International Journal of Nutrology
(Official Journal of the ABRAN - Brazilian Association of Nutrology)

REVIEW ARTICLE

DOI: 10.54448/ijn25212

Current scientific perspectives on probiotics and gut health

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DOI: https://doi.org/10.54448/ijn25212
Received: 03-16-2025; Revised: 05-22-2025; Accepted: 05-24-2025; Published: 05-26-2025; IJN-id: e25212

Editor: Dr. Idiberto José Zotarelli-Filho, MSc, Ph.D., Post-Doctoral.

Abstract

Probiotics are live microorganisms that have gained significant attention due to their potential to improve human health. Nowadays, probiotics are widely used to prevent and treat gastrointestinal disorders, such as irritable bowel syndrome, diarrhea, and inflammatory bowel disease. In the past few years, probiotics have been explored for their role in immune modulation, mental health, and skin conditions. Probiotic strains from the bacterial genus Lactobacillus, Bifidobacterium, and yeast *Saccharomyces boulardii* have demonstrated positive effects on gut microbiota composition as well as overall health. Advances in machine learning models based on next-generation genomic sequencing information and microbiome research are unveiling new probiotic strains and supporting further development of personalized probiotic therapies tailored to individual microbiomes. In spite of their promising health benefits, many challenges still remain, including strain-specific variability, regulatory hurdles, and long-term safety and efficacy concerns. This review article covers the overall current market scenario, probiotic research and development, and new bioinformatics approaches in the discovery of new probiotic strain identification for health benefits.

Keywords: Probiotic, Lactobacillus, Bifidobacterium, Health Benefits, Digestion.

Introduction

Probiotics are live microorganisms that confer health benefits to the host when administered in adequate amounts. This probiotic definition has been widely accepted and is also supported by various authoritative bodies, including the Food and Agriculture Organisation and the World Health Organisation **[1,2]**. For a long period of time, probiotics were primarily recognized for their role in enhancing gut health, modulating the immune response, and preventing gastrointestinal disorders such as diarrhea and irritable bowel syndrome (IBS) **[3,4]**.

In recent years, more research has been carried out on probiotics and has developed many probiotics-based products that are good for health benefits. Many systematic reviews and meta-analytic research data have highlighted the efficacy of probiotics in managing IBS symptoms. For instance, Dale et al. (2019) conducted a comprehensive review confirming probiotics' limited yet significant effects on gastrointestinal symptoms associated with irritable bowel syndrome **[3]**. Similarly, another study also reported that probiotics can help restore microbial balance in the gut, which is crucial for alleviating symptoms of IBS **[5]**. The probiotics' main key factor is strain-specific efficacy, as different strains exhibit varying therapeutic effects depending on the clinical context **[6]**.

In pediatric populations, probiotics are frequently

used to improve digestive disorders, particularly following antibiotic treatment, which can disrupt the gut microbiota **[7,8]**. The specific probiotic strains can be beneficial for children with various gastrointestinal conditions such as gastroenteritis, colic, etc **[4]**. Probiotics and their metabolic pathway product showed beneficial effects in a multifaceted manner. For example, the production of fatty acids (particularly short-chain fatty acids) helps in maintaining gut pH level and promotes a healthy gut environment **[9,10]**.

Probiotics also compete with pathogenic bacteria for resources, thereby inhibiting their growth and reducing the risk of infections **[11]**. Few studies have reported that probiotics can produce some enzymes and their activities detoxify harmful metabolites and improve gut health **[12-14]**. Progressing research work explores the broader implications of probiotics to the other side of gastrointestinal health. For instance, many studies indicated that probiotics play potential roles in metabolic health, including obesity and insulin resistance **[15,16]**. The interaction relationship between the gut microbiome and overall health underscores the importance of probiotics in modern-day health strategies **[17,18]**.

Thus, this review article covers the overall current market scenario, probiotic research and development, and new bioinformatics approaches in the discovery of new probiotic strain identification for health benefits.

Global market scenario and future predictions

According to Polaris's market research report (2022-2030), the global probiotics market was valued at USD 61.15 billion in 2021 and is projected to grow at a CAGR of 7.7% throughout the forecast period. This growth is primarily driven by rising demand for preventive, consumer-focused healthcare and advancements in targeted probiotic strains. Nowadays, key growth drivers are increasing consumer awareness of probiotics and their key role in gut health **[19]**.

The market ecosystem of probiotics is segmented into two main sides: supply-side and demand-side players. The manufacturing units, regulatory bodies, startups, and distributors are supply side. Manufacturers are seeing increased R&D investment and strategic collaborations to innovate, enhance quality and personalised probiotic products. At present, major players are Probi (Sweden) (https://www.probi.com/), Nestlé (https://www.nestle.com/), ADM (US, https://www.adm.com/), Danone (France, https://www.danone.com/), International Flavours & Fragrances Inc. (US), Yakult Honsha Co., Ltd. (Japan), BioGaia (Sweden, https://se.biogaia.com/), General Mills Inc. (US), Chr. Hansen Holding A/S (Denmark) and Moringa Milk Industry Co., Ltd. (Japan). On the demand side, the ecosystem encompasses retailers, wholesalers, and companies in food & beverage, pharmaceuticals, and animal feed. Supermarkets and hypermarkets also play a key role in making probiotic products available to consumers.

