

Developments in Applied Microbiology and Biotechnology



Probiotics

A Comprehensive Exploration of
Health Benefits and Innovation

Edited by
Ranbir Chander Sobti



PROBIOTICS

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DEVELOPMENTS IN APPLIED MICROBIOLOGY
AND BIOTECHNOLOGY

PROBIOTICS

A COMPREHENSIVE EXPLORATION OF HEALTH BENEFITS AND INNOVATION

Edited by

RANBIR CHANDER SOBTI

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Pot and its potential: Role of probiotics from fermented soybean foods to combat diabetes

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1 Introduction

Fermented foods are the result of a fascinating process: microbes transforming raw ingredients into flavorful and nutritious delights. This ancient practice, dating back to the dawn of civilization, has been a part of human diets worldwide (Narzary et al., 2021). From dairy products like yogurt and cheese to pickled vegetables, fermented meats, and fish, fermented foods come in countless forms. The type and preparation of fermented foods vary widely across

cultures, influenced by factors such as geography, climate, and available resources (Kalita et al., 2023). Microbes, including lactic acid bacteria (LAB), *Propionibacterium*, *Acetobacter*, yeasts, molds, and *Bacillus* species, play a pivotal role in the fermentation process. These microorganisms produce beneficial compounds like lactic, acetic, and propionic acids, alcohol, ammonia, and fatty acids, which contribute to the unique flavors, textures, and nutritional profiles of fermented foods (Marco et al., 2017). Beyond their deliciousness, fermented foods

offer numerous health benefits. Fermentation can enhance the nutritional value of foods, improve digestibility, and extend shelf life. By consuming fermented foods, we tap into a rich culinary heritage and harness the power of nature's microbial wonders (Chilton et al., 2015).

Traditionally, fermentation has relied on the naturally occurring microorganisms present in raw materials. However, to ensure food safety, quality, and enhanced health benefits, modern fermentation techniques have emerged (Borresen et al., 2012).

Fermented foods are a valuable source of bioactive microbes, offering a multitude of health-promoting properties. Emerging research suggests that these ancient foods may play a significant role in preventing and managing various health conditions, including metabolic disorders (Sivamaruthi et al., 2018), cardiovascular diseases (Li et al., 2022), and cognitive decline (Zheng et al., 2023). In addition, fermented foods can bolster the immune system and improve overall well-being. One notable benefit is the alleviation of lactose intolerance. Fermented foods containing galactosidase-producing microbes can help individuals with lactose intolerance digest dairy products without experiencing discomfort (Kalita et al., 2023).

Beyond their nutritional value, fermented plant extracts have found applications in the cosmetic industry (Majchrzak et al., 2022). However, while the potential of fermented foods is promising, further clinical trials are necessary to definitively confirm their functional benefits.

Recent studies have highlighted the potential of fermented foods in managing diabetes mellitus. By incorporating fermented foods into their diets, individuals with diabetes mellitus may experience reduced health risks associated with the condition (Zhang et al., 2024).

This review aims to provide a comprehensive overview of the latest research on the antidiabetic properties of probiotic-rich fermented

foods. By exploring the sustainable use of functional fermented foods, we can work toward developing effective strategies for managing DM and improving overall health.

2 Literature search

A comprehensive literature search was conducted using databases such as PubMed, Google Scholar, Science Direct, and Embase. Key search terms included "Lactobacillus," "fermented food," "Metabolic Syndrome," "Inflammation and Diabetes Mellitus," and related phrases. Additionally, a manual search of relevant literature was performed to identify additional studies that met the inclusion criteria (Narzary et al., 2023).

3 Microbial diversity in fermented foods

Fermented foods are teeming with microbes! These can be naturally occurring or added as starter cultures. They transform food biochemically, making it delicious and safe to eat. LAB are superstars in this process. They create lactic acid, which improves nutrition and gives fermented foods their tang (Ashaolu and Reale, 2020).

LAB come in many forms, found in everything from our gut to vegetables and soil. Some LAB excel at starting fermentation (homofermentative), while others contribute to flavor development (heterofermentative). *Lactobacillus* is a popular choice for both starter cultures and probiotics due to its health benefits. Other important LAB include *Lactococcus*, *Streptococcus*, and *Bifidobacterium* (Yerlikaya, 2019).

Fermented foods come in a vast array, from dairy products like yogurt and cheese to fermented vegetables like kimchi and sauerkraut (Girish et al., 2024). Different cultures use different starter cultures depending on the

desired outcome. For example, milk fermentation relies heavily on *Lactococcus lactis* to create the right acidity (Kondrotiene et al., 2024). In cheese-making, secondary cultures like *Propionibacterium freudenreichii* are introduced to develop specific flavors and textures (Garofalo et al., 2024).

