrition. Although increasing evidence supports fermented foods as an effective complementary nutritional strategy for mental well-being, further large-scale randomized controlled trials are required to establish standardized dietary recommendations.

Keywords: Gut–brain axis, fermented foods, probiotics, psychobiotics, gut microbiota, depression, anxiety, mental health, nutrition

Introduction

Mental health disorders affect more than one billion individuals worldwide and contribute substantially to disability, healthcare costs, and reduced quality of life (Arias *et al*., 2022) [3]. Depression and anxiety are among the leading causes of disease burden, while stress-related disorders continue to increase due to urbanization, lifestyle changes, poor dietary habits, and chronic inflammation (Magomedova and Fatima, 2025) [24]. Traditional treatment strategies primarily rely on pharmacological interventions and psychotherapy; however, these approaches often have limited efficacy, side effects, and high relapse rates (Huhn *et al*., 2014) [20]. Consequently, there is growing interest in nutritional interventions that may complement conventional treatments.

The gut microbiota consists of trillions of microorganisms residing in the gastrointestinal tract, including bacteria, viruses, fungi, archaea, and protozoa (Gomaa, 2020) [18]. These microorganisms perform essential physiological functions such as digestion, vitamin synthesis, immune regulation, metabolic homeostasis, and protection against pathogens (Colella *et al*., 2023) [12]. Emerging evidence indicates that gut microorganisms communicate continuously with the central nervous system through the gut–brain axis, influencing cognition, behaviour, emotional regulation, and neurological health (Morais *et al*., 2021) [29].

Fermented foods have been consumed for thousands of years and represent one of the oldest methods of food preservation (Tamang *et al*., 2020) [45]. Besides improving food safety and sensory characteristics, fermentation increases nutritional value by producing beneficial microorganisms and bioactive compounds (Sharma *et al*., 2020) [43]. Modern research has demonstrated that regular consumption of fermented foods may positively influence gut microbial diversity, reduce systemic inflammation, and enhance mental well-being through modulation of the gut–brain axis (Selhub *et al*., 2014) [50]. This review provides an updated overview of current evidence regarding fermented foods as a promising nutritional strategy for promoting mental health.

The Gut–Brain Axis

The gut–brain axis is a sophisticated bidirectional communication network that links the gastrointestinal tract with the central nervous system (CNS), enabling continuous interaction between the gut microbiota and the brain through neural, endocrine, immune, and metabolic pathways (Wang and Wang, 2016) [51]. Its key components include the CNS, the enteric nervous system (ENS), the vagus nerve, the gut microbiota, the hypothalamic–pituitary–adrenal (HPA) axis, the immune system, and a range of neurotransmitters and microbial metabolites (Carabotti *et al*., 2015) [7]. Together, these elements regulate essential physiological processes such as digestion, metabolism, immune function, stress responses, mood, cognition, and behaviour. The vagus nerve serves as a major neural communication pathway, while the HPA axis coordinates the body's response to psychological and physiological stress (Breit *et al.*, 2018) [6]. Gut microorganisms contribute to this communication by producing bioactive compounds, including short-chain fatty acids, serotonin precursors, gamma-aminobutyric acid (GABA), dopamine precursors, and other metabolites that influence neuronal signaling and brain function (Chen *et al.*, 2021) [11]. Additionally, immune mediators such as cytokines facilitate communication between the gut and the brain, highlighting the close relationship between intestinal health and neurological function. Under normal conditions, this integrated system maintains physiological homeostasis and supports mental well-being (Powell *et al.*, 2017) [36]. However, disruptions in gut microbial composition, increased intestinal permeability, chronic inflammation, or dysregulation of the HPA axis can impair gut–brain communication, contributing to the development and progression of psychiatric and neurological disorders, including depression, anxiety, autism spectrum disorder, schizophrenia, Alzheimer's disease, and Parkinson's disease (Marano *et al.*, 2023) [25]. Consequently, maintaining a healthy gut microbiota through dietary interventions, particularly the consumption of fermented foods rich in beneficial microorganisms, has emerged as a promising strategy for supporting gut–brain axis function and improving mental health (Mukherjee *et al.*, 2024) [30].

