

Probiotic Dairy Products: An overview and Health Policy

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Abstract

Background and Objective: Probiotic dairy products are offering nutritional value and reliable vehicle for delivering beneficial microorganisms. This review has provided a comprehensive synthesis of current knowledge on probiotic dairy products, including their health benefits, technological and industrial challenges, market trends, regulatory frameworks and policy considerations, with focus on emerging digitalization strategies.

Materials and Methods: A literature search was carried out within major databases for studies published between 2000 and January 2026, resulting in 18 eligible review articles. Due to methodological variability, findings were synthesized qualitatively. Additionally, a structured policy dialogue involving a diverse group of stakeholders from academia, regulatory agencies, scientific associations and dairy industry was used to assess their viewpoints. Participants were selected through purposive sampling and invited to provide their perspectives on the prioritization of proposed strategies, potential limitations of each strategy, their feasibility and possible obstacles, with the study objectives.

Results and Conclusion: The evidence demonstrates that probiotic dairy products support gastrointestinal health, immune function and metabolic regulation, with potential adjunctive benefits in managing infectious and inflammatory conditions. These effects are strain-specific, dose-dependent and condition-specific. Dairy matrices play a critical role in enhancing probiotic viability and survival through the gastrointestinal tract. However, inconsistencies are between regulatory standards and commercial practices, particularly in strain identification, viable cell counts at shelf life and labeling transparency. Consumer behavior is affected by knowledge, sociodemographic factors and price sensitivity, while industry challenges include maintaining microbial stability and overcoming technological and regulatory constraints. Policy discussions emphasized the need of standardized regulations, improved monitoring, consumer education and investment in advanced technologies. Strengthened collaboration within stakeholders is essential to ensure product efficacy, safety and sustainable growth.

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What is “already known” on this topic:

- The selection of probiotic is challenging due to strain-specific and disease specific efficacy, different mechanisms of action, manufacturing practices and quality control and international regulatory guidelines.
- Probiotic dairy products support gastrointestinal health, immune function and metabolic regulation, with potential adjunctive benefits in managing infectious and inflammatory conditions.
- These effects are strain-specific, dose-dependent and condition-specific. Dairy matrices play a critical role in enhancing probiotic viability and survival through the gastrointestinal tract.

What this article adds:

- Policy discussions emphasized the need of standardized regulations, improved monitoring, consumer education and investment in advanced technologies.
- Strengthened collaboration within stakeholders is essential to ensure product efficacy, safety and sustainable growth.

1. INTRODUCTION

Food plays a fundamental role in preserving human health by supplying essential nutrients, providing energy and supporting normal physiological functions. In addition to basic nutrition, food can serve as a delivery vehicle for probiotics, which are live microorganisms widely recognized for their beneficial effects on gastrointestinal health [1]. Therefore, the concept of functional foods emerged in Japan in the early 1990s as an innovative approach to disease prevention and the decrease of healthcare costs [2]. Functional foods are defined as natural or modified foods; in which, specific components are added, removed or altered through technological or biotechnological processes to provide health benefits in addition to basic nutrition [3]. This category includes probiotics, prebiotics, vitamins and minerals incorporated into diverse products such as fermented milk, sports beverages, infant foods and chewing gum [4]. Owing to their health-promoting characteristics and increasing consumer awareness, functional foods have become a rapidly expanding segment of the global food industry.

Within functional foods, dairy-based products represent one of the most significant and widely consumed categories, encompassing low-fat and skim dairy products [5], as well as probiotic-enriched dairy foods [6]. Milk and dairy matrices are considered ideal carriers for probiotics because of their favorable physicochemical characteristics, including appropriate pH, temperature stability, storage conditions and nutrient composition, all of which support probiotic viability and functionality [9, 10]. Therefore, probiotic dairy products constitute one of the fastest-increasing sectors of the functional food market, driven by increasing consumer interest in health promotion and disease prevention. Dairy products, including milk, yogurt, cheese and ice cream, are well-established carriers of probiotic microorganisms. Their physicochemical characteristics provide a buffering effect during gastrointestinal transit, enhancing probiotic survival, viability and transient persistence in the gastrointestinal tract (GIT) [11, 12].

Milk fermented with “*Lactocaseibacillus casei*” has been reported as beneficial for patients with dyslipidemia, suggesting its potential as a functional dietary intervention [13]. In another study, bacteriocin-like inhibitory substances produced by lactic acid bacteria (LAB) demonstrated significant antimicrobial activity, indicating their potential

use as natural food preservatives to enhance food safety and quality by preventing foodborne infections [14]. Furthermore, four “*Lactobacillus*” strains have been identified as promising probiotic candidates due to their ability to decrease the risk of dental caries and other oral diseases. These strains interfere with the adhesion of “*Streptococcus mutans*” to tooth surfaces, a critical step in the development of dental caries [15].

Over time, the definition of probiotics has evolved in the widely accepted Food and Agriculture Organization/World Health Organization (FAO/WHO) description of probiotics as “live microorganisms that, when administered in adequate amounts, confer a health benefit on the host” [17]. The majority of commercially available probiotics belong to bacterial genera such as *Lactobacillus*, *Bifidobacterium*, *Lactocaseibacillus*, *Lactiplantibacillus*, *Enterococcus* and *Streptococcus*. The probiotic yeast *Saccharomyces boulardii* is classified separately because it is a yeast rather than a bacterium. Although the minimum effective dose varies based on the strain and clinical indication, probiotic products are generally recommended to contain at least 10^{6-8} CFU ml⁻¹ or CFU g⁻¹ at the time of consumption to provide health benefits [19].

Probiotic containing foods are recognized as functional foods and have attracted increasing scientific and commercial interests due to their broad spectrum of health promoting effects [20]. In probiotic dairy products, viable LAB [21] have been associated with numerous health benefits, such as decreasing the severity of diarrhea, modulating gut microbiota through antimicrobial activity, lessening lactose intolerance, preventing food allergies, enhancing immune responses and exerting antioxidant and antitumor effects [22]. Recent research has further highlighted the role of probiotics in immune modulation and production of bioactive metabolites [23, 24], leading to the development of probiotic formulations targeting oral and skin health, as well as therapeutic uses for allergies, metabolic disorders, cancers and inflammatory bowel disease (IBD) [25].

Advances in molecular biology, including genetic sequencing and bioinformatics, have significantly accelerated probiotic research, enabling the identification and characterization of novel strains with enhanced functional potential [26]. Clinically, probiotics have demonstrated efficacy in preventing and lessening



gastrointestinal disorders such as acute, antibiotic-associated and *Clostridium difficile* associated diarrheas; allergic conditions including atopic dermatitis and allergic rhinitis in infants; and selected IBDs in adults. Moreover, probiotics have shown promises as adjunct therapies for metabolic disorders such as obesity, metabolic syndrome, nonalcoholic fatty liver disease (NAFLD) and type 2 diabetes [27]. These effects are mediated through multiple mechanisms, including restoration of microbial balance, competitive exclusion of pathogens, bacteriocin production, modulation of bile salt metabolism, production of short-chain fatty acids (SCFA), enhancement of epithelial barrier function, immune regulation and interactions in the gut-brain axis [27]. Additional evidence suggests their potential to decrease stress-associated biomarkers such as cortisol [28].

