



Review Article

From probiotics to postbiotics: Emerging bioactive ingredients for functional ice cream production

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Among dairy foods, ice cream has emerged as an attractive carrier for bioactive ingredients due to its widespread consumer acceptance, favorable sensory characteristics, and protective matrix. This review provides an overview of the evolution of biotic ingredients in ice cream, highlighting the transition from conventional probiotic formulations to next-generation postbiotic-based products. Probiotic strains, particularly *Lactobacillus* and *Bifidobacterium* spp., have been incorporated into ice cream and shown satisfactory survival during frozen storage, with potential benefits for gut health and immune regulation. Prebiotics, including inulin, fructooligosaccharides, galactooligosaccharides, and dietary fibers, have been used to support microbial viability and functionality, contributing to the development of synbiotic ice cream with improved technological and health-promoting properties. Recent research has increasingly focused on postbiotics, comprising organic acids, bioactive peptides, exopolysaccharides, and microbial cell components. Unlike probiotics, postbiotics do not require viability to exert biological effects, offering advantages in terms of stability, safety, and processing tolerance. This review also discusses the effects of biotics on the rheological behavior, texture, melting resistance, and sensory properties of ice cream, as well as their potential health benefits.

Keywords: Ice Cream, Functional Food, Prebiotics, Probiotics, Synbiotics.**Introduction**

Consumer demand for foods that provide health benefits beyond basic nutrition has stimulated the rapid development of functional food products enriched with probiotics, prebiotics, synbiotics, and more recently, postbiotics (Kaya et al., 2026). Among dairy products, ice cream has emerged as an attractive vehicle for delivering bioactive ingredients because of its widespread popularity, pleasant sensory characteristics, and ability to protect sensitive functional compounds within its complex matrix (Lisboa et al., 2025).

Over the past two decades, probiotic ice cream has received considerable attention. Various probiotic strains, including *Lactobacillus acidophilus*, *Lactocaseibacillus casei*, *Lactiplantibacillus plantarum*, and *Bifidobacterium animalis* subsp. *lactis*, have been successfully incorporated into ice cream formulations; several studies have reported satisfactory survival during frozen storage (Goktas et al., 2022; Villalva et al., 2017). Nevertheless, maintaining probiotic viability remains a major challenge because freezing stress, oxygen exposure, and storage conditions can reduce microbial survival

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and consequently limit health benefits (Szydlowska et al., 2024). However, the incorporation of a biotic ingredient into a food product does not, by itself, establish a health benefit. For probiotics, health effects are strain-specific and depend on the administration of an adequately characterized microorganism at an appropriate dose.

To address these limitations, researchers have increasingly incorporated prebiotic ingredients such as inulin, fructooligosaccharides (FOS), galactooligosaccharides (GOS), oat flour, apple fiber, and yacon flour into ice cream formulations. These compounds not only stimulate beneficial gut microbiota but also improve technological

properties, including viscosity, overrun, melting resistance, texture, and sensory acceptance (**Table 1**) (Ahmadi et al., 2014; Akalın & Erişir, 2008; Mabrouk et al., 2021; Parussolo et al., 2017). Recent clinical evidence suggests that some synbiotic ice cream formulations may influence selected health-related outcomes; however, the available evidence remains limited and formulation- and strain-specific. For example, synbiotic ice cream containing *Lactobacillus acidophilus* LA-5, *Bifidobacterium animalis* BB-12, and 2.3 g of inulin per serving positively modulated gut microbiota and improved well-being indicators in military personnel subjected to intensive field training (Valle et al., 2021).

Table 1. Effects of functional ingredients on physicochemical, rheological, and sensory properties of ice cream

Functional ingredient	Rheology	Overrun	Melting Resistance	Texture	Sensory Acceptance	Reference
Inulin	↑ Viscosity	↑	↑	Improved creaminess	Positive	Akalın & Erişir, 2008
FOS	↑ Apparent viscosity	↔ / ↑	↑	Improved body	Positive	Sabet-Sarvestani et al., 2021
Apple fiber	↑ Consistency	↔	↑	Improved structure	Positive	Kowalczyk et al., 2021
Oat flour	↑ Water holding capacity	↔	↑	Improved texture	Positive	Panwar et al., 2019
Yacon flour	↑ Mix stability	↔	↑	Improved mouthfeel	Positive	Gupta & Gautam, 2026
Fermentation-derived postbiotics	↑ Consistency	Not reported	Potential improvement	Improved adhesiveness	Positive	Ozcan et al., 2026
EPS	Strong viscosity enhancement	↑ Air stability	↑↑	Improved creaminess	Positive	Pourjafar et al., 2023

More recently, postbiotics have emerged as promising alternatives to conventional probiotics (Sharafi & Ebrahimi Tirtashi, 2025). According to the International Scientific Association of Probiotics and Prebiotics (ISAPP), postbiotics are preparations of inanimate microorganisms and/or their components that confer health benefits on the host

(Salminen et al., 2021). Such preparations may contain inactivated microbial cells, cellular components, and associated microbial metabolites, depending on the microorganism and production process (Barros et al., 2020; Vermelho et al., 2025). Importantly, purified microbial metabolites alone do

not meet the ISAPP definition of a postbiotic (Salminen et al., 2021).

