

## THE ROLE OF FERMENTED CEREALS IN THE MODULATION OF THE INTESTINAL MICROBIOTA AND THEIR BENEFITS TO HUMAN HEALTH

### O PAPEL DOS CEREAIS FERMENTADOS NA MODULAÇÃO DA MICROBIOTA INTESTINAL E SEUS BENEFÍCIOS À SAÚDE HUMANA

### EL PAPEL DE LOS CEREALES FERMENTADOS EN LA MODULACIÓN DE LA MICROBIOTA INTESTINAL Y SUS BENEFICIOS PARA LA SALUD HUMANA



<https://doi.org/10.56238/sevenced2026.008-032>

**Luciene dos Santos Sobczak<sup>1</sup>, Jessyca Caroline Rocha Ribas<sup>2</sup>, Leandra da Silva Florentino<sup>3</sup>, Isabela Lima Quadros<sup>4</sup>, Luciana Alves da Silva<sup>5</sup>, Renan Gustavo Rodrigues da Luz<sup>6</sup>, Okelyton Ayres Pacheco<sup>7</sup>, Samara Thais Peixoto de Oliveira<sup>8</sup>**

#### ABSTRACT

Fermented cereals have emerged as functional foods capable of modulating the gut microbiota and promoting significant health benefits. Fermentation enhances grain digestibility, increases the bioavailability of bioactive compounds, enriches the food matrix with probiotic microorganisms, and intensifies the production of metabolites such as short-chain fatty acids (SCFAs). These metabolites play a key role in intestinal barrier integrity, immune regulation, energy metabolism, and gut–brain axis communication. This review discusses the role of fermented cereals in microbiota modulation, the mechanisms underlying microbial and metabolite activity, and their impact on metabolic, immune, and gastrointestinal health. The evidence evaluated in this review indicates that fermented cereal-based products may contribute to chronic disease prevention, improved digestion, balanced microbiota, and enhanced intestinal function.

**Keywords:** Cereal-Based Fermented Foods. Intestinal Ecosystem. Lactic Acid Bacteria. Bioactive Compounds. Microbial Metabolites. Postbiotics.

#### RESUMO

Os cereais fermentados têm ganhado destaque como alimentos funcionais capazes de modular a microbiota intestinal e promover efeitos benéficos à saúde humana. A fermentação melhora a digestibilidade dos grãos, aumenta a biodisponibilidade de compostos bioativos, enriquece o alimento com microrganismos probióticos e intensifica a produção de

<sup>1</sup> Graduated in Nutrition. Universidade Estadual de Maringá. E-mail: [nutrilucienesobczal@gmail.com](mailto:nutrilucienesobczal@gmail.com)

<sup>2</sup> Dr. in Animal Science. Universidade Estadual de Maringá. E-mail: [jrocharibas@gmail.com](mailto:jrocharibas@gmail.com)

<sup>3</sup> Master's degree in Animal Science. Universidade Estadual de Maringá.

E-mail: [leandrasilva.leeh@gmail.com](mailto:leandrasilva.leeh@gmail.com)

<sup>4</sup> Graduated in Nutrition. IES UniFatecie. E-mail: [isabelalimaquadros@gmail.com](mailto:isabelalimaquadros@gmail.com)

<sup>5</sup> Dr. in Food Sciences. Centro Universitário Cidade Verde (UNICV).

E-mail: [prof.luciana.alvesdasilva@gmail.com](mailto:prof.luciana.alvesdasilva@gmail.com)

<sup>6</sup> Master's degree in Animal Science. Universidade Estadual de Maringá. E-mail: [renan.zoot@gmail.com](mailto:renan.zoot@gmail.com)

<sup>7</sup> Master's degree in Food Engineering. Universidade Estadual de Maringá. E-mail: [okelyton@gmail.com](mailto:okelyton@gmail.com)

<sup>8</sup> Graduated in Nutrition. IES: Unifatecie. E-mail: [samarapeixoto4@gmail.com](mailto:samarapeixoto4@gmail.com)

metabólitos como os ácidos graxos de cadeia curta (AGCC). Estes metabólitos desempenham papel fundamental na integridade da barreira intestinal, na resposta imune, no metabolismo energético e na comunicação microbiota-intestino-cérebro. Esta revisão discute o papel dos cereais fermentados na modulação da microbiota, os mecanismos envolvidos na ação dos microrganismos e metabólitos derivados da fermentação, e os impactos desses alimentos na saúde metabólica, imunológica e gastrointestinal. Os estudos analisados evidenciam que os produtos fermentados à base de cereais podem contribuir para a prevenção de doenças crônicas, melhora da digestão, equilíbrio da microbiota e reforço da função intestinal.

**Palavras-chave:** Alimentos Fermentados à Base de Cereais. Ecosistema Intestinal. Bactérias Ácido-Láticas. Compostos Bioativos. Metabólitos Microbianos. Pós-Bióticos.