The Asia Pacific region leads the global market, driven by heightened consumer awareness and strategic moves by international companies. High demand from countries like China, India, and Australia, combined with rising disposable incomes and improving living standards, further fuels regional growth. Previously, the industry faced technological barriers, particularly with probiotics lacking room-temperature stability. However, innovations such as microencapsulation have significantly improved the shelf life and effectiveness of probiotic strains. Continued R&D aimed at developing heat-resistant, multifunctional strains is expected to support market growth further in the coming years.

The probiotics market is segmented by source into yeast-based and bacteria-based products. In 2021, the bacteria segment held the largest share of the global market, driven by rising global consumption of dairy products. Bacteria-based probiotics are favoured for their proven health benefits, including improved digestion, enhanced immune response, and increased lactase production **[20,21]**. Probiotics are increasingly being added to enhance the nutritional profile and flavor of products such as baked goods, including probiotic muffins and health bars. The growing interest in preventive healthcare has led to greater consumption of these fortified food items **[22,23]**.

In the past few years, probiotic dietary supplements have gained popularity among consumers seeking natural alternatives for health management. Unlike synthetic pharmaceutical chemical options, probiotics offer a natural and less risky approach to supporting gut health, alleviating gastrointestinal disorders, and strengthening immunity **[24]**.

Innovations in formulations and delivery formats, such as effervescent powders, gummies, and chewable supplements, are further driving consumer interest and expanding market reach. In recent years, consumer behaviour has changed, and there's a noticeable shift towards nutrition-rich products over processed or junk food, particularly after the COVID-19 pandemic. In response to heightened health awareness and concerns over virus transmission across all age groups, manufacturers are now focusing on developing personalised probiotic solutions that deliver targeted health benefits **[25,26]**.

Research and key manufacturing players

Several key players in the global probiotics market include Arla Foods amba, BioGaia AB, Chr. Hansen

Holding A/S, Danisco A/S, Danone S.A., Ganeden Inc., General Mills Inc., Lallemand Inc., Lifeway Foods Inc., Mother Dairy Fruit & Vegetable Pvt. Ltd., Nebraska Cultures Inc., Nestlé S.A., PepsiCo Inc., Probi AB, Protexin, and Yakult Honsha Co., Ltd. One of the primary challenges in the probiotics market is the high cost of research and development required to create new and effective probiotic strains. Significant investment is needed in laboratories, advanced research equipment, and the recruitment of skilled professionals, creating substantial barriers to entry for new players **[27]**.

Scientific validation of probiotic efficacy is critical for manufacturers to achieve a return on investment, especially considering the high upfront costs. Industry leaders such as Probi (Sweden), Nestlé, ADM (US), Danone (France), and Yakult Honsha (Japan) have heavily invested in strengthening their R&D infrastructure to maintain a competitive edge, further raising the entry threshold for newcomers. Moreover, the development and manufacturing of probiotic products are governed by stringent international food safety regulations, which contribute to elevated production costs **[28]**.

These costs are compounded by the need for specialised packaging and distribution channels, distinct from those used for conventional food and beverage products. While consumer awareness regarding the health benefits of probiotics continues to grow, the premium pricing of these products remains a key challenge. The higher cost can limit broader consumer adoption, posing a significant hurdle for manufacturers aiming for mass-market appeal **[28,29]**.

Uses of probiotics and their health benefits

Probiotics are living microorganisms that, when consumed in sufficient quantities, provide health benefits to the host. They are most commonly used to improve gut health and prevent various gastrointestinal disorders **[30]**. The most frequently used probiotic strains include members of the genera *Lactobacillus* and *Bifidobacterium*, which have been extensively studied for their health benefits (Table 1).

Lactobacillus species, such as *Lactobacillus acidophilus*, *Lactobacillus rhamnosus*, and *Lactobacillus plantarum*, are among the most commonly used probiotics **[30,31]**. These strains are known for their ability to survive gastrointestinal transit and adhere to intestinal mucosa, enhancing their effectiveness in promoting gut health and modulating immune responses **[32]**. For instance, *Lactobacillus rhamnosus* has been highlighted for its role in preventing antibiotic-associated diarrhea and improving gut microbiota balance **[33]**. *Bifidobacterium* species, including *Bifidobacterium bifidum*, *Bifidobacterium longum*, and *Bifidobacterium breve*, are also widely recognised for their probiotic properties and used for health benefits. These strains are particularly beneficial for infants and have been shown to support gut health and immune function **[34]**.

For example, *Bifidobacterium breve* has been studied for its efficacy in preventing necrotizing enterocolitis in preterm infants, demonstrating its critical role in pediatric health **[35,36]**. Other notable probiotic strains include *Saccharomyces boulardii*, a yeast that has been shown to be effective in treating various forms of diarrhea, including those caused by *Clostridium difficile* infections **[37]**. Additionally, *Lactococcus* and *Streptococcus* species are utilised in various fermented foods and are recognised for health benefits, particularly to gut health **[32]**.