Table 2. Applications of probiotic, prebiotic, synbiotic, and postbiotic-related ingredients in ice cream formulations

Functional Ingredient	Ice Cream Formulation	Major Findings	Reference
Probiotics			
<i>Lactocaseibacillus paracasei</i> GV17	Lactose-free probiotic ice cream enriched with fruit co-products	The probiotic maintained high viability during frozen storage, while the formulations showed acceptable technological and sensory properties.	(Costa et al., 2026)
Encapsulated <i>Lactobacillus acidophilus</i>	Ice cream containing alginate–ora-pro-nobis mucilage probiotic microparticles	Microencapsulation improved probiotic survival and increased viscosity and melting resistance without compromising overall product quality.	(de Moraes et al., 2026)
<i>Latilactobacillus sakei</i> microcapsules	Functional yak-milk probiotic ice cream	Microencapsulation enhanced probiotic protection and supported the development of ice cream with suitable functional and quality characteristics.	(Li, et al. 2026)
<i>Lactiplantibacillus plantarum</i> Jb21-11	Probiotic ice cream	The probiotic strain showed suitable incorporation into ice cream, while EPS production contributed to improved physicochemical properties and melting resistance.	(Gomri et al., 2026)
Probiotic culture	Red kidney bean milk vegan ice cream	Probiotic incorporation was feasible in the plant-based matrix and resulted in acceptable technological, biofunctional, and sensory characteristics.	(Acar et al., 2025)
<i>Lactobacillus acidophilus</i> DSM 20079	Probiotic ice cream with blueberry and/or jujube	High probiotic viability was maintained during frozen storage, while fruit addition improved functional and physicochemical properties without significantly affecting probiotic counts.	(Şentürk et al., 2024)
Prebiotics			
Inulin and fructooligosaccharides with different degrees of polymerization	Additive-free prebiotic ice cream	Prebiotic improved mix stability and melting resistance, degree of polymerization influenced viscosity, hardness, and overrun.	(Guimarães et al., 2025)
Synbiotics			
<i>Bifidobacterium longum</i> subsp. <i>longum</i> TISTR 2195 + prebiotics	Synbiotic yogurt ice cream	Prebiotic supplementation supported probiotic survival and influenced the rheological, physicochemical, and microstructural properties of ice cream.	(Toommuangpak & Thaiudom, 2024)
<i>Shouchella clausii</i> / <i>Heyndrickxia coagulans</i> + dietary fiber/inulin	Fiber-enriched probiotic ice cream	Prebiotic fiber, particularly inulin, supported probiotic survival during frozen storage and influenced the physicochemical quality of ice cream.	(Sezer & Ayar, 2024)
<i>S. cerevisiae</i> var. <i>boulardii</i> CNCM I-745 + 1% inulin	Synbiotic ice cream	Inulin was associated with improved probiotic yeast survival and altered functional metabolite levels during frozen storage.	(Zhou et al., 2024)
Postbiotics			
Fermentation-derived microbial metabolites	Fermented functional ice cream	Fermentation increased antiradical activity and generated bioactive metabolites with anti-inflammatory potential while maintaining desirable product functionality.	(Polo, et al., 2023)

Unlike probiotics, postbiotics do not require viable microorganisms to exert their biological effects,

which may reduce some of the technological constraints associated with maintaining microbial

viability during food processing and frozen storage (Kaya et al., 2026; Salminen et al., 2021). In addition to their biological activities, postbiotics may offer technological advantages in ice cream systems. Some fermentation-derived metabolites have been associated with improved viscosity, texture, melting resistance, microbial safety, antioxidant activity, and sensory quality (Ozcan et al., 2026; Polo et al., 2023). Despite these advantages, research on postbiotics-enriched ice cream remains limited compared with the extensive literature available on probiotic and synbiotic formulations. Therefore, the purpose of this review is to critically summarize current knowledge on the application of probiotics, prebiotics, synbiotics, and postbiotics in functional ice cream (**Table 2**), with particular emphasis on their effects on product quality, technological characteristics, and potential health benefits.

Materials and Methods

This narrative review of the current literature on the application of probiotics, prebiotics, synbiotics, and postbiotics in functional ice cream was conducted. Scientific literature pertaining to the use of probiotics, prebiotics, synbiotics, and postbiotics in ice cream was gathered. Relevant keywords for the search include “ice cream,” “probiotics,” “prebiotics,” “synbiotics,” “postbiotics,” and “functional ice cream.” Articles that dealt specifically with the technological aspects, stability, sensory attributes, bioactivity, and possible health benefits of biotic ingredients in ice cream were selected. Information from these articles was organized and analyzed based on the type of biotic ingredient and their effect on ice cream.

Results and Discussion

Functional ice cream as a delivery matrix

Ice cream is a suitable matrix for the incorporation of functional ingredients; however, their addition may modify key physicochemical and sensory attributes, including pH and acidity, viscosity, texture, melting behavior, flavor, and overall acceptability, depending on the type and concentration of the incorporated ingredient (Şentürk et al., 2024; Soodbar et al., 2025). The production process and storage conditions may

affect the stability and functionality of biotics, particularly those containing viable microorganisms (Öztürk-Yalçın et al., 2024; Sezer & Ayar, 2024). Therefore, the development of functional ice cream requires simultaneous consideration of the stability and functionality of the incorporated bioactive or biotic components and the technological and sensory quality of the final product (**Table 1**).