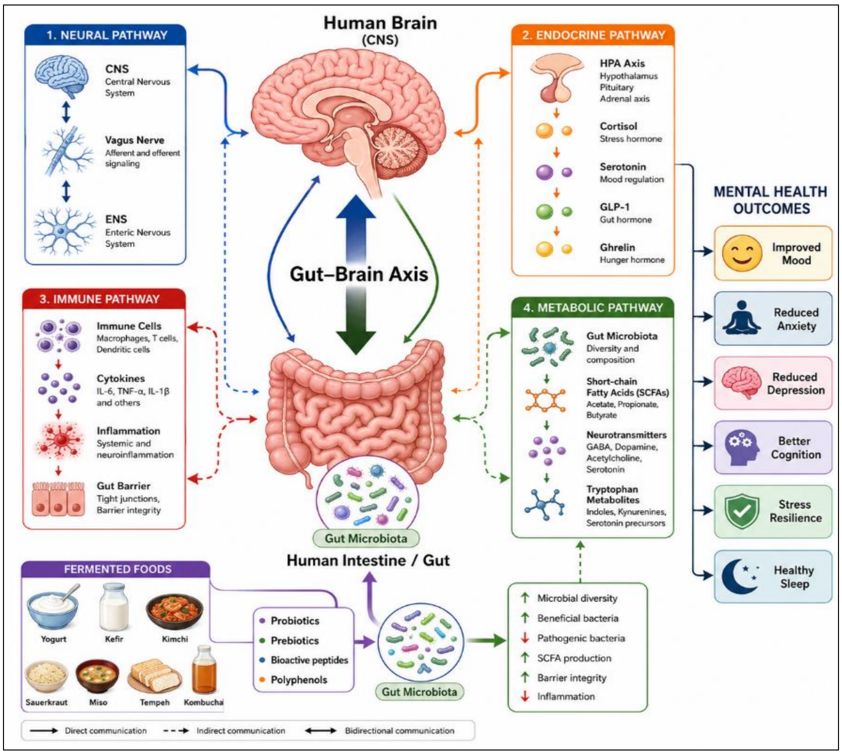

Fig 1: Schematic illustration of the gut–brain axis showing neural, endocrine, immune, and metabolic communication pathways

Mechanisms of Gut–Brain Communication

1. Neural Pathway

The vagus nerve represents the primary neural pathway connecting the gut and brain. Gut microbes stimulate vagal afferent neurons either directly or through microbial metabolites, transmitting signals that regulate emotional behaviour, appetite, stress response, and cognition (Mukherjee *et al.*, 2023).

2. Endocrine Pathway

Gut microbiota influence secretion of hormones including cortisol, serotonin, ghrelin, peptide YY, glucagon-like peptide-1 (GLP-1), and leptin. Dysregulation of the hypothalamic–pituitary–adrenal axis contributes to chronic stress and mood disorders (Neuman *et al.*, 2015) [31].

3. Immune Pathway

Approximately 70% of immune cells reside within the gastrointestinal tract. Dysbiosis promotes intestinal permeability ("leaky gut"), allowing endotoxins such as lipopolysaccharides (LPS) to enter circulation. This stimulates production of inflammatory cytokines including IL-6, IL-1β, and TNF-α, which can cross the blood–brain barrier and impair neuronal function (Di Vincenzo *et al.*, 2024) [13].

4. Microbial Metabolites

Gut microorganisms produce a wide range of bioactive metabolites that play a crucial role in maintaining communication between the gut and the brain (Parker *et al.*, 2020) [34]. Among the most important are short-chain fatty acids (SCFAs), including acetate, propionate, and butyrate, which are generated through the fermentation of dietary fibres and help maintain intestinal barrier integrity, regulate immune responses, and reduce systemic inflammation (Zhang *et al.*, 2023) [54]. The gut microbiota also synthesizes or influences the production of several neurotransmitters and their precursors, including gamma-aminobutyric acid (GABA), serotonin, dopamine, acetylcholine, and various tryptophan metabolites (Mhanna *et al.*, 2024) [28]. These microbial-derived compounds modulate neural signaling by influencing neurotransmitter synthesis, receptor activity, and communication along the gut–brain axis. Additionally, tryptophan metabolites regulate serotonin biosynthesis and activate signaling pathways involved in immune and neuronal function. Collectively, these metabolites promote neurogenesis, enhance synaptic plasticity, support neurotransmission, and suppress neuroinflammation, thereby contributing to cognitive function, emotional regulation, and mental well-being. Alterations in the production or availability of these microbial metabolites due to gut dysbiosis have been associated with several neurological and psychiatric disorders, including depression, anxiety, autism spectrum disorder, and neurodegenerative diseases, highlighting their importance as potential therapeutic targets in nutritional interventions (Rogers *et al*., 2016) [40].

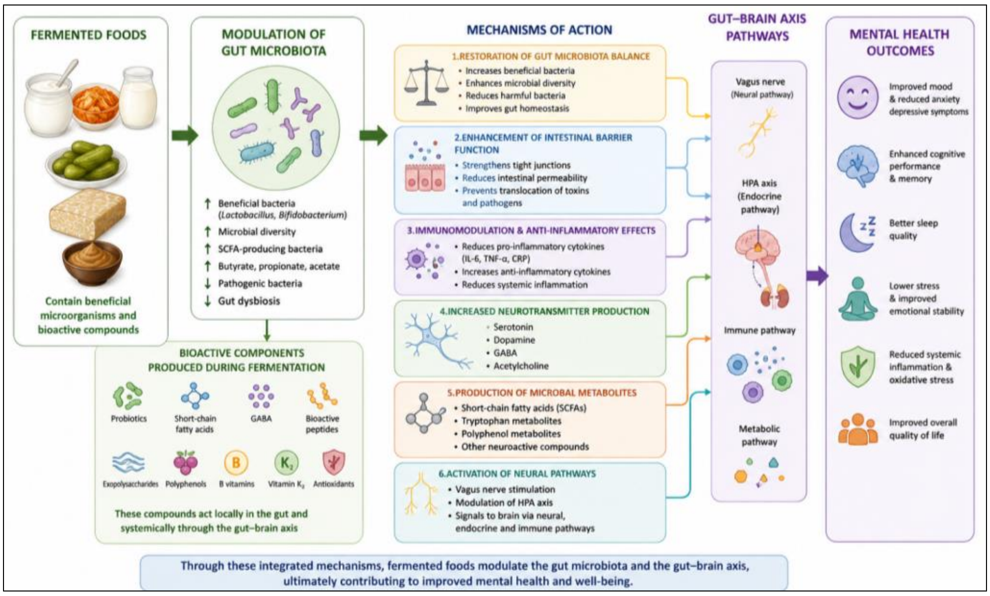

Fig 2: Mechanisms by which fermented foods modulate the gut microbiota and influence mental health outcomes

