Journal of Traditional Chinese Medical Sciences 12 (2025) 499–508

Contents lists available at ScienceDirect

Journal of Traditional Chinese Medical Sciences

journal homepage: www.elsevier.com/locate/jtcms

Integrative gut health: How fermented foods bridge ancient Eastern wisdom and modern microbiome science

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ARTICLE INFO

Article history:
Received 7 May 2025
Received in revised form
15 July 2025
Accepted 15 July 2025
Available online 21 July 2025

Keywords:
Gut microbiota
Integrative medicine
Fermented foods
Microbiome-gut-brain axis
Probiotics

ABSTRACT

In recent years, the gut microbiota has become an integral research topic in human health owing to its impact on digestion, immunity, metabolic processes, and mental health. The possibilities of microbiome treatment have increased interest in dietary approaches, with a special focus on the intake of fermented foods. This has revived some of the most profound and practical constructs derived from food therapy in Chinese medicine (CM), where food therapy, along with fermented options, actively preserves health and prevents disease. In CM, the spleen and stomach system refers to the postnatal foundation of the body, which controls the processes of chewing, nutrient assimilation, and energy production (qi). The balance between intestinal and overall health is the foundation of psychosomatic well-being and is of utmost importance. Fermented foods can boost the spleen, alleviate stagnant food syndrome, dispel excess fluids, enhance protective functions, and strengthen the immune system. This review aimed to integrate the conceptual and clinical paradigms of CM with those of Western medicine, focusing on the role of fermented foods in gut microbiota regulation. This article discusses prominent fermented foods in CM and their classical functions, alongside the currently available peer-reviewed literature (published within the last 7 years) on their impact on gut flora and other clinical outcomes. Mechanistic considerations regarding the production of probiotics and other active metabolites, such as short-chain fatty acids, and the modulation of the intestinal barrier are discussed. This review also examines multidisciplinary approaches to dietary customs worldwide and outlines the clinical applications of these findings in the context of chronic disease management and gastrointestinal health.

1. Introduction

Over the past few decades, the gut microbiota has been recognized as a crucial component of human health. It is estimated that more than 100 trillion microorganisms live in the human digestive system, and their effects on digestion, metabolism, the immune system, and neural signaling are well recognized.[1,2] Damage to this microbial ecosystem, known as dysbiosis, has been associated with several chronic health conditions, such as obesity, inflammatory bowel disease, type 2 diabetes, and clinical depression.[3–5] Therefore, modulating the gut microbiota through diet is crucial in preventive medicine.

There is a greater recognition of these foods in the context of supporting a healthy microbiome. Fermented foods result from controlled microbial and chemical reactions, and the end-products contain probiotics, bioactive peptides, and metabolites that improve health.[6] Surprisingly, modern research parallels ancient wisdom, as noted in Chinese medicine (CM), where fermented foods or herbal ferments have long been used to treat problems associated with the gastrointestinal system, especially metabolic stagnation, and strengthen the spleen-stomach system, which is responsible for digestion and postnatal vitality.[7,8]

This review investigates the intersection of CM dietary teachings and western microbiota science in the context of fermented foods. This study aimed to provide a rationale for incorporating fermented foods into integrative dietary plans, particularly in the context of chronic illnesses and digestive disorders, by considering traditional applications and contemporary clinical evidence.

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Peer review under responsibility of Beijing University of Chinese Medicine.

https://doi.org/10.1016/j.jtcms.2025.07.002
2095-7548/

2. Methodology

A comprehensive literature search was conducted using databases such as PubMed, Scopus, ScienceDirect, and Google Scholar. Search terms included keyword combinations, such as "fermented foods," "gut microbiota," "Chinese medicine," "spleen-stomach theory," and "probiotic mechanisms." Only articles published within the last 7 years were included, with an emphasis on studies that explored mechanistic insights, clinical applications, and microbial interactions relevant to the consumption of fermented food. Studies or articles that did not contain original data, articles without sufficient methodological details, non-peer-reviewed sources, opinion pieces, or studies lacking microbial or clinical outcomes were excluded. Relevant articles were identified by reviewing the references and citations of the selected articles.

3. The spleen-stomach system and postnatal health

CM emphasizes the spleen-stomach system as an essential hub for coordinating physiology. This system is generally considered responsible for digestion, assimilation, and the intricate processes of converting ingested food and fluid into vital energy (qi), blood, and *jin ye* (bodily fluids). As illustrated in Fig. 1, the spleen is