The selection of specific probiotic strains is essential, as the health benefits and safety profiles of probiotics are strain-specific. This necessitates careful evaluation of probiotic products to ensure they contain the appropriate strains and viable counts throughout their shelf life **[38,39]**. Moreover, the World Health Organisation (WHO) emphasises the importance of using probiotics that have been validated through clinical studies to ensure their efficacy and safety **[32]**.

Table 1. List of the most commonly used probiotic bacterial and yeast strains and their health benefits.

Microbes	Class/family	Common Uses	Description
Lactobacillus acidophilus	*Lactobacillaceae*	Digestive health, Immune support, Lactose digestion	Found in yoghurt and fermented foods. Used for maintaining healthy gut flora
Lactobacillus rhamnosus GG	*Lactobacillaceae*	Gastrointestinal issues, Immune support, Diarrhea prevention	Used to survive stomach acid and bile, allowing it to reach the intestines effectively
Lactobacillus casei	*Lactobacillaceae*	Digestive health, Immune system, Constipation, Diarrhea	Ability to survive in the acidic environment of the stomach
Lactobacillus plantarum	*Lactobacillaceae*	IBS, Bloating, Digestive health	Ability to survive the digestive process, making it effective for treating various gut disorders
Lactobacillus reuteri	*Lactobacillaceae*	Colic in infants, Diarrhea, Gastrointestinal health	Produces reuterin, an antimicrobial substance that can help reduce harmful bacteria in the gut
Bifidobacterium bifidum	*Bifidobacteriaceae*	Gut health, IBS, Diarrhea, Constipation	A major early colonizer of the infant gut
Bifidobacterium longum	*Bifidobacteriaceae*	Digestive health, Immune system, Inflammation	It breaks down complex carbohydrates and helps to strengthen the gut barrier.
Bifidobacterium breve	*Bifidobacteriaceae*	Infant gut health, IBS, and Inflammatory conditions	Alleviating colic in infants and balancing the gut in adults
Bifidobacterium infantis	*Bifidobacteriaceae*	Infant colic, Constipation, Gut health	Helps develop gut health in infants by establishing the microbiome early in life

Bifidobacterium lactis	*Bifidobacteriaceae*	Immune support, Digestive health, Allergies	It helps to support healthy digestion and protect against gastrointestinal infections
Streptococcus thermophilus	*Streptococcaceae*	Yogurt production, Lactose digestion	It helps break down lactose, making it more digestible for those with lactose intolerance
Saccharomyces boulardii	*Saccharomycetaceae*	Diarrhoea, Gut infections	Yeast-based probiotics, helpful for preventing and treating diarrhoea
Enterococcus faecium	*Enterococcaceae*	Digestive health, Antibiotic recovery	Aids in maintaining gut health and improving digestion after antibiotic use

Source: Own authorship.

As was discussed earlier, among the most commonly utilised probiotics are strains from the genera *Lactobacillus* and *Bifidobacterium*. For instance, Ahmadian et al. (2022) reported that a daily dose of 10^9 CFU of probiotics, including *Lactobacillus acidophilus*, *Lactobacillus rhamnosus*, *Bifidobacterium longum*, and *Bifidobacterium breve*, effectively reduced blood glucose levels and insulin resistance in adults with type 2 diabetes mellitus **[40,41]**. Similarly, a systematic review concluded that Lactobacillus species are effective in improving glycemic control in managing type 2 diabetes **[42]**.

Furthermore, a meta-analysis indicated that the administration of *Lactobacillus* during pregnancy may help prevent atopic dermatitis, highlighting their versatility in addressing various health issues **[43]**. In addition to *Lactobacillus* and *Bifidobacterium*, probiotic yeasts such as *Saccharomyces boulardii* and *Kluyveromyces marxianus* have also been recognized for their health benefits. *Saccharomyces boulardii* is particularly noted for its ability to enhance gut health and combat gastrointestinal disorders **[44]**. *Kluyveromyces marxianus* has demonstrated anti-inflammatory properties and is being explored for its potential in managing conditions like colitis **[45]**.

The use of these yeasts is gaining traction, especially in aquaculture, where they are employed to improve fish health and growth **[46]**. The effectiveness of probiotics can be influenced by several factors, including the specific strains used, their dosage, and the health condition being targeted. A systematic review emphasized that the efficacy of probiotics is strain-specific, underscoring the need for careful selection based on the intended health outcome **[47]**.