Probiotics have been investigated as complementary agents to conventional antimicrobial therapies. For

example, in treatment of *Helicobacter pylori* induced gastric ulcers, antibiotic therapy alone achieves an eradication rate of approximately 71%, whereas co-administration with probiotics increases this rate to nearly 81% while significantly decreasing treatment-associated side effects [29]. Furthermore, probiotics have been investigated for their potential benefits in autism, osteoporosis, cardiovascular diseases (CVDs), respiration and central nervous system (CNS) [30]. Particularly, meta-analytical evidence suggests that probiotic supplementation in COVID-19 patients may contribute to improved clinical outcomes, including decreased mortality and faster recovery [31]. Probiotic bacteria possess the ability to synthesize and accumulate essential micronutrients such as trace metals, vitamins and bioactive peptides, highlighting their potential as cost-effective agents for food fortification (Figure 1).

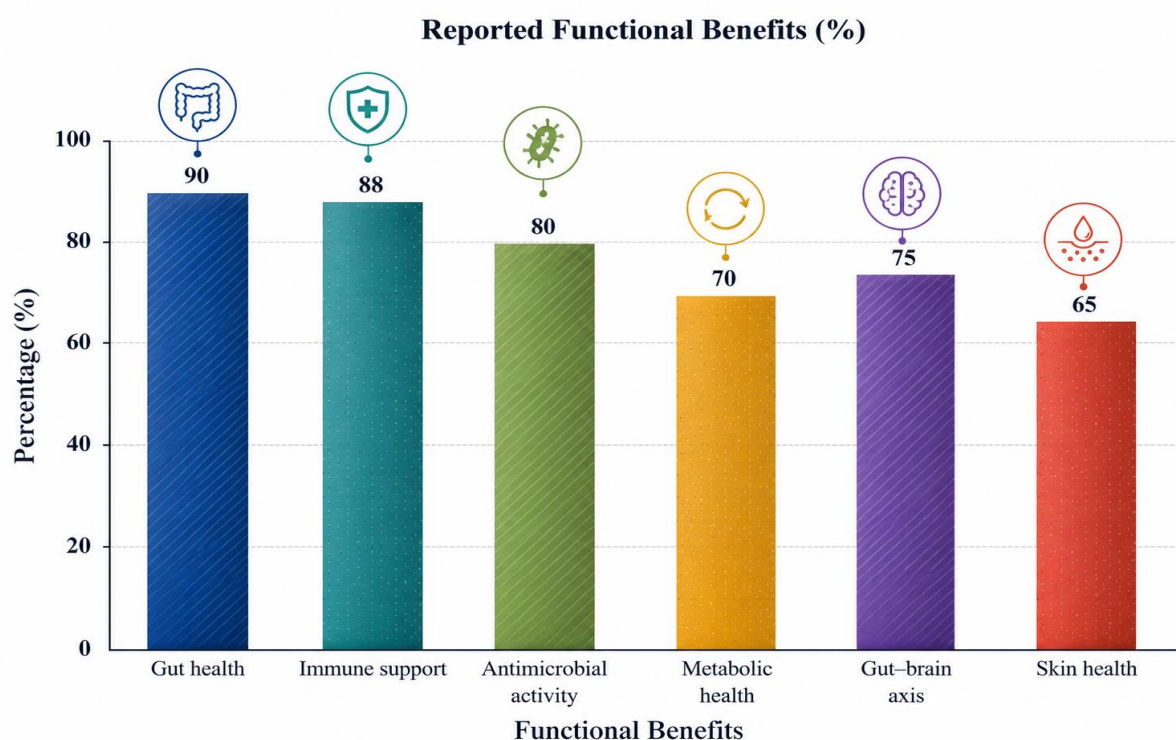


Figure 1. Functional benefit levels of probiotic dairy products

This approach is particularly relevant for low and middle-income countries, where a large portion of the population fails to meet recommended daily intakes of key micronutrients. Incorporating nutrient-producing probiotic bacteria into widely consumed foods may offer a sustainable scalable strategy to improve micronutrient deficiencies while concurrently promoting gut health [32]. These

observations are particularly concerning, as insufficient intake of essential micronutrients can impair immune function and heighten susceptibility to infections and diseases [33].

Probiotics and prebiotics, defined as non-digestible oligosaccharides that beneficially affect the host, are widely incorporated into dairy products such as fermented milk,



yogurt, cheese, ayran and kefir [34]. Probiotics naturally occur in traditional fermented foods, human breast milk and the GIT of humans and animals [35]. However, the selection of appropriate probiotic strains are challenging due to strain-specific and disease specific efficacy, variability in mechanisms of action, differences in manufacturing practices and quality control and inconsistencies in international regulatory guidelines [36]. Despite these challenges, dairy and dairy-based products have long served as effective vehicles for probiotic delivery, with a history of use in centuries [37-39]. Important gaps are in understanding evolution of probiotic health benefits, potential adverse effects, quality associated challenges and industrial opportunities within probiotic dairy production.

To the best of the authors' knowledge, this review provides a comprehensive and integrative perspective on probiotic dairy products by simultaneously addressing these interconnected aspects. Importantly, this study has highlighted the emerging role of digitalization in overcoming current and further challenges in probiotic dairy production, an area that has received a limited attention in previous reviews. The findings offer practical insights for improving probiotic product quality and industrial processes and may support researchers, food producers and policymakers in developing further effective probiotic dairy products and promoting public health.

2. MATERIALS AND METHODS

2.1. Phase I: A review of reviews

2.1.1 Literature search

A comprehensive literature search was carried out to identify studies published between 2000 and January 20, 2026. This time was selected to capture the most recent and relevant developments in probiotic research over the past quarter century. This timeframe allowed for a comprehensive analysis of contemporary scientific advances, regulatory changes and industry trends, while ensuring that the data reflect current methodologies, market dynamics and public health considerations. Limiting the study to this time helped set consistency in study design and reporting standards, which have evolved significantly in recent decades.

The search strategy combined keywords including "probiotics," "gut microbiota," "probiotic dairy foods," and "health," using Boolean operators "AND" and "OR." Electronic databases searched included PubMed, Scopus,

Web of Science, ScienceDirect and Google Scholar. To ensure comprehensive coverage, additional sources such as reference lists of relevant articles, project reports, conference abstracts, dissertations and reviews were investigated as gray literature. After initial screening of titles and abstracts for relevance, full texts of potentially eligible articles were assessed. Duplicate records were removed following importation into EndNote X7 (Thomson Research Soft, USA).

2.1.2 Inclusion and Exclusion Criteria

Initially, abstracts were screened to exclude studies that were not relevant. Full-text eligibility was assessed based on the following criteria of studies published in English, available in full text, providing detailed information on the health effects of probiotics, investigating the relationship between probiotics as functional foods and disease outcomes and discussing probiotics producing and consuming challenges in individuals and industries. Studies were excluded if they were duplicates, lacked sufficient detail or did not meet the predefined inclusion criteria.