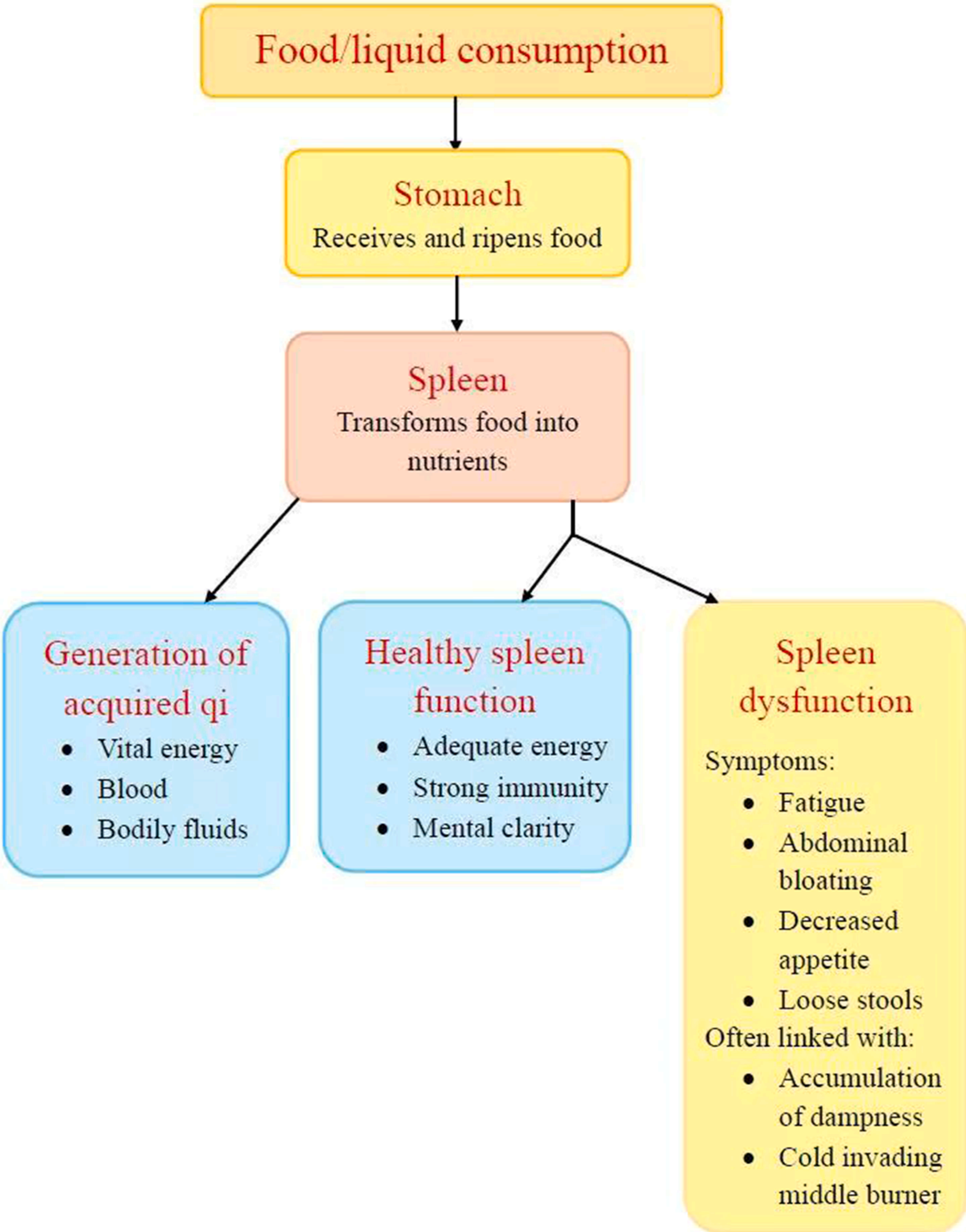

Fig. 1. Key functions of the foundation of postnatal existence.

responsible for transformation and transportation, metabolizing and distributing nutrients. The stomach is responsible for receiving and ripening, which describes the storage function of the organ where food is processed.[9]

In CM, all acquired qi is believed to originate from the food and liquids consumed and processed by the spleen and stomach, thereby designating the system as the "foundation of postnatal existence." An adequate spleen ensures energy, immunity, and mental clarity, whereas splenic dysfunction presents as fatigue, abdominal bloating, decreased appetite, loose stools, and a pale or scalloped tongue.[10] As outlined above, these symptoms are understood as spleen qi deficiency combined with the accumulation of dampness or cold invading the middle burner.

As mentioned in CM, erratic eating patterns, mental or emotional stress, and overthinking can be detrimental to the spleen. CM practitioners are careful in their dietary recommendations to preserve the integrity of the spleen by suggesting warm, cooked, and easily digestible foods. Chinese dietary therapy is characterized by the use of herbal medicines and medicinal foods that are integrated into everyday meals.

4. Fermented foods in CM: function and formulation

Fermentation has been practiced in Asia and China for millennia as a preservation technique with therapeutic benefits. According to CM dietary theory, fermented foods are believed to have warming properties and are classified as being able to stimulate digestive fires. This function is beneficial for individuals with excessive dampness or stagnant qi. Qi stagnation can be defined as the suspension or slowing of background activities in the life force. Examples of fermented foods in CM include:

(1) Suan Cai: This food includes fermented mustard greens or cabbage and is helpful in the improvement of digestion, along with hunger stimulation.
(2) Dou Chi: Also known as fermented black soybeans, it is known for its detoxifying and heat-clearing capabilities.
(3) Jiu Niang: Sweet fermented rice is best known for its post-pregnancy tonifying effect on qi and blood.
(4) Medicinal wines: Alcohol-based ferments with the ability to invigorate blood and dispel wind-cold.

These foods are frequently included in therapeutic meals, a distinctive type of dietary therapy that combines cooking and medicine.[11] For example, Suan Cai pork soup is used to treat digestive and appetite issues in patients with weak spleen qi, and Jiu Niang may be recommended for elderly patients with cold and deficient constitution.

Recent research has confirmed that microbial activity and diversity are associated with functional metabolites in traditionally fermented foods. For instance, *Lactobacilli* in Suan Cai and *Bacillus* species in Dou Chi have been shown to exhibit probiotic properties, aiding gut health and immune system modulation.[12] These discoveries provide scientific evidence to support the ancient medicinal wisdom of CM, which suggests that fermented foods can improve gut health.

In addition, the dynamic interplay between food energetics and individual constitution in CM permits the individualization of dietary prescriptions. The incorporation of CM into these foods is based on seasonal or illness-specific adjustments that correspond to patients' symptoms, highlighting CM's holistic and adaptive nature. The focus on postnatal nourishment through the spleen-stomach system and the harmony of digestion in CM, together with the practical use of fermentation, makes CM a significant contributor to modern conversations about diet, microbiota, and health.