Biotic ingredients in functional ice cream

Probiotics in ice cream

Among the microorganisms used as probiotics, lactic acid bacteria (LAB) and *Bifidobacteria* are particularly important, and several strains belonging to the former *Lactobacillus* group and *Bifidobacterium* spp. have been investigated for the development of probiotic ice cream (Sarkar, 2024). Other microorganisms, such as *Saccharomyces boulardii*, have also been investigated because of their probiotic potential and technological compatibility with frozen dairy products (Goktas et al., 2022). Importantly, probiotic functionality is strain- and dose-dependent; therefore, health effects demonstrated for a particular strain should not be generalized to other strains within the same species or genus (El-Saadony et al., 2026). Some probiotic microorganisms can maintain high viable counts in ice cream during prolonged frozen storage, although their survival is strongly influenced by formulation and the presence of protective ingredients. Şentürk et al. (2024) reported that *L. acidophilus* DSM 20079 remained at 8.42–8.80 log₁₀ CFU/g after 60 days of storage at – 18 °C in probiotic ice creams formulated with or without blueberry and jujube. However, the addition of these fruits did not significantly affect probiotic counts. In another study, Sezer and Ayar (2024) demonstrated that spore-forming probiotics remained viable during 90 days of storage at – 25 °C, with *Shoucheella clausii* maintaining counts of ≥ 8.25 log₁₀ CFU/g. Notably, the incorporation of inulin resulted in the highest viability of *S. clausii* at the end of storage, suggesting that selected prebiotic ingredients may contribute to improved probiotic survival during frozen storage. The level of viable probiotic cells required to obtain a specific health effect cannot be generalized across strains or outcomes, as probiotic efficacy depends on the characteristics of the strain, administered dose, food

matrix, and target health outcome. Therefore, maintaining a high viable cell count during storage is an important technological consideration, but viability alone does not establish probiotic efficacy or a health benefit (Al-shawi & Ali, 2020; Banuree et al., 2022).

Probiotic survival is highly dependent on the characteristics of the strain, food matrix, and processing and storage conditions; therefore, appropriate strain selection and optimization of formulation and freezing conditions are essential for maintaining probiotic viability throughout the product shelf life (Lisboa et al., 2025; Yaekob et al., 2026). For example, during freezing, probiotic cells are exposed to multiple stresses, including low temperature, osmotic stress, oxidative conditions, and mechanical damage associated with ice crystal formation. As water crystallizes, solutes become increasingly concentrated in the unfrozen phase, creating osmotic imbalance and cellular dehydration, while the formation and growth of ice crystals may disrupt cellular membranes and compromise cell viability (Lisboa et al., 2025). Despite these challenges, numerous studies have demonstrated the successful survival of probiotics in ice cream systems. Silva et al., (2015) reported that *B. animalis* subsp. *lactis* BLC1 maintained populations between 6.00 and 7.00 log₁₀ CFU/g throughout 120 days of frozen storage in goat milk ice cream. Similarly, Goktas et al., (2022) observed that both *Lactobacillus rhamnosus* GG and *Saccharomyces boulardii* survived at levels above 6.18 log₁₀ CFU/g during storage while maintaining acceptable technological and sensory characteristics. Costa et al., (2026) further demonstrated exceptional stability of *Lactocaseibacillus paracasei* GV17, with counts remaining above 9.30 log₁₀ CFU/mL during frozen storage and exceeding 11.50 log₁₀ CFU/mL after simulated gastrointestinal digestion. Several studies have highlighted the protective role of the ice cream matrix itself. Camelo-silva et al., (2022) demonstrated that concentrated milk-based ice cream provided substantial protection for *Bifidobacterium* BB-12 during simulated gastrointestinal digestion. Likewise, Villalva et al., (2017) reported that *Bifidobacterium lactis* Bb-12 decreased from 4×10^8 CFU/mL initially to 1.5×10^7 CFU/mL after 21 days of storage, while still

remaining within the range considered beneficial for human health.

Current strategies for improving probiotic survival in ice cream include the selection of stress-resistant strains, incorporation of protective agents such as prebiotics and cryoprotectants, optimization of freezing conditions, and application of microencapsulation technologies (Li et al., 2026). Among these approaches, microencapsulation can provide a protective microenvironment that reduces probiotic exposure to adverse processing and storage conditions, thereby improving cell viability during freezing and frozen storage (Homayouni et al., 2008). Recent studies also demonstrated that encapsulated probiotic cells can maintain high survival during ice cream storage and recrystallization conditions (de Moraes et al., 2026). Nevertheless, maintenance or improvement of probiotic viability should not be considered equivalent to demonstrated health efficacy, as confirmation of health benefits requires appropriate biological evidence and, ultimately, well-designed human clinical studies (Lisboa et al., 2025). The effectiveness of probiotic ice cream is influenced not only by microbial survival but also by its impact on product quality. In many cases, probiotic cultures contribute positively to flavor development, acidity, and functional value (Tidona et al., 2017), while in some cases, negative impacts have been reported (Aryana & Summers, 2006).

Prebiotics in ice cream

A prebiotic is defined as a substrate that is selectively utilized by host microorganisms and confers a possible health benefit (Hutkins et al., 2025). Among prebiotic ingredients, inulin and FOS have been widely investigated in functional foods, including ice cream formulations (Sabet-Sarvestani et al., 2021; Villalva et al., 2017). Beyond their microbiota-related functionality, the incorporation of inulin may also modify technological characteristics of ice cream, including viscosity, texture, and melting behavior, depending on its concentration and the composition of the formulation (Diez-libreros et al., 2025).