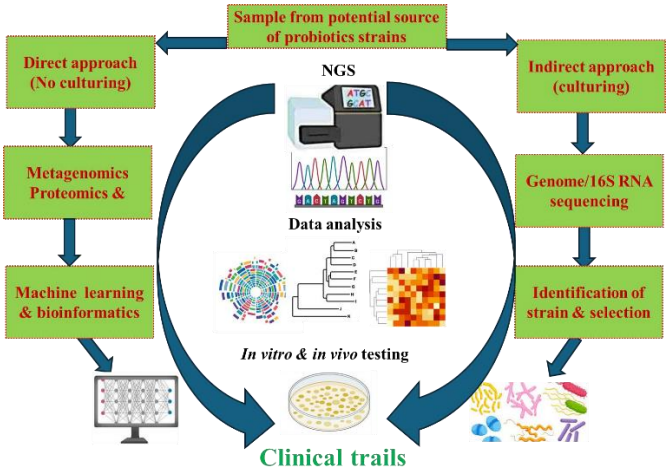
Moreover, the survival of probiotics in the gastrointestinal tract can be enhanced by their incorporation into food products, such as yogurt and fermented milk, which may buffer stomach acid and facilitate better colonization in the gut **[42]**. In summary, the landscape of probiotics is diverse, encompassing various strains of bacteria and yeasts, each with distinct health benefits. The choice of probiotics should be tailored to the specific health condition being addressed, with a focus on strain-specific efficacy and appropriate delivery methods to maximise health benefits.

Role of Bioinformatics in the field of probiotics

In the past few years, the amount of bacterial genome sequencing information has increased exponentially. This genome sequence information, with the integration of advanced bioinformatics and an artificial intelligence approach, provides invaluable tools and methods for exploring probiotics' genetic makeup, functionality, safety, and interactions **[48]**. These computational prediction tools allow for deeper insights into how probiotics work, how they can be optimised, and how they can be personalised to target specific health concerns.

As we continue to gather more genomic and microbiome data, bioinformatics plays an important role in the development of next-generation probiotic therapies (Figure 1) **[48,49]**. At present, numerous potential probiotic bacterial genomes have been completed or draft genomes sequenced. For example, the most commonly used probiotic bacterial genus *Lactobacillus* 5,282 and *Bifidobacterium* 7,265 genomes sequence information are available in the NCBI genome assembly database. That information would be helpful for the design and identification of new probiotics.

Figure 1. An overview of the bioinformatics strategy for the identification of new probiotic strains.



Source: Own authorship.

Wu et al. (2024) created a language model–based tool called metaProbiotics to find probiotic-related genetic bins in metagenomes quickly. It performed very well in tests using simulated data. When applied to gut samples from people who had taken probiotics, it identified both the expected probiotic bins and new ones not seen in the training data, including a bin similar to a

plasmid. Further analysis showed different probiotic functions in these bins and suggested that the *bai* operon could be a useful marker for probiotic *Ruminococcaceae* **[50]**.

Liu et al. (2023) developed ProbioMinServer, a tool that helps researchers find detailed information about probiotics, including their safety (like resistance to antibiotics or presence of harmful genes) and functionality (such as enzyme activity and metabolite production). Since probiotics are considered functional foods, understanding their safety and benefits is important for health. Genomic tools have become key in studying these aspects **[51]**.

Another machine learning tool, iProbiotics, was created by Sun *et al.* (2022) to identify probiotic features from whole-genome sequences quickly **[52]**. The NIZO FOOD RESEARCH BV in the Netherlands led a project to develop tools for sequencing and analyzing probiotic strains. They focused on bacteria from *Lactobacillus, Lactococcus, Streptococcus*, and *Bifidobacterium* to find genes linked to helpful traits-like flavour production for cheese or gut health benefits for probiotic use. Researchers also worked on identifying molecular markers to predict certain traits. All the data from this project was made publicly available through the GENOBOX platform. GENOBOX has already helped improve fermentation processes and track specific probiotic strains in mixtures. Small business partners confirmed the predictions in lab tests. Since foods like cheese, yogurt, bread, and wine are common in diets, this research has strong economic and health relevance. In the future, the food industry may use this data to create personalized foods tailored to individual health needs.

Probiotics Formulation Types

Probiotic formulations are typically designed to deliver live beneficial bacteria (or yeast, in some cases) to the gut. These formulations are based on their intended use and the types of strains included. Currently, several methods are used for probiotic formation for better health, such as capsules, tablets, and powders. Fermented foods like yogurt are often used for ongoing gut health maintenance **[53]**. Capsules or chewables containing strains like *Lactobacillus rhamnosus* are useful for boosting immune function. Formulations containing *Bifidobacterium longum* and *Lactobacillus helveticus* may help support mental well-being. Probiotic suppositories with strains like *Lactobacillus reuteri* and *Lactobacillus rhamnosus* can help restore vaginal flora balance. Topical probiotics can help support the skin microbiome and treat conditions like acne or eczema **[54]**.

At present, common strains in probiotic formulations such as *Lactobacillus* species (e.g., *Lactobacillus acidophilus, Lactobacillus rhamnosus*) for digestive health, immunity, and vaginal health. *Bifidobacterium species* (e.g., *Bifidobacterium bifidum, Bifidobacterium lactis*) are used to support gut health and immune function. *Saccharomyces boulardii* is a yeast probiotic often used for preventing or treating diarrhea. *Streptococcus thermophilus* aids in lactose digestion and may support gut health. *Enterococcus faecium* is used for balancing gut flora and supporting intestinal health **[55,56]**.