5. The gut microbiome in western medicine

5.1. Composition and functional roles

Often referred to as a "virtual organ," the gut microbiome contains an estimated 100 trillion bacteria, most of which are symbiotic, living within the gastrointestinal tract. These microorganisms surpass human cells in number and have over a hundred times more genes than the human genome.[1] Microbial communities comprise four dominant phyla: *Firmicutes*, *Bacteroidetes*, *Actinobacteria*, and *Proteobacteria*. Their composition varies significantly among individuals, and is influenced by diet, age, environment, medication, and genetics.[13]

The microbiome is responsible for ontogeny and immunity, as well as important physiological tasks such as the fermentation of complex carbohydrates and dietary fibers into short-chain fatty acids (SCFAs), synthesis of the vitamin B group and K, bile acid metabolism, detoxification of xenobiotics, and immunomodulation.[2] Moreover, the gut microbiota sustains the intestinal barrier and modulates signaling in the gut–brain axis, thus influencing mood, cognition, and behavior.[3]

5.2. Dysbiosis and disease

Dysbiosis is characterized by an imbalance or mismanagement of the gut microbiota that disrupts the host–microbe equilibrium. Some defining features of dysbiosis include decreased microbial diversity, absence of protective commensals, and pathogenic bacterial overgrowth. This imbalance is linked to weakened epithelial barriers, which permit microbial constituents, such as lipopolysaccharides (LPS), to enter the systemic circulation and initiate inflammation and metabolic derangements.[5]

Research associates dysbiosis with a broad spectrum of diseases such as inflammatory bowel disease (IBD), type-2 diabetes mellitus (T2DM), obesity, cardiovascular disease, colorectal cancer, and neuropsychiatric disorders such as anxiety and depression.[2,4] For example, in T2DM, dysbiosis reduces the number of SCFA-producing bacteria and increases LPS levels, contributing to insulin resistance.[14]

Novel methods targeting dysbiosis-related pathologies focus on manipulating the gut microbiota using dietary fiber supplementation, prebiotics, probiotics, and fecal microbiota transplantation. This demonstrates the active clinical contribution of gut microbial ecology to health-sustaining, complex network systems.

6. Fermented foods and microbiota modulation

Among dietary approaches, fermented foods are unique in their ability to deliver beneficial microorganisms and provide nutrition to the resident microbiota. Fermented foods are rich sources of probiotic cultures, including *Lactobacillus*, *Bifidobacterium*, and *Bacillus* species, which improve the gut microbial diversity and support balanced immune responses.[6,15]

A randomized controlled trial demonstrated that a diet rich in fermented foods resulted in higher gut microbial alpha-diversity and reduced levels of certain circulating inflammatory markers, including interleukin-6 (IL-6) and tumor necrosis factor-α (TNF-α).[16] Interestingly, these changes were not observed in the high-fiber diet group, highlighting the unique immunomodulatory effects of fermented products.

Moreover, fermented foods play a direct or indirect role in SCFA production through microbial activity or by promoting the growth of SCFA-producing microbes. SCFAs possess anti-inflammatory properties, enhance insulin sensitivity, and maintain colonic integrity. Other metabolites present in fermented foods, such as bacteriocins, organic acids, and peptides, may inhibit pathogenic bacteria and strengthen epithelial barrier function.[17]

The combined results of these studies highlight the significance of fermented foods in modulating the gut microbiota, as illustrated in Fig. 2. As with CM dietary therapy, their benefits focus on enhancing digestion and immunity, revealing a potential focal point for developing integrated health approaches.

7. Fermented foods and their effects on the microbiome

Traditional Chinese fermented foods exemplify the relationship between ancient traditions and modern microbiological sciences. While CM has always regarded these foods for their effects on balancing digestion and promoting health, western research is now explaining their specific relationships with gut microbial diversity, immune responses, and metabolic processes.

7.1. Suan Cai — fermented cabbage

Suan Cai is produced by fermenting cabbage and Chinese mustard greens in brine (high salt concentration), which enhances the concentration of *Lactobacillus plantarum* and other lactic acid bacteria (LAB). In CM, Suan Cai is considered to have a mildly warming nature and is prescribed to assist digestion, promote the movement of stagnant qi, and increase appetite, particularly in individuals with weak splenic function. Recent studies have demonstrated that Suan Cai aids in maintaining the gut barrier function, modulating the production of inflammatory regulators (cytokines), and enhancing microbial diversity by promoting the growth of LAB.[18]

7.2. Dou Chi — fermented black beans

Dou Chi refers to soybeans fermented with *Aspergillus* or *Bacillus subtilis*. It is used for its medicinal properties to clear body heat, detoxify, and relieve digestive stagnation. *Bacillus subtilis* plays a vital role in gut immunity and gut flora enhancement by modulating beneficial bacteria.[12] Dou Chi also yields anti-inflammatory and cardiovascular-protective bioactive compounds similar to those found in natto.

7.3. Jiu Niang — fermented rice wine lees

Jiu Niang is a mildly sweetened fermented rice product that is often used in postpartum recovery as a source of qi, blood, or both. It contains traces of alcohol and glucose and numerous strains of yeast and bacteria. Animal studies suggest that Jiu Niang may help regulate gut microbiota balance, promote the production of SCFAs, and modulate inflammatory responses within the gut.[19] In CM, Jiu Niang is consumed warm, with ingredients that enhance warmth in the spleen and promote blood circulation.