Gut Microbiota and Mental Health

Numerous studies demonstrate associations between gut microbial imbalance and psychiatric disorders (Nikolova *et al*., 2021) [16].

Depression

Patients with depression often exhibit reduced microbial diversity, decreased abundance of *Faecalibacterium* and *Bifidobacterium*, increased inflammatory markers, and impaired serotonin metabolism (Caspani *et al*., 2019) [9].

Anxiety Disorders

Anxiety is associated with increased intestinal permeability, altered stress hormone secretion, reduced *Lactobacillus* species, and elevated inflammatory cytokines (Marwaha *et al*., 2025) [27].

Autism Spectrum Disorder

Children with autism frequently display gastrointestinal symptoms accompanied by altered gut microbial composition, suggesting microbial involvement in behavioural manifestations (Ristori *et al*., 2019) [39].

Alzheimer's Disease

Microbial dysbiosis contributes to neuroinflammation, amyloid deposition, oxidative stress, and cognitive decline (Liu *et al*., 2020) [23].

Parkinson's Disease

Alterations in intestinal microbiota precede motor symptoms and influence α-synuclein aggregation through inflammatory pathways (Fang *et al*., 2024) [15].

Fermented Foods

Fermented foods are produced through controlled microbial metabolism of carbohydrates, proteins, and lipids by bacteria, yeasts, or molds. Fermentation improves food preservation, digestibility, nutrient bioavailability, flavour, and functional properties (Sharma *et al*., 2010).

Major Types

Fermented Food	Major Microorganisms	Functional Components
Yogurt	*Lactobacillus, Streptococcus*	Probiotics, peptides
Kefir	Lactic acid bacteria, yeast	SCFAs, vitamins
Kimchi	*Lactobacillus plantarum*	Polyphenols, probiotics
Sauerkraut	Lactic acid bacteria	Vitamin C, probiotics
Tempeh	*Rhizopus oligosporus*	Isoflavones
Miso	*Aspergillus oryzae*	Peptides
Natto	*Bacillus subtilis*	Vitamin K_2
Kombucha	Yeasts, acetic acid bacteria	Organic acids

Bioactive Components Produced During Fermentation

The fermentation process enhances the nutritional and functional properties of foods by generating a diverse range of bioactive compounds that contribute to gut health and neurological function (Inmyoung and Mannaa *et al*., 2025) [21]. Beneficial microorganisms involved in fermentation produce probiotics that help maintain a balanced gut microbiota, strengthen intestinal barrier function, and inhibit the growth of pathogenic bacteria (Chandrasekaran *et al*., 2024) [10]. Fermented foods also contain prebiotics and fermentation-derived substrates that selectively stimulate the growth of beneficial microbes, thereby increasing microbial diversity and metabolic activity (Inmyoung and Mannaa, 2025) [21]. Among the most important microbial metabolites are short-chain fatty acids (SCFAs), including acetate, propionate, and butyrate, which regulate immune responses, reduce intestinal and systemic inflammation, maintain epithelial integrity, and influence brain function through the gut–brain axis. Certain lactic acid bacteria synthesize gamma-aminobutyric acid (GABA), an inhibitory neurotransmitter that plays a crucial role in reducing anxiety, promoting relaxation, and maintaining emotional balance. Fermentation also releases bioactive peptides through the enzymatic breakdown of food proteins; these peptides exhibit antioxidant, antihypertensive, antimicrobial, immunomodulatory, and neuroprotective properties. Additionally, many probiotic microorganisms produce exopolysaccharides, which enhance gut microbial colonization, improve intestinal barrier integrity, and modulate immune responses. The fermentation process further increases the bioavailability of polyphenols by converting them into more absorbable forms with enhanced antioxidant and anti-inflammatory activities. Fermented foods are also rich sources of essential micronutrients, including B-complex vitamins such as folate, riboflavin, niacin, pyridoxine, and vitamin B_{12}, which are involved in neurotransmitter synthesis, energy metabolism, and cognitive function (Rastogi *et al*., 2024) [37]. Certain fermented products, particularly those produced by *Bacillus* species, are excellent sources of vitamin K_2 (menaquinone), an important nutrient for bone health, vascular function, and emerging aspects of neurological health. Furthermore, fermentation increases the concentration and bioavailability of natural antioxidants, which help neutralize reactive oxygen species, reduce oxidative stress, and protect neuronal cells from damage. Collectively, these bioactive components work synergistically to enhance gut microbial diversity, regulate immune and inflammatory pathways, improve intestinal and blood–brain barrier integrity, support neurotransmitter production, and promote cognitive function and mental well-being, making fermented foods an important component of therapeutic nutrition targeting the gut–brain axis (Ashique *et al*., 2024) [37].