2.1.3 Data Extraction

Data extraction and quality assessment were carried out independently by two reviewers, with discrepancies resolved through discussion or consultation with a third reviewer [40-42]. Extracted information included study characteristics (first author, year of publication and study design) and primary outcomes associated to probiotic effects on health. Discrepancies between the reviewers were resolved through discussion and consensus.

2.1.4 Study Selection Process

The initial database search identified 2,455 records. After removal of 1,354 duplicates, 1,099 articles were selected for title and abstract screening. Then, 335 full-text articles were assessed for eligibility, while 730 reports were requested for retrieval. Of these, 395 were excluded due to inaccessibility ($n = 12$), insufficient information ($n = 183$), low methodological quality ($n = 85$), or non-English language ($n = 37$). Ultimately, 18 review studies met the inclusion criteria and were included in the final analysis (Figure 2).

2.2. Phase II: Policy Dialogue

A policy discussion session was organized to assess the strategies developed from the literature review, with focus on assessing their feasibility and identifying potential obstacles in policy formulation. This approach provided



valuable insights for policymakers, as it recognized that individuals operating in various contexts and environments bring unique perspectives to the issue. Although the specific objectives of policy dialogues may vary depending on the timing and stage of the policy development process, their primary purpose is consistently to support informed decision making [43].

A meeting was organized with a diverse group of stakeholders from the probiotic dairy product sector. Data and information were achieved from scientific associations, regulatory organizations and academic experts (Table 1). Representing various backgrounds, expertise and perspectives, to collect a broad spectrum of opinions. Participants were selected through purposive sampling and their consent to attend the policy discussion was achieved

via phone or email. To ensure neutrality amid existing conflicts between the producer groups, the session was held at the National Nutrition and Food Research Institute (NNFTRI; Tehran, Iran). The policy dialogue session was tape-recorded and then content was written down verbatim.

At the beginning of the discussion, after introducing the participants and reviewing the agenda, the research team presented an overview of the study, highlighting key challenges and affecting factors. Participants were then invited to provide their perspectives on the prioritization of proposed strategies, the potential limitations of each strategy, their feasibility and possible obstacles, in accordance with the study objectives [21].

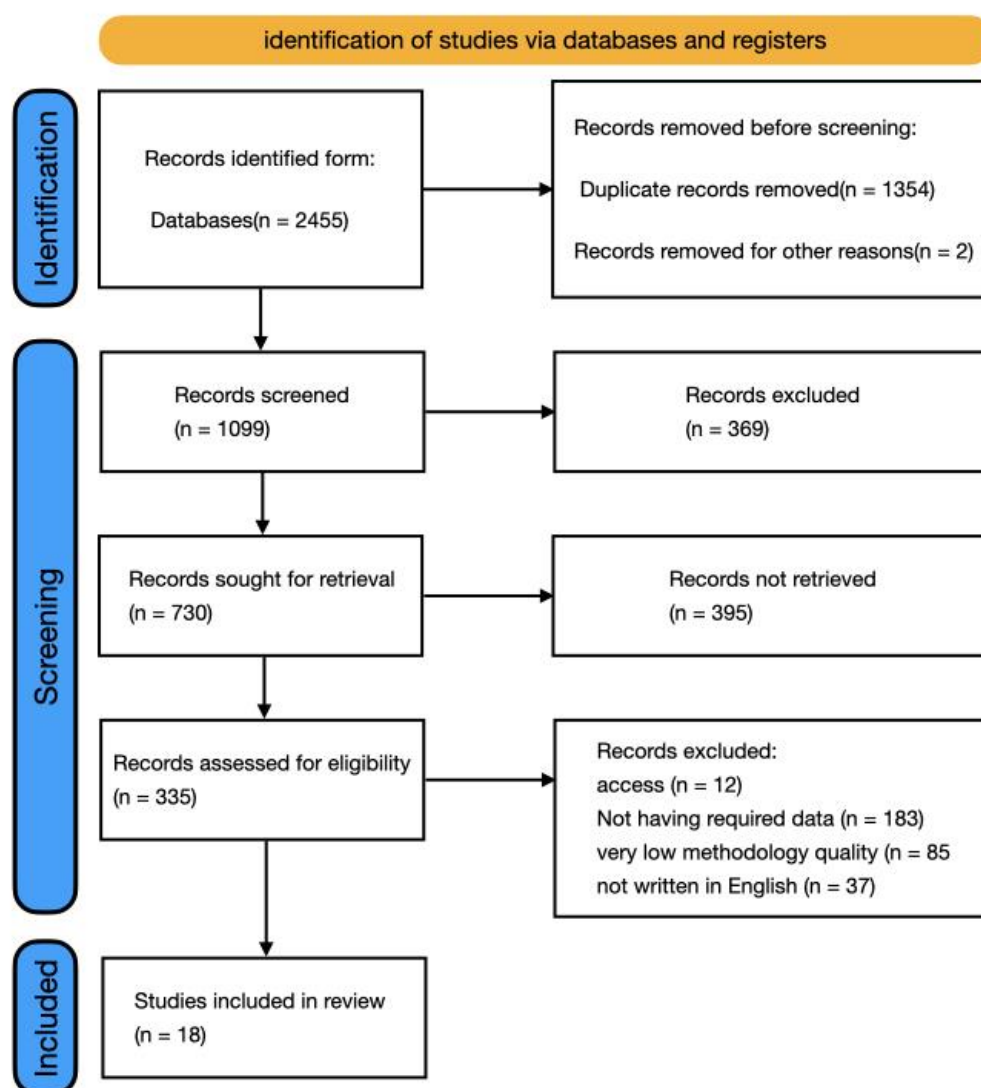


Figure 2. Flowchart of the literature search strategy and study selection process

Table 1. Characteristics of the policy dialogue session

Category	Role / Contribution
Scientific Associations (n=2)	Provided guidance on research trends, best practices and emerging scientific evidence in probiotics and dairy science
Regulatory Organizations (n=2)	Supplied regulatory frameworks, standards, compliance guidelines and safety oversight
Iran National Standards Organization (INSO) (n=1)	Provided global standards, comparative policies and guidance on harmonization of probiotic regulations based on International Organizations (e.g., WHO, FAO, Codex Alimentarius)
Academic Experts (n=3)	Offered expert opinions, validated data and assisted in interpretation of scientific evidence
Industry Managers (Dairy Products) (n=3)	Shared practical insights on production processes, market trends and feasibility of probiotic applications
Government Policymakers / Public Health Authorities(n=2)	Provided input on national health priorities, regulatory policy and program implementation
Consumer Advocacy Groups / NGOs(n=2)	Represented public perspectives, consumer concerns and acceptability of probiotic products
Pharmaceutical / Supplement Industry Representatives (n=2)	Offered insights on commercialization, regulatory alignment and cross-sector collaboration

To ensure the accuracy of the data and continuous comments, the validation of the subject should be addressed by the researchers during the planning, data analysis and assessment of the quality of the research. In the present study, triangulation was carried out via the requirement gathering process through the convergence of data from the participants in the veterinary and food industries. The results were checked and validated by two stakeholders, who met the inclusion criteria but did not participate in the research. For reliability verification, two researchers rechecked the findings. The results were then shared and summarized after the discussion to improve accuracy, validity, credibility and transferability.