7.4. Miso and natto — soybean ferments

Miso and natto are of Japanese origin but trace back to East Asian fermentation traditions and are used by CM practitioners. Miso is a soybean paste fermented with *Aspergillus oryzae,* which contains many probiotics that aid digestion and replenish qi. Natto is fermented by *Bacillus subtilis* and contains a component called nattokinase, which is believed to improve blood circulation. They have been reported to improve gut microbial composition, reduce systemic inflammation, and improve metabolic markers.[20]

7.5. Kimchi — Korean fermentation with roots in CM

According to the principles of CM, kimchi is a fermented dish that contains diverse ingredients, such as cabbage, radish, garlic,

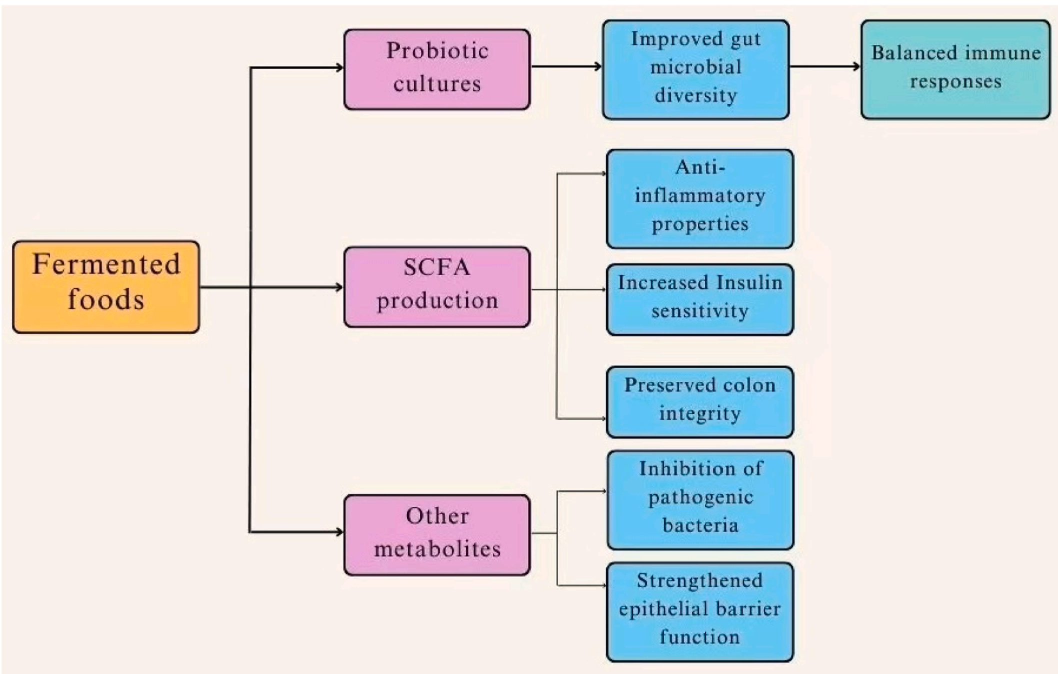

Fig. 2. Fermented foods and their effects on the microbiome.
Notes: SCFA: short-chain fatty acid.

and chili peppers. Kimchi is rich in *Lactobacillus kimchii* and other strains that have shown anti-obesity, anti-inflammatory, and lipid-lowering properties in many studies conducted on humans and animals.[21] Regular consumption of these dishes enhances the count of butyrate-producing bacteria and reduces gut permeability.

These examples illustrate the interrelationship between the energetic classification of foods in CM and microbiota studies in modern science. Table 1 lists the fermented dishes, their functions in CM, and their microbiome-related functions as confirmed by Western medicine.

8. Mechanistic insights: how fermented foods influence gut health

CM considers the thermal characteristics and energetic influence of fermented foods, whereas modern biomedical science examines their inner mechanisms at the molecular and microbial scales. Microbiological mechanisms can be categorized into three main types: probiotic and prebiotic effects, intestinal barrier regulation, and SCFA production.

8.1. Probiotic and prebiotic effects

Fermented foods contain live microorganisms that provide health benefits when consumed in sufficient quantities. Such probiotics, mainly *Lactobacillus*, *Bifidobacterium*, and *Bacillus* strains, only partially dominate their activity and enhance the host microbiota by supporting potency through the competitive elimination of infecting microbes, perturbation of immune cells, or rebuilding microbial equilibrium.[15] Fig. 3 provides an overview and summary of the probiotic and prebiotic effects.

Lactobacillus plantarum, found in Suan Cai, can reduce inflammation, increase immunoglobulin A (IgA) secretion, and enhance mucin production. Dou Chi and natto's resilient spore-forming bacterium, *Bacillus subtilis*, also produces antimicrobial peptides (bacteriocins) and contributes to epithelial healing and homeostasis.[12] Moreover, certain products derived from the fermentation processes, such as polysaccharides, may act as prebiotics.[6] Such substrates facilitate the production of SCFAs, promoting the growth of beneficial bacteria, such as *Bifidobacteria* and *Lactobacilli*, and inhibiting potentially pathogenic bacteria in the host gut.[22]

8.2. Regulation of the intestinal barrier

An intact intestinal epithelial barrier is crucial for maintaining gut health and preventing systemic inflammation. This can be understood in CM as dampness accumulation and spleen qi deficiency, corresponding to the modern concepts of "leaky gut." Some constituents of fermented foods, such as lactic acid, polysaccharides, and bioactive peptides, increase the expression of tight junction proteins (occludin, claudin, zonula occludens-1) and mitigate endotoxin efflux.[23]

Miso, kimchi, and Jiu Niang have been shown to fortify the gut barrier. These foods downregulate the synthesis of pro-inflammatory cytokines TNF-α and IL-6 while upregulating anti-inflammatory mediators interleukin-10 (IL-10) and transforming growth factor-β (TGF-β). These observations are significant in the context of chronic inflammation associated with IBD and the metabolic syndrome.