Mechanisms by Which Fermented Foods Influence Mental Health

1. Restoration of Gut Microbial Balance

The restoration of a healthy gut microbial balance is one of the primary mechanisms through which fermented foods promote mental health via the gut–brain axis. Regular consumption of fermented foods introduces beneficial microorganisms, particularly species of *Lactobacillus*, *Bifidobacterium*, *Streptococcus*, and certain yeasts, which help maintain a diverse and stable intestinal microbial ecosystem (Fassarella *et al*., 2021) [16]. These probiotics compete with pathogenic microorganisms for nutrients and adhesion sites, produce antimicrobial compounds such as bacteriocins and organic acids, and lower intestinal pH, thereby suppressing the growth of harmful bacteria. As a result, microbial diversity and abundance of beneficial bacteria increase, enhancing the overall resilience and stability of the gut microbiome. A balanced gut microbiota also improves the fermentation of dietary fibers, leading to increased production of short-chain fatty acids (SCFAs), including acetate, propionate, and butyrate, which strengthen the intestinal barrier, regulate immune function, and reduce systemic inflammation. Furthermore, restoration of microbial homeostasis supports the synthesis of neuroactive compounds, including serotonin precursors, gamma-aminobutyric acid (GABA), and other metabolites that facilitate communication along the gut–brain axis. By preventing dysbiosis, reducing colonization by pathogenic microorganisms, and promoting intestinal resilience, fermented foods contribute to improved gut health, enhanced immune regulation, and optimal gut–brain signaling. These combined effects may reduce the risk of stress-related disorders, anxiety, depression, and cognitive dysfunction, supporting the role of fermented foods as an important component of therapeutic nutrition for mental health (Ansari *et al*., 2020) [2].

2. Increased Neurotransmitter Production

One of the most important mechanisms through which fermented foods influence mental health is by enhancing the production and regulation of neurotransmitters through the activity of beneficial gut microorganisms (Shawky *et al*., 2025) [44]. Several probiotic strains, particularly species of *Lactobacillus* and *Bifidobacterium*, are capable of synthesizing or modulating neuroactive compounds, including serotonin, dopamine, gamma-aminobutyric acid (GABA), and acetylcholine (Wall *et al*., 2014) [50]. Although most serotonin is produced in the gastrointestinal tract, gut microbes regulate its synthesis by influencing the metabolism of tryptophan, the essential amino acid precursor of serotonin, thereby indirectly affecting brain function and emotional well-being. GABA, the primary inhibitory neurotransmitter in the central nervous system, is produced by certain lactic acid bacteria and plays a critical role in reducing neuronal excitability, alleviating anxiety, promoting relaxation, and improving sleep quality. Similarly, microbial modulation of dopamine production contributes to reward processing, motivation, attention, and cognitive performance, while acetylcholine supports learning, memory, and neuromuscular function. These neurotransmitters communicate with the brain through neural pathways such as the vagus nerve, as well as through endocrine and immune signaling mechanisms within the gut–brain axis. In addition to direct neurotransmitter production, probiotic microorganisms influence the expression of neurotransmitter receptors, regulate synaptic plasticity, and promote the release of neurotrophic factors such as brain-derived neurotrophic factor (BDNF), which is essential for neuronal growth, learning, and memory (Nisa *et al*., 2025) [33]. By enhancing neurotransmitter synthesis and maintaining neurochemical balance, fermented foods may contribute to improved mood, emotional stability, cognitive function, stress resilience, and sleep quality, supporting their potential role as complementary dietary interventions in the prevention and management of mental health disorders.