2.3 Statistical Analysis

The recorded audio of the session was transcribed and the notes were used to resolve possible differences. The transcripts were investigated precisely based on the codes set for the data section, which was investigated by highlighting the exact words of the text that were developed to record significant ideas for providing the initial coding framework. The transcripts were analyzed precisely and then codes were classified into relevant categories based on the similarities. Data synthesis was the primary analytical approach. Meta-analysis was not carried out due to the methodological and outcome heterogeneity within the included studies. Accordingly, results were present as a

combination of qualitative and quantitative syntheses, depending on the study type and reported outcomes.

3. RESULTS AND DISCUSSION

3.1. Phase I

The characteristics of 18 review studies included in the reviews were summarized in Table 2.

3.1.1. Criteria for “probiotic”

The production and marketing of probiotics are the responsibility of manufacturers, who must ensure that products meet rigorous scientific and regulatory standards. Clear criteria for the term “probiotic” are essential to prevent misuse and guarantee consumer safety and efficacy. A probiotic strain must adequately be characterized, including identification by accepted scientific techniques, assignment of a retrievable strain identifier and use of correct and current nomenclature. Strains should be deposited in recognized culture collections and their techniques of identification may evolve with advances in technology. Safety and efficacy are paramount. Strains must be proven safe for their intended use and demonstrate a health benefit supported by at least one study meeting widely accepted scientific standards or in accordance with national or local regulatory guidelines. Products must contain an adequate number of viable microorganisms throughout shelf life to confer the claimed benefit. For



Table 2. Summary of the review studies on the probiotic dairy products

No	Author, date	Study design	Probiotic types/products	Main outcomes
1	Bari Shah A, et al., 2024	Review study	The <i>Lactobacillus</i> probiotic, i.e, <i>Lactobacillus plantarum</i> , <i>Lactobacillus paracasei</i> , <i>Lactobacillus acidophilus</i> , <i>Lactobacillus casei</i> , <i>Lactobacillus rhamnosus</i> , <i>Lactobacillus crispatus</i> , <i>Lactobacillus gasseri</i> , <i>Lactobacillus reuteri</i> and <i>Lactobacillus bulgaricus</i>	The gastrointestinal and urinary tracts host probiotic <i>Lactobacilli</i> , which are essential for the microbial flora in both humans and animals. These beneficial strains are particularly abundant in fermented foods such as kimchi, sauerkraut, koumiss, yogurt, kurut, cheese, kefir and kombucha.
2	Taşkoparan Ş, Altınay C, Özer H. B, 2025	Review study	Next-generation probiotics, postbiotics and paraprobiotics in dairy-based probiotic beverages, conventional milk-, whey- and buttermilk-based probiotic beverages, personalised probiotic milk-based beverages	Maintaining enough probiotic microorganisms in milk-based beverages poses a significant challenge, limiting their industrial use. Both the metabolites from these microorganisms and dead probiotic cells can benefit human health. Conventional dairy-based probiotic beverages have seen commercial success.
3	Sarita B, et al., 2025	Review study	Probiotics, prebiotics and synbiotics	Combining probiotics with prebiotics, known as synbiotics, enhances their effectiveness. Probiotics can help treat diabetes, obesity, inflammatory and cardiovascular diseases, respiratory issues, central nervous system disorders and digestive problems. Encapsulation prolongs their viability and enables their use in functional food products. Probiotics may benefit conditions such as obesity, type 2 diabetes, autism, osteoporosis and certain immunological illnesses. They enhance intestinal, nutritional and oral health and support neurological health through the gut-brain axis, affecting mood and thought processes. However, immunocompromised patients, infants, the elderly with comorbidities and critically ill patients should avoid probiotics.
4	Gul S & Durante-Mangoni E, 2024	Review study	Most popular probiotics such as <i>lactic acid bacteria</i> and <i>bifidobacteria</i>	Probiotics enhance nutritional value by providing bioactive compounds and synthesizing essential nutrients like vitamins and peptides. Optimizing the preparation of fortified dairy products can further maximize these benefits.
5	V.H Urrutia-Baca, et al., 2024	Review study	Probiotics in dairy foods	NGPs can target specific diseases and act therapeutically like drugs. They hold promise for treating chronic inflammation-associated conditions, including colitis, IBD, IBS, obesity, diabetes, liver and cardiovascular diseases, cancer and neurodegenerative disorders. NGPs may lead to more personalized and targeted probiotic therapies.
6	Abouelela M.E & Helmy Y.A, 2024	Review study	Next-generation probiotics (NGPs)	Probiotic strains must be viable during manufacturing to maintain the sensory qualities of dairy products. Recent technologies like microencapsulation, prebiotic addition and laser techniques can enhance their
7	Elshaghabe F.M. F, 2023	Review study	Probiotics in dairy foods	



8	Al-Fakhrany O & Elekhrawy E, 2024	Review study	Next-generation probiotics (NGPs) specifically <i>Eubacterium hallii</i> , <i>Faecalibacterium prausnitzii</i> , <i>Roseburia spp.</i> , <i>Akkermansia muciniphila</i> , and <i>Bacteroides fragilis</i>	stability. Cheddar cheese and ice cream are excellent carriers for different probiotic species. Next-generation probiotics (NGPs) enhance gastrointestinal immunity, improve immunotherapy efficacy in cancer patients, maintain intestinal barrier integrity, produce beneficial metabolites like short-chain fatty acids and reduce chemotherapy and radiotherapy complications. However, their broader market use is limited by challenges in culturing and storing these oxygen-sensitive microbes. Buffalo milk is rich in bioactive components, including higher fat, vitamin A and biotin levels and contains similar calcium but less sodium than cow milk. Buffalo milk probiotics could significantly contribute to the functional dairy market with their nutritional richness and microbiological stability.
9	Habiba M.U, et al., 2025	Review study	Buffalo milk-based products	More than 90% of market influencers in Iran's probiotic industry evaluate the situation as moderate to low. The low knowledge of decision-makers in this field has created obstacles for product justification.
10	Damari B, Tajabadi Ebrahimi M, Jafarvand E, 2021	Review study	Probiotic industry	Environmental factors, food composition and processing methods greatly affect the survival of beneficial microorganisms. Microencapsulation enhances probiotics' resistance to acidity, bile salts and oxidative stress, allowing for controlled release in the gut. Additionally, choosing proper packaging and storage conditions, such as low-oxygen environments and suitable temperatures, is essential for prolonging the shelf life of probiotic products.
11	Asadi S, et al., 2025	Review study	<i>Lactobacillus</i> strains in probiotic food products	The strain must be identified using recognized scientific methods and assigned a valid name along with a retrievable strain designation. The final product should contain adequate levels of probiotic strains throughout its shelf life to deliver the claimed health benefits. Manufacturers are responsible for ensuring their probiotics comply with local regulations.
12	Binda S, et al., 2020	Review study	Probiotics in foods and dietary supplements	Probiotics are often used alone or with traditional starter cultures and can be found in both fermented and non-fermented dairy products as functional ingredients.
13	Gao Jie, et al., 2021	Review study	Probiotics, paraprobiotics and postbiotics in dairy industries	Dairy producers must ensure that the probiotic cell levels meet the claims on the food label throughout the product's shelf life. There is a need to develop optimal starter cultures that combine traditional starters with probiotics for dairy products.
14	Merenstein D, et al., 2023	Expert panel review	Probiotics	Probiotics designed for specific patient populations should undergo rigorous testing to meet quality standards. The safety of probiotics from untested species should be evaluated individually and understanding their complete genetic makeup is crucial for safety assessment.