The specific LAB species used vary depending on the food type and desired characteristics. Dominant players in vegetable fermentation include *Lactobacillus* and *Pediococcus*, while cereals favor *Pediococcus*, *Enterococcus*, *Weissella*, *Lactococcus*, *Leuconostoc*, *Streptococcus*, and *Lactobacillus* (Raungrusmee et al., 2022). This diversity of microbes is what makes fermented foods so interesting and beneficial!

4 Antidiabetic potential of fermented soybean foods and their microbiota

Recent studies have highlighted the significant role of the gut microbiota in the development of type 2 diabetes (Zhou et al., 2022).

Gut microbiota produces a variety of metabolites with diverse functions, such as energy metabolism, signaling, epigenetic regulation, and coenzyme activity (Hosseinkhani et al., 2021). These metabolites are believed to play a role in the pathogenesis of diabetes. However, it's important to note that the composition of the gut microbiota can vary across different populations, influenced by factors like geographic location, ethnicity, and dietary habits (Patel et al., 2023).

Fermented foods, particularly fermented soybean products, have the potential to modulate the gut microbiota and its associated metabolites, including short-chain fatty acids (SCFAs) and bile acids. SCFAs, for instance, have been shown to exert protective effects against diabetes by enhancing energy expenditure, insulin sensitivity, and insulin secretion through the activation of the G-protein-coupled receptors GPR41 and GPR43. Secondary bile acids, on the

other hand, can mitigate diabetes risk by acting as ligands for the nuclear receptors FXR and TGR5 (Mukherjee et al., 2024).

Numerous studies have demonstrated the potential health benefits of LAB, particularly in managing diabetes. Fermented soybean foods are rich in beneficial microbes such as *Bacillus* sp., *Lactobacillus* sp., *Leuconostoc* sp., *Streptococcus* sp., *Saccharomyces* sp., *Aspergillus* sp., and *Rhizopus* sp., having a positive impact on human health (Table 23.1).

Probiotics are beneficial live microorganisms, primarily bacteria and yeasts, that, when consumed in adequate amounts, promote gut health and overall well-being (Anee et al., 2021). These “good bacteria” colonize the intestines, aiding digestion and supporting the immune system (Lutfi, 2019). Ideal probiotic strains possess several key qualities: survival in the harsh gastrointestinal environment, adherence to intestinal walls, utilization of dietary nutrients, and a nonpathogenic nature (Das et al., 2022). To assess these properties, researchers employ various methods, including acid and bile salt tolerance tests (Kim et al., 2019a, 2019b), thermotolerance tests (Correa Deza et al., 2017), antibacterial assays (Kim et al., 2019a, 2019b), cell adhesion tests (Kim et al., 2019b), and lysosomal and proteolytic activity assays. Numerous studies have confirmed the significant health benefits of probiotics for humans (Kim et al., 2019b).

Probiotics, beneficial live microorganisms, can reshape the gut microbiota, leading to various health benefits (Tsai et al., 2021). Beyond their role in food and agriculture, they are increasingly used for disease prevention, treatment, and overall well-being. By combating harmful bacteria and bolstering the immune system (Stavropoulou and Bezirtzoglou, 2020), probiotics offer a natural approach to health maintenance.

A subset of probiotics, known as immunobiotics, can directly influence the immune response. They activate key immune cells, such

TABLE 23.1 Summary of studies on fermented soybean foods, their associated microorganisms, and their role in diabetes management.

Fermented food	Study design/Experimental model	Microorganisms	Key findings	Country	References
Miso	In vivo, 8-week-old male C57BL/6 J mice were fed with a high-fat/high-sucrose diet	<i>Aspergillus oryzae</i>	↓ Insulin resistance	Japan	(Hashimoto et al., 2024)
Miso	In vivo, cross-sectional study (1274 subjects), aged 34–70 years	<i>Aspergillus oryzae</i>	↓ Insulin resistance	Japan	(Nakamoto et al., 2015)
Miso	In vivo cross-sectional analysis (4327 subjects)	<i>Aspergillus oryzae</i>	↓ Insulin resistance	Japan	(Ikeda et al., 2018)
Miso	In vivo cross-sectional analysis (523 patients)	<i>Aspergillus oryzae</i>	↑ Glycemic control ↓ HbA1c levels	Japan	(Takahashi et al., 2021)
Natto	In vitro, Caco-2 cells are human intestinal epithelial cells	<i>Bacillus subtilis</i> , <i>Bacillus natto</i>	↓ Glucose uptake	Japan	(Matsumoto et al., 2020)
Cheong-gukjang	In vivo, male Sprague-Dawley rats with 90% pancreatectomy	<i>Bacillus licheniformis</i>	↑ Phosphorylation of Akt ↑ Glucose homeostasis ↑ Hepatic insulin signaling	Korea	(Yang et al., 2013)
Cheong-gukjang	In vivo, male Sprague-Dawley rats with 90% pancreatectomy	<i>Bacillus subtilis</i>	↑ Insulinotropic action in islets ↑ Insulin secretion	Korea	(Kwon et al., 2007)
Cheong-gukjang	In vivo, male Sprague-Dawley rats with 90% pancreatectomy	<i>Bacillus licheniformis</i>	↑ Insulin secretion sensitivity ↑ β -cell function ↓ Insulin resistance	Korea	(Yang et al., 2012)
Cheong-gukjang	In vivo, high-fat diet-induced obese C57BL/6 J mice	<i>Bacillus licheniformis</i> -67	↓ Weight gain ↑ Glycemic control ↓ Serum and hepatic lipid profiles ↓ blood glucose	Korea	(Choi et al., 2016)
Cheong-gukjang	In vivo, C75BL/KsJ-db/db mice	<i>Bacillus subtilis</i>	↓ Blood glucose ↑ Plasma and pancreatic insulin levels ↑ Hepatic glucokinase activity ↓ Glucose-6-phosphatase ↓ phosphoenol pyruvate carboxykinase activity	Korea	(Kim et al., 2008)

