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Sources of Probiotics for Dosage Forms Formulation – Future Challenges

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Abstract

The development of various probiotic pharmaceutical dosage forms is gaining considerable attention owing to the emerging recognition of probiotics. Probiotics, live microorganisms which confer a health benefit on the host, when administered in adequate amounts, have emerged as important ingredients in pharmaceutical and nutraceutical formulations. Successful formulation of probiotic dosage forms depends largely on selecting well-characterized and physiologically compatible microbial strains. The common sources are fermented foods, the human gastrointestinal tract, dairy products, plants, and other natural habitats. However, translating these natural isolates into stable and effective formulations still poses overwhelming challenges. The major concerns are strain-specific functionality, safety assessment, large-scale cultivation, and viability of the cells while processing, formulation, and storage. Moreover, environmental factors such as heat, moisture, and oxygen that cause deterioration in probiotics make their formulation into solid and liquid dosage forms complicated. Future directions emphasize sustainable sourcing, advanced protection systems based on microencapsulation and nanotechnology, and the search for novel probiotic sources. The present review covers the sources of probiotics, discusses the limitations in developing the dosage forms, and outlines some prospective strategies to overcome these future challenges for improved therapeutic efficacy and commercial success.

Key words: Probiotics, probiotics sources, probiotic formulation, probiotic dosage forms.

Introduction

Over recent decades, there has been remarkable scientific and commercial interest in probiotics due to their beneficial effects on human health, (Hill *et al.*, 2014; Markowiak and Śliżewska, 2017).The World Health Organization defined probiotics as live microorganisms that, when administered in adequate amounts, confer a health benefit on the host (FAO/WHO, 2002). However, the demand for more stable, more controlled, and effective delivery systems has necessitated the development of pharmaceutical and nutraceutical dosage forms such as capsules, tablets, sachets, and functional beverages (Tripathi and Giri, 2014; Chen *et al.*, 2012). Despite their increasing demand, various scientific and technological challenges exist for the formulation of probiotics into dosage forms. Probiotic cell viability often suffers due to environmental stresses brought by heat, oxygen, moisture, and gastric acidity (Soccol *et al.*, 2010). Besides, the choice of an appropriate source of probiotic strains from humans, food, plants, or the environment is essential in order to attain the proper functional and safety profile of the strains (Marco and Tachon, 2013). This will mean that the origin of any probiotic microorganism usually contributes to determining its physiological characteristics, survivability, as well as functional performance in pharmaceutical formulations. Choosing an appropriate source ensures compatibility of the strain with the intended therapeutic or nutritional application. Moreover, there is still a lack of standardization and harmonization at the global

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level regarding probiotic classification, labeling, and quality control issues (Sanders *et al*., 2019). Efforts to overcome these problems have been addressed by recent research on advanced technologies for enhancing the stability and targeted delivery of the probiotic formula, such as microencapsulation, nanocarriers, and genetic engineering (Chen *et al*., 2012). Hence, it is crucial to understand sources, formulation challenges, and future prospects regarding probiotics for the development of effective dosage forms. This review summarizes the current knowledge on the sources of probiotics, both biological and environmental, and then explores the challenges that their incorporation into pharmaceutical dosages has brought, while focusing on the innovative strategies allowing enhancement of product stability, functionality, and further regulatory compliance.

Sources of Probiotics for Dosage Forms Formulation. In general, probiotic strains are sourced from food-based, human, animal, and environmental origins, each of which has different advantages and disadvantages with respect to functionality, safety, and industrial scalability.

Human Origin Probiotics: Human origin probiotics have been considered the most physiologically compatible and effective for therapeutic purposes since these microorganisms are naturally adapted to the human gastrointestinal and mucosal environments. The human gastrointestinal tract (GIT), oral cavity, and urogenital tracts are potential sources of beneficial microbial species that are capable of surviving under acidic and bile-rich conditions, are able to attach themselves to intestinal mucosa, and are antimicrobial and immunomodulatory in nature. According to FAO/WHO (2002) and Hill *et al*. (2014), among the commonly isolated *Lactobacillus* species, *Lactobacillus acidophilus, Lacticaseibacillus rhamnosus, Limosilactobacillus reuteri, Ligilactobacillus salivarius, Lactobacillus gasseri,* and *Lactobacillus johnsonii* have been prominent ones. These strains show strong adhesion to intestinal epithelial cells, the ability of producing compounds antagonistic to microbes, and modulation of gut immunity. According to Fontana *et al.* (2020) and Marco *et al*. (2021*), Lactobacillus acidophilus* and *Lacticaseibacillus rhamnosus* (formerly *L. rhamnosus*) have broad applications in probiotic formulations due to their satisfactory survival in the gastrointestinal tract along with well-documented safety. *Limosilactobacillus reuteri* (formerly *L. reuteri*) and *Lactobacillus gasseri* are known for their role in maintaining urogenital and intestinal health due to their production of reuterin and lactic acid, respectively, which inhibit pathogenic colonization.

The genus Bifidobacterium consists mainly of species found in the human colon and feces, such as *Bifidobacterium bifidum, Bifidobacterium longum, Bifidobacterium breve, Bifidobacterium adolescentis,* and *Bifidobacterium infantis.* These species contribute to carbohydrate metabolism and gut microbiota modulation, and they are implicated in immune system development, especially in infants. Different studies have described the health benefits of the two most important species, *B. bifidum* and *B. longum*, suggesting that these species are commonly used in the formulation of different types of probiotic preparations because they improve gut barrier integrity and provide protection against intestinal infections. Other human origin probiotics are *Streptococcus salivariu, Ligilactobacillus salivarius* (formerly *L. salivarius*) originally isolated from the oral cavity and recognized for contributing to oral health by producing bacteriocins. Other examples are Enterococcus faecium, non-pathogenic strains that promote intestinal balance, and *Escherichia coli* strain Nissle 1917, an extensively studied intestinal probiotic with documented benefits for preventing pathogenic infections and enhancing intestinal barrier integrity. Certain *Bacillus coagulans* strains of human intestinal origin have been used as a spore-forming probiotic owing to their resistance to environmental stress and ability to maintain viability during processing. According to Marco *et al.* (2021), human origin probiotics remain the preferred choice

for pharmaceutical and nutraceutical applications due to natural compatibility in human physiology, established safety, and proven functional benefit in gut and systemic health. Probiotic microorganisms from human origin with their site of action and functional benefits are listed in Table 1.

Table 1. Probiotic microorganisms from human origin.