15	Spacova I, et al., 2023	Review study	Probiotic foods (PF), probiotic dietary supplements(PDS) and live <i>biotherapeutics</i> (LBP) as probiotic products	Global markets differ significantly in legislation, claims, market value and quality requirements for probiotic products. Transitioning from lab to industrial conditions can affect the viability of beneficial probiotic strains if they can't be produced in sufficient quantities. Therefore, both industrialization and effectiveness should be assessed together. Furthermore, prolonged clinical development of Live <i>Biotherapeutic</i> Products (LBPs) may lead to higher costs, as LBPs are classified as drugs intended for treating, preventing and lessening diseases.
16	Kolac̣ek S, et al., 2017	Review study	Probiotic products	Product label inconsistencies are common, including misidentified strains, contamination with pathogens, nonviable strains, unverifiable colony counts and reduced functional properties that limit expected health benefits.
17	Scourboutakos MJ, et al., 2017	Review study	Probiotic food products	Probiotic food products may offer health benefits that are not currently listed on their labels. However, many of these products contain dosages that are too low to deliver the benefits shown in clinical trials. Additionally, fewer products include mixtures of strains, as food companies currently have little incentive to take advantage of potential strain synergies. Furthermore, single-strain probiotics are more easily patentable than multi-strain probiotics. <i>Bacillus</i> bacteria offer several health benefits, such as enhancing immunity, decreasing bone loss and lessening allergies. They are commonly included in food products and supplements for these purposes.
18	Raman J, et al., 2025	Review study	<i>Bacillus</i> species	Additionally, <i>Bacillus</i> species are essential for breaking down organic matter in the environment. In industrial production, <i>Bacillus</i> is important for creating lipopeptides with emulsifying, antimicrobial and surfactant properties. These lipopeptides are utilized in biotechnology, medicine, food and cosmetics.

commonly used species such as *L. acidophilus* and bifidobacteria, industry guidelines recommend levels of 10^6 – 10^8 CFU g⁻¹ at the time of consumption [44, 45].

Probiotic strains must set stability during processing and storage without adversely affecting the sensory qualities of the product. Manufacturing should follow good manufacturing practices (GMP) to ensure safety, purity and consistency [46]. Product labeling must transparently convey critical information, including strain designation, viable counts at the end of shelf life and approved health claims. Additional recommended characteristics of a probiotic include human origin or evidence of safe use in humans, absence of pathogenicity, toxicity and transferable antibiotic resistance factors, resistance to gastrointestinal conditions such as acidic pH, digestive enzymes and bile

salts, demonstrated maintenance of activity, survivability and growth after technological processing [47]. In practice, development and marketing of probiotics must align with local regulatory requirements as well as international scientific standards. Manufacturers include the responsibility of ensuring that probiotic products are safe, effective and evidence based, reflecting global trends in dietary enhancement, innovation and targeted consumer use [48].

3.1.2. Guideline Standards for Defining Probiotics

The formal definition of probiotics was first established by an expert consultation convened under the FAO [49] and WHO, 2001 [49]. This definition was later refined in 2014



for clarity to read: “live microorganisms that, when administered in adequate amounts, confer a health benefit on the host” [50, 51]. Based on these guidelines, probiotics must be safe for their intended use, have defined contents, set an appropriate viable count throughout shelf life and be supported by robust evidence of health benefits. The International Scientific Association for Probiotics and Prebiotics (ISAPP) reaffirmed these principles in its 2018 policy statement, emphasizing scientific rigor and transparency in probiotic characterization, safety and efficacy [52].

3.1.3. Consumer Awareness, Preferences and Sociodemographic Effects

Probiotic products are often costly to produce and need specialized formulation, technological expertise, compliance with regulatory standards and consumer acceptance. Such strategies should focus on innovative and practical approaches to reach individuals seeking to improve health, wellbeing and quality of life. Manufacturers must recognize that consumer perceptions are critical in the successful design and adoption of functional foods and integrating these insights is key to product innovation and market success. Consumer awareness, knowledge and perceptions play a critical role in the acceptance and consumption of probiotic dairy products. These products are often costly to produce and need specialized formulation, technological expertise, regulatory compliance and consumer acceptance. Insights into consumer interest and demand can support innovative approaches to reach individuals seeking to improve health, wellbeing and quality of life. Educational initiatives are particularly important to promote the acceptance and use of probiotic dairy products and to increase awareness of their health benefits. Further research should address i) relationships between consumer knowledge and food-associated wellbeing, ii) effect of socio-demographic factors on purchasing behavior, and iii) assessment of consumer acceptability of probiotic dairy products. Such studies provide actionable insights for manufacturers, marketers, health professionals and policymakers to design targeted awareness campaigns and support healthier dietary choices [53].

Evidence indicates that women are often the primary decision-makers in household food purchases, demonstrating greater health consciousness and nutritional knowledge than those men are [54, 55]. Education and gender significantly affect shopping behaviors, with women

typically shopping further frequently and showing distinct preferences for product attributes and marketing strategies. A 2018 study in Iran showed that women’s preferences for functional dairy products are divided into four major categories of i) product attributes, including sensory and non-sensory qualities, ii) price, iii) points of sale, and iv) promotional strategies, subdivided into education, advertising and recommendation. The study assessed women’s willingness to pay, preferred product characteristics, purchasing locations and effective promotional channels [10].

Understanding these preferences enables the design of tailored marketing strategies, enhances product acceptability and facilitates adoption within various consumer segments. For the dairy industry, such insights inform product innovation and market targeting while for the health sector, they support development of interventions that encourage informed dietary choices. Importantly, the study accounted for a diverse sample of participants within socioeconomic and occupational backgrounds, ensuring broad applicability of the findings [10].