## RESUMEN

Los cereales fermentados han ganado relevancia como alimentos funcionales capaces de modular la microbiota intestinal y promover efectos beneficiosos para la salud humana. La fermentación mejora la digestibilidad de los granos, aumenta la biodisponibilidad de compuestos bioactivos, enriquece los alimentos con microorganismos probióticos e intensifica la producción de metabolitos como los ácidos grasos de cadena corta (AGCC). Estos metabolitos desempeñan un papel fundamental en la integridad de la barrera intestinal, la respuesta inmunitaria, el metabolismo energético y la comunicación microbiota-intestino-cerebro. Esta revisión discute el papel de los cereales fermentados en la modulación de la microbiota, los mecanismos implicados en la acción de los microorganismos y los metabolitos derivados de la fermentación, así como los impactos de estos alimentos en la salud metabólica, inmunológica y gastrointestinal. Los estudios analizados evidencian que los productos fermentados a base de cereales pueden contribuir a la prevención de enfermedades crónicas, a la mejora de la digestión, al equilibrio de la microbiota y al fortalecimiento de la función intestinal.

**Palabras clave:** Alimentos Fermentados a Base de Cereales. Ecosistema Intestinal. Bacterias Ácido-Láticas. Compuestos Bioactivos. Metabolitos Microbianos. Postbióticos.

## 1 INTRODUCTION

Cereals represent one of the bases of human nutrition, providing energy, fiber, proteins, essential vitamins and minerals, as well as bioactive compounds capable of performing antioxidant and anti-inflammatory functions (Sharma et al., 2024; Avnee et al., 2023). In developing countries, foods such as rice, wheat, maize, sorghum, and oats constitute the main dietary source for the population, being fundamental for global food security (FAO, 2022; Patra et al., 2023).

In recent decades, fermented foods have received increasing scientific attention due to their ability to improve nutrient bioavailability, increase the concentration of bioactive compounds, and modulate the gut microbiota, becoming relevant for health promotion and prevention of chronic diseases (Bruce et al., 2025). Cereal fermentation, in particular, has proven to be a promising technological alternative, as it uses widely consumed and accessible matrices, enabling the production of functional foods enriched with probiotics, postbiotics, and beneficial metabolites (Setta et al., 2020; Sharma et al., 2024).

At the same time, the gut microbiota has been recognized as an essential component for the body's homeostasis, influencing metabolic, immunological, and neurological processes through the gut-brain axis (Valdes et al., 2018; Chevalier et al., 2020). Changes in this microbial community — known as dysbiosis — have been associated with obesity, diabetes, inflammatory diseases, anxiety, and depression (Xu et al., 2024; Gomaa, 2020).

Given this scenario, there is growing interest in identifying ingredients and technological processes capable of positively modulating the gut microbiota. Among them, fermented cereals emerge as potential allies, as they can favor the growth of beneficial microorganisms, increase the production of short-chain fatty acids (SCFAs), and improve the integrity of the intestinal barrier, reflecting in systemic benefits (Setta et al., 2020).

Thus, it becomes relevant to gather and discuss the evidence on the role of fermented cereals in modulating the gut microbiota and its impacts on human health.

**Objective:** This article aims to review the scientific evidence on the effects of fermented cereals on the gut microbiota and the potential benefits arising from this modulation for human health.

## 2 THEORETICAL FRAMEWORK

### 2.1 THE IMPORTANCE OF CEREALS IN HUMAN NUTRITION

Cereals, widely consumed around the world, are essential sources of carbohydrates, proteins, lipids, vitamins, minerals and bioactive compounds, such as phenolics and antioxidants, as well as micronutrients such as iron (Fe), zinc (Zn), copper (Cu), iodine (I),

selenium (Se) and several vitamins, contributing significantly to human health. In several regions — especially developing countries — foods such as rice, maize, and wheat constitute more than 50% of daily caloric intake (Avnee et al., 2023). Globally, these grains represent about 45% of the arable areas (Galati et al., 2014), standing out as the most important agricultural crops and the main dietary sources of micronutrients and vitamins for the population, being consumed raw or fermented (Galati et al., 2014; Soro-Yao et al., 2014).

Botanically, cereals belong to the Poaceae family, characterized by their edible grains called caryopses (Holban; Grumezescu, 2020). However, grains such as quinoa and buckwheat, although not grasses, are classified as pseudocereals due to their similar use in human food. According to FAO (2023), the main cereals produced in the world include maize, rice, wheat, barley, sorghum, millet and oats, buckwheat, standing out for their wide agricultural and nutritional relevance (Patra et al., 2023).

In addition to energy intake, cereals contribute significantly to the intake of bioactive compounds, such as polyphenols, carotenoids, phytoestrogens, phenolic acids, and antioxidant fibers (Sharma et al., 2024). These compounds exert protective functions, modulate inflammation, and stand out as important precursors for functional formulations (Setta et al., 2020).