Probiotic Species	Site of Isolation	Functional Benefits	References
Lactobacillus acidophilus	Human gastrointestinal tract	Enhances digestion, inhibits pathogens, and improves immune modulation	FAO/WHO, 2002; Hill *et al*., 2014
Lacticaseibacillus rhamnosus (formerly *L. rhamnosus*)	Human intestine and oral cavity	Adheres to intestinal mucosa, prevents diarrhea, and enhances mucosal immunity	Fontana *et al*., 2020; Marco *et al*., 2021
Limosilactobacillus reuteri (formerly *L. reuteri*)	Gastrointestinal and urogenital tracts	Produces reuterin (antimicrobial), reduces intestinal inflammation, supports oral and vaginal health	Hill *et al*., 2014; Marco *et al*., 2021
Ligilactobacillus salivarius (formerly *L. salivarius*)	Human intestine and saliva	Promotes intestinal barrier integrity and antagonizes pathogens	Fontana *et al*., 2020
Lactobacillus gasseri	Gastrointestinal and vaginal tracts	Maintains vaginal microbiota and reduces cholesterol	Marco *et al*., 2021
Lactobacillus johnsonii	Human intestine	Enhances mucosal immunity and protects against enteric pathogens	Hill *et al*., 2014
Limosilactobacillus fermentum (formerly *L. fermentum*)	Gastrointestinal tract	Antioxidant activity, inhibits harmful bacteria, and modulates immune response	Fontana *et al*., 2020
Lactobacillus crispatus	Vaginal and intestinal mucosa	Produces lactic acid, maintains vaginal pH, and prevents bacterial vaginosis	Marco *et al*., 2021
Lactobacillus jensenii	Vaginal microbiota	Promotes urogenital health and prevents pathogen colonization	Fontana *et al*., 2020
Lactobacillus paracasei	Human intestine	Enhances intestinal immunity and exerts anti-inflammatory effects	Hill *et al*., 2014
Bifidobacterium bifidum	Colon and feces	Improves lactose digestion and supports immune function	Fontana *et al*., 2020
Bifidobacterium longum	Human colon	Strengthens gut barrier, reduces inflammation, and regulates bowel movement	Hill *et al*., 2014
Bifidobacterium breve	Intestine and infant feces	Supports gut microbiota and improves skin and respiratory health	Marco *et al*., 2021
Bifidobacterium adolescentis	Adult human intestine	Ferments carbohydrates and enhances microbial balance	Fontana *et al*., 2020
Bifidobacterium infantis (*B. longum* subsp. *infantis*)	Infant intestine	Promotes infant gut health and reduces gastrointestinal discomfort	Hill *et al*., 2014
Streptococcus salivarius	Oral cavity and pharynx	Produces bacteriocins and supports oral health	Marco *et al*., 2021
Enterococcus faecium (non-pathogenic strains)	Human intestine	Balances intestinal flora and exhibits antimicrobial properties	Fontana *et al*., 2020
Escherichia coli Nissle 1917	Human intestine	Prevents enteric infections and restores intestinal barrier	Hill *et al*., 2014
Bacillus coagulans	Human Intestine	Spore-forming probiotic, survives harsh conditions and promotes gut health	Marco *et al*., 2021

Dairy Sources: Traditional and easily accessible sources of probiotics are fermented foods. The most common types of probiotics found in yogurt, kefir, and cheese are *Lactobacillus delbrueckii subsp. bulgaricus, Streptococcus thermophilus,* and *Bifidobacterium spp.* (Rezac *et al.*, 2018; Tamang *et al.*, 2020). These sources are highly valued for the isolation of acid-tolerant strains and desired flavor production that could be used in food and nutraceutical formulations. Various dairy sources of probiotic microorganisms with their functional properties are given in Table 2.

Plant and Vegetable Sources: There is a growing interest in plant-based materials such as cereals, fruits, and vegetables for the isolation of probiotics. These ecological niches contain LAB that can withstand different pH and temperature profiles. Examples include *Lactiplantibacillus plantarum* from fermented pickles, *Levilactobacillus brevis* from sauerkraut, and *Pediococcus acidilactici* from cereal

Table 2. Dairy sources of probiotic microorganisms.

Probiotic Species	Dairy fermented Food	Functional Properties	References
Lactobacillus delbrueckii subsp. *bulgaricus*, *Streptococcus thermophilus*, *Lactobacillus acidophilus*, *Bifidobacterium bifidum*	Yogurt	Enhances lactose digestion, modulates gut microbiota, improves immunity and inhibits pathogens	Marco *et al*., 2021; Hill *et al*., 2014
Lactobacillus kefiri, *Lactococcus lactis*, *Leuconostoc mesenteroides*, *Saccharomyces cerevisiae*	Kefir	Antimicrobial activity, supports gut health, antioxidant properties and immune modulation	Fontana *et al*., 2020; Rezac *et al*., 2018
Lactococcus lactis, *Lactobacillus helveticus*, *Lactobacillus casei*, *Bifidobacterium longum*	Cheese	Improves gut microbiota, enhances digestion, produces bioactive peptides and antioxidant activity	Ranadheera *et al*., 2017; Marco *et al*., 2021
Lactobacillus acidophilus, *Limosilactobacillus fermentum*, *Lactobacillus plantarum*	Buttermilk, curd	Enhances probiotic viability, supports intestinal health and immune modulation	Tamang *et al*., 2020; Fontana *et al*., 2020

Table 3. Probiotic microorganisms from plant and plant based fermented product sources.

Probiotic Species	Raw or spontaneously fermented vegetables and fruits.	Plant based Fermented product	Functional Properties	References
Lactiplantibacillus plantarum (formerly *L. plantarum*)	Tomatoes, marrows, carrots, cucumbers, eggplants, red-beets, capers, pineapple, plums, kiwi, papaya, fennels, cherries, cabbages	Sauerkraut, kimchi, pickled vegetables, fermented olives	High acid and salt tolerance, antioxidant properties, pathogen inhibition, contributes to flavor and texture in fermented vegetables	Di Cagno *et al*., 2008a,b, 2010, 2011a,b; Marco *et al*., 2021; Sánchez *et al*., 2000; Tamang *et al*., 2016
Leuconostoc mesenteroides	White cabbages, carrots, peppers, cucumbers, eggplants, lettuce, cherries	Kimchi, sauerkraut, pickled vegetables	Produces exopolysaccharides, improves texture and flavor, initiates fermentation, produces lactic acid and bacteriocins	Di Cagno *et al*., 2008a; Di Cagno *et al*., 2010; 2011b; Sánchez *et al*., 2000; Tamang *et al*., 2016; Fontana *et al*., 2020
Pediococcus pentosaceus	French beans, tomatoes, cucumbers, capers, cherries, cabbages	Fermented soy, vegetables, and cereals	Produces antimicrobial peptides (pediocins), enhances shelf-life, acid and bile tolerance	Di Cagno *et al*., 2008a,b, 2011b; Hill *et al*., 2014; Marco *et al*., 2021
Weissella cibaria *Weissella confusa*	Peppers, tomatoes, blackberries, papaya	Kimchi, fermented mustard greens, and pickled vegetables	Produces bacteriocins; exhibits antioxidant and anti-inflammatory properties and potential oral health benefits	Di Cagno *et al*., 2008b, 2010; 2011a; Fontana *et al*., 2020; Lee *et al*., 2023; Tamang *et al*., 2016
Lactobacillus brevis	Tomatoes, capers, eggplants, cabbages, cucumbers, melon pod	Fermented cucumber, sauerkraut, and pickled vegetables	Produces γ-aminobutyric acid (GABA), enhances gut health and reduces stress	Di Cagno *et al*., 2008b; Pulido *et al*., 2012; Seseña and Palop, 2007; Sánchez *et al*., 2000; Offonry and Achi, 1998; Hill *et al*., 2014; Marco *et al*., 2021
Lactobacillus fermentum	French beans, red beets, capers, eggplants, melon pod	Fermented cereals and vegetables	Produces antimicrobial compounds and strengthens gut barrier	Di Cagno *et al*., 2008a; Seseña and Palop, 2007; Pulido *et al*., 2012; Sánchez *et al*., 2000; Offonry and Achi, 1998; Fontana *et al*., 2020
Enterococcus faecium (plant isolate, non-pathogenic strains)	French beans, tomatoes, capers, melon pod, anango baca slurry	Fermented soybean, maize products and vegetable sources	Bile tolerance, antimicrobial activity and improves gut microbial balance	Di Cagno *et al*., 2008a,b; Pulido *et al*., 2012; Aka-Gbezo *et al*., 2017, Fontana *et al*., 2020