Cheong-gukjang	In vivo, KK-Ay/TaJcl diabetic mice	<i>Bacillus</i> sp. (KCTC 11351BP), <i>Bacillus subtilis</i> (KCTC 11352BP), <i>Bacillus sonorensis</i> (KCTC 11354BP), <i>Bacillus circulans</i> (KCTC 11355BP)	↓ Glycosylated hemoglobin (HbA1c) levels ↑ Insulin sensitivity ↓ Serum triglycerides ↓ Low-density lipoprotein (LDL) cholesterol	Korea	(Lee et al., 2012)
Cheong-gukjang	In vivo: 45 subjects	<i>Bacillus subtilis</i>	↓ Plasma total cholesterol ↓ Plasma low-density lipoprotein (LDL) cholesterol ↓ Fasting blood glucose	Korea	(Shin et al., 2011)
Doenjang	In vitro	<i>Bacillus</i> spp., <i>Aspergillus oryzae</i>	↑ α -glucosidase inhibitory activity	Korea	(Yang et al., 2019)
Doenjang	In vivo, high-fat diet-induced obese male mice	<i>Bacillus</i> spp., <i>Aspergillus oryzae</i>	↑ Glucose tolerance ↑ Adiponectin levels ↑ AMPK activation	Korea	(Kim et al., 2018)
Kochujang	In vitro	<i>Bacillus</i> spp.	↑ α -glucosidase-inhibitory activity	Korea	(Yang et al., 2019)
Kochujang	In vivo, rats were fed a high-fat diet and underwent a 90% pancreatectomy	<i>Bacillus subtilis</i> , <i>Aspergillus sojae</i>	↑ Insulin sensitivity ↑ Glucose tolerance ↓ Body weight ↓ Visceral fat ↓ Serum leptin levels	Korea	(Kwon et al., 2009)
Douchi	In vivo, rats	<i>Aspergillus oryzae</i> , <i>A. elegans</i> , <i>Rhizopus arrhizus</i>	↑ α -glucosidase inhibitory activity	China	(Wang et al., 2007)
Touchi	In vivo, KKA ^y genetically modified diabetic mice	<i>Aspergillus</i> sp.	↓ Postprandial blood glucose ↓ Fasting blood glucose ↓ Total cholesterol ↓ Triglycerides ↑ α -glucosidase inhibitory activity	China	(Fujita and Yamagami, 2001)
Touchi	In vivo, male rats, 47 borderline diabetic and mild-diabetic subjects	<i>Aspergillus</i> sp.	↑ α -glucosidase-inhibitory activity ↓ Fasting blood glucose	China	(Fujita et al., 2001)
Touchi	In vivo: male rats, 08 borderline diabetic, and 04 diabetic subjects.	<i>Aspergillus</i> sp.	↓ Postprandial blood glucose ↑ α -glucosidase inhibitory activity ↓ Glycosylated hemoglobin (HbA1c) levels ↓ Triglycerides	China	(Fujita et al., 2003)

Continued

TABLE 23.1 Summary of studies on fermented soybean foods, their associated microorganisms, and their role in diabetes management—cont'd