Inulin is a non-digestible fructan that promotes the growth of beneficial microorganisms and

simultaneously acts as a fat replacer and texture modifier in dairy systems. Akalin and Erişir (2008) demonstrated that the incorporation of inulin improved the survival of *L. acidophilus* and *B. animalis* BB-12 in synbiotic ice cream and positively affected viscosity and melting resistance. Similar observations were reported by Villalva et al. (2017), who found that ice cream containing 10% inulin successfully maintained viable counts of *Bifidobacterium lactis* BB-12 above 10^7 CFU/mL during frozen storage and simulated gastrointestinal conditions. These findings suggest that inulin can provide both nutritional and technological advantages in frozen dairy formulations. FOS is another widely applied prebiotic ingredient in ice cream production. Due to their excellent fermentability by probiotic microorganisms and mild sweetness, FOS can enhance both functionality and sensory quality. Sabet-Sarvestani et al. (2021) reported that synbiotic ice cream containing *Lactocaseibacillus casei* and FOS exhibited improved viscosity, enhanced antioxidant activity, and superior probiotic viability compared with control samples. Likewise, Falah et al. (2021) observed that the addition of inulin and FOS significantly increased the survival of *L. brevis* while improving the antioxidant properties of the final product. These improvements were attributed to the protective effects of prebiotics against freezing stress and their ability to support probiotic metabolism. The technological performance of prebiotic ingredients in ice cream depends on factors such as their concentration, degree of polymerization, and interactions with other matrix components. In particular, the degree of polymerization of inulin-type fructans can markedly influence mix viscosity, structural stability, hardness, overrun, and melting behavior. Longer-chain inulin may enhance mix viscosity and stability but can also increase product hardness and potentially compromise mouthfeel, whereas shorter-chain fructans such as FOS may produce different structural responses (Guimarães et al., 2025). Therefore, the type and incorporation level of prebiotic ingredients should be carefully optimized to achieve the intended functional benefits while maintaining desirable technological and sensory characteristics.

In recent years, researchers have explored alternative sources of dietary fiber and prebiotic

compounds for the development of novel synbiotic ice creams. Apple fiber has attracted particular attention because of its dual functionality as a prebiotic substrate and texture-enhancing ingredient. Kowalczyk et al. (2021) reported that apple fiber improved the rheological properties and physical stability of probiotic ice cream. In a subsequent study, Kowalczyk et al. (2022) demonstrated that formulations containing 2.5 – 4.0% apple fiber significantly improved the survival of *Bifidobacterium animalis* BB-12 during simulated gastrointestinal digestion while maintaining favorable sensory characteristics. These findings indicate that fruit-derived fibers can simultaneously contribute to nutritional value and technological performance.

Yacon flour has also emerged as a promising prebiotic ingredient due to its high fructooligosaccharide content. Studies involving synbiotic ice cream formulations containing yacon flour and *Lactobacillus acidophilus* NCFM demonstrated enhanced probiotic viability and improved functional properties (Gupta & Gautam, 2026). Similarly, oat flour and β -manno-oligosaccharides have been investigated as alternative substrates capable of improving microbial survival while contributing additional nutritional benefits (Gupta & Gautam, 2026; Panwar et al., 2019; Toommuangpak & Thaiudom, 2024). Additionally, prebiotic addition may serve as a cryoprotective agent for improving the physicochemical properties of frozen dairy products (Muzammil et al., 2017). Cryoprotectants are functional agents used to enhance the quality and stability of frozen foods by lowering their freezing point and preventing the formation and growth of ice crystals within them, thus increasing their shelf life. There are several types of food additives that can serve as cryoprotectants, particularly those that have $-\text{COOH}$ and $-\text{OH}$ groups, as well as secondary groups $-\text{SH}$, $-\text{NH}_2$, and $-\text{SO}_3\text{H}$ (Ma et al., 2023). The storage of ice cream results in 30% to 40% growth of ice crystals, mainly because of ice recrystallization due to temperature fluctuations. The presence of prebiotic ingredients, such as GOS, is likely to prevent ice recrystallization through increased viscosity of the serum phase and water movement. Furthermore, GOS may reduce perceived iciness by modifying the viscosity and water mobility of the

serum phase, thereby potentially contributing to a smoother texture. It is worth noting that inulin is known to increase the glass transition temperature (T_g) of ice cream mixes, implying that it decreases the mobility of water and minimizes the movement of water molecules towards the surface of the ice crystals (Cook & Hartel, 2010).

Synbiotics in ice cream

According to the ISAPP consensus, a synbiotic is defined as “a mixture comprising live microorganisms and substrate(s) selectively utilized by host microorganisms that confers a health benefit on the host” (Swanson et al., 2020). Within this framework, synbiotics are classified as complementary or synergistic. Complementary synbiotics combine established probiotic and prebiotic components that may act independently,

whereas synergistic synbiotics have a substrate that is specifically selected for utilization by the co-administered microorganism(s). Thus, classification as a synbiotic depends on evidence of selective substrate utilization and health benefits rather than merely the co-occurrence of ingredients labelled as probiotics and prebiotics (Swanson et al., 2020). Synbiotic formulations are of particular interest in ice cream because the incorporated substrate may contribute to both microbial functionality and the technological characteristics of the product (**Fig. 1**). Recent studies support the feasibility of incorporating defined probiotic–prebiotic combinations into frozen dairy systems. For example, Zhou et al. (2024) developed synbiotic ice cream containing *S. cerevisiae* var. *bouardii* CNCM I-745 and 1% inulin and demonstrated that inulin incorporation influenced the metabolic profile of the product during 30 days of frozen storage at –18 °C.