The increasing volume of publications and accessibility of online platforms have created a knowledge overload that can be challenging for consumers to navigate. Surveys indicate that only 12% of probiotic users rely on their physicians to recommend a product [56]. In another survey of 632 doctors, 60% recommended probiotics and 40% allowed patients to select the product themselves [57]. The increasing reliance on online information exposes consumers to unverified sources, where accuracy varies widely and controlled validation is often lacking [58]. Probiotic specialists have reported widespread confusion within consumers regarding product types and reported that label information sometimes do not accurately reflect the strains or quantities [59].

Purchase decisions are strongly affected by consumer knowledge, perceived benefits, income and price sensitivity. Statistically significant positive correlations have been observed between perceived necessity and benefit of probiotics and the consumer’s level of knowledge, as well as purchase intention and factors such as knowledge, income, benefit perception and cost awareness [60]. Over the past two decades, increased awareness of healthy living and nutrition, including interest in organic and functional foods, has fundamentally altered consumer consumption habits, highlighting the need of targeted education and



guidance to support informed choices regarding probiotic products.

3.1.4. Commercial Probiotics and Market Trends

Probiotic dairy products represent one of the fastest increasing segments in the global food industry. In addition to yogurt, probiotics are increasingly incorporated into dairy-based beverages, with numerous commercial formulations available worldwide. The global market for probiotic dairy-based drinks was estimated at 39.74 and is projected to reach 95.52 billion \$ by 2033 [61]. The Asia-Pacific region is recognized as a major source of probiotic microorganisms because of its rich tradition of fermented dairy products, including dahi (India), yak yogurt (China and Tibet) and traditional fermented milk products from Japan, Korea, Mongolia and Southeast Asia. These products include diverse probiotic bacteria that have extensively been investigated for their technological characteristics and health-promoting potentials [62-65].

The commercial probiotic industry is dominated by three major segments of probiotic yogurts, sour milk products and dietary supplements. Probiotic yogurts include plain, flavored and drinking yogurts enriched with probiotic strains. In 2019, the largest markets for probiotic yogurt were Asia-Pacific, the EU and North America. Global consumption patterns vary, with reported probiotic usage ranging from 5% of the population in the USA to 25% in NZ [66]. There is evidence from Iran showing that the probiotic market experienced a significant decrease from 2009 to 2014, specifically an annual market contraction of 54% during that time. This was reported in a national review of probiotics and functional foods in Iranian food industry, which analyzed industry, policy and market trends and highlighted structural and cultural challenges facing the sector [67]. However, the specific projection that the market grows by +40% by 2025 could not independently be verified in available indexed sources during this study (e.g., FAO/WHO databases or major market research reports) [67].

A recent assessment of 18 commercially available probiotic dairy products in Iran revealed that only one sample (5.5%) satisfied the probiotic standard by containing the minimum needed viable bacterial count. This finding emphasized a significant gap between regulatory guidelines

for probiotic formulation and their practical implementation, highlighting the necessity for further rigorous monitoring and enforcement. The observed deficiency in viable microorganisms might originate from intentional decreases aimed at preserving sensory attributes acceptable to consumers, as well as suboptimal storage, distribution practices and inconsistencies in the quality of starter cultures used during production. These results emphasized the critical need of stringent quality control measures within manufacturing and supply chains to ensure that probiotic products deliver their intended health benefits [68].

Within the surveyed participants, 180 individuals (57.5%) reported incomes higher this level, indicating that probiotic dairy products were predominantly consumed by higher income households [69]. With the advancement of digitalization and industrial automation, adoption of innovative technologies such as artificial intelligence (AI) can improve efficiency and decrease production costs in probiotic dairy manufacturing.

3.2. Phase II: Results of Policy Dialogue

The results of policy dialogue in the probiotic dairy product industry showed that dairy products enriched with probiotics (e.g., probiotic yogurts, cheeses and drinks) were increasingly produced and consumed in Iran and the market showed increase potential as health awareness increased within the consumers (Table 3). However, production was still limited, compared to traditional dairy and broader commercialization depended on improved culture technologies and regulatory frameworks. Traditional Iranian dairy products such as yogurt and cheese naturally contain beneficial bacteria (e.g., *Lactobacillus* and bifidobacteria) that can serve as probiotic strains for health-oriented foods. Researchers isolate and identify these strains to use in commercial probiotic dairy production. Several studies have detected probiotic strains from traditional dairy with acid/bile tolerance and antimicrobial activity, making them good candidates for functional dairy products.

Table 3. Policy dialogues on probiotic dairy products



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Opportunities & Challenges of probiotic dairy products

Opportunities	• Growing health awareness: Increasing health awareness is driving demand for probiotic dairy products. Supportive programs are needed to increase children's consumption of probiotic dairy products. • Local strain development: Iran's traditional dairy products offer novel probiotic strains for commercialization • Industry capacity building: Domestic production of probiotic cultures strengthens industrial capacity and supply chain resilience. • Social responsibility: Food industries should integrate social responsibility by developing health-oriented products alongside profitability. • Food industry integration: As probiotics are widely used in pharmaceuticals, their incorporation into foods particularly dairy as the primary global source should be expanded. • Animal feed: Probiotics in animal feed can help decrease microbial resistance.
Challenges	• Standardization and regulation: Region specific, standardized regulations are required for probiotic claims, strain identification, stability and consumer safety. • Infrastructure limitations: Insufficient infrastructure and limited governmental support hinder standardized evaluation of probiotic quality and quantity. • Consumer knowledge gap: Consumer awareness may lag behind scientific progress, decreasing demand unless strengthened through education and marketing. • Technological challenges: Technological challenges in maintaining probiotic viability during processing, storage and digestion necessitate improved delivery systems. Verification of probiotic gene sequences and the high cost of specialized personnel and equipment are significant industry barriers. • Industry motivation: Probiotic development should be driven by functional value and efficacy rather than solely financial, cultural, or competitive motivations.

3.3. Implementing Strategies

3.3.1 Policymakers

3.3.1.1 Monitoring

- Focus on developing an action plan for, enforcing food labeling to include probiotic content and developing legislation for monitoring implementation.
- Governments need to consider potential policy measures and further programs are needed to increase consumer awareness.
- Creating a national standard for the probiotic in dairy products.
- Menu labeling of probiotic foods sold in schools, hospitals, cafes and restaurants.
- Leadership and regulatory processes are essential for prioritizing and driving action. Effective leadership involves allocating funds, seeking technical support and establishing policies or regulations.
- Promote the food industry to increase probiotic dairy product (tax decrease or subsidies as an incentive), Governments may incentivize research and development of functional dairy or provide grants for marketing health

foods. This can decrease costs to manufacturers and consumers, improving affordability.

- Allocating funds, seeking technical support and establishing policies or regulations.
- Quality Standards; voluntary certification programs (e.g. "probiotic seal") ensure quality and distinguish products. Industry consensus on minimum probiotic counts helps normalize expectations.

3.3.1.2 Reformulation

- All the reformulation initiatives were led by governmental authorities while engaging with the food industry.

3.3.1.3 Consumer awareness

- Increasing consumer knowledge and education on probiotic dairy product consumption in food is a part of most methods put into practice. Academicians lead this aspect of the awareness campaign, while the government spearheaded the majority of it. Public advertisements, media interviews and instructional initiatives at schools were all part of the campaign.