## 2.2 NUTRITIONAL COMPOSITION AND BIOACTIVE COMPOUNDS OF CEREALS

The composition of cereals is complex, with the main classes of nutrients represented by complex carbohydrates — predominantly starch — and by different types of soluble and insoluble fibers. The protein intake varies between 8% and 15%, with gluten standing out in the case of wheat, while lipids are present in a smaller proportion (1–7%). Nutritionally, cereals are important sources of micronutrients, including iron, zinc, selenium, copper, magnesium, and several B vitamins. In addition, they are rich in bioactive phytochemicals, such as flavonoids, lignans, phenolic acids (ferulic, caffeic), tocopherols, and  $\beta$ -glucans.

Recent research shows that whole grains provide antioxidants capable of neutralizing free radicals and reducing oxidative stress (Setta et al., 2020). Phenolic compounds present in the bark and germ are particularly important, exerting anti-inflammatory, antimicrobial and modulating actions on the gut microbiota.

In cereals such as oats, the presence of  $\beta$ -glucans promotes an increase in the production of short-chain fatty acids (SCFAs) — especially butyrate — which strengthen the intestinal barrier and modulate the immune response (Patra et al., 2023).

### 3 CEREAL FERMENTATION: PROCESSES AND MICROORGANISMS

Fermented foods constitute an important category of products capable of influencing the intestinal microbiota and, consequently, physiological processes related to host health. These foods contain active microbial consortia that modulate metabolic pathways, contribute to cellular redox balance, and enrich the diet with bioactive compounds produced throughout fermentation. The predominant microbial composition includes acetic, lactic, non-lactic, Gram-negative bacteria, filamentous fungi and yeasts, whose action is decisive for the formation of the sensory and functional characteristics of these products (Tamang et al., 2016). In traditional systems, these microorganisms metabolize the constituents of raw materials, triggering biochemical transformations that result in foods with greater nutritional and functional complexity (Laya et al., 2023).

Several strains involved in the fermentation process have the ability to synthesize or increase the availability of vitamins, antioxidants, peptides, exopolysaccharides, organic acids and other metabolites of interest. These compounds are associated with antioxidant and antimicrobial properties widely described in the literature, contributing not only to health benefits but also to natural food preservation (Alkalbani et al., 2019; Kandylis et al., 2016; McGovern et al., 2004). Together, these evidences reinforce the role of fermented foods as important nutritional allies, in addition to highlighting their biotechnological potential for the development of functional products.

Cereals have been used throughout history in the production of fermented foods — such as pozol, ogi, boza, injera, rice kimchi, and traditional fermented beverages — due to the ability of their matrices to favor the growth of beneficial microorganisms.

Fermentation is carried out mainly by:

#### 3.1 LACTIC ACID BACTERIA (LAB)

- *Lactobacillus* spp.
- *Leuconostoc* spp.
- *Pediococcus* spp.

These bacteria produce lactic acid, acetic acid, and antimicrobial compounds that inhibit pathogens.

#### 3.2 YEASTS

- *Saccharomyces cerevisiae*
- *Candida* spp.

They contribute to aroma, texture and increase of B vitamins.

### 3.3 FILAMENTOUS FUNGI

Less common in cereals, but present in traditional African and Asian foods (Aspergillus, Rhizopus).

## 4 IMPACT OF FERMENTATION ON NUTRITIONAL QUALITY

Fermentation stands out for its ability to transform agri-food by-products into bioactive compounds and biopolymers with high added value, several studies show that fermenting microorganisms can generate peptides, antioxidants, polysaccharides and other metabolites with functional applications, while contributing to human health and environmental sustainability and from a health point of view, fermented foods that have high acidity, Significant salt content or moderate alcohol levels have a long history of safe consumption, an effect attributed mainly to environmental conditions unfavorable to the growth of pathogenic microorganisms. Lactic acid bacteria (LAB) play a key role in this process, as they reduce pH, synthesize antimicrobial metabolites, and actively inhibit pathogens, contributing to the stability and safety of fermented foods. Fermentation is also crucial for improving the nutritional quality of foods widely consumed in different regions of the world. By reducing antinutrients and removing toxic compounds, it increases the safety and bioavailability of nutrients present in raw materials such as cassava, cereals, and legumes. A well-documented example is the sourdough fermentation process, which favors the release of essential minerals and can even improve wheat tolerance by modulating digestive and metabolic responses (Fitsum et al., 2025).

Traditional fermented foods — which include dairy, cereal, and vegetable products — stand out for their potential to promote broad nutritional benefits, such as improved digestion and prevention of diseases related to the gastrointestinal tract. As consumer awareness of the impacts of diet on immunity and digestive balance grows, these products gain relevance, driven by the strong scientific evidence supporting their positive effects on health

Fermentation:

- increases the bioavailability of minerals, reducing phytate, the main antinutrient in cereals;
- improves protein and carbohydrate digestibility;
- reduces allergenic compounds;
- synthesizes vitamin K, B12 and B9 in some fermented matrices;
- increases the concentration of phenolic compounds and antioxidants.