fermentations. Probiotic microorganisms from plant and plant based fermented product sources are listed in Table 3. Strains isolated from these sources are desirable for vegan formulations and hold better prospects in the context of sustainability compared with dairy-based sources (Mishra, V. and Prasad, D. N. 2005; Di Cagno *et al*. 2013).

Animal and Environmental Sources: Probiotic strains have also been isolated from animals and diverse environmental niches, including soil, water, and fermented feed. Strains that are of animal intestinal or dairy origin may be suitable for veterinary or agricultural probiotic products. Some strains, such as *Lactobacillus reuteri*, *Bifidobacterium animalis,* and *Enterococcus faecium*, are of animal intestinal origin (Hill *et al*., 2014; Marco *et al.,* 2021). These strains are normally hardy, spore-forming, and resistant to processing stresses. They find widespread applications in veterinary and aquaculture applications and, likewise, are increasingly explored for human ingestion. Regulatory safety evaluation and strain-specific pathogenicity remain important challenges for translation of animal origin probiotics into human dosage forms. Soil, fermented feeds, and aquatic environments are some of the environmental isolates that contribute to spore-forming probiotics such as *Bacillus subtilis, Bacillus coagulans,* and *Bacillus clausii*. These strains provide extremely high thermal stability, acid resistance, and extended shelf life, fitting for industrial processing (Fontana *et al*., 2020). However, despite all these advantages, environmental strains need serious safety and functionality consideration before they could ever be integrated into human dosage forms. Probiotic microorganisms from animal and environmental sources with their sources and functional properties are discussed in Table 4.

Table 4. Probiotic microorganisms from animal and environmental sources.

Probiotic Species	Source/Isolation Site	Functional Properties	References
Lactobacillus reuteri	Intestinal tract of pigs, poultry and rodents	Produces reuterin (broad-spectrum antimicrobial), supports gut integrity and reduces enteric pathogens	Hill *et al*., 2014; Fontana *et al*., 2020
Lactobacillus animalis	Feces and intestines of animals (dogs, pigs)	Enhances intestinal health, improves digestion and supports immune response	Tamang *et al*., 2016; Marco *et al*., 2021
Limosilactobacillus mucosae	Intestinal mucosa of pigs	Adheres to intestinal cells, produces lactic acid and exhibits antimicrobial activity	Fontana *et al*., 2020
Enterococcus faecium (non-pathogenic strains)	Animal intestine (poultry, swine)	Competitive exclusion of pathogens, improves growth performance and gut balance in livestock	Marco *et al*., 2021
Bifidobacterium animalis subsp. *lactis*	Intestine and feces of healthy animals (mainly cattle)	Tolerates bile and acid, improves intestinal microbiota and nutrient absorption	Hill *et al*., 2014; Fontana *et al*., 2020
Streptococcus thermophilus	Milk of cows and fermented dairy products	Lactic acid production; improves lactose digestion and antioxidant activity	Marco *et al*., 2021; Tamang *et al*., 2016
Bacillus subtilis	Soil and animal gut (especially poultry)	Spore-forming and enhances feed efficiency amodulates immune function	Fontana *et al*., 2020; Hill *et al*., 2014
Bacillus coagulans	Soil and animal intestine	Spore-forming, survives processing and storage, supports gut health and reduces diarrhea	Marco *et al*., 2021
Bacillus licheniformis	Soil, poultry gut, and fermented animal feed	Produces antimicrobial peptides, improves digestion and enhances animal growth performance	Tamang *et al*., 2016
Saccharomyces boulardii	Isolated from tropical fruits and lychee skins (environmental yeast)	Non-pathogenic yeast, prevents antibiotic-associated diarrhea and restores intestinal microbiota	Hill *et al*., 2014; Marco *et al*., 2021
Lactobacillus delbrueckii subsp. *bulgaricus*	Dairy environment (yogurt cultures)	Produces lactic acid, enhances dairy fermentation and supports lactose digestion	Fontana *et al*., 2020
Bacillus clausii	Soil and animal intestine	Spore-forming, antibiotic-resistant probiotic used in pharmaceutical preparations and improves gut health	Marco *et al*., 2021; Hill *et al*., 2014
Paenibacillus polymyxa	Soil and fermented animal feed	Produces antimicrobial peptides (polymyxins) and enhances gut microbial diversity	Tamang *et al*., 2016
Lactococcus garvieae	Aquatic animals (fish gut)	Produces bacteriocins and potential probiotic in aquaculture	Fontana *et al*., 2020

There is an increasing interest in environmental isolates, especially from marine and extremophilic ecosystems, owing to their resistance to stress conditions like salinity, pressure, and temperature extremes. Such properties provide the potential for the development of robust probiotic formulations with enhanced shelf life and stress tolerance.

Probiotic Strains Used in Pharmaceutical Formulations: Selection of a probiotic strain for pharmaceutical rather than food use requires strict criteria concerning safety, functional efficacy, genomic characterization, feasibility of manufacture, and regulatory acceptance. Unlike food probiotics, pharmaceutical probiotics must be able to demonstrate strain-specific evidence, validated mechanisms, and stability in a controlled dosage forms. A pharmaceutical-grade probiotic should have accurate identification of species and strain by molecular methods and deposition in an international culture collection such as ATCC or DSMZ (Zheng *et al*., 2020). In Table 5 probiotic strains commonly used in pharmaceutical formulations are given with their therapeutic applications and dosage forms.

Table 5. Probiotic strains commonly used in pharmaceutical formulations.