8.3. SCFAs and metabolic health

Primary SCFAs (acetate, propionate, and butyrate) are produced by microbial fermentation of complex carbohydrates and dietary fibers. They are important for both metabolism and immunity. Acetate is metabolized for the cholesterol and appetite-regulating centers; propionate inhibits hepatic gluconeogenesis and increases satiety factors peptide YY (PYY) and glucagon-like peptide-1 (GLP-1); butyrate fuels colonocytes and inhibits pro-inflammatory nuclear factor-kappa B (NF-kB) signaling pathways.[17]

Fermented foods enhance SCFA production directly through the metabolism of microbially fermented foods and indirectly through the activation of SCFA-producing microbes. Clinical studies have linked high SCFA concentrations to improved insulin sensitivity, decreased body weight, and reduced risk of colorectal cancer.[24,25]

Western medicine provides new evidence that reinforces the long-held belief in CM that fermented foods enhance digestion, dispel dampness, and restore internal balance. The primary SCFAs and their clinical significance are listed in Table 2.

From a clinical translation standpoint, the mechanistic effects of fermented foods, such as SCFA production, enhanced barrier integrity, and the modulation of anti-inflammatory cytokines, correlate with improved outcomes in metabolic and inflammatory diseases. These effects include reduced insulin resistance, improved bowel regularity and enhanced immunity. These effects align with the clinical goals of CM, wherein fermented foods support the spleen and resolve dampness. Thus, the convergence of traditional energetics with molecular outcomes renders fermented foods viable adjuncts for chronic disease management.

9. Fermentation and disease prevention: a cross-cultural comparison

9.1. Traditional vs. western dietary patterns

Fermented foods, along with whole grains and vegetables, are staples in the traditional diets of Chinese, Korean, and Japanese people. Throughout the different seasons, they focus on moderation and balance, which aligns with the principles of CM of internal harmony and digestion. Fermented foods such as miso, kimchi, natto, Dou Chi, and Suan Cai are staples that serve as tonics for health and are consumed daily in small quantities as digestive aids.[27] As shown in Fig. 4, increased health issues, such as neuroinflammation, metabolic syndrome, and cardiovascular diseases, are the result of consuming red meat, sugar, and refined

Table 1
Selected CM-fermented foods and their microbiological effects.

Fermented food	CM functions	Microbiota effects (Western medicine)
Suan Cai	Resolves food stagnation, promotes appetite	Rich in *Lactobacillus plantarum*, supports mucosal integrity[18]
Dou Chi	Clears heat, detoxifies, tonifies digestion	Contains *Bacillus subtilis*, increases gut microbial diversity[12]
Jiu Niang	Warms the spleen, enhances circulation	Produces SCFAs; supports growth of *Bifidobacterium* and *Faecalibacterium*[19]
Miso/natto	Tonifies qi, supports digestion	Contains *Bacillus spp.*, provides nattokinase; enhances SCFA production[20]
Kimchi	Clears heat, resolves dampness	Contains *Lactobacillus kimchii*, modulates inflammatory pathways[21]

Notes: CM: Chinese medicine; SCFA: short-chain fatty acid.

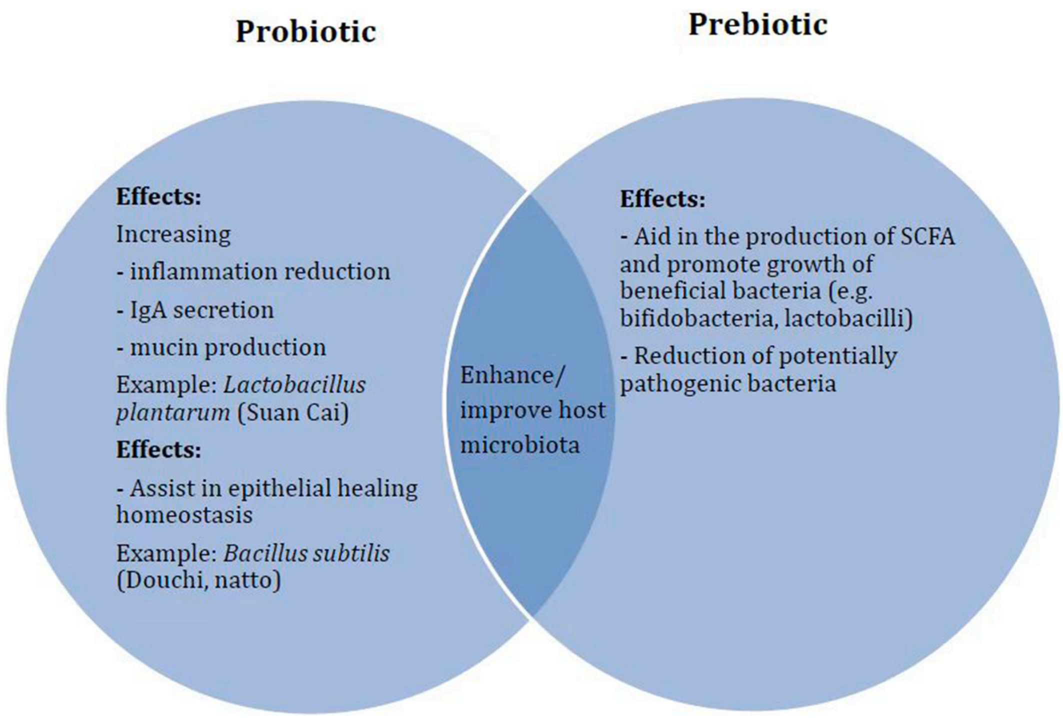

Fig. 3. Prebiotic and probiotic effects of fermented foods.
Notes: IgA: immunoglobulin A; SCFA: short-chain fatty acid.