Fermented cereals have a higher nutritional profile than their non-fermented versions, mainly due to the enzymatic action of LAB, which releases previously inaccessible bioactive compounds (Sharma et al., 2024).

## **5 GUT MICROBIOTA: FUNCTIONS, COMPOSITION, AND CLINICAL RELEVANCE**

The gut microbiota plays an essential role in regulating host metabolic functions, including energy uptake, storage, and expenditure. Among the most well-known mechanisms is the production of short-chain fatty acids during fermentation, which increase efficiency in obtaining energy. The establishment of a specific microbiota is crucial for the proper maturation of the intestinal immune system, a process of coevolution between host and microorganisms that begins in early life (Chung et al., 2012).

The gut microbiota is composed of trillions of microorganisms — predominantly bacteria from the phyla Firmicutes, Bacteroidetes, Actinobacteria, and Proteobacteria — performing essential functions in the body (Valdes et al., 2018).

Followed in a smaller proportion by Actinobacteria, Proteobacteria, Verrucomicrobia, Fusobacteria and Euryarchaeota. Microbial composition varies along the gastrointestinal tract, reflecting marked differences in pH, oxygen availability, and nutritional content between segments such as the stomach, small intestine, and colon. These specific conditions shape the colonization capacity and distribution of microbial communities. For example, due to the higher concentration of oxygen in the proximal portion of the small intestine, facultative and aerotolerant anaerobic microorganisms predominate, while the colon, a strictly anaerobic environment, harbors a high diversity of completely anaerobic bacteria.

Understanding the diversity and function of the microbiota requires the use of advanced molecular tools, with metagenomics being essential to characterize microbial communities, especially in niches such as the small intestine (Booijink et al., 2007).

The close interaction between the host and its microbiota gives these microorganisms a fundamental role in physiological and metabolic regulation. The collective genetic potential of the microbiome is estimated to be at least one hundred times the number of human genes, and its metabolic products exert a direct influence on essential biological processes (Olofsson, 2017).

They contribute to the production of important vitamins, such as those of the B complex (B9 and B12) and vitamin K. In addition, they help neutralize carcinogenic compounds, including pyrolysates. These effects occur because their metabolites are able to interact with cell membranes and nuclear receptors of the host, influencing essential processes of human physiology (Ho; Chan; Li, 2015).

Among its functions, the following stand out:

- maturation of the immune system;
- production of IgA and IgG against pathogens (Siddiqui et al., 2021);
- vitamin synthesis;
- fermentation of dietary fibers in SCFAs;
- modulation of energy metabolism;
- protection of the intestinal barrier;
- interaction with the central nervous system via the gut-brain axis.

The intestinal mucosa functions as a natural filter, rich in antimicrobial peptides that coordinate immune responses, while the microbiome helps defend against pathogens (Kamada et al., 2013).

## 6 GUT DYSBIOSIS AND RELATIONSHIP TO DISEASE

Dysbiosis is characterized by colonic dysfunction resulting from alterations in the intestinal microbiota, in which there is a predominance of pathogenic microorganisms to the detriment of beneficial bacteria — a concept that was widely disseminated at the end of the nineteenth century in Europe. The accumulation of aggressions to intestinal function compromises the balance of the microbiota, favoring the increase of potentially harmful bacteria and configuring a state of risk for the host. Some of these bacteria can colonize the small intestine, resulting in relevant consequences, such as improper digestion of nutrients and the formation of toxic peptides from the combination of proteins and toxins. Dysbiosis is a condition recognized as an important disorder associated with the diagnosis of several diseases (Almeida et al., 2008).

Several factors are associated with the development of dysbiosis, including the indiscriminate use of antibiotics, which eliminate both useful and harmful bacteria, as well as hormonal and non-hormonal anti-inflammatory drugs; the abuse of laxatives; excessive consumption of processed foods instead of fresh foods; high exposure to environmental toxins; consumptive diseases, such as cancer and acquired immunodeficiency syndrome (AIDS); hepatopancreatic dysfunctions; chronic stress; and diverticulosis. Age, intestinal transit time, luminal pH, availability of fermentable substrate and host immunological status are also considered important determinants (Almeida et al., 2008).

Dysregulation of the innate immune response at the intestinal interface is a key factor in several pathologies, and understanding the modulation of host defense by infectious agents is crucial for new therapeutic approaches (Katze et al., 2022)."

Advances in next-generation sequencing have revealed that alterations in the microbiota — the so-called dysbiosis — are associated with obesity, diabetes, chronic inflammation, liver disease, depression, and anxiety (Marco; Tachon, 2013; Liu et al., 2021).

Evidence indicates that gut dysbiosis not only alters the local energy metabolism of the cecum, but also exerts a significant influence on distant organs, such as the prefrontal cortex, olfactory bulb, and liver, demonstrating the breadth of systemic effects mediated by the microbiome, and may also influence conditions such as obesity (Heiss; Olofsson, 2017).