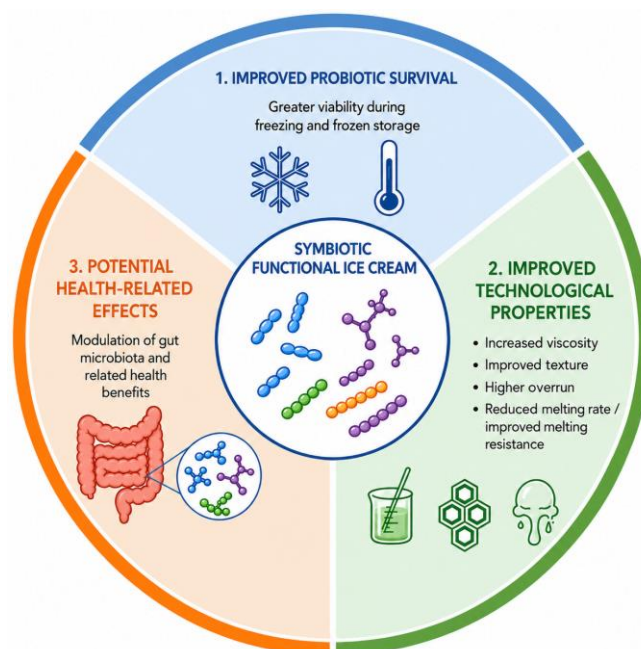


Figure 1. Schematic representation of synbiotic-enriched functional ice cream and its potential technological and health-related effects.

Postbiotics in ice cream

According to the ISAPP definition, a postbiotic is “a preparation of inanimate microorganisms and/or their components that confers a health benefit on the host”. Importantly, this definition requires the presence of inanimate microbial cells and/or their

components; therefore, purified microbial metabolites alone should not be classified as postbiotics (Villalva et al., 2017). Nevertheless, metabolites may be present as part of a postbiotics preparation together with inanimate microbial biomass or cellular components. Postbiotic preparations may contain a diverse range of

microbial cellular components and associated bioactive compounds. Depending on the microbial strain and production process, these preparations may include inactivated microbial cells, cell wall fragments, peptidoglycans, teichoic acids, and EPS, together with associated metabolites such as organic

acids, short-chain fatty acids (SCFAs), bioactive peptides, amino acids, vitamins, and enzymes (Elmas et al., 2026; Vermelho et al., 2025). Such preparations may provide both functional and technological benefits when incorporated into the ice cream matrix (Fig. 2).

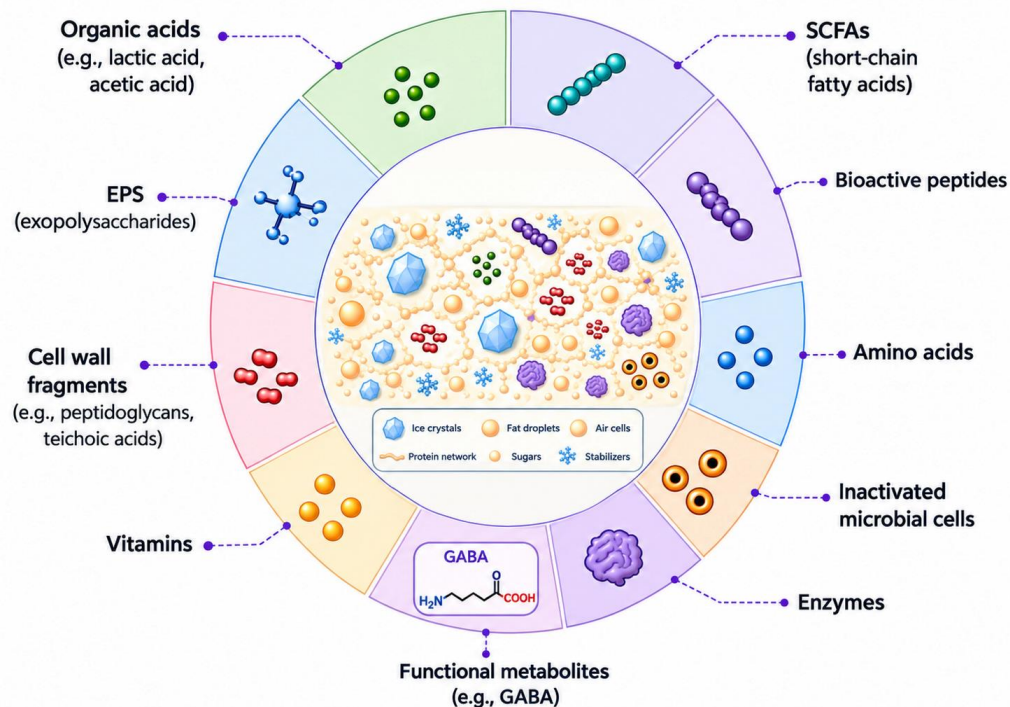


Figure 2. Postbiotic-Enriched ice cream matrix.