Probiotic Strain	Therapeutic Applications	Dosage Forms	References
Lactobacillus rhamnosus GG (ATCC 53103)	Antibiotic-associated diarrhea, acute diarrhea, allergies and gut inflammation	Capsules, sachets, freeze-dried powders	Segers and Lebeer, 2014; Szajewska *et al*., 2019; Doron *et al*., 2005
Bifidobacterium longum BB536	Immune regulation, constipation relief and respiratory health	Capsules, granules	Xiao et al., 2021; Odamaki *et al*., 2016; Higashikawa *et al.*, 2020
Bifidobacterium animalis subsp. lactis (HN019/BB-12)	GI health, immunity and constipation	Capsules, sachets, tablets	Gill & Prasad, 2008; Romero-Luna et al., 2023; Saxelin *et al*., 2010
Lactobacillus acidophilus NCFM	Lactose intolerance improvement and gut microbiota modulation	Capsules, tablets	Sanders & Klaenhammer, 2001; Goh and Klaenhammer, 2010; Amaretti *et al*., 2013
Lactobacillus casei Shirota	GI health and immune modulation	Capsules, drinkable formulations	Matsumoto *et al*., 2010; Takeda *et al*., 2006; Dong *et al*., 2010
Lactobacillus plantarum 299v	IBS management, gas/bloating reduction and gut barrier support	Capsules (Probi Mage®), sachets	Goossens *et al*., 2003; Niedzielin *et al*., 2001; Ducrotté *et al*., 2012
Streptococcus thermophilus TH-4	Lactose metabolism support and gut epithelial integrity	Capsules, powders	O'Hara and Shanahan, 2007; Pérez-Alvarado *et al*., 2022
Saccharomyces boulardii CNCM I-745	Acute diarrhea, antibiotic-associated diarrhea and *C. difficile* recurrence prevention	Capsules, sachets	McFarland and Li, 2025; Pontier-Bres *et al*., 2015; Kelesidis and Pothoulakis, 2012
Lactobacillus reuteri DSM 17938	Infant colic, H. pylori adjunct therapy and anti-pathogenic effects (reuterin)	Drops, capsules, powders	Indrio *et al*., 2017; Morita *et al*., 2008; Mu *et al*., 2018
Lactobacillus helveticus R0052	Anti-inflammatory, anti-stress, psychobiotic potential	Capsules, sachets	Messaoudi *et al*., 2011
Bifidobacterium breve M-16V	Premature infant health and reduces NEC risk	Sachets, neonatal probiotic formulations	Patole *et al*., 2016; Wong *et al*., 2019

Probiotics Formulation of Dosage Forms. The development of appropriate dosage forms of probiotics is an important step in the formulation of stable and effective probiotic-based pharmaceutical or nutraceutical products. Because probiotics are living microorganisms, their formulations differ considerably from those of conventional drugs. Probiotic dosage forms and their formulation characteristics along with their advantages are given in Table 6. The viability of probiotic strains should be maintained during manufacturing, storage, and gastrointestinal transit for therapeutic efficiency (Anal and Singh, 2007; Tripathi and Giri, 2014). Capsules, tablets, powders, granules, sachets, and

suspensions are common dosage forms of probiotics. Of these, capsules are the most widely used because they protect the probiotic from oxygen and moisture and release them at targeted sites in the intestine. Enteric-coated and microencapsulated powder dosage forms are also widely used today because these delivery systems protect the cells from acidic breakdown in the stomach and increase their survival in the gastrointestinal tract (Kailasapathy, 2002; Chandramouli *et al*., 2004). Microencapsulation is one of the most promising methods in probiotic formulation technology. In this process, the viable microorganisms are entrapped within a protective polymer matrix, such as alginate, chitosan, or carrageenan. This process protects not only the probiotics from environmental stress during processing and storage but also allows controlled release in the intestine (Ranadheera *et al*., 2017; Vidhyalakshmi *et al*., 2009). Other advanced technologies, such as lyophilization, spray drying, and freeze-drying, are some of the most common methods for enhancing stability and prolonging shelf life (Karthikeyan *et al*., 2021).

The choice of excipients is crucial for maintaining the viability of probiotics. Cryoprotectants like skim milk powder, trehalose, and inulin are usually added to preserve cell integrity during drying and storage. More recently, increasing attention has been paid to symbiotic formulation, which combines probiotic cells with prebiotics; this could stimulate microbial growth and improve colonization in the gut (Sanders *et al*., 2019). In general, for the successful formulation of probiotic dosage forms, strain selection, process parameters, excipient compatibility, and packaging conditions all need to be optimized to ensure sufficient microbial viability for therapeutic performance.

Table 6. Probiotic dosage forms and their formulation characteristics.

Dosage Form	Formulation Characteristics	Advantages	References
Capsules (hard or soft gelatin)	Encapsulated probiotic powders or granules, may include excipients and cryoprotectants	Protects probiotics from oxygen and moisture, easy to administer and can include multiple strains	Anal and Singh, 2007; Kailasapathy, 2002
Enteric-Coated Tablets	Compressed probiotic tablets with acid-resistant coating	Protects probiotics from gastric acid, allows targeted intestinal release and enhances viability	Chandramouli *et al*., 2004; Tripathi and Giri, 2014
Powders/ Granules	Lyophilized or spray-dried probiotic powders, may be mixed with carriers	Longer shelf life, flexible administration (mixed with water or food) and cost-effective	Karthikeyan *et al*., 2021; Ranadheera *et al*., 2017
Microencapsulated Probiotics	Probiotics encapsulated within polymers (e.g., alginate, chitosan, carrageenan)	Protects against heat, moisture, and bile salts, controlled release and improves survival in GI tract	Ranadheera *et al*., 2017; Vidhyalakshmi *et al*., 2009
Liquid Suspensions/ Drinks	Probiotic strains suspended in dairy, juice, or aqueous media	Immediate consumption, palatable, and suitable for children and elderly	Tripathi & Giri, 2014; Marco *et al*., 2021
Synbiotic Formulations	Combination of probiotics and prebiotics in any dosage form	Enhances probiotic survival and colonization, promotes gut health and improves functional efficacy	Sanders *et al*., 2019; Marco *et al*., 2021
Chewable Tablets/ Lozenges	Probiotic tablets designed for oral cavity delivery	Supports oral and gut health, convenient and improves patient compliance	Kailasapathy, 2002; Fontana *et al*., 2020
Spore-Forming Probiotics	Bacillus-based probiotics in powder or capsule form	Heat- and acid-resistant, long shelf life and survives processing	Hill *et al*., 2014; Marco *et al*., 2021

Probiotic strain selection for pharmaceutical formulation. Robust formulation technology is needed to retain viability and activity through processing, storage, and GI transit from promising isolate to pharmaceutical product (Figure-1). In the case of most vegetable, fruit, marine, and fermented foods isolates, studies stay at the phenotypic characterization and animal model step. Targeted human trials and GMP production case studies are still relatively scarce. Novel isolates with promising *in vitro* and animal model results are continuously being found, but human clinical evidence is concentrated around a limited set of strains. None of these properties precludes the use of WGS as an

increasingly expected screen for virulence, antimicrobial-resistance genes, and mobile elements before formulation.