Dysbiosis corresponds to the imbalance of the microbiota, characterized by:

- reduction of beneficial bacteria (e.g., *Bifidobacterium*, *Lactobacillus*);
- increase in pathogenic or opportunistic species;
- lower microbial diversity;
- change in the production of SCFAs.

This imbalance compromises:

- the intestinal barrier, increasing permeability;
- anti-inflammatory mechanisms;
- neurotransmitter metabolism;
- immune response;
- insulin sensitivity.

Studies show a relationship between dysbiosis and:

- hepatitis B and C (Padilha et al., 2025);
- neurological diseases (Siddiqui et al., 2021);
- depression (Chevalier et al., 2020; Zheng et al., 2021);
- obesity and hepatic steatosis;
- irritable bowel syndrome.

## 7 THE GUT-BRAIN AXIS AND THE INFLUENCE OF THE MICROBIOTA

The gut microbiota plays a central role in regulating neural development, brain function, and different behaviors, composing a highly integrated axis that connects the gut to the central nervous system. Experimental models with germ-free animals demonstrate that the absence of microorganisms results in important structural and functional changes, evidencing the microbial influence on neural circuits and behavioral responses. This communication occurs through neural, immunological, metabolic, and endocrine pathways, forming the gut-brain axis, whose dysregulation can increase susceptibility to neuropsychiatric disorders.

According to Liu et al. (2021), changes in microbial composition are associated with physiological modifications related to conditions such as autism spectrum disorder, schizophrenia, and Alzheimer's disease. Such evidence supports the hypothesis that the microbiota plays a determining role in brain homeostasis, reinforcing its relevance for mental health.

The gut-brain axis includes:

- vagus nerve,
- immune system,
- microbiota,
- intestinal hormones,
- metabolism of tryptophan, GABA and serotonin.

The microbiota modulates the CNS through:

- metabolites such as SCFAs;
- inflammatory cytokines;
- neurotransmitter production;
- signaling via the hypothalamic–pituitary–adrenal axis.

Changes in these mechanisms are directly related to the development of depressive disorders, anxiety, and behavioral changes (Liu et al., 2021).

**Table 1**

*Main mechanisms of the gut-brain axis and their implications for mental health*

Communication Mechanism	Process Description	Mental Health Impacts	Evidence
Neural Pathway (Vagus Nerve)	The gut microbiota produces metabolites and neurotransmitters that stimulate intestinal receptors linked to the vagus nerve.	"Mood regulation; stress response; behavioral changes."	Liu et al. (2021); Mayer et al. (2015).
Immune pathway	"Microorganisms modulate pro- and anti-inflammatory cytokines, influencing neuroinflammation."	"Association with depression, anxiety, and neurodegenerative diseases."	Liu et al. (2021); Cryan et al. (2019).
Microbial Metabolites (SCFAs)	"Production of short-chain fatty acids (acetate, propionate, butyrate)."	"Modulation of the blood-brain barrier; influence on neurotransmitters."	Dalile et al. (2019).
Neurotransmitters and Precursors	"Bacteria produce GABA, serotonin, dopamine, or influence their synthesis."	"Regulation of mood, memory, and behavior."	Strandwitz (2018).

Communication Mechanism	Process Description	Mental Health Impacts	Evidence
Endocrine Axis (HPA)	Microbiota influences cortisol release and activity of the hypothalamic–pituitary–adrenal axis.	Stress response and emotional vulnerability.	Liu et al. (2021); Dinan; Cryan (2017).
Gut Barrier Integrity	Microorganisms maintain or impair the integrity of the mucosa.	Increased intestinal permeability can lead to neuroinflammation.	Kelly et al. (2015).

## 8 HOW FERMENTED CEREALS MODULATE THE GUT MICROBIOTA

Fermented cereals influence the microbiota in three ways:

### 8.1 PROBIOTIC ACTION

Probiotics are live microorganisms that, when consumed in adequate quantities, contribute to the health of the host by favoring the balance of the intestinal microbiota. Its beneficial effect is associated with the ability to compete with undesirable microorganisms, modulate the immune system, and promote an intestinal environment that is more resistant to colonization by pathogens. By stimulating the growth of beneficial bacteria and reducing the proliferation of potentially harmful ones, probiotics strengthen natural defense mechanisms and contribute to the maintenance of intestinal homeostasis (Saad, 2006).

Microorganisms present in fermentation:

- increase *Lactobacillus* and *Bifidobacterium*;
- compete with pathogens;
- strengthen epithelial junctions;
- improve intestinal barrier function.

BAL produce lactic acid, which lowers intestinal pH and inhibits harmful bacteria.