Fermented food	Study design/Experimental model	Microorganisms	Key findings	Country	References
Fermented soy milk	In vivo, female <i>Wistar</i> rats	Kefir grains	↓ α -amylase inhibitory activity ↓ Pancreas lipase activity ↑ High-density lipoprotein (HDL) cholesterol ↓ Body weight	China	(Tiss et al., 2020)
Fermented soy milk	In vitro	Kefir yogurt (<i>Lactobacillus casei</i> , <i>Lactobacillus plantarum</i> , <i>Leuconostoc cremoris</i> , <i>Streptococcus lactis</i> , <i>Streptococcus cremoris</i> , <i>Streptococcus diacetyllactis</i> , and <i>Saccharomyces fragilis</i>)	↓ α -amylase-inhibitory activity ↑ α -glucosidase inhibitory activity	China	(Kwon et al., 2006)
Tempeh	In vivo, diabetic subjects	<i>Rhizopus oligosporus</i>	↓ Glycosylated hemoglobin (HbA1c) levels ↓ Triglycerides	Taiwan	(Su et al., 2021)
Tempeh	In vivo, BKS.Cg-Dock7 ^m +/+ + Lepr ^{db} /JNarl (db/db) mice	<i>Rhizopus oligosporus</i>	↓ Blood glucose levels ↓ Body weight	Taiwan	(Su et al., 2023)
Tempeh	In vivo, male Sprague–Dawley rats	<i>Lactobacillus plantarum</i> , <i>Rhizopus oligosporus</i>	↓ HbA1c ↓ Serum glucose ↓ Total cholesterol ↓ Triglyceride ↓ Free fatty acid ↓ Low-density lipoprotein contents ↑ High-density lipoprotein content	Taiwan	(Huang et al., 2018)
Tempeh	In vivo, diabetic mice	<i>Rhizopus oligosporus</i>	↓ Fasting blood glucose ↓ NF- κ B expression ↓ Receptor AGE expression	Indonesia	(Miftakhul Jannah et al., 2024)

as B and T cells, through Toll-like receptors, thereby modulating both innate and adaptive immunity (Raheem et al., 2021). Recent research has highlighted the immune-stimulating properties of probiotics, particularly LAB (Mubarik et al., 2024).

Bacillus subtilis has emerged as a promising probiotic with potential benefits for individuals with diabetes (Akinsemolu et al., 2024; Cardinali et al., 2020). *Bacillus subtilis* may help manage diabetes, probably by improving glucose metabolism and modulating gut microbiota (Li et al., 2023). Bacterial species like *Lactobacillus casei* exert antihyperglycemic effects by regulating glucose metabolism and gut microbiota (Zhang et al., 2021), whereas *L. plantarum* inhibits α -glucosidase activity (Zare et al., 2024).

Fungal microorganisms, like those inhabiting fermented soybean foods such as *Aspergillus sojae*, *Aspergillus oryzae*, *A. elegans*, *Rhizopus arrhizus*, and *Rhizopus oligosporus*, may offer some health benefits, including improved digestion and potential blood sugar regulation, but their direct impact on diabetes is less studied.

5 Conclusion

Fermented soybean foods have shown promise in mitigating type 2 diabetes. This is likely due to their influence on gut microbiota, a complex community of microorganisms in the intestine. These foods are rich in beneficial compounds that can improve gut health by reducing dysbiosis, a state of microbial imbalance. This, in turn, can boost the production of beneficial metabolites like SCFAs and bile acids.

Regional and racial dietary variations can impact gut microbiota composition. Therefore, consuming fermented soybean foods tailored to specific regions and ethnicities may offer more targeted benefits in addressing dysbiosis and modulating gut microbiota-related metabolites.

AI disclosure

During the preparation of this work, the author(s) used ChatGPT to improve the English language. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication

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Probiotics

Ranbir Chander Sobti

Probiotics: A Comprehensive Exploration of Health Benefits and Innovation explores the potential of probiotics and their fundamental role in human health and disease prevention. It offers a thorough understanding of how beneficial microorganisms can enhance overall well-being and potentially transform treatment approaches across multiple disciplines.

The book is structured into seven thematic sections that trace probiotics from fundamental biology to broad clinical and translational applications. Beginning with fundamentals (Section 1) and expanding through immunology (Section 2), general health and gut biology (Section 3), organ-system impacts (Section 4), nutritional issues (Section 5), specialized health applications (Section 6), and future directions (Section 7), the book interweaves mechanistic insights with preclinical and clinical perspectives on efficacy, safety, and delivery. Collectively, the chapters illuminate how probiotics influence host physiology across various systems and health states and explore innovative strategies in delivery, therapy, and disease prevention. With contributions from a diverse group of experts in the field, the book serves as an interdisciplinary resource for researchers, clinicians, and industry professionals eager to explore the therapeutic potential and benefits of probiotics.

Key Features

- Provides comprehensive coverage of probiotics integrating fundamental biology with diverse clinical and translational applications
- Explores multiomics mechanisms, including genomics, metabolomics, and immune interactions, to explain probiotic action
- Describes the impact of probiotics on health and disease management across multiple body systems and how these mechanisms translate into therapeutic applications
- Explains how probiotics contribute to nutrition and how they can be incorporated into everyday foods and dietary strategies for health and disease prevention
- Addresses future directions and opportunities at the intersection of probiotics with vaccines, antibiotic resistance, and cancer therapy to guide future research and clinical practice

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