Formulation Requirements for Pharmaceutical-Grade Probiotics. Unlike food-grade probiotics, pharmaceutical probiotics must resist stresses associated with large-scale industrial manufacturing, survive long-term storage under variable environmental conditions, and maintain functional activity upon ingestion. The formulation strategy must therefore address several biopharmaceutical challenges related to oxygen sensitivity, moisture vulnerability, thermal instability, and loss of viability through gastric passage (Tripathi and Giri, 2014).

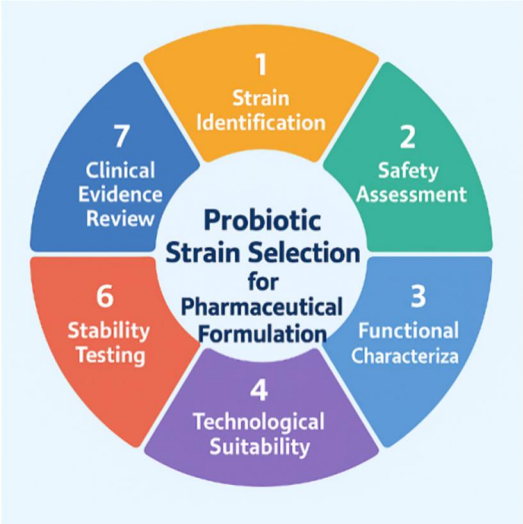

Figure 1. Probiotic strain selection process for pharmaceutical formulation

Cellular robustness is a critical determinant of probiotic performance, varying widely among strains. Pharmaceutical candidates must intrinsically resist acid, bile salts, and digestive enzymes in order to ensure that sufficient numbers of cells reach the intestine alive. These include alginate beads, chitosan coatings, starch matrices, and lipid-based microcapsules, which have been variously applied to enhance protection against harsh gastric conditions and to improve targeted delivery to the intestine (Cook *et al.*, 2012; Burgain *et al.*, 2011). Such encapsulation systems protect the cells not only from acidity but also offer the possibility of controlled release, enhancing therapeutic predictability.

Lyophilization or freeze-drying remains the most commonly used method of preservation for pharmaceutical probiotics. Addition of cryoprotectants, like trehalose, skim milk, or sucrose averts cellular injury through membrane and protein stabilization during dehydration (Morgan *et al.*, 2006). More recently, spray-drying has gained acceptance due to its cost-effectiveness and suitability for large scale production. The addition of thermoprotectants like inulin or maltodextrin can enhance survival during spray-drying significantly (Ananta *et al*., 2005). Spray-dried formulations often require encapsulation layers to make up for heat-induced stress.

Pharmaceutical probiotics must remain viable during the shelf life of the product, which is normally 18–24 months. Various factors like moisture content, oxygen permeability of packaging, residual water activity, and storage temperature have huge impacts on cell survival. Newer packaging technologies like oxygen impermeable blister packs, desiccant-integrated caps, and nitrogen-flushed containers are used to reduce degradation (Saarela *et al.*, 2000). Stability studies carried out at conditions according to International Council for Harmonisation guarantees assured potency and quality consistently.

Transitioning from the laboratory isolate to pharmaceutical products is also tied to strict adherence to GMP practices including correct identification of strain type, confirmation at a genotypic level, antibiotic resistant profiling, and contaminant-free production. Various potential probiotic strains that originate from vegetables, fruits, marine products, and fermented foods normally give positive *in vitro* results and those involving animal models. According to Sanders *et al.* (2019), very few human trials are still a significant bottleneck toward the requirement for long-term stability testing and assessment of the pharmacokinetic properties before substantive therapeutic claims can be made.

Overall, the formulation of pharmaceutical probiotics is fundamentally a multidisciplinary

challenge that requires optimization in microbial physiology, material science, encapsulation technology, and regulatory compliance. Proper integration of these elements is important to develop stable, efficacious, and clinically reliable probiotic therapeutics.

Probiotics Dosage Forms Formulation – Challenges Ahead. The formulation of probiotics into stable and effective pharmaceutical dosage forms is beset with a lot of scientific and technological challenges. According to Anal and Singh, 2007; Karthikeyan *et al*., 2021, ensuring viable cells survive processing, storage, and gastrointestinal transit while maintaining functional activity remains one of the key challenges for both researchers and manufacturers.

One major future challenge is to enhance strain stability and viability throughout the industrial processes. Methods widely used include freeze-drying and spray-drying, however, these can result in significant loss of viability due to thermal and oxidative stress (Tripathi and Giri, 2014). Development of novel encapsulation methods, such as microencapsulation, nanoencapsulation, and coating with polymers, may provide new avenues for enhancing the survival of probiotics during both the manufacturing and storage stages of products containing them (Ranadheera *et al*., 2017). Another fundamental challenge is controlled and targeted delivery of probiotics to a specific region of the GI tract. Classical dosage forms like capsules, tablets, and sachets may not be able to protect probiotics against acidity in the stomach and from bile salts. Advanced delivery systems like enteric coated capsules, multilayer microcapsules, and synbiotic matrices are under exploration for enhancing site specific release and colonization (Kailasapathy, 2002; Chandramouli *et al*., 2004).

Table 7. Future challenges in probiotic formulation and potential solutions.

Challenges	Description	Potential Solutions/ Strategies	References
Viability and Stability	Loss of probiotic viability during processing, storage, or gastrointestinal transit	Microencapsulation, freeze-drying, spray-drying, use of cryoprotectants, enteric coating	Ranadheera *et al*., 2017; Anal and Singh, 2007
Strain-Specific Functional Efficacy	Not all strains provide consistent health benefits, effects are strain-dependent	Rigorous in vitro and in vivo functional validation, genomic and metabolomic profiling	Hill *et al*., 2014; Marco *et al*., 2021
Selection of Appropriate Source	Human, food, plant, animal, or environmental origin impacts safety, survivability, and functionality	Careful source selection based on intended application, safety and efficacy evaluation	Fontana *et al*., 2020; Tamang *et al*., 2020
Protection Against Environmental Stresses	Exposure to heat, moisture, oxygen, and acidic conditions during processing and storage	Use of protective matrices (alginate, chitosan, starch), spore-forming strains, optimized packaging	Kailasapathy, 2002; Tripathi and Giri, 2014
Regulatory Compliance and Safety	Ensuring safety for human or animal consumption, meeting regulatory standards	Strain characterization, toxicological studies, adherence to international probiotic guidelines (FAO/WHO, ISAPP)	Hill *et al*., 2014; Marco *et al*., 2021
Integration into Dosage Forms	Incorporating probiotics into capsules, tablets, powders, liquids, or functional foods without loss of activity	Formulation optimization, carrier selection, combination with prebiotics (synbiotics) and controlled-release systems	Sanders *et al*., 2019; Ranadheera *et al*., 2017
Industrial Scalability and Cost	Large-scale production may reduce viability and increase costs	Process optimization, cost-effective cultivation, use of robust and spore-forming strains	Anal and Singh, 2007; Marco *et al*., 2021