### 8.2 PREBIOTIC ACTION

Prebiotics, in turn, correspond to non-digestible food components that exert positive effects by selectively stimulating the growth or activity of specific groups of beneficial microorganisms in the colon. In addition to favoring the desirable microbiota, they can also hinder the multiplication of pathogenic microorganisms, offering additional protection to the host. Although they act predominantly in the large intestine, these compounds may influence, to a lesser extent, the microbial ecosystem of the small intestine. (Saad, 2006).

Fiber and indigestible carbohydrates in cereals—beta-glucans, arabinoxylans, fructans—serve as a selective substrate for beneficial fermenters.

This increases the production of SCFAs, mainly:

- acetate,
  - propionate,
  - butyrate,
- essential for gut integrity and inflammation reduction.

### 8.3 Release of bioactive compounds during fermentation

Fermentation:

- increases antioxidants;
- generates bioactive peptides;
- reduces antinutrients;
- It favors the formation of immunomodulatory compounds.

These compounds contribute to:

- less systemic inflammation;
- better insulin sensitivity;
- reduction of oxidative stress;
- modulation of the gut-brain axis.

(Silveira; Furlong, 2007; Heiss; Olofsson, 2017).

**Table 2**

*Mechanisms by which fermented cereals modulate the gut microbiota*

Mechanism	How it works	Impacts on the microbiota	Key References
Probiotic action	Introduction of live microorganisms from fermentation (BAL).	↑ <i>Lactobacillus</i> , ↑ <i>Bifidobacterium</i> ; competition with pathogens; strengthening of the intestinal barrier; pH reduction via lactic acid.	Saad (2006)
Prebiotic action	Fiber and non-digestible carbohydrates serve as a selective substrate.	SCFAs (acetate, propionate, butyrate); ↑ beneficial fermenters; ↓ inflammation.	Saad (2006)
Bioactive compounds released	Fermentation increases antioxidants, bioactive peptides, reduces antinutrients.	↓ systemic inflammation; better insulin sensitivity; Modulation of the gut-brain axis.	Silveira; Furlong (2007); Heiss; Olofsson (2017)

## 9 HUMAN HEALTH BENEFITS

Based on the evidence, the consumption of fermented cereals is associated with:

- improved digestion and absorption of nutrients;

- strengthening immunity;
- prevention of gastrointestinal diseases;
- reduction of inflammation;
- liver protection;
- mood and stress regulation;
- lower risk of obesity and insulin resistance.

In addition, fermented products stimulate microbial diversity — one of the best markers of gut health.

In a study carried out by Oliveira (2021) he demonstrated that the action of functional foods in the human body contributes to the balance of the intestinal microbiota and, consequently, to the improvement of health. In the context of the mechanisms of beneficial action of functional feeding, its performance in preventing the colonization of the intestinal mucosa by microorganisms considered pathogenic is highlighted. It has also been shown that the beneficial effect of functional foods is to protect individuals from possible diseases associated with the imbalance of the intestinal microbiota, such as dysbiosis, for example.

Therefore, an adequate diet, with bioactive compounds also coming from the fermentation of cereals, can exert a decisive influence on the composition of the intestinal microbiota, directly modulating which metabolites will be produced and how they will act in the body. Among these metabolites, short-chain fatty acids and secondary bile acids stand out, capable of activating specific signaling pathways through interaction with their receptors in the host.

These compounds also regulate the release of hormones that are fundamental to the gut-brain axis, such as GLP-1, PYY, and leptin, which modulate food intake both by systemic circulation and by activation of afferent vagal nerves. In addition, microbial products such as LPS and proteins derived from microorganisms have the potential to influence central metabolic processes, including hypothalamic neuronal pathways related to appetite control and energy expenditure. The microbiota also influences the integrity of the intestinal barrier, immune activity, and inflammatory response, composing a complex set of signals that affect gastrointestinal motility, nutrient absorption, and the body's energy balance (Heiss; Olofsson, 2017).

## 10 CONCLUSION

In summary, the present review demonstrated that fermented cereals are important food matrices capable of positively modulating the gut microbiota. This modulation occurs mainly through the symbiotic action of the microorganisms present (probiotics) and the native

and modified fibers (prebiotics), resulting in increased production of short-chain fatty acids (SCFAs). Such effects translate into systemic benefits, such as improving the integrity of the intestinal barrier, reducing inflammation, and modulating the gut-brain axis. Despite the growing interest and potential role of these foods in promoting health, there is still an important gap in the literature related to the specific mechanisms by which these products act on beneficial microbial populations. Available studies describe the presence of lactic acid bacteria, bioactive compounds, and general effects on gut health; However, there is a lack of deeper and standardized investigations that identify which microorganisms, metabolites, and signaling pathways are directly involved in the interaction between fermented cereals and the gut-brain axis. In addition, many studies use different methodologies, small samples and different types of cereals, which makes comparisons difficult. Thus, it is necessary to expand scientific production with controlled clinical studies, metagenomic analyses, and experimental models that allow us to elucidate more precisely how these foods contribute to the modulation of the intestinal microbiota and its possible systemic impacts.