- Consumer behavior showed that attitudes, perceived benefits and social media affected significantly shape intentions to consume probiotic food products, suggesting increased acceptance and potential market expansion domestically.
- Nutrition Guidelines, including probiotic dairy in dietary recommendations legitimizes them as part of a healthy diet. Public health campaigns highlighting fermented foods can increase awareness.

3.3.2 Food Industry

The producers need cautions when using probiotic dairy products. Although the functional effects of probiotic strains on human health have clinically been verified, the incorporation of these strains into food matrices are a significant challenge for the food industry. In particular, conditions is an important problem for the food industry.

3.3.2.1 Traditional and Industrial Origins

Probiotic microorganisms, especially LAB [21] and bifidobacteria, include a long history in traditional dairy products such as yogurt, cheese and kefir. These products naturally contain health promoting microbes that can be developed into industrial probiotic strains.

3.3.2.2 Domestic Production of Probiotics

Iran includes domestic biotech producers (e.g., firms such as Bioluence) that manufacture probiotic cultures and ingredients used by food industries potentially decreasing reliance on imported strains and supporting local dairy innovation.

3.3.2.3 Innovation and Technology Trends

Worldwide research is focusing on advanced delivery systems, probiotic strain diversification and functional formulations that improve stability and survivability in the gut and targeted health benefits.

These technological shifts almost affect dairy innovation; however, innovative and emerging technologies such as changing the food matrix need further expand. Social marketing is necessary to affect consumers' behavior in probiotic daily intake.

3.3.2.4 Marketing, Labeling and Communication

- **Transparent Labeling:** Labels should clearly list probiotic genus, species and strain names with CFU quantities and expiration. If local regulations allow, authorized health claims can be included. Consistency with guidelines builds credibility. Educational notes on packaging [short taglines] can reinforce key benefits at point of sale.
- **Brand Positioning:** Brands can position probiotic dairy as part of a healthy lifestyle. Packaging design that emphasizes freshness and natural ingredients can attract health-oriented consumers. Digital marketing [e.g., social media influencers and healthy living blogs] can reach younger demographics.
- **Promotions and Sampling:** Free samples or in-store tastings can overcome initial reluctance by letting consumers try the product. Loyalty programs or coupons for probiotic lines encourage repeat purchase once benefits are experienced. Collaborations with fitness or wellness events can target receptive audiences.
- **Messaging to Segments:** Various consumer groups may be motivated by various messages. Tailoring advertise copies and choosing appropriate media channels for each group improve relevance.

3.3.3. Consumers

- Consumers are increasingly interested in preserving health through foods.
- Choose probiotic dairy products with low sodium, low sugar and low fat.
- Consumer perceptions to better understand the effectiveness of probiotic dairy products.
- Check the nutrition labels and the ingredients including salt or contents.

3.4. inter-associated barriers inhibit consumer uptake of probiotic dairy products:

- **Physiological and Dietary Restrictions:** Lactose intolerance and milk-protein allergies are common in several populations, making traditional dairy unappealing or harmful for these individuals. In addition, awareness of saturated fat and cholesterol in full-fat dairy can prevent health-conscious consumers.
- **Sensory and Quality Factors:** Taste, texture and appearance strongly affect consumer preferences. Similarly, variability in quality or visible spoilage can undermine trust in probiotic formulations.



- **Cost and Access:** Probiotic dairy products are often priced higher than that conventional dairies are, reflecting added processing or premium ingredients. High cost can prevent purchase, especially if consumers are unsure of the benefits. Limited distribution (only in specialty stores or sections) decreases visibility; therefore, many consumers are unaware or unable to easily try these products.
 - **Knowledge and Perception:** Many consumers lack clear understanding of what probiotics are and why they matter. Without this knowledge, potential buyers cannot appreciate the health rationale for paying a premium. Misconceptions (e.g., equating probiotics with “bacteria” in a negative sense) can inhibit acceptance. Additionally, regulatory ambiguity in health claims can leave labels non-informative or confusing.
 - **Cultural and Habitual Preferences:** Dairy consumption habits vary widely by culture. Younger consumers or those in Western countries may grow up on other probiotic sources (e.g. supplements and cultured vegetables) rather than dairies, making probiotics-in-dairy less familiar. Overcoming such ingrained habits needs further targeted outreach.
- Regarding well-established roles of the human microbiota in health and disease, developing strategies to modulate and promote balanced beneficial microbiota has become increasingly important [30].

3.5. Future outlook for Probiotic Dairy

Scientific development: Solid research foundation investigating probiotic strains and functional benefits.

Market potential: Increasing consumer acceptance and health focus can boost product demand, use of probiotics in animal feed to decrease antibiotic resistance.

Industrial capacity: Local probiotic production supports product development and scalability. Strong scientific research on local probiotic strains, demonstrated health benefits, increasing consumer interest in functional foods and expanding probiotic dairy production indicate significant potential; however, stronger standards and advanced production technologies are needed to fully realize these opportunities. Therefore, the future of probiotics in dairy products looks promising. However, preserving sufficient numbers of viable probiotic microorganisms in dairy products are a major challenge. The consumption of these live bacteria has been shown to contribute to the prevention and treatment of certain

diseases, as well as modulation and enhancement of immune and digestive system functions. Survival and activity of probiotic strains are affected by multiple factors, including characteristics of the product matrix, environmental conditions and intrinsic characteristics of the specific bacterial strains [70].

Ensuring that consumers receive an adequate daily dose of bioactive compounds is critical for promoting health, underscoring needs to develop strategies that enhance nutrient delivery through probiotic bacteria in dairy products. The survival and activity of these microorganisms are affected by multiple factors, including characteristics of the product matrix, environmental conditions and intrinsic characteristics of the bacterial strains. Probiotic viability can further be compromised by gastric acidity, digestive enzymes, bile salts, suboptimal processing, storage conditions and product composition. By understanding and controlling these factors, it is possible to produce probiotics with higher viability and functional efficacy; thereby, maximizing their potential health benefits [70].

Effective delivery of probiotics to their site of action are a significant challenge; however, several strategies have been developed to address this limitation. One widely used approach involves the encapsulation of probiotic cells within a protective carrier medium that is resistant to gastric acids, bile salts and temperature fluctuations; thereby, enhancing their viability and functional efficacy. Another strategy to improve probiotic effectiveness involves co-administration with antibiotics, which can improve side effects and enhance microbial eradication while minimizing the risk of antibiotic resistance [29]. Strengthened collaboration within researchers, industry partners and policymakers is essential to establish regulatory frameworks that promote innovation while maintaining safety and ethical standards. Overcoming regulatory barriers and improving public acceptance play a critical role in facilitating the successful implementation and widespread adoption of these emerging biotechnologies [71].