There are a few key points that are considered for probiotic formulation, such as (i) Strain-Specific Benefits: Different strains of probiotics offer unique benefits. For example, *Lactobacillus* strains are typically linked to digestive health, while *Bifidobacterium* strains may be more associated with immune health. (ii) CFU (Colony Forming Units): this indicates the potency of the probiotics in the formulation. A higher CFU count does not always mean better, but you should look for a product that offers a sufficient number of CFUs for the desired benefits. (iii) Survivability: probiotics must survive stomach acid to reach the intestines, so formulations with enteric coatings or delayed-release mechanisms are beneficial. (iv) Diversity of Strains: multi-strain formulations may offer broader health benefits compared to single-strain products, as they can address a wider range of gut microbiota imbalances **[53,57,58]**.

Conclusion

The most commonly used probiotics include Lactobacillus species for example *L. acidophilus, L. rhamnosus, and L. plantarum*), Bifidobacterium species for example, *B. bifidum, B. longum, and B. breve*, and Saccharomyces boulardii. These probiotics have been extensively researched and are widely recognized for their beneficial effects on gut health and overall well-being. This review discussed the current market status, overall health benefits, and the role of bioinformatics prediction models based on genome sequence information and the discovery of new potential probiotic strains. Probiotics represent a natural and promising avenue for enhancing health through the modulation of the gut microbiome. Probiotics application in clinical practice is supported by a growing body of evidence demonstrating their efficacy in treating and preventing various gastrointestinal disorders, particularly in vulnerable populations such as children. As scientific research continues to evolve, the future of probiotics will likely see greater integration into personalized medicine. Probiotic therapies can be used not only for general health maintenance but also as targeted treatments for specific conditions, providing tailored solutions to optimize health at an individual level.

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Author contributions: **TN, KN**, **SV:** Conceptualisation, Methodology, Data curation, Writing- Original draft preparation. **TN** and **SV**: Investigation and Supervision, Reviewing and Editing.

Acknowledgment

Not applicable.

Ethical Approval

Not applicable.

Informed Consent

Not applicable.

Funding

Not applicable.

Data Sharing Statement

No additional data are available.

Conflict of Interest

The authors declare no conflict of interest.

Similarity Check

It was applied by Ithenticate®.

Application of Artificial Intelligence (AI)

Not applicable.

Peer Review Process

It was performed.

References

1. Manasian P, Bustos AS, Pålsson B, Håkansson A, Peñarrieta JM, Nilsson L, Linares-Pastén JA. First Evidence of Acyl-Hydrolase/Lipase Activity From Human Probiotic Bacteria: Lactobacillus rhamnosus GG and Bifidobacterium longum NCC 2705. Front Microbiol. 2020 Jul 24;11:1534. doi: 10.3389/fmicb.2020.01534.
2. Rahimi AL, Himmat AM. Probiotics and health benefits, Int J Res Appl Sci Biotechnol. 2022, 9:298-303. DOI: https://doi.org/10.31033/ijrasb.9.2.25
3. Dale HF, Rasmussen SH, Asiller ÖÖ, Lied GA. Probiotics in Irritable Bowel Syndrome: An Up-to-Date Systematic Review. Nutrients. 2019 Sep 2;11(9):2048. doi: 10.3390/nu11092048.
4. Hojsak I, Fabiano V, Pop TL, Goulet O, Zuccotti GV, Çokuğraş FC, Pettoello-Mantovani M, Kolaček S. Guidance on the use of probiotics in clinical practice in children with selected clinical conditions and in specific vulnerable groups. Acta Paediatr. 2018 Jun;107(6):927-937. doi: 10.1111/apa.14270.
5. Maity C, Gupta AK. Therapeutic efficacy of probiotic Alkalihalobacillus clausii 088AE in antibiotic-associated diarrhea: A randomized controlled trial. Heliyon. 2021 Sep 15;7(9):e07993. doi: 10.1016/j.heliyon.2021.e07993.
6. Gwee KA, Lee WW, Ling KL, Ooi CJ, Quak SH, Dan YY, Siah KT, Huang JG, Chua ASB, Hilmi IN, Raja Ali RA, Ong C, Simadibrata M, Abdullah M, Sollano JD, Leelakusolvong S, Gonlachanvit S, Lee YY, Ricaforte-Campos JD, Yin YK, Chong KM, Wong CY. Consensus and contentious statements on the use of probiotics in clinical practice: A south east Asian gastro-neuro motility association working team report. J Gastroenterol Hepatol. 2018 Oct;33(10):1707-1716. doi: 10.1111/jgh.14268.
7. Gwee KA, Lee WRW, Chua Q, Chiou FK, Aw MM, Koh YH. The evidence for probiotics in the treatment of digestive disorders in the pediatric population. J Gastroenterol Hepatol. 2025 Jan;40(1):41-47. doi: 10.1111/jgh.16809.
8. Bezek K, Fajković E, Stubelj M. Parents' Perspective on Probiotics in Preschool Children: A Cross-sectional Survey. Zdr Varst. 2022 Dec 28;62(1):5-12. doi: 10.2478/sjph-2023-0002.
9. Liu W, Chen M, Duo L, Wang J, Guo S, Sun H, Menghe B, Zhang H. Characterization of potentially probiotic lactic acid bacteria and bifidobacteria isolated from human colostrum. J Dairy Sci. 2020 May;103(5):4013-4025. doi: 10.3168/jds.2019-17602.
10. Tijjani KI, James M, Altın C. Probiotics and their attributes in human health therapy: review. Int. J. Res. Granthaalayah [Internet]. 2020 Jun. 4 [cited 2025 May 26];8(5):158-64. Available from: https://www.granthaalayahpublication.org/journals/granthaalayah/article/view/IJRG20_B05_3331.
11. Kartjito MS, Umam AF. Probiotics and Synbiotics as Potential Biotics in Gut Health-Promoting Nutrition, Journal of Indonesian Specialized