The formulation difficulties also arise from excipient compatibility issues. Common pharmaceutical excipients may have adverse effects on the viability or activity of probiotics. Future challenges in probiotic formulation and potential solutions are discussed in Table 7. Thus, future research should be directed toward the development of biocompatible and protective excipient systems

capable of maintaining cell viability and functionality throughout the shelf life of a product (Vidhyalakshmi *et al*., 2009) Optimization of moisture control, packaging, and storage conditions is very essential to maintaining potency. Another emerging challenge is regulatory harmonization. Present global regulations fail to give uniform standards on the issues of strain identification, declaration of potency, and efficacy validation of different dosage forms of probiotics (Sanders *et al*., 2018). Development of clearly defined and globally accepted guidelines will be crucial in maintaining product consistency, safety and consumer trust. Clinical validation through well-designed trials is needed for confirmation of health benefits specific to strains and therapeutic claims.

Figure 2. Future challenges and potential solutions in probiotic formulation.

In the future, biotechnological and omics-based approaches, such as genomic, metabolomic, and proteomic analyses, will be increasingly integrated into probiotic dosage form development to gain further insights into strain functionality and to optimize formulation strategies. Further, the next generation of probiotic pharmaceuticals might be created based on sustainable production methods, precision selection of strains and personalized probiotic formulations.

Conclusion

The selection of an appropriate source for probiotic strains from humans, foods, plants, animals, or environmental niches has to balance physiological compatibility and safety with industrial scalability. Regulatory compliance and quality control remain important, as new strains derived from different sources must be validated for safety before clinical and commercial use. Probiotics formulation into effective, safe, and stable dosage forms represents a dynamic area of research with considerable promise for both human and animal health. Despite advances in microencapsulation, lyophilization, enteric coating, and symbiotic integration, several critical challenges persist. Among those, maintaining strain viability and functional activity during the manufacturing process, storage, and gastrointestinal transit represents a central issue. Microencapsulation techniques such as nanotechnology-based delivery systems and the

use of biocompatible polymers are likely to improve protection against heat, moisture, oxygen, and gastric acidity. Personalized probiotic formulations are anticipated to emerge as a major trend. It is expected that novel systems such as mucoadhesive formulations, orally disintegrating tablets, chewable gummies, sachets, synbiotic products, and targeted colon-delivery systems will become more popular in addition to traditional dosage forms. Therefore, strain-specific probiotic effects need intense functional validation to ensure therapeutic efficacy. Future studies shall focus on enhancing strain stability, optimization of delivery systems, and validation of health benefits through robust clinical studies. Meeting these challenges will pave the way for the next generation of probiotic formulations that are accessible-to create new opportunities for their wider use in health and nutrition.

Conflict of interest

The authors declare no conflict of interest.

References

Aka-Gbezo, S., Konan, A. G., N'Cho, M., Achi, P., Koffi-Nevry, R., Koussemon-Camara, M., and Bonfoh, B. 2017. Screening of antimicrobial activity of lactic acid bacteria isolated from anango baca slurry, a spontaneously fermented maize product used in Côte d'Ivoire. *Int. J. Biol. Chem. Sci*. **11**, 2616-2629.

Amaretti, A., Di Nunzio, M., Pompei, A., Raimondi, S., Rossi, M., and Bordoni, A. 2013. Antioxidant properties of potentially probiotic bacteria: *in vitro* and *in vivo* activities. *Appl. Microbiol. Biotechnol.* **97**, 809-817.

Anal, A. K. and Singh, H. 2007. Recent advances in microencapsulation of probiotics for industrial applications and targeted delivery. *Trends Food Sci. Technol*. **18**, 240–251.

Ananta, E., Volkert, M. and Knorr, D. 2005. Cellular injuries and storage stability of spray-dried *Lactobacillus rhamnosus* GG. *J. Food Eng*. **67**, 135–143.

Burgain, J., Gaiani, C., Linder, M. and Scher, J. 2011. Encapsulation of probiotic living cells: From laboratory scale to industrial applications. *J. Food Eng*. **104**, 467-483(purched).

Chandramouli, V., Kailasapathy, K., Peiris, P. and Jones, M. 2004. An improved method of microencapsulation and its evaluation to protect *Lactobacillus spp.* in simulated gastric conditions. *J. Microbiol. Methods*. **56**, 27–35.

Purches Chen, S., Zhao, Q., Ferguson, L. R., Shu, Q., Weir, I. and Garg, S. 2012. Development of a novel probiotic delivery system based on microencapsulation with protectants. *Appl. Microbiol. Biotechnol*. **93**, 1447-1457.

Cook, M. T., Tzortzis, G., Charalampopoulos, D. and Khutoryanskiy, V. V. 2012. Microencapsulation of probiotics for gastrointestinal delivery. *J. Contr. Release*. **162**, 56-67.

Di Cagno, R., Surico, R. F., Siragusa, S., De Angelis, M., Paradiso, A., Minervini, F… and Gobbetti, M. 2008a. Selection and use of autochthonous mixed starter for lactic acid fermentation of carrots, French beans or marrows. *Int. J. Food Microbiol*. **127**, 220-228.

Di Cagno, R., Rizzello, C. G., De Angelis, M., Cassone, A., Giuliani, G., Benedusi, A., ... and Gobbetti, M. 2008b. Use of selected sourdough strains of Lactobacillus for removing gluten and enhancing the nutritional properties of gluten-free bread. *J. Food Prot*. **71**, 1491-1495.

Di Cagno, R., Cardinali, G., Minervini, G., Antonielli, L., Rizzello, C. G., Ricciuti, P. and Gobbetti, M. 2010. Taxonomic structure of the yeasts and lactic acid bacteria microbiota of pineapple (Ananas comosus L. Merr.) and use of autochthonous starters for minimally processing. *Food Microbiol*. **27**, 381-389.

Di Cagno, R., Surico, R. F., Minervini, G., Rizzello, C. G., Lovino, R., Servili, M., ... and Gobbetti, M. 2011a. Exploitation of sweet cherry (Prunus avium L.) puree added of stem infusion through fermentation by selected autochthonous lactic acid bacteria. *Food microbiol*. **28**, 900-909.

Di Cagno, R., Minervini, G., Rizzello, C. G., De Angelis, M. and Gobbetti, M. 2011b. Effect of lactic acid fermentation on antioxidant, texture, color and sensory properties of red and green smoothies. *Food microbiol.* **28**, 1062-1071.

Di Cagno, R., Coda, R., De Angelis, M. and Gobbetti, M. 2013. Exploitation of vegetables and fruits through lactic acid fermentation. *Food microbial*. **33**, 1-10.