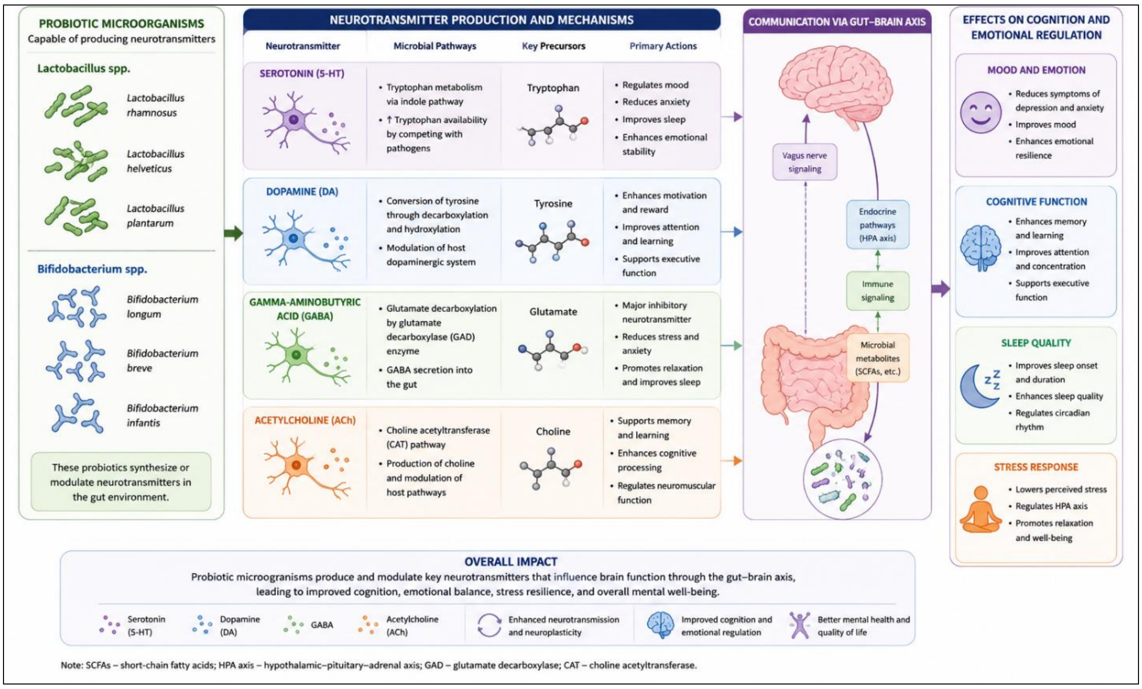

Fig 3: Neurotransmitter production by probiotic microorganisms and their effects on cognition and emotional regulation

3. Reduction of Inflammation

Chronic low-grade inflammation is increasingly recognized as a key contributor to the development and progression of mental health disorders through its effects on the gut–brain axis (Serra *et al*., 2019) [42]. Dysbiosis of the gut microbiota can increase intestinal permeability, allowing bacterial endotoxins such as lipopolysaccharides (LPS) to enter systemic circulation and trigger the release of pro-inflammatory cytokines, including tumor necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), and interleukin-1 beta (IL-1β) (Peña-Durán *et al*., 2025) [35]. These inflammatory mediators can cross or alter the permeability of the blood–brain barrier, activate microglial cells, and promote neuroinflammation, ultimately impairing neurotransmitter synthesis, synaptic plasticity, and neuronal function (Gu *et al*., 2021) [29]. Fermented foods rich in probiotic microorganisms help counteract these processes by restoring a healthy gut microbial balance, strengthening the intestinal barrier, and modulating immune responses. Beneficial bacteria, particularly *Lactobacillus* and *Bifidobacterium* species, enhance the production of anti-inflammatory metabolites such as short-chain fatty acids (SCFAs), especially butyrate, which suppress inflammatory signaling pathways and promote the release of anti-inflammatory cytokines while reducing circulating levels of TNF-α, IL-6, and C-reactive protein (CRP) (Markowiak-Kopeć and Śliżewska, 2020) [26]. In addition, fermented foods are rich in antioxidants, polyphenols, bioactive peptides, and vitamins that neutralize reactive oxygen species, decrease oxidative stress, and protect neuronal cells from oxidative damage (do Prado *et al*., 2022) [14]. Through these combined anti-inflammatory and antioxidant mechanisms, fermented foods improve immune regulation, reduce systemic and neuroinflammation, preserve neuronal integrity, and support healthy gut–brain communication, thereby contributing to improved mood, cognitive function, and overall psychological well-being (Zang *et al*., 2026) [53].

4. Strengthening the Intestinal Barrier

The intestinal barrier plays a crucial role in maintaining gut homeostasis by preventing the passage of harmful microorganisms, toxins, and inflammatory molecules from the intestinal lumen into the bloodstream while allowing the selective absorption of nutrients (Di Vincenzo *et al*., 2024) [13]. This barrier is primarily maintained by epithelial cells connected through tight-junction proteins, including occludin, claudins, and zonula occludens (ZO) proteins. Disruption of these tight junctions leads to increased intestinal permeability, commonly referred to as "leaky gut," which permits the translocation of bacterial endotoxins such as lipopolysaccharides (LPS) into systemic circulation. The resulting activation of immune responses promotes the release of pro-inflammatory cytokines that contribute to systemic inflammation, neuroinflammation, and dysfunction of the gut–brain axis, thereby increasing the risk of depression, anxiety, and other neuropsychiatric disorders (Warren *et al*., 2024) [52]. Fermented foods rich in probiotic microorganisms, particularly *Lactobacillus* and *Bifidobacterium* species, help preserve intestinal barrier integrity by enhancing the expression of tight-junction proteins, stimulating mucus production, promoting epithelial cell repair, and increasing the production of short-chain fatty acids (SCFAs), especially butyrate, which serves as the primary energy source for colonocytes. These beneficial effects reduce intestinal permeability, inhibit the translocation of inflammatory endotoxins into systemic circulation, and suppress excessive immune activation. By maintaining a healthy intestinal barrier and limiting chronic inflammation, fermented foods support effective gut–brain communication and contribute to improved neurological function, emotional regulation, and overall mental health (Krishna Rao and Samak, 2013) [22].