Nutrition. 2024, 2(1) 29-36. DOI: https://doi.org/10.46799/jisn.v1i3.16

12. Arun KB, Madhavan A, Sindhu R, Emmanual S, Binod P, Pugazhendhi A, Sirohi R, Reshmy R, Awasthi MK, Gnansounou E, Pandey A. Probiotics and gut microbiome - Prospects and challenges in remediating heavy metal toxicity. J Hazard Mater. 2021 Oct 15;420:126676. doi: 10.1016/j.jhazmat.2021.126676.
13. Średnicka P, Juszczuk-Kubiak E, Wójcicki M, Akimowicz M, Roszko MŁ. Probiotics as a biological detoxification tool of food chemical contamination: A review. Food Chem Toxicol. 2021 Jul;153:112306. doi: 10.1016/j.fct.2021.112306.
14. Ansari F, Lee CC, Rashidimehr A, Eskandari S, Ashaolu TJ, Mirzakhani E, Jafari SM. The role of probiotics in improving food safety; detoxification of heavy metals and chemicals. Toxin Reviews, 2023, 43(1), 63–91. https://doi.org/10.1080/15569543.2023.2283768.
15. Sáez-Lara MJ, Robles-Sanchez C, Ruiz-Ojeda FJ, Plaza-Diaz J, Gil A. Effects of Probiotics and Synbiotics on Obesity, Insulin Resistance Syndrome, Type 2 Diabetes and Non-Alcoholic Fatty Liver Disease: A Review of Human Clinical Trials. Int J Mol Sci. 2016 Jun 13;17(6):928. doi: 10.3390/ijms17060928.
16. Amiri S, Nezamdoost-Sani N, Mostashari P, McClements DJ, Marszałek K, Mousavi Khaneghah A. Effect of the molecular structure and mechanical properties of plantbased hydrogels in food systems to deliver probiotics: an updated review. Crit Rev Food Sci Nutr. 2024;64(8):2130-2156. doi: 10.1080/10408398.2022.2121260.
17. Saleem, A., Elaref, M. Y., Bassiony, S., Abdelnour, S., Helal, A. A., Abdel-Monem, U., Al-Marakby, K. The Effect of Adding Multi-Strain Probiotics (MSP) on the Hematological, Immunological and Antioxidant Parameters of Male Saidi Sheep. Egyptian Journal of Veterinary Sciences, 2024; (): 1-8. doi: 10.21608/ejvs.2024.294580.2143.
18. Khan MN, Bashir S, Afzal A, Andleeb N, Krych L, Nielsen DS, Imran M. Probiotic characteristics and survival of a multi-strain lactic acid bacteria consortium in simulated gut model. Folia Microbiol (Praha). 2025 Feb 9. doi: 10.1007/s12223-025-01244-w.
19. López-Palestino A, Gómez-Vargas R, Suárez-Quiroz M, González-Ríos O, Hernández-Estrada ZJ, Castellanos-Onorio OP, Alonso-Villegas R, Estrada-Beltrán AE, FigueroaHernández CY. Probiotic Potential of Lactic Acid Bacteria and Yeast Isolated from Cocoa and Coffee Bean Fermentation: A Review. Fermentation. 2025; 11(2):95. https://doi.org/10.3390/fermentation11020095.
20. Kaur H, Kaur G, Ali SA. Dairy-Based Probiotic-Fermented Functional Foods: An Update on Their Health-Promoting Properties. Fermentation. 2022; 8(9):425. https://doi.org/10.3390/fermentation8090425
21. Staniszewski A, Kordowska-Wiater M. Probiotic and Potentially Probiotic Yeasts-Characteristics and Food Application. Foods. 2021 Jun 7;10(6):1306. doi: 10.3390/foods10061306.
22. Sadeghi A, Ebrahimi M, Assadpour E, Jafari SM. Recent advances in probiotic breads; a market trend in the functional bakery products. Crit Rev Food Sci Nutr. 2024;64(33):13163-13174. doi: 10.1080/10408398.2023.2261056.
23. Longoria-García S, Cruz-Hernández MA, Flores-Verástegui MIM, Contreras-Esquivel JC, Montañez-Sáenz JC, Belmares-Cerda RE. Potential functional bakery products as delivery systems for prebiotics and probiotics health enhancers. J Food Sci Technol. 2018 Mar;55(3):833-845. doi: 10.1007/s13197-017-2987-8.
24. Pattarabovornwut K, Watthanabut B, Chaikhumwang P. Development of Innovative Dietary Supplements from DHA And Probiotics. JoE [Internet]. 2024Dec.13 [cited 2025May26];3(8):7060 -. Available from: https://ecohumanism.co.uk/joe/ecohumanism/article/view/5303.
25. Liang D, Wu F, Zhou D, Tan B, Chen T. Commercial probiotic products in public health: current status and potential limitations. Crit Rev Food Sci Nutr. 2024;64(19):6455-6476. doi: 10.1080/10408398.2023.2169858.
26. Daisley BA, Allen-Vercoe E. Microbes as medicine. Ann N Y Acad Sci. 2024 Nov;1541(1):63-82. doi: 10.1111/nyas.15237.
27. Petrov S. At the boundaries of food and medicine: The role of the regulation on the transformation of the probiotic applications in Europe and the United States from 2000 until present time.
28. Mukherjee A, Gómez-Sala B, O'Connor EM, Kenny JG, Cotter PD. Global Regulatory Frameworks for Fermented Foods: A Review. Front Nutr. 2022 May 23;9:902642. doi: 10.3389/fnut.2022.902642.
29. Kabir SL, Islam SS, Akhter AT. Production, cost analysis, and marketing of probiotics, Food Microbiology Based Entrepreneurship: Making Money From Microbes, Springer, 2023, pp. 305-326.