## REFERENCES

- Alkalbani, N. S., Turner, M. S., & Ayyash, M. M. (2019). Isolation, identification, and potential probiotic characterization of isolated lactic acid bacteria and in vitro investigation of the cytotoxicity, antioxidant, and antidiabetic activities in fermented sausage. *Microbial Cell Factories*, 18, Article 188. <https://doi.org/10.1186/s12934-019-1239-1>
- Almeida, L. B., et al. (2008). Disbiose intestinal. *Revista Brasileira de Nutrição Funcional*.
- Avnee, et al. (2023). Biofortification: An approach to eradicate micronutrient deficiency. *Frontiers in Nutrition*, 10, Article 1233070. <https://doi.org/10.3389/fnut.2023.1233070>
- Booijink, C. C., et al. (2007). Comunidades microbianas no intestino delgado humano: Relacionando a diversidade à metagenômica. *Future Microbiology*, 2, 285–295.
- Bruce, B. B., Boateng, I. D., & Boateng, C. (2025). Avanços recentes em peptídeos bioativos de alimentos fermentados de origem vegetal e suas bioatividades. *Química dos Alimentos: X*, 32, Article 103291. <https://doi.org/10.1016/j.fochx.2025.103291>
- Chevalier, G., et al. (2020). Effect of gut microbiota on depressive-like behaviors in mice is mediated by the endocannabinoid system. *Nature Communications*, 11, Article 6363. <https://doi.org/10.1038/s41467-020-19931-2>
- Chung, H., et al. (2012). Gut immune maturation depends on colonization with a host-specific microbiota. *Cell*, 149(7), 1578–1593. [https://doi.org/10.1016/S0092-8674\(12\)00629-0](https://doi.org/10.1016/S0092-8674(12)00629-0)
- Cryan, J. F., et al. (2019). The microbiota–gut–brain axis. *Physiological Reviews*, 99(4). <https://doi.org/10.1152/physrev.00018.2018>
- Dalile, B., et al. (2019). The role of short-chain fatty acids in microbiota–gut–brain communication. *Nature Reviews Gastroenterology & Hepatology*, 16, 461–478. <https://www.nature.com/articles/s41575-019-0157-3>

- Dinan, T. G., & Cryan, J. F. (2017). The microbiome–gut–brain axis in health and disease. *Clinics in Gastroenterology and Hepatology*, 46(1), 77–89. <https://doi.org/10.1016/j.gtc.2016.09.007>
- Food and Agriculture Organization of the United Nations. (2023). World food and agriculture – Statistical yearbook 2023. <https://doi.org/10.4060/cc8166en>
- Food and Agriculture Organization of the United Nations; International Fund for Agricultural Development; United Nations Children’s Fund; World Food Programme; World Health Organization. (2022). The state of food security and nutrition in the world 2022: Repurposing food and agricultural policies to make healthy diets more affordable. <https://www.fao.org/3/cc0639en/cc0639en.pdf>
- Fitsum, S., et al. (2025). Bioactive compounds in fermented foods: Health benefits and prospective applications. *Current Research in Food Science*. <https://doi.org/10.1016/j.crfs.2025.5236509>
- Galati, A., et al. (2014). The cereal market and the role of fermentation in cereal-based food production in Africa. *Food Reviews International*, 30(4), 317–337. <https://doi.org/10.1080/87559129.2014.929143>
- Gomaa, E. Z. (2020). Human gut microbiota/microbiome in health and diseases: A review. *Antonie van Leeuwenhoek*, 113(12), 2019–2040. <https://doi.org/10.1007/s10482-020-01474-7>
- Heiss, C. N., & Olofsson, L. E. (2017). Modulação do metabolismo energético dependente da microbiota intestinal. *Journal of Innate Immunity*, 10(3), 163–171.
- Ho, J. T. K., Chan, G. C. F., & Li, J. C. B. (2015). Systemic effects of gut microbiota and its relationship with diseases and modulation. *BMC Immunology*, 16, Article 21. <https://doi.org/10.1186/s12865-015-0085-7>
- Holban, A. M., & Grumezescu, A. (2020). Progresso biotecnológico e consumo de bebidas (Vol. 19). Academic Press.
- Kamada, N., et al. (2013). Control of pathogens and pathobionts by the gut microbiota. *Nature Immunology*, 14, 685–690. <https://doi.org/10.1038/ni.2608>
- Kandylis, P., et al. (2016). Dairy and non-dairy probiotic beverages. *Current Opinion in Food Science*, 7, 58–63. <https://doi.org/10.1016/j.cofs.2015.11.012>
- Katze, M. G., et al. (2022). Vírus e interferon: Uma luta pela supremacia. *Nature Reviews Immunology*, 2, 675–687.
- Kelly, J. R., et al. (2015). Breaking down the barriers: Gut microbiota, intestinal permeability and stress-related psychiatric disorders. *Frontiers in Cellular Neuroscience*, 9, Article 392. <https://doi.org/10.3389/fncel.2015.00392>
- Laya, A., et al. (2023). Bioactive ingredients in traditional fermented food condiments: Emerging products for prevention and treatment of obesity and type 2 diabetes. *Journal of Food Quality*, Article 5236509. <https://doi.org/10.1155/2023/5236509>
- Liu, L. X., et al. (2021). Comprehensive analysis of lysine acetylome and succinylome in the hippocampus of mice with gut microbiota dysbiosis. *Journal of Advanced Research*, 30, 27–38. <https://doi.org/10.1016/j.jare.2020.12.002>
- Liu, Y., et al. (2021). Proteomic analysis of the gut–brain axis in a depression model with gut microbiota dysbiosis. *Translational Psychiatry*, 11(1), Article 568. <https://doi.org/10.1038/s41398-021-01689-w>