Table 2
Health effects of SCFAs generated from fermented foods.

SCFA	Function	Clinical benefit
Acetate	Energy for peripheral tissues	Modulates appetite, lipid metabolism[26]
Propionate	Inhibits hepatic lipogenesis	Improves insulin sensitivity, reduces gluconeogenesis[24]
Butyrate	Anti-inflammatory, trophic for colonocytes	Enhances gut barrier, protects against colon cancer[25]

Notes: SCFA: short-chain fatty acid.

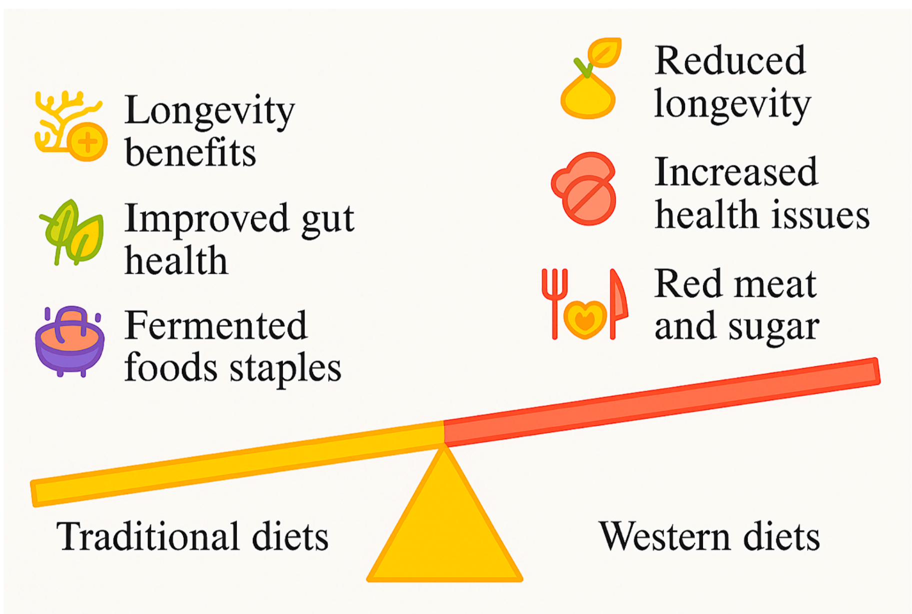

Fig. 4. Comparison of dietary impacts on health and longevity.

carbohydrates, which is characteristic of western diets. People in the East, who are now integrating western diets, add several emulsifiers to their food, which harms the gut microbiota by lowering its diversity and increasing pro-inflammatory species. Chronic consumption of this diet can lead to obesity, metabolic syndrome, cardiovascular disease, and even neuroinflammation.[28]

9.2. Gut microbiota and longevity

Plant-based, fermented, and minimally processed foods are dietary staples for centenarians in Okinawa (Japan), Guangxi (China), and Jeju (Korea). Their eating habits reflect the strong cultural traditions that predate them, emphasizing moderation and gut-friendly foods.[29]

Traditionally fermented foods may promote longevity by modulating intestinal microecology, particularly by enriching the gut with beneficial microbial taxa, such as Bifidobacteria and Faecalibacteria. *Bifidobacterium*, *Faecalibacterium prausnitzii*, and *Akkermansia muciniphila* are enriched in the microbiota of these populations, which in turn have protective anti-inflammatory roles in gut inflammation, gut barrier function, and control metabolically active tissue health and inflammation, all of which are vital in aging populations.[30] The spleen-strengthening properties attributed to such foods in CM align with the observed reduction in systemic inflammation and increased resilience in elderly cohorts that consume traditional diets rich in fermented foods.

Evidence suggests that fermented foods not only improve gut health but also systemically enhance the control of longevity-related inflammation, kidney or liver function (mitochondrial function), and fuel-adaptable metabolism (metabolic flexibility). Balancing diet and microbiome composition provides an innovative approach to healthy aging.

10. Clinical applications and integrative approaches

10.1. Dietary recommendations

The dietary principles of CM can be integrated into nutritional counselling by suggesting appropriate fermented foods based on an individual's constitution and disease presentation. For example, Suan Cai may alleviate bloating. Warming ferments, such as Jiu Niang, can help recover from fatigue and cold. This is in agreement with modern insights into the gut microbiome and metabolic crosstalk.[31] Combining CM-fermented foods with probiotic-rich alternatives such as kefir, yoghurt, and sauerkraut may offer combined benefits. The effectiveness of these foods depends on essential factors such as dosage, interval, proprietary blend of microbes, and gut tolerance. Educating patients on symptom monitoring during the transition to a new diet can help avoid digestive discomfort.