Unlike probiotics, their functionality does not require the presence of viable microorganisms, potentially reducing some of the technological constraints associated with maintaining cell survival under adverse processing and storage conditions (Li & Ren, 2024; Yan et al., 2024). However, this advantage should not be interpreted as inherent stability under all conditions, as the biological activity of postbiotic preparations may depend on their composition, progenitor microorganism, inactivation method, and subsequent processing and storage conditions (Li & Ren, 2024; Vinderola et al., 2024). Recent metabolomic investigations have further expanded the spectrum of recognized postbiotic compounds. In synbiotic ice cream produced with *S. boulardii* CNCM I-745, Zhou et al. (2024) identified numerous potential functional metabolites, including citric acid, D-glucuronic acid,

ornithine, gamma-aminobutyric acid (GABA), L-glutamic acid, tryptophan, trehalose, stachyose, and several maltooligosaccharides. These metabolites are believed to contribute to both the biological functionality and technological performance of the final product.

Postbiotics have also shown potential as natural preservation tools in other food matrices, beyond frozen dairy applications. For example, *Lactiplantibacillus plantarum* postbiotics, particularly when combined with thyme essential oil nanoemulsion, improved the microbial, chemical, and sensory quality of refrigerated rainbow trout fillets and contributed to extending their shelf life (Sharafi et al., 2025). In addition to their technological stability, postbiotics exhibit a broad spectrum of biological activities. Numerous studies

have reported antimicrobial, antioxidant, anti-inflammatory, immunomodulatory, and potential biological effects relevant to gastrointestinal health associated with postbiotics (Barros et al., 2020; Kaya et al., 2026). For example, fermented ice cream formulations developed by Polo et al. (2023) contained elevated concentrations of fermentation-derived metabolites, including lactic acid at 49.60 – 69.20mM. These products demonstrated enhanced antiradical activity and significantly reduced the production of inflammatory mediators such as IL-6 and IL-8 in Caco-2 cells while preserving intestinal barrier integrity.

Among the different categories of postbiotics, microbial EPS have attracted particular attention for ice cream applications. EPS are extracellular polysaccharides synthesized by lactic acid bacteria and other beneficial microorganisms during fermentation. In addition to their biological properties, EPS possess remarkable technological functionality. In a study, EPS-producing cultures generated highly viscous, pseudoplastic systems that improved the structural characteristics of fermented functional ice cream (Pourjafar et al., 2023). The authors further suggested that EPS may reduce or eliminate the need for synthetic stabilizers by enhancing viscosity and water-binding capacity. Similar observations demonstrated that EPS-producing *Lactiplantibacillus plantarum* improved the physicochemical properties of ice cream and significantly reduced melting rates. These findings indicate that EPS can simultaneously serve as bioactive compounds and natural texture modifiers (Gomri et al., 2026). Although postbiotics are increasingly being investigated in dairy products, their application in ice cream remains considerably less explored than that of probiotics, and further studies are required to establish their technological performance, appropriate incorporation levels, stability, sensory effects, and biological functionality in frozen dairy matrices.

Effects on physicochemical and sensory properties

The successful development of functional ice cream depends not only on the biological efficacy of incorporated ingredients but also on their effects on physicochemical, rheological, and sensory characteristics.

Rheological properties

The addition of prebiotic fibers generally increases the viscosity of ice cream mixes because of their water-binding capacity and ability to interact with milk proteins. Akalın and Erişir (2008) reported that inulin supplementation increased mix viscosity and contributed to improved structural stability in synbiotic ice cream. Similar findings were reported for formulations containing FOS, apple fiber, and oat-derived ingredients, which enhanced apparent viscosity and promoted more stable frozen structures (Kowalczyk et al., 2021; Toommuangpak & Thaiudom, 2024). Postbiotic-derived EPS appear particularly promising, as Toommuangpak natural rheology modifiers. EPS-producing cultures generate highly viscous systems exhibiting pseudoplastic behavior, which is desirable for frozen dairy products (Pourjafar et al., 2023). Likewise, Gomri et al., (2026) demonstrated that EPS-producing probiotic strains act as natural biothickeners, improving the consistency and flow characteristics of fermented ice cream. Such findings suggest that postbiotic EPS may partially replace synthetic stabilizers while maintaining desirable rheological properties.

In addition to microbial viability, prebiotics substantially influence the physicochemical properties of ice cream. The incorporation of inulin, FOS, and dietary fibers generally increases the viscosity and water-holding capacity of the mixture, resulting in improved body, texture, and melting resistance (Akalın & Erişir, 2008). Increased viscosity can enhance air incorporation and stabilize air cells within the frozen matrix, thereby improving overrun and structural stability. Moreover, the water-binding capacity of prebiotic fibers may contribute to reduced ice crystal growth during storage, potentially resulting in a smoother texture (Mabrouk et al., 2021; Parussolo et al., 2017).

Overrun

Overrun, defined as the amount of air incorporated during freezing, is one of the most important quality parameters in ice cream manufacturing because it directly influences texture, melting behavior, and consumer perception (Sofjan & Hartel, 2004).