3.6. Limitations and Further Research

This review has identified several key limitations that must be addressed to advance probiotic dairy research and policy. First, there is a lack of reliable region-specific data on the consumption and composition of probiotic dairy products in Iran, which limits evidence informed policymaking and the development of targeted interventions. Second, while next generation probiotics



(NGPs) offer promising functional and therapeutic potential, the current evidence for their efficacy and safety is low to moderate, certainty based on the GRADE principles. Due to the small number of articles selected for inclusion in the review, assessment of the methodological quality of the included reviews was not carried out. Practical challenges, including limited isolation sources, cultivation and scale up difficulties and regulatory restrictions on genetically modified organisms (GMO), further limit their use in food products. Additionally, gaps exist in verifying product quality, including strain viability, labeling accuracy and adherence to international standards, highlighting the need of strengthened monitoring systems and regulatory oversight.

Further research should prioritize:

- Developing rapid, regionally tailored dietary assessment tools.
- Establishing laboratory supported databases for product composition, strain viability and compliance with labeling standards.
- Generating higher certainty evidence on health outcomes using robust clinical and mechanistic studies.
- Investigating industrial uses of indigenous probiotic strains to support local innovation, ensure functional efficacy and inform regulatory frameworks.

Addressing these limitations is critical for guiding safe, making evidence-based policy, promoting consumer trust and enabling the sustainable expansion of probiotic dairy products.

4. CONCLUSION

This review of reviews has provided a comprehensively integrative analysis of probiotic dairy products, encompassing their scientifically supported health benefits, technological and industrial challenges, market evolution, and policy implications. The accumulated evidence verifies that probiotic dairy foods can meaningfully contribute to gastrointestinal health, immune modulation, metabolic regulation and prevention or management of selected infectious and non-communicable diseases (NCD) when delivered in adequate doses and appropriate formulations. However, high-quality clinical evidences are needed.

Dairy products are of the most effective vehicles for probiotic delivery due to their favorable physicochemical characteristics, buffering capacity and nutritional composition. However, setting sufficient viable cell counts

throughout processing, storage, distribution and gastrointestinal transit represents a major industrial challenge. The observed gap between international probiotic standards and real-world market practices, particularly regarding strain specificity, viability throughout shelf life, labeling accuracy and microbial viability, highlights the urgent need of integration of technological innovations with strengthened regulatory harmonization frameworks and quality control systems.

Findings from the policy dialogue highlight significant opportunities and existing constraints, especially within emerging markets. Indigenous dairy traditions offer valuable reservoirs of probiotic strains with promising functional potential. Nevertheless, limitations in technological capacity, standardization, monitoring systems and consumer education delay broader commercialization and public health effects. Addressing these barriers need coordinated actions, including development of national probiotic standards, investment in advanced delivery technologies such as microencapsulation, digitalization of production and traceability systems, and implementation of targeted educational campaigns.

Further research should prioritize strain-specific clinical validation, next-generation probiotics, personalized nutrition approaches and sustainable industrial innovations. Strengthening the evidence base while aligning scientific advances with regulatory policies and industrial practices is critical to ensuring that probiotic dairy products deliver consistent, measurable and safe health benefits. Overall, probiotic dairy products represent a promising intersection of nutrition, biotechnology and preventive healthcare. Their long-term success depends on scientific rigor, technological advancement, transparent regulation and informed consumer engagement.

5. DECLARATION STATEMENTS

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5.2. Conflicts of Interest

The authors declare no conflicts of interest.



5.3. Author contributions

All the authors have significantly contributed to the conceptualization and design of the study; collection, analysis and interpretation of data; writing of the article or its critical revision for significant intellectual content and final approval of the version.

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5.5. Data Availability Statement

No data availability for this review article.

5.6. Ethics.

The ethics approval of this study was coded as IR.SBMU.nnftri.Rec.1404.034

5.7. Using Artificial Intelligent Chatbots

During the preparation of this study, the authors used open AI for grammatical editing. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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فرآورده‌های لبنی پروبیوتیک: مروری کلی و سیاست‌گذاری سلامت

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چکیده

سابقه و هدف: محصولات لبنی پروبیوتیک، ارزش غذایی و حامل قابل اعتمادی برای ارائه میکروارگانیسم‌های مفید هستند. این بررسی، ترکیبی جامع از دانش فعلی در مورد محصولات لبنی پروبیوتیک، از جمله فواید سلامتی آنها، چالش‌های فناوری و صنعتی، روندهای بازار، چارچوب‌های نظارتی و ملاحظات سیاسی، با تمرکز بر راهکارهای نوظهور دیجیتالی ارائه داده است.

مواد و روش‌ها: جستجوی متون در پایگاه‌های داده اصلی برای مطالعات منتشر شده بین سال‌های 2000 تا ژانویه 2026 انجام شد که منجر به ورود 18 مقاله مروری واجد شرایط شد. با توجه به تنوع روش‌شناختی، یافته‌ها به صورت کیفی ترکیب شدند. علاوه بر این، از یک گفتگوی سیاسی ساختاریافته شامل گروه متنوعی از ذی‌نفعان از دانشگاه‌ها، سازمان‌های نظارتی، انجمن‌های علمی و صنایع لبنی برای ارزیابی دیدگاه‌های آنها استفاده شد. شرکت‌کنندگان از طریق نمونه‌گیری هدفمند انتخاب شدند و از آنها دعوت شد تا دیدگاه‌های خود را در مورد اولویت‌بندی راهکارهای پیشنهادی، محدودیت‌های بالقوه هر راهکار، امکان‌پذیری و موانع احتمالی آنها، با اهداف مطالعه ارائه دهند.

یافته‌ها و نتیجه‌گیری: شواهد نشان می‌دهد که مصرف محصولات لبنی پروبیوتیک با سلامت دستگاه گوارش، عملکرد ایمنی و تنظیم متابولیک ارتباط دارند و مزایای بالقوه‌ای در مدیریت بیماری‌های عفونی و التهابی دارند. این اثرات وابسته به سویه، دوز و شرایط هستند. ماتریس‌های لبنی نقش مهمی در افزایش زنده‌مانی و بقای پروبیوتیک‌ها از طریق دستگاه گوارش دارند. با این حال، بین استانداردهای نظارتی و شیوه‌های تجاری، به ویژه در شناسایی سویه، تعداد سلول‌های زنده در طول عمر مفید و شفافیت برچسب‌گذاری، تناقضاتی وجود دارد. رفتار مصرف‌کننده تحت تأثیر دانش، عوامل اجتماعی-جمعیتی و حساسیت به قیمت قرار دارد، در حالی که چالش‌های صنعت شامل حفظ پایداری میکروبی و غلبه بر محدودیت‌های فناوری و نظارتی است. بحث‌های مربوط به سیاست‌گذاری بر نیاز به مقررات استاندارد، بهبود نظارت، آموزش مصرف‌کننده و سرمایه‌گذاری در فناوری‌های پیشرفته تأکید کرد. تقویت همکاری بین ذی‌نفعان برای اطمینان از اثربخشی محصول، ایمنی و رشد پایدار ضروری است.

واژگان کلیدی: پروبیوتیک‌ها، محصولات لبنی، سیاست‌گذاری سلامت، مرور

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