10.2. CM concepts in personalized diets

Dietary customization is important for both CM and precision nutrition. In CM, practitioners evaluate an individual's body constitution, *yin-yang* balance, and pattern of disharmony to make food choices. For example, individuals with spleen qi deficiency and dampness may benefit from mildly warming and drying fermented foods such as Dou Chi or miso soup. In contrast, patients with heat or *yin* deficiencies may need to select less-stimulating options or combine cooling herbs with fermented foods. This strategy is similar to advanced western models of personalized nutrition, which use genetic and metabolic information and even microbiome structures for diet customization.[32]

11. Safety and contraindications

Although fermented foods are generally well accepted, some groups may be at risk. Individuals with histamine sensitivity, small intestinal bacterial overgrowth, or low immune function may experience adverse effects, such as abdominal pain, skin rash, or relentless exhaustion. Careful balancing of these foods in the diet is necessary for this demographic population, preferably under the guidance of a clinician.

Moreover, traditional fermented products may differ in terms of microbial content, salt concentration, and hygiene. Consistency and safety must be regulated through standardization, good manufacturing practices (GMP), and clear labeling.[33] When applied and selected with proper caution, fermented foods have the most significant potential for managing chronic conditions and as proactive measures for preventive healthcare.

12. Future directions in research and practice

The incorporation of fermented foods into CM and nutritional science presents essential opportunities for innovation in healthcare. Nonetheless, as illustrated in Fig. 5, challenges and opportunities remain in further defining and expanding the validation of fermented foods in CM through scientific evidence.

13. Microbiome-targeted CM and standardized research

Research interest in the microbiota-modulating effects of fermented foods is still relatively low for traditional CM-fermented products. The currently available information mainly stems from *in vitro* or animal studies, which, although promising, do not necessarily translate to human physiology. There is a gap in the literature regarding randomized controlled trials that target specific CM-fermented foods, such as Suan Cai, Dou Chi, or Jiu Niang, and use clinically relevant endpoints, including insulin sensitivity, inflammatory markers, or microbiome diversity.[34]

Moreover, other CM constitutions and associated side effects should also be investigated in combination with the gut microbiome. How do different CM constitutions interact with a gut microbial response? For instance, does the gut microbiome of a patient with spleen qi deficiency respond differently to fermented rice products than that of a patient with liver *yang* excess? Studying these relationships offers significant potential for identifying specific dietary biases tailored to individual constitutions.

Despite limited evidence, recent studies suggest that fermented foods may have beneficial effects on health by modulating the gut microbiota. These studies tend to be disparate, and there is a distinct lack of human trials compared to promising *in vitro* and animal testing.[35–37] Evidence from randomized controlled trials suggests that kefir may aid in the management of lactose malabsorption and eradication of *H. pylori*.[38] Various mechanisms, such as the action of probiotics, release of bioactive peptides, and metabolism of phenolic compounds, may explain the impact of fermented foods on gut health.[38] However, most studies focusing on traditional fermented foods have not combined robust human data with standard methodologies.[39] Of all fermented dairy products, yoghurt has the most robust evidence supporting its role in lowering the risk factors for T2DM. In contrast, fermented dairy products have been shown to have little to no association with cancer and may have a positive impact on cardio-metabolic health.[40] Further research in humans is required to determine the effects of fermented foods on health.[41]

An array of omics technologies, including 16S rRNA sequencing, shotgun metagenomics, metabolomics, and proteomics, has the potential to dissect the effects of fermentation on host-microbiota

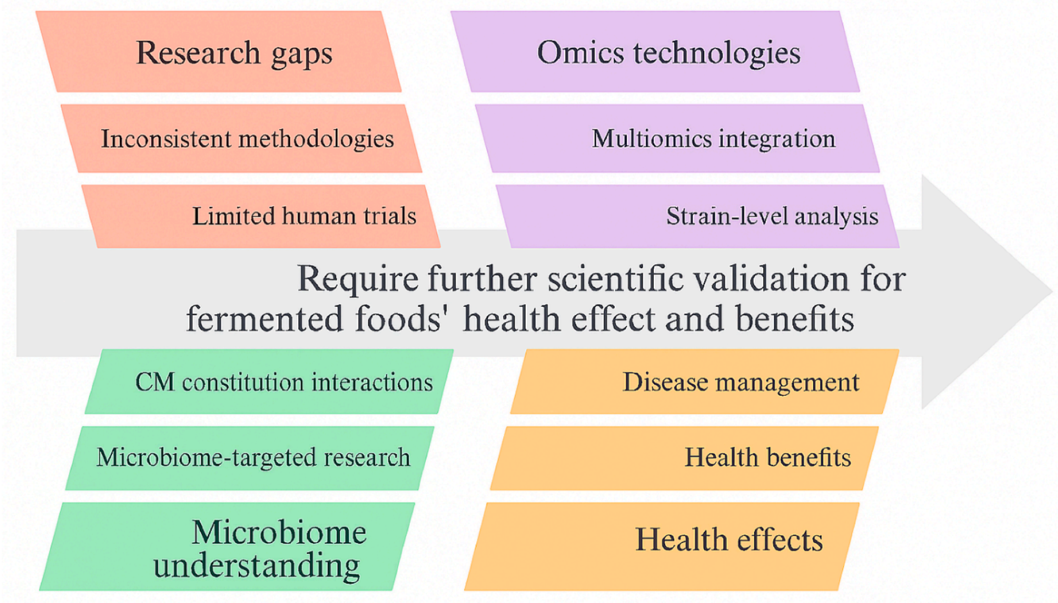

Fig. 5. Challenges in validating the health effects and benefits of fermented foods.

relationships at the strain level. Wen et al and Shi et al argued that multi-omics approaches such as metagenomics, metatranscriptomics, metaproteomics, and metabolomics provide holistic views of the microbial consortia, metabolic pathways, and bioactive compounds present in fermented foods.[42,43] These techniques help trace the microbial–host interaction pathways, explaining how fermented foods modulate gut microbiota structure and activity.[44,45] According to Sarkar et al and Jacobs et al, metabolomics has successfully identified bioactive metabolites that act as potent anti-inflammatory and immunomodulatory agents.[46,47] High-throughput sequencing technologies enable the strain-level analysis of microorganisms present in fermented foods and their relationship with probiotic effects.[48] The integration of multiomics data provides a deeper understanding of the fermentation processes and mechanisms involved in flavor formation and the functional properties of fermented foods.[42,49] These approaches may help elucidate the detailed pathways through which fermented foods in CM deliver their anti-inflammatory, metabolism-modifying, and immune system-regulating functions. Fig. 6 summarizes the future opportunities and directions of fermented food research.