Dong, H., Rowland, I., Tuohy, K. M., Thomas, L. V. and Yaqoob, P. 2010. Selective effects of *Lactobacillus casei* Shirota on T cell activation, natural killer cell activity and cytokine production. *Clin. Exp. Immunol*. **161**, 378-388.

Doron, S., Snydman, D. R. and Gorbach, S. L. 2005. Lactobacillus GG: bacteriology and clinical applications. Gastroenterol. Clin. **34**, 483-498.

Ducrotté, P., Sawant, P. and Jayanthi, V. 2012. Clinical trial*: Lactobacillus plantarum* 299v (DSM 9843) improves symptoms of irritable bowel syndrome. *World J. Gastroenterol*. **18**, 4012.

FAO/WHO, 2002. Guidelines for the Evaluation of Probiotics in Food. Food and Agriculture Organization of the United Nations and World Health Organization Working Group Report.

Fontana, L., Bermudez-Brito, M., Plaza-Díaz, J., Muñoz-Quezada, S. and Gil, A. 2020. Sources, isolation, characterization and evaluation of probiotics. *Br. J. Nutr*. **123**, 1–14.

Gill, H. and Prasad, J. 2008. Probiotics, immunomodulation, and health benefits. In: Bioactive Components of Milk. Springer, New York, pp. 423-454.

Goh, Y. J., and Klaenhammer, T. R. 2010. Functional roles of aggregation-promoting-like factor in stress tolerance and adherence of *Lactobacillus acidophilus* NCFM. *Appl Environ Microbiol*. **76**, 5005-5012.

Goossens, D., Jonkers, D. M. A. E., Russel, M. G. V. M., Stobberingh, E., Van Den Bogaard, A. E. J. M. and Stockbrügger, R.2003. The effect of *Lactobacillus plantarum* 299v on the bacterial composition and metabolic activity in faeces of healthy volunteers: a placebo-controlled study on the onset and duration of effects. *Aliment. Pharmacol. Ther.* **18**, 495-505.Gupta, S., Bhargava, V., Kaur, J. and Lata, P. (2025). Adaptations, diversity, and biotechnological potential of thermophilic microorganisms: exploring culture-dependent and culture-independent approaches in extreme environments. *BioTech.* **15**, 1-24.

Higashikawa, F., Danshiitsoodol, N., Kanno, K., Ishida, R., Tazuma, S. and Sugiyama, M. 2020. *Lactobacillus plantarum* SN13T cells improve hepatic dysfunction and fecal microbiota: A randomized pilot study. *Arch. Clin. Biomed. Res.* **4**, 605-625.

Hill, C., Guarner, F., Reid, G., Gibson, G. R., Merenstein, D. J., Pot, B. and Sanders, M. E. 2014. Expert consensus document: The ISAPP consensus statement on the scope and appropriate use of the term probiotic. *Nat. Rev. Gastroenterol. Hepatol.* **11**, 506–514.

Indrio, F., Riezzo, G., Giordano, P., Ficarella, M., Miolla, M. P., Martini, S. and Francavilla, R. 2017. Effect of a partially hydrolysed whey infant formula supplemented with starch and *Lactobacillus reuteri* DSM 17938 on regurgitation and gastric motility. *Nutrients.* **9**, 1181.

Kailasapathy, K. (2002). Microencapsulation of probiotic bacteria: technology and potential applications. Current Issues in Intestinal Microbiology. **3**, 39–48.

Karthikeyan, S., Krishna, K. S. and Kumar, R. 2021. Stability and formulation challenges of probiotic dosage forms: A review. *Int. J. Pharm.* **597**, 120313.

Kelesidis, T. and Pothoulakis, C. 2012. Efficacy and safety of the probiotic *Saccharomyces boulardii* for the prevention and therapy of gastrointestinal disorders. *Ther Adv Gastroenterol*. **5**, 111-125.

Lee, J. K., Baek, J. H., Han, D. M., Lee, S. H., Kim, S. Y. and Jeon, C. O. 2023. Description and Genomic Characteristics of *Weissella fermenti* sp. nov., Isolated from Kimchi. *J. Microbiol. Biotechnol.* **33**, 1448.

Marco, M. L., Sanders, M. E., Gänzle, M., Arrieta, M. C., Cotter, P. D., De Vuyst, L. and Hutkins, R. 2021. The International Scientific Association for Probiotics and Prebiotics (ISAPP) consensus on fermented foods. *Nat. Rev. Gastroenterol. Hepatol.* **18**, 196–208.

Marco, M. L., & Tachon, S. 2013. Environmental factors influencing the efficacy of probiotic bacteria. *Curr. Opin. Biotechnol.* **24**, 207-213.

Markowiak, P. and Śliżewska, K. 2017. Effects of probiotics, prebiotics, and symbiotic on human health. Nutrients. 9, 1021.

Matsumoto, K., Takada, T., Shimizu, K., Moriyama, K., Kawakami, K., Hirano, K.. and Nomoto, K. 2010. Effects of a probiotic fermented milk beverage containing *Lactobacillus casei* strain Shirota on defecation frequency, intestinal microbiota, and the intestinal environment of healthy individuals with soft stools. *J. Biosci. Bioeng*. **110**, 547-552.

McFarland, L. V. and Li, T. 2025. Efficacy and safety of *Saccharomyces boulardii* CNCM I-745 for the treatment of pediatric acute diarrhea in China: a systematic review and meta-analysis. *Front. Cell. Infect. Microbiol.* **15**, 1587792.

Messaoudi, M., Violle, N., Bisson, J. F., Desor, D., Javelot, H. and Rougeot, C. 2011. Beneficial psychological effects of a probiotic formulation (*Lactobacillus helveticus* R0052 and *Bifidobacterium longum* R0175) in healthy human volunteers. *Gut microbes.* **2**, 256-261.

Mishra, V. and Prasad, D. N. 2005. Application of in vitro methods for selection of *Lactobacillus casei* strains as potential probiotics. *Int. J. Food Microbiol.* **103**, 109-115.

Morgan, C. A., Herman, N., White, P. A. and Vesey, G. 2006. Preservation of microorganisms by drying. *J. Microbiol. Methods*. **66**, 183–193.

Morita, H., Toh, H., Fukuda, S., Horikawa, H., Oshima, K., Suzuki, T. and Hattori, M. 2008. Comparative genome analysis of *Lactobacillus reuteri* and *Lactobacillus fermentum* reveal a genomic island for reuterin and cobalamin production. *DNA research*. **15**, 151-161.

Mu, Q., Tavella, V. J. and Luo, X. M. 2018. Role of *Lactobacillus reuteri* in human health and diseases. *Front microbial*. **9**, 757.