5. Regulation of the HPA Axis

The hypothalamic–pituitary–adrenal (HPA) axis is the body's primary neuroendocrine system responsible for coordinating physiological responses to psychological and physical stress. Chronic activation of the HPA axis results in excessive secretion of cortisol, which has been associated with anxiety, depression, cognitive impairment, immune dysregulation, and alterations in gut microbial composition. Emerging evidence suggests that fermented foods may help regulate HPA axis activity by restoring gut microbial balance and enhancing communication along the gut–brain axis. Beneficial microorganisms present in fermented foods, particularly *Lactobacillus* and *Bifidobacterium* species, produce bioactive metabolites such as short-chain fatty acids (SCFAs) and gamma-aminobutyric acid (GABA), which influence vagus nerve signaling, reduce systemic inflammation, and improve intestinal barrier integrity. These effects collectively contribute to normalization of cortisol secretion and attenuation of stress-induced activation of the HPA axis. Experimental and clinical studies have shown that regular consumption of probiotic-rich fermented foods may lower circulating cortisol levels, enhance resilience to psychological stress, reduce anxiety-related behaviours, and improve emotional stability. By modulating neuroendocrine, immune, and microbial interactions, fermented foods may therefore serve as a valuable complementary dietary strategy for maintaining HPA axis homeostasis and supporting overall mental health.

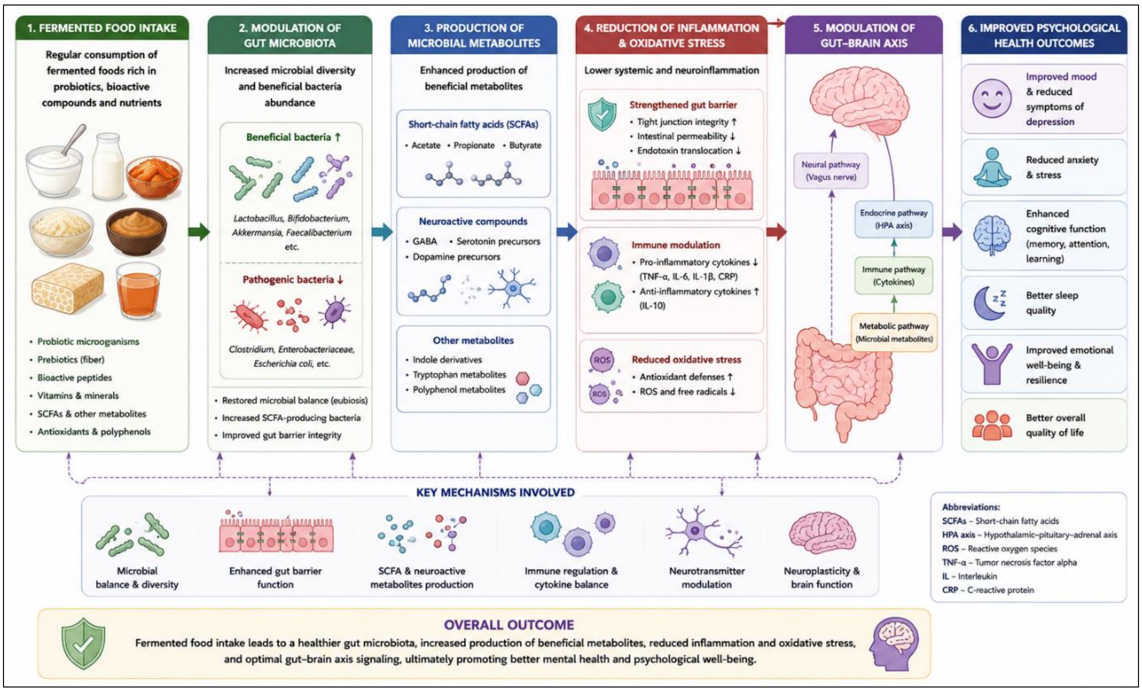

Fig 4: Proposed pathway linking fermented food intake, gut microbiota modulation, reduced inflammation, and improved psychological health

Psychobiotics

Psychobiotics are a specialized class of live microorganisms that, when administered in adequate amounts, confer mental health benefits by modulating the gut–brain axis and influencing communication between the gastrointestinal tract and the central nervous system. These beneficial microbes exert their effects through multiple mechanisms, including restoration of gut microbial balance, enhancement of intestinal barrier integrity, regulation of immune and inflammatory responses, production of neuroactive compounds, and modulation of neurotransmitter synthesis. Among the most extensively studied psychobiotic strains are *Lactobacillus rhamnosus*, *Lactobacillus helveticus*, *Lactobacillus plantarum*, *Bifidobacterium longum*, *Bifidobacterium breve*, and *Bifidobacterium infantis*. These microorganisms have demonstrated the ability to produce or influence the synthesis of gamma-aminobutyric acid (GABA), serotonin precursors, dopamine precursors, short-chain fatty acids, and other microbial metabolites that regulate neuronal signaling, neuroplasticity, and stress responses. In addition, psychobiotics can modulate the hypothalamic–pituitary–adrenal (HPA) axis, reduce circulating pro-inflammatory cytokines, decrease oxidative stress, and stimulate vagus nerve signaling, thereby contributing to improved emotional and cognitive function. Clinical studies and randomized controlled trials have reported that supplementation with specific psychobiotic strains or regular consumption of psychobiotic-rich fermented foods may reduce symptoms of anxiety and depression, alleviate psychological stress, improve mood, enhance cognitive performance and memory, support better sleep quality, and increase resilience to stress. Although the findings are promising, the therapeutic effectiveness of psychobiotics depends on factors such as microbial strain specificity, dosage, treatment duration, host microbiota composition, and individual health status. Therefore, while psychobiotics represent a promising adjunctive strategy in therapeutic nutrition and mental healthcare, further large-scale, well-designed clinical trials are required to establish standardized treatment protocols and confirm their long-term efficacy and safety in the prevention and management of psychiatric and neurodegenerative disorders.