14. Integration of CM and fermentation science

The integration of traditional fermentation methods with contemporary biotechnological techniques can enhance the safety and consistency of fermented products. Table 3 presents the three domains and research gaps that require attention. For example, the standardization of fermentation starters can include beneficial microbial strains, so that each batch poses minimal therapeutic risk. Moreover, fermentation conditions such as temperature, humidity, and duration can be precisely controlled using bioreactors to maximize the production of active compounds, such as SCFAs, bacteriocins, and polysaccharide.[42]

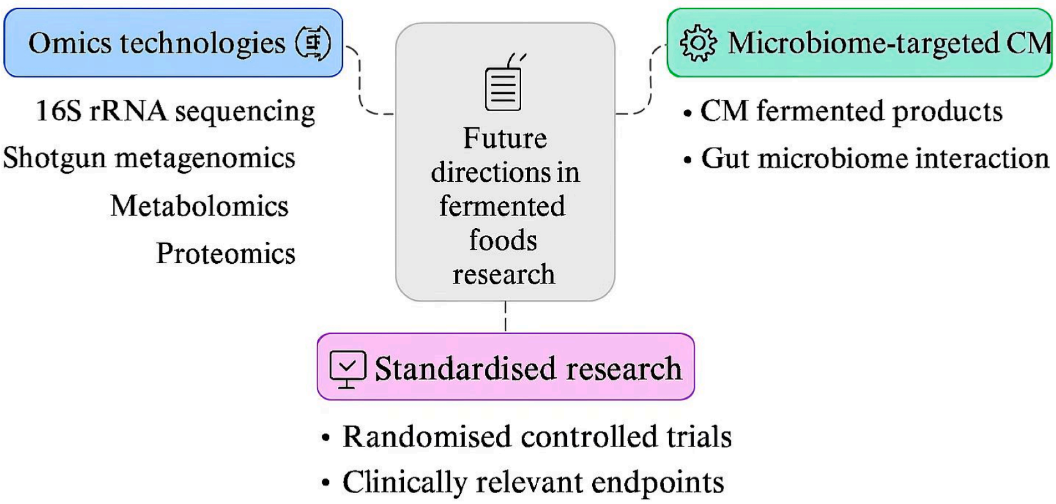

Fig. 6. Future directions of fermented food research.
Notes: CM: Chinese medicine.

Table 3
Research gaps and opportunities in CM-fermented foods.

Domain	Research gap	Proposed direction
Clinical trials	Limited RCTs on CM fermented food outcomes	Conduct multi-center studies on chronic disease cohorts
Microbiota characterization	Lack of specific microbial strain data	Apply 16S and shotgun metagenomic sequencing
Safety & standardization	Variable quality and microbial content	Develop GMP guidelines for traditional products

Notes: CM: Chinese medicine; GMP: good manufacturing practices; RCTs: randomized controlled trials.

In addition, sponsors of interdisciplinary research programs that combine microbiologists with CM researchers, dietitians, and clinicians are required to formulate evidence-based frameworks. Clinical guidelines and educational initiatives that integrate microbiota science into CM dietary theory will enable practitioners to provide nutritionally sound and culturally sensitive care.

The health of the general population can be improved by incorporating fermented foods as nutritionally inexpensive options, particularly in areas where microbiota-depleting diets are prevalent. Policies that support the use of traditional foods, diversify agriculture, and educate people on fermentation can enhance the resilience and sustainability of food systems.

15. Conclusion

Modern medical science and CM integrate knowledge regarding the effects of fermented foods on gut health. The ancient understanding of fermentation by CM fills the gaps in modern science regarding gut flora and immunological function. Foods such as Suan Cai, Jiu Niang, and Eastern kimchi exemplify the value of traditional ferments (as medicine) because they provide microbes to the body while also following the Chinese Medical principles of balance and individualization. Research suggests that these foods promote good gut health through various mechanisms and have the potential to manage disorders ranging from diabetes to mood disorders.

Fermented foods represent unique and sustainable solutions to noncommunicable diseases aggravated by cultural factors, although their standardization is lacking. The future research direction lies in the collaboration of CM researchers, dietitians, clinicians, and medical scientists to formulate evidence-based and individualized strategies that best utilize fermentation for health. This combination of disciplines provides a strengthening and unifying approach to integrative personalized medicine and public health.

Funding

There is no funding support for this study.

CRediT authorship contribution statement

Enoch Chi Ngai Lim: Conceptualization, data curation, methodology, formal analysis, investigation, visualization, writing – original draft, and writing – review & editing. **Wing Tung Stephanie Yu:** Formal analysis, investigation, visualization, writing – review & editing. **Chi Eung Danforn Lim:** Conceptualization, resources, formal analysis, investigation, supervision, validation, visualization, and writing – review & editing.

Declaration of competing interest

The authors declare that there are no conflicts of interest.

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