- Marco, M. L., & Tachon, S. (2013). Environmental factors influencing the efficacy of probiotic bacteria. *Current Opinion in Biotechnology*, 24(2), 207–213. <https://doi.org/10.1016/j.copbio.2012.10.002>
- Mayer, E. A., Tillisch, K., & Gupta, A. (2015). Gut–brain axis and the microbiota. *Journal of Clinical Investigation*, 125(3), 926–938. <https://doi.org/10.1172/JCI76304>
- McGovern, P. E., et al. (2004). Fermented beverages of pre- and proto-historic China. *Proceedings of the National Academy of Sciences of the United States of America*, 101(51), 17593–17598. <https://doi.org/10.1073/pnas.0407921102>
- Oliveira, S. (2021). O efeito dos alimentos funcionais na modulação da microbiota intestinal [Trabalho de Conclusão de Curso, Graduação em Nutrição, Faculdade Pitágoras].
- Padilha, M. D. M., et al. (2025). Dysregulation in the microbiota by HBV and HCV infection induces an altered cytokine profile in the pathobiome of infection. *Brazilian Journal of Infectious Diseases*, 29, Article 104468. <https://doi.org/10.1016/j.bjid.2024.104468>
- Patra, M., et al. (2023). A comprehensive review on functional beverages from cereal grains: Characterization of nutraceutical potential, processing technologies and product types. *Heliyon*, 9(6), Article e16804. <https://doi.org/10.1016/j.heliyon.2023.e16804>
- Saad, S. M. I. (2006). Probióticos e prebióticos: O estado da arte. *Revista Brasileira de Ciências Farmacêuticas*, 42(1), 1–16. <https://doi.org/10.1590/S1516-93322006000100002>
- Setta, M. C., Matemu, A., & Mbega, E. R. (2020). Potential of probiotics from fermented cereal-based beverages in improving health of poor people in Africa. *Journal of Food Science and Technology*, 57(11), 3935–3946. <https://doi.org/10.1007/s13197-020-04432-3>
- Sharma, R., et al. (2024). Traditional cereal-based cuisines from Himachal Pradesh Palampur region and their nutritional profile. *Journal of Applied Biology & Biotechnology*. <https://doi.org/10.7324/JABB.2024.155471>
- Siddiqui, R., et al. (2021). Effect of microgravity environment on gut microbiome and host health. *Life*, 11(10), Article 1008. <https://doi.org/10.3390/life11101008>
- Silveira, C. M. da, & Furlong, E. B. (2007). Caracterização de compostos nitrogenados presentes em farelos fermentados em estado sólido. *Food Science and Technology*, 27(4), 825–831. <https://doi.org/10.1590/S0101-20612007000400021>
- Soro-Yao, A. A., et al. (2014). The use of lactic acid bacteria starter cultures during the processing of fermented cereal-based foods in West Africa: A review. *Tropical Life Sciences Research*, 25(2), 81–100.
- Strandwitz, P. (2018). Neurotransmitter modulation by the gut microbiota. *Brain Research*, 1693, 128–133. <https://doi.org/10.1016/j.brainres.2018.03.015>
- Tamang, J. P., et al. (2016). Functional properties of microorganisms in fermented foods. *Frontiers in Microbiology*, 7, Article 578. <https://doi.org/10.3389/fmicb.2016.00578>
- Valdes, A. M., et al. (2018). Role of the gut microbiota in nutrition and health. *BMJ*, 361, Article k2179. <https://doi.org/10.1136/bmj.k2179>
- Xu, Q., et al. (2024). Gut microbiota dysbiosis contributes to depression-like behaviors through NLRP3-mediated neuroinflammation in the hippocampus in a postpartum depression mouse model. *Brain, Behavior, and Immunity*. <https://doi.org/10.1016/j.bbi.2024.04.002>



Zheng, P., et al. (2021). The gut microbiota and neurological diseases: The gut-brain axis and the role of its microbial members. *Molecular Psychiatry*, 26(6), 3020–3049. <https://doi.org/10.1038/s41380-021-01050-x>