Functional ingredients can significantly affect air incorporation by modifying the viscosity and stability of the ice cream mix. Moderate increases in viscosity resulting from prebiotic incorporation often improve air retention and foam stability. Studies involving inulin, FOS, and dietary fibers generally reported improved or maintained overrun values compared with conventional formulations (**Table 1**) (Akalin & Erişir, 2008; Parussolo et al., 2017). In functional strawberry ice cream containing probiotic cultures, Tidona et al. (2017) reported an overrun of approximately 24.7%, indicating satisfactory air incorporation despite the presence of added functional ingredients. However, excessively high fiber concentrations may increase mix viscosity to a level that restricts air incorporation, highlighting the importance of formulation optimization.

Melting resistance

Numerous studies have demonstrated that functional ingredients can significantly improve melting behavior by increasing water retention, strengthening the frozen matrix, and reducing ice crystal mobility. Prebiotic fibers, such as inulin and apple fiber, enhance water-holding capacity and contribute to slower melting rates (Akalin & Erişir, 2008; Kowalczyk et al., 2022). Similar improvements have been reported in formulations containing oat-derived ingredients and other dietary fibers (Panwar et al., 2019). Among postbiotics components, EPS have shown particularly strong potential for improving melting resistance. Gomri et al. (2026) reported that incorporation of an EPS-producing *L. plantarum* strain significantly reduced melting rates compared to control formulations. The enhanced water-binding properties of EPS likely contribute to improved structural stability during melting.

Texture and sensory acceptance

Texture is one of the primary determinants of consumer satisfaction and is strongly influenced by the incorporation of functional ingredients. Several studies have demonstrated that prebiotic fibers improve body, creaminess, and smoothness by increasing total solids and reducing ice crystal growth during storage. Kefir-enriched ice cream formulations showed improvements in texture, aroma, taste, and overall acceptability compared with control samples (Köroğlu & Dayısoylu, 2025).

However, probiotic incorporation does not always improve product quality. Aryana and Summers (2006) observed that high concentrations of probiotic cultures negatively affected flavor, body, and texture scores in fat-free, sugar-free ice cream. These findings indicate that strain selection and inoculation level must be carefully optimized to balance health benefits with consumer acceptance. Apple fiber, inulin, and FOS have been reported to improve textural attributes by enhancing water retention and creating a more homogeneous matrix (Kowalczyk et al., 2021; Sabet-Sarvestani et al., 2021). In addition, fermentation-derived postbiotics may positively affect texture through the production of organic acids and EPS. Ozcan et al., (2026) observed improvements in penetration characteristics and adhesiveness in fermented functional ice cream, suggesting that postbiotic metabolites contribute to desirable textural modifications. It is worth pointing out that the process of preparation of postbiotics in commercial culture media, such as the De Man Rogosa Sharpe (MRS) medium, might give a yellowish brown color, which is not desirable in dairy foods like ice cream (Sharafi et al., 2024). In this way, cheese whey, which is cheap and easily available and has a white coloration, can serve as an alternative medium for the production of postbiotics that will be applied to dairy products (Sharafi et al., 2022). Moreover, the acids found in postbiotics and the natural flavor of the media can change the taste and smell of the food items (Zheng et al., 2022). In this regard, selecting an appropriate probiotic strain for postbiotic production may help overcome these challenges in the application of postbiotics in ice cream. EPS-producing cultures have similarly been associated with increased creaminess and improved structural integrity (Pourjafar et al., 2023).

Regardless of their functional value, novel ice cream formulations must maintain high sensory quality to achieve consumer acceptance. Several studies have reported positive sensory responses to synbiotic formulations containing inulin, FOS, and fruit-derived fibers (Kowalczyk et al., 2022; Villalva et al., 2017). Soodbar et al. (2025) reported that increasing the concentration of propolis extract in probiotic ice cream altered viscosity, hardness, color, and sensory characteristics, with the highest incorporation level (0.8%) significantly reducing flavor, odor, and

overall acceptability compared with the control. Kefir-enriched and probiotic ice creams have also demonstrated favorable consumer acceptance due to improvements in flavor complexity and perceived creaminess (Köroğlu & Dayısoylu, 2025). Furthermore, Polo et al. (2023) and Ozcan et al. (2026) reported that fermentation-derived metabolites contribute to distinctive flavor profiles and enhance the overall acceptability of functional frozen dairy products. Nevertheless, excessive concentrations of functional ingredients may negatively affect sensory attributes. Aryana and Summers (2006) reported reductions in flavor and texture scores when probiotic cultures were incorporated at high levels. Similarly, excessive dietary fiber addition may lead to undesirable mouthfeel, increased hardness, or altered flavor perception. Therefore, careful optimization of ingredient type and concentration remains essential to ensure a balance between health functionality and sensory quality.

Potential health benefits

The incorporation of probiotics, prebiotics, synbiotics, and postbiotics into ice cream has transformed this traditionally dairy dessert into a potential vehicle for delivering health-promoting bioactive compounds. Beyond their technological functions, these ingredients have been associated with improvements in gastrointestinal health, antioxidant status, immune regulation, and metabolic well-being. Probiotics may exert strain-specific effects through multiple mechanisms, including modulation of the intestinal microbiota, interactions with the intestinal epithelium and immune system, and the production or transformation of biologically active compounds (Hutkins et al., 2025; Zhang et al., 2024). In a randomized controlled feasibility study, (Borum et al., 2025) evaluated probiotic-enriched ice cream in women at high risk of preterm birth and reported changes in the gut and vaginal microbiota, including recovery of several administered probiotic strains from rectal and vaginal samples.