Clinical Evidence

A growing number of randomized controlled trials (RCTs) and systematic reviews provide encouraging evidence that fermented foods may contribute to improved mental health by modulating the gut–brain axis and restoring a healthy gut microbiota (Zhang *et al*., 2024) [55]. Clinical studies have reported that regular consumption of fermented foods, including yogurt, kefir, kimchi, fermented milk products, and other probiotic-rich foods, is associated with reductions in depressive symptoms, improvements in anxiety scores, lower perceived stress levels, enhanced emotional resilience, and better overall psychological well-being. Several interventions have also demonstrated improvements in cognitive performance, including attention, memory, executive function, and cognitive flexibility, particularly among individuals experiencing chronic stress or mild cognitive impairment. Furthermore, fermented food consumption has been linked to improved sleep quality, possibly through enhanced production of neuroactive compounds such as gamma-aminobutyric acid (GABA) and serotonin precursors that regulate circadian rhythms and emotional balance. Beyond psychological outcomes, clinical trials have shown that fermented foods can reduce systemic inflammation by lowering circulating inflammatory biomarkers such as C-reactive protein (CRP), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF-α), while simultaneously increasing gut microbial diversity and promoting the growth of beneficial bacterial genera, including *Lactobacillus* and *Bifidobacterium*. These microbiome changes are often accompanied by improved intestinal barrier integrity, enhanced production of short-chain fatty acids, and better immune regulation, collectively contributing to improved overall quality of life. Nevertheless, despite these promising findings, the current body of evidence remains heterogeneous. Considerable variability exists in probiotic strains, microbial viability, fermentation methods, food matrices, intervention duration, dosage, participant age, baseline health status, dietary habits, and outcome assessment tools, making direct comparisons across studies challenging. Additionally, many trials involve relatively small sample sizes and short follow-up periods, limiting the ability to establish long-term efficacy and causality. Consequently, future research should prioritize large, well-designed, multicenter randomized controlled trials with standardized fermented food formulations, clearly defined probiotic compositions, and consistent clinical outcome measures to better determine the therapeutic potential of fermented foods in the prevention and management of mental health disorders (Ribeiro and Vieira, 2025) [38].

Fermented Foods and Neurotransmitter Production (Casertano *et al*., 2022) [8]

Neurotransmitter	Function	Fermented Food Source
Serotonin	Mood regulation	Yogurt, kefir
GABA	Anxiety reduction	Kimchi, fermented vegetables
Dopamine	Motivation	Fermented soy products
Acetylcholine	Memory	Fermented dairy products

Factors Affecting the Efficacy of Fermented Foods

The therapeutic effects of fermented foods on mental health are influenced by numerous biological, dietary, and environmental factors that determine their ability to modulate the gut microbiota and the gut–brain axis (Aslam *et al*., 2020) [34]. One of the most important determinants is microbial strain specificity, as different probiotic strains possess distinct functional properties, including their ability to produce neurotransmitters, generate short-chain fatty acids, regulate immune responses, and survive passage through the gastrointestinal tract (Fijan, 2014) [17]. The duration of fermentation also affects the nutritional quality of fermented foods by influencing the concentration of beneficial microorganisms, bioactive peptides, vitamins, organic acids, and other metabolites (Uhegwu and Anumudu, 2025) [48]. Similarly, storage conditions, including temperature, packaging, oxygen exposure, and storage duration, can significantly affect the viability and stability of probiotic microorganisms and their bioactive compounds (Terpou *et al*., 2019) [46]. The food matrix, or the physical and chemical composition of the fermented food, influences microbial survival during digestion and the bioavailability of health-promoting compounds, with dairy, cereal, vegetable, and soy-based products differing in their protective effects on probiotic viability (Valero-Cases *et al*., 2020) [49]. Individual differences in gut microbiota composition are another critical factor, as the baseline microbial community determines colonization success and the host's response to fermented food consumption. In addition, dietary habits strongly influence gut microbial diversity; diets rich in dietary fibre, fruits, vegetables, and whole grains generally enhance the beneficial effects of fermented foods, whereas highly processed diets may diminish these benefits. The use of antibiotics can disrupt the gut microbial ecosystem by reducing microbial diversity and eliminating beneficial bacteria, thereby altering the effectiveness of probiotic interventions. Host-related factors such as age also play an important role because the composition and stability of the gut microbiota change throughout life, affecting microbial resilience and responsiveness to dietary modulation. Furthermore, genetic factors influence immune regulation, metabolism, intestinal barrier function, and host–microbe interactions, contributing to individual variability in treatment outcomes. Finally, lifestyle factors, including physical activity, sleep quality, psychological stress, smoking, alcohol consumption, and environmental exposures, interact with dietary habits to shape the gut microbiome and influence mental health. Collectively, these factors highlight the complexity of fermented food interventions and emphasize the need for personalized nutritional strategies to maximize their therapeutic potential in supporting the gut–brain axis and improving psychological well-being (Almahal *et al*., 2025) [1].