30. Dempsey E, Corr SC. Lactobacillus spp. for Gastrointestinal Health: Current and Future Perspectives. Front Immunol. 2022 Apr 6;13:840245. doi: 10.3389/fimmu.2022.840245.
31. Kleerebezem M, Vaughan EE. Probiotic and gut lactobacilli and bifidobacteria: molecular approaches to study diversity and activity. Annu Rev Microbiol. 2009;63:269-90. doi: 10.1146/annurev.micro.091208.073341.
32. Sarita B, Samadhan D, Hassan MZ, Kovaleva EG. A comprehensive review of probiotics and human health-current prospective and applications. Front Microbiol. 2025 Jan 6;15:1487641. doi: 10.3389/fmicb.2024.1487641.
33. Kullar R, Goldstein EJC, Johnson S, McFarland LV. Lactobacillus Bacteremia and Probiotics: A Review. Microorganisms. 2023 Mar 30;11(4):896. doi: 10.3390/microorganisms11040896.
34. A Siddiqui A, Haider R, Aaqil SI, Vohra LI, Qamar K, Jawed A, Fatima N, Adnan A, Parikh V, Ochani S, Hasibuzzaman MA. Probiotic formulations and gastro-intestinal diseases in the paediatric population: a narrative review. Ann Med Surg (Lond). 2024 Apr 4;86(5):2836-2847. doi: 10.1097/MS9.0000000000002007.
35. Bi LW, Yan BL, Yang QY, Li MM, Cui HL. Probiotic strategies to prevent necrotizing enterocolitis in preterm infants: a meta-analysis. Pediatr Surg Int. 2019 Oct;35(10):1143-1162. doi: 10.1007/s00383-019-04547-5.
36. Zhu XL, Tang XG, Qu F, Zheng Y, Zhang WH, Diao YQ. Bifidobacterium may benefit the prevention of necrotizing enterocolitis in preterm infants: A systematic review and meta-analysis. Int J Surg. 2019 Jan;61:17-25. doi: 10.1016/j.ijsu.2018.11.026.
37. Fijan S, Frauwallner A, Langerholc T, Krebs B, Ter Haar Née Younes JA, Heschl A, Mičetić Turk D, Rogelj I. Efficacy of Using Probiotics with Antagonistic Activity against Pathogens of Wound Infections: An Integrative Review of Literature. Biomed Res Int. 2019 Dec 12;2019:7585486. doi: 10.1155/2019/7585486.
38. Hanan R. Shehata, Steven G. Newmaster, Chapter 18 - Fraud in probiotic products, Editor(s): Rosalee S. Hellberg, Karen Everstine, Steven A. Sklare, Food Fraud, Academic Press, 2021, Pages 361-370, ISBN 9780128172421, https://doi.org/10.1016/B978-0-12-817242-1.00011-7.
39. Sniffen JC, McFarland LV, Evans CT, Goldstein EJC. Choosing an appropriate probiotic product for your patient: An evidence-based practical guide. PLoS One. 2018 Dec 26;13(12):e0209205. doi: 10.1371/journal.pone.0209205.
40. Ahmadian F, Razmpoosh E, Ejtahed HS, Javadi M, Mirmiran P, Azizi F. Effects of probiotic supplementation on major cardiovascular-related parameters in patients with type-2 diabetes mellitus: a secondary-data analysis of a randomized double-blind controlled trial. Diabetol Metab Syndr. 2022 Apr 13;14(1):52. doi: 10.1186/s13098-022-00822-z.
41. Shabani-Mirzaee H, Haghshenas Z, Malekiantaghi A, Vigeh M, Mahdavi F, Eftekhari K. The effect of oral probiotics on glycated haemoglobin levels in children with type 1 diabetes mellitus - a randomized clinical trial. Pediatr Endocrinol Diabetes Metab. 2023;29(3):128-133. doi: 10.5114/pedm.2023.132025.
42. Li G, Feng H, Mao XL, Deng YJ, Wang XB, Zhang Q, Guo Y, Xiao SM. The effects of probiotics supplementation on glycaemic control among adults with type 2 diabetes mellitus: a systematic review and meta-analysis of randomised clinical trials. J Transl Med. 2023 Jul 6;21(1):442. doi: 10.1186/s12967-023-04306-0.
43. Panduru M, Panduru NM, Sălăvăstru CM, Tiplica GS. Probiotics and primary prevention of atopic dermatitis: a meta-analysis of randomized controlled studies. J Eur Acad Dermatol Venereol. 2015 Feb;29(2):232-242. doi: 10.1111/jdv.12496.
44. Kelesidis T, Pothoulakis C. Efficacy and safety of the probiotic Saccharomyces boulardii for the prevention and therapy of gastrointestinal disorders. Therap Adv Gastroenterol. 2012 Mar;5(2):111-25. doi: 10.1177/1756283X11428502.
45. Romanin DE, Llopis S, Genovés S, Martorell P, Ramón VD, Garrote GL, Rumbo M. Probiotic yeast Kluyveromyces marxianus CIDCA 8154 shows anti-inflammatory and anti-oxidative stress properties in in vivo models. Benef Microbes. 2016 Feb;7(1):83-93. doi: 10.3920/BM2015.0066.
46. Rosidah R, Mulyani Y, Pratiwy F, Shabirah A, Sinaga J. Effectiveness of lactic acid bacteria to increase the body resistance of common carp, Cyprinus carpio Linnaeus, 1758 against Aeromonas hydrophila. JII [Internet]. 31Oct.2021 [cited 26May2025];21(3):291-04. Available from: https://jurnaliktiologi.org/index.php/jii/article/view/593
47. McFarland LV, Evans CT, Goldstein EJC. Strain-Specificity and Disease-Specificity of Probiotic Efficacy: A Systematic Review and Meta-Analysis. Front Med (Lausanne). 2018 May 7;5:124. doi:

10.3389/fmed.2018.00124.

48. Tan H, Zhai Q, Chen W. Investigations of Bacteroides spp. towards next-generation probiotics. Food Res Int. 2019 Feb;116:637-644. doi: 10.1016/j.foodres.2018.08.088.

49. D'Urso F, Broccolo F. Applications of Artificial Intelligence in Microbiome Analysis and Probiotic Interventions—An Overview and Perspective Based on the Current State of the Art. Applied Sciences. 2024; 14(19):8627. https://doi.org/10.3390/app14198627.

50. Wang XW, Wang T, Liu YY. Artificial Intelligence for Microbiology and Microbiome Research, 2024, arXiv preprint arXiv:2411.01098.

51. Liu YY, Hsu CY, Yang YC, Huang CH, Chen CC. ProbioMinServer: an integrated platform for assessing the safety and functional properties of potential probiotic strains. Bioinform Adv. 2023 Oct 18;3(1):vbad153. doi: 10.1093/bioadv/vbad153.

52. Sun Y, Li H, Zheng L, Li J, Hong Y, Liang P, Kwok LY, Zuo Y, Zhang W, Zhang H. iProbiotics: a machine learning platform for rapid identification of probiotic properties from whole-genome primary sequences. Brief Bioinform. 2022 Jan 17;23(1):bbab477. doi: 10.1093/bib/bbab477.

53. Fenster K, Freeburg B, Hollard C, Wong C, Rønhave Laursen R, Ouwehand AC. The Production and Delivery of Probiotics: A Review of a Practical Approach. Microorganisms. 2019 Mar 17;7(3):83. doi: 10.3390/microorganisms7030083.

54. Mishra S, Rath S, Mohanty N. Probiotics-A complete oral healthcare package. J Integr Med. 2020 Nov;18(6):462-469. doi: 10.1016/j.joim.2020.08.005.

55. Iannitti T, Palmieri B. Therapeutical use of probiotic formulations in clinical practice. Clin Nutr. 2010 Dec;29(6):701-25. doi: 10.1016/j.clnu.2010.05.004.

56. Nader-Macías MEF, De Gregorio PR, Silva JA. Probiotic lactobacilli in formulas and hygiene products for the health of the urogenital tract. Pharmacol Res Perspect. 2021 Oct;9(5):e00787. doi: 10.1002/prp2.787.

57. Kiepś J, Dembczyński R. Current Trends in the Production of Probiotic Formulations. Foods. 2022 Aug 4;11(15):2330. doi: 10.3390/foods11152330.

58. Grumet L, Tromp Y, Stiegelbauer V. The Development of High-Quality Multispecies Probiotic Formulations: From Bench to Market. Nutrients. 2020 Aug 15;12(8):2453. doi: 10.3390/nu12082453.