Prebiotics are selectively utilized by host microorganisms and may promote health-associated changes in microbial composition or function (Hutkins et al., 2025). The addition of prebiotics

further enhances these benefits by selectively stimulating the growth and activity of beneficial gut microorganisms. In a randomized intervention study, Valle et al. (2021) reported that daily consumption of synbiotic ice cream containing *L. acidophilus* LA-5, *B. animalis* BB-12, and 2.3 g of inulin positively modulated intestinal microbiota and improved health-related indicators in military personnel exposed to intensive physical activity. Prebiotic fibers, such as inulin and FOS, can influence carbohydrate metabolism, satiety, and microbial fermentation patterns in the colon, potentially supporting metabolic health (Akalın & Erişir, 2008; Valle et al., 2021). Earlier studies similarly observed increases in fecal populations of beneficial microorganisms following the consumption of synbiotic ice cream formulations, confirming the ability of these products to effectively deliver functional ingredients to the gastrointestinal tract (Pandiyani et al., 2012a, 2012b). Several studies have demonstrated that functional ice cream formulations exhibit enhanced antioxidant activity compared with conventional products. Falah et al., (2021) reported that the incorporation of prebiotic ingredients significantly enhanced the antioxidant capacity of synbiotic ice cream containing *L. brevis*. Similarly, Sabet-Sarvestani et al. (2021) observed increased antioxidant activity in FOS-containing probiotic ice cream formulations.

Postbiotics may provide comparable gut health benefits without requiring microbial viability. Organic acids, peptides, exopolysaccharides, and microbial cell components can interact with the intestinal environment and contribute to the maintenance of gut homeostasis (Divsalar et al., 2025; Mojgani et al., 2026). In addition, recent studies suggest that postbiotics may further strengthen the antioxidant properties of frozen dairy products. Fermentation-derived metabolites, including organic acids, peptides, amino acids, and exopolysaccharides, have been associated with free radical scavenging activity and oxidative stress reduction (Păcularu-Burada & Bahrim, 2021). Fermented ice cream formulations developed by Polo et al. (2023) exhibited improved antiradical activity and reduced the production of pro-inflammatory mediators, including IL-6 and IL-8, in Caco-2 cells while preserving epithelial barrier integrity. These observations suggest that postbiotic

compounds may contribute to immune regulation and anti-inflammatory activity in functional dairy products. Metabolomic analysis of synbiotic ice cream revealed the presence of compounds such as GABA, D-glucuronic acid, citric acid, and various amino acids that may contribute to health-promoting activities beyond traditional probiotic effects (Zhou et al., 2024). GABA, in particular, has attracted attention because of its potential immunomodulatory effect in gut-brain axis and supporting neurological health (Wan-Mazlan et al., 2026).

Challenges and future perspectives

Despite the substantial progress achieved in the development of functional ice cream, several scientific, technological, and regulatory challenges continue to limit the large-scale commercialization of these products. The most significant challenge associated with probiotic ice cream remains the maintenance of microbial viability throughout manufacturing, frozen storage, distribution, and gastrointestinal transit. Although the incorporation of prebiotics has improved microbial stability in many formulations, ensuring consistent delivery of adequate probiotic populations throughout product shelf life remains a major concern. Another challenge relates to the optimization of formulation characteristics. Functional ingredients can significantly affect viscosity, overrun, melting behavior, texture, and sensory properties. While moderate concentrations of prebiotics and postbiotic-derived EPS often improve product quality, excessive incorporation levels may negatively influence flavor, mouthfeel, sweetness perception, or overall consumer acceptance. In the case of postbiotics, standardization of postbiotics preparations represents an additional challenge for future applications. Unlike conventional food ingredients, postbiotics comprise complex mixtures of microbial metabolites, cell components, and inactivated cells whose composition can vary considerably depending on microbial strain, fermentation conditions, culture medium, and inactivation method. In addition, while regulatory frameworks for probiotics and prebiotics are relatively well established in many countries, specific regulations governing postbiotics use in foods remain under development. The absence of

harmonized definitions, characterization criteria, and health claim regulations may slow commercial adoption and create uncertainty for manufacturers.

From a research perspective, future studies should move beyond simple viability assessments and focus on understanding the mechanisms by which functional ingredients influence both product quality and human health. The application of metabolomics, proteomics, and other multi-omics approaches may facilitate the identification of key bioactive compounds responsible for the beneficial effects observed in functional ice cream.

Conclusion

Biotic-enriched ice cream represents a promising intersection of functional nutrition and food technology. Probiotics currently have the strongest evidence base, whereas prebiotics and synbiotics provide additional opportunities to combine microbiota-related functions with desirable formulation properties. Postbiotics are an emerging approach with potential technological advantages, but ice-cream-specific evidence remains limited. The successful development of these products depends on balancing their biological functionality with their stability, texture, melting behavior, and sensory acceptance. A more meaningful framework is to establish whether the selected biotic component remains functional throughout processing and shelf life and whether the final product delivers a demonstrated health benefit at an appropriate dose. This distinction between survival, biological functionality, and clinical efficacy should guide future research on functional ice cream.

Conflicts of interest

The authors declare no conflicts of interest.

Disclaimer

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