Challenges and Limitations

Despite the growing evidence supporting the beneficial effects of fermented foods on mental health through modulation of the gut–brain axis, several challenges and limitations hinder their translation into routine clinical practice. One of the primary limitations is the scarcity of large-scale, long-term human clinical trials, with many existing studies involving small sample sizes, short intervention periods, and heterogeneous study populations. Furthermore, there is currently no consensus regarding the most effective probiotic strains, microbial combinations, or dosages for improving specific mental health outcomes, making comparisons across studies difficult. Considerable variability also exists among fermented food products due to differences in raw materials, microbial cultures, fermentation conditions, storage practices, and processing methods, all of which can influence the viability of beneficial microorganisms and the concentration of bioactive compounds. In addition, manufacturing techniques and post-fermentation treatments, such as pasteurization, may reduce or eliminate live probiotic microorganisms, thereby affecting their therapeutic potential. Another important challenge is the marked inter-individual variability in gut microbiota composition, which influences how different individuals respond to fermented food interventions. Factors such as genetics, age, diet, lifestyle, medication use, geographic location, and existing health conditions contribute to these differences and may affect treatment efficacy. Moreover, establishing direct causal relationships between fermented food consumption and improvements in mental health remains difficult because psychological well-being is influenced by numerous interacting biological, environmental, and social factors. Confounding variables, including overall dietary quality, physical activity, stress levels, sleep patterns, and concurrent medical treatments, further complicate the interpretation of study findings. Addressing these limitations through standardized research methodologies, well-designed randomized controlled trials, and personalized microbiome-based approaches will be essential to strengthen the evidence base and support the integration of fermented foods into therapeutic nutrition for mental health.

Future Perspectives

The growing body of evidence linking fermented foods, the gut microbiome, and mental health highlights several promising directions for future research and clinical application. One of the most important areas is the development of personalized nutrition strategies based on individual gut microbiome profiles, recognizing that variations in microbial composition may influence responses to dietary interventions. Advances in precision medicine are also expected to facilitate the development of psychobiotic therapies that utilize specific probiotic strains, fermented foods, or microbial metabolites tailored to prevent or manage particular psychiatric conditions. The integration of multi-omics technologies—including microbiomics, metabolomics, transcriptomics, proteomics, and nutrigenomics—will provide a more comprehensive understanding of host–microbiome interactions and identify novel biomarkers associated with mental health outcomes. Furthermore, large-scale, long-term randomized controlled clinical trials involving diverse populations are essential to establish causal relationships, determine optimal dosages and intervention durations, and evaluate the long-term safety and efficacy of fermented foods in therapeutic nutrition. Standardization of fermented food production, including microbial composition, probiotic viability, and bioactive compound content, will be critical for ensuring product consistency, reproducibility, and reliable clinical outcomes. Future research should also focus on developing functional fermented foods enriched with targeted probiotic strains or bioactive compounds designed to address specific psychiatric disorders such as depression, anxiety, autism spectrum disorder, schizophrenia, and stress-related conditions. In addition, expanding investigations into the role of fermented foods in neurodegenerative diseases, including Alzheimer's disease, Parkinson's disease, and multiple sclerosis, may reveal novel dietary strategies for delaying disease progression and preserving cognitive function. Finally, integrating fermented foods into public health nutrition policies and dietary guidelines represents an important opportunity to promote mental wellness, reduce the burden of psychiatric disorders, and encourage preventive healthcare through accessible, culturally appropriate, and evidence-based nutritional interventions. Continued collaboration among nutrition scientists, microbiologists, neuroscientists, psychiatrists, clinicians, and food technologists will be essential for translating emerging research into practical therapeutic and public health applications.

Conclusion

The gut–brain axis represents a transformative concept in understanding the intricate relationship between nutrition, intestinal microbiota, and mental health. Growing evidence indicates that fermented foods are more than traditional dietary components; they function as natural carriers of probiotics, bioactive peptides, short-chain fatty acids, vitamins, and antioxidants that positively influence gut microbial composition and brain function. Through modulation of neural, endocrine, immune, and metabolic pathways, fermented foods may reduce inflammation, enhance neurotransmitter synthesis, strengthen gut barrier integrity, and improve psychological well-being. Emerging research on psychobiotics further supports the therapeutic potential of specific probiotic strains in alleviating symptoms of depression, anxiety, stress, and cognitive impairment. While current evidence is promising, additional large-scale, well-designed clinical trials are needed to determine optimal strains, doses, and dietary recommendations. Incorporating fermented foods into a balanced diet represents a safe, affordable, and sustainable nutritional strategy that may complement conventional therapies and contribute to improved mental health across diverse populations.

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