Niedzielin, K., Kordecki, H. and ena Birkenfeld, B. 2001. A controlled, double-blind, randomized study on the efficacy of *Lactobacillus plantarum* 299V in patients with irritable bowel syndrome. *Eur. J. Gastroenterol. Hepatol.* **13**, 1143-1147.

Odamaki, T., Kato, K., Sugahara, H., Xiao, J. Z., Abe, F. and Benno, Y. 2016. Effect of probiotic yoghurt on animal-based diet-induced change in gut microbiota: an open, randomised, parallel-group study. *Benef. Microbes*. **7**, 473-484.

Offonry, S. U. and Achi, O. K. 1998. Microbial populations associated with the retting of melon pods (*Colocynthis citrullus L.*) during seed recovery. *Plant Foods Hum. Nutr*. **52**, 37-47.

O′ Hara, A. M. and Shanahan, F. 2007. Mechanisms of action of probiotics in intestinal diseases. *Sci. World J.* **7**, 31-46.

Patole, S. K., Rao, S. C., Keil, A. D., Nathan, E. A., Doherty, D. A. and Simmer, K. N. 2016. Benefits of *Bifidobacterium breve* M-16V supplementation in preterm neonates-a retrospective cohort study. *PloS one*. **11**, e0150775.

Pérez-Alvarado, O., Zepeda-Hernández, A., Garcia-Amezquita, L. E., Requena, T., Vinderola, G. and García-Cayuela, T. 2022. Role of lactic acid bacteria and yeasts in sourdough fermentation during breadmaking: Evaluation of postbiotic-like components and health benefits. *Front. Microbiol*. **13**, 969460.

Pontier-Bres, R., Rampal, P., Peyron, J. F., Munro, P., Lemichez, E. and Czerucka, D. 2015. The Saccharomyces boulardii CNCM I-745 strain shows protective effects against the B. anthracis LT toxin. Toxins. **7**, 4455-4467.

Pulido, R. P., Benomar, N., Cañamero, M. M., Abriouel, H. and Gálvez, A. 2012. Fermentation of caper products. Handbook of Plant-based Fermented Food and Beverage Technology, second ed. CRC Press, Boca Raton, USA, 201-208.

Ranadheera, C. S., Baines, S. K. and Adams, M. C. 2017. Importance of dairy matrix effects on the viability of probiotics during storage. *Food Res. Int.* **43**, 1–7.

Rezac, S., Kok, C. R., Heermann, M. and Hutkins, R. 2018. Fermented foods as a dietary source of live organisms. *Front. Microbiol.* **9,** 1785.

Romero-Luna, H. E., Peredo-Lovillo, A. G. and Jiménez-Fernández, M. 2023. Probiotic and potentially probiotic bacteria with hypocholesterolemic properties. *Food Rev. Int*. **39**, 689-707.

Sanchez, I., Palop, L. and Ballesteros, C. 2000. Biochemical characterization of lactic acid bacteria isolated from spontaneous fermentation of ‘Almagro’eggplants. *Int. J. Food Microbiol.* **59**,9-17.

Sanders, M. E., Merenstein, D. J., Reid, G., Gibson, G. R. and Rastall, R. A. 2019. Probiotics and prebiotics in intestinal health and disease: From biology to the clinic. *Nat. Rev. Gastroenterol. Hepatol*. **16**, 605–616.

Sanders, M. E. and Klaenhammer, T. R. 2001. Invited review: the scientific basis of *Lactobacillus acidophilus* NCFM functionality as a probiotic. *J. Dairy Sci.* **84**, 319-331.

Saarela, M., Mogensen, G., Fondén, R., Mättö, J. and Mattila-Sandholm, T. 2000. Probiotic bacteria: Safety, functional and technological properties. *J. Biotechnol*. **84**, 197–215.

Saxelin, M., Lassig, A., Karjalainen, H., Tynkkynen, S., Surakka, A., Vapaatalo, H., ... and Hatakka, K. 2010. Persistence of probiotic strains in the gastrointestinal tract when administered as capsules, yoghurt, or cheese. *Int. J. Food Microbiol.* **144**, 293-300.

Segers, M. E. and Lebeer, S. 2014. Towards a better understanding of *Lactobacillus rhamnosus* GG-host interactions. *Microb. Cell Fact*. **13**, S7.

Seseña, S. and Palop, M. L. 2007. An ecological study of lactic acid bacteria from Almagro eggplant fermentation brines. *J. Appl. Microbiol*. **103**, 1553-1561.

Soccol, C. R., Vandenberghe, L. D. S., Spier, M. R., Medeiros, A. B. P., Yamaguishi, C. T., Lindner, J. D. D. .and Thomaz-Soccol, V. 2010. The potential of probiotics: a review. 413-434.

Szajewska, H., Kołodziej, M., Gieruszczak-Białek, D., Skorka, A., Ruszczyński, M. and Shamir, R. 2019. Systematic review with meta-analysis: *Lactobacillus rhamnosus* GG for treating acute gastroenteritis in children–a 2019 update. *Aliment. Pharmacol. Ther*. **49**, 1376-1384.

Takeda, K., Suzuki, T., Shimada, S. I., Shida, K., Nanno, M. and Okumura, K. 2006. Interleukin-12 is involved in the enhancement of human natural killer cell activity by Lactobacillus casei Shirota. *Clin. Exp. Immunol*. **146**, 109-115.

Tamang, J. P., Cotter, P. D., Endo, A., Han, N. S., Kort, R., Liu, S. Q. and Hutkins, R. 2020. Fermented foods in a global age: East meets West. *Compr. Rev. Food Sci. Food Saf*. 19, 184-217.

Tamang, J. P., Watanabe, K. and Holzapfel, W. H. (2016). Diversity of microorganisms in global fermented foods and beverages. *Front. Microbiol*. **7**, 377.

Tripathi, M. K. and Giri, S. K. 2014. Probiotic functional foods: Survival of probiotics during processing and storage. *J. Funct. Foods*. **9**, 225–241.

Wong, C. B., Iwabuchi, N. and Xiao, J. Z. 2019. Exploring the science behind Bifidobacterium breve M-16V in infant health. Nutrients. **11**, 1724.

Xiao, Y., Wang, C., Zhao, J., Zhang, H., Chen, W., & Zhai, Q. 2021. Quantitative detection of *bifidobacterium longum* strains in feces using strain-specific primers. *Microorganisms*. **9**, 1159.

Zheng, J., Wittouck, S., Salvetti, E., Franz, C. M., Harris, H. M., Mattarelli, P. and Lebeer, S. 2020. A taxonomic note on the genus Lactobacillus: Description of 23 novel genera, emended description of the genus Lactobacillus Beijerinck 1901, and union of Lactobacillaceae and Leuconostocaceae. *Int. J. Syst. Evol. Microbiol*. **70**, 2782-2858.

Vidhyalakshmi, R., Bhakyaraj, R. and Subhasree, R. S. 2009. Encapsulation “the future of probiotics” – A review. *Adv. Biol. Res*. **3**, 96–103