



An overview of the importance of probiotics in health and industry: A Mini-Review

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Abstract

Probiotics are living microorganisms, most of which belong to the bacterial genera *Lactobacillus* and *Bifidobacterium*. These microorganisms are part of the natural intestinal microbiome. Many studies have shown that consuming sufficient quantities of probiotics helps maintain intestinal microbiome homeostasis by strengthening the immune and antioxidant systems, producing antimicrobial substances and various inhibitors, and competing with pathogenic agents. Although some probiotic mechanisms have not been fully elucidated, their effects in preventing and treating many diseases, including digestive disorders, infections, and even cancer, have been demonstrated. In addition to their direct effects on health, the industrial use of these microorganisms also indirectly affects human health. Therefore, this mini-review introduces probiotics and discusses some of their roles in medicine and industry in improving human health.



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Introduction

The first definition of probiotics was proposed in 1965 by Lilly and Stillwell and was limited to substances produced by bacteria that promote the growth of other bacteria. The current definition describes probiotics as living microorganisms that must be ingested in sufficient quantities to exert health benefits beyond their nutritional effects. The inherent properties of probiotics include a lack of toxicity and pathogenicity and the ability to improve host health (1). The principal mechanisms through which probiotics affect human health are as follows:

1. Strengthening the intestinal barrier by stimulating the production of occludin and claudin 1, which are essential proteins in the formation of tight junctions (2).
2. Regulation of innate and adaptive immune responses through the production of anti-inflammatory cytokines and modulation of the functions of dendritic cells, macrophages, and lymphocytes (3).
3. Reduction of intestinal pathogens through competition with these pathogenic microorganisms for binding to receptors on intestinal epithelial cells and through the production of short-chain fatty acids, organic acids, hydrogen peroxide, and bacteriocins (4,5).
4. Regulation of the intestinal flora by increasing the abundance and diversity of specific bacterial strains.

The composition of the intestinal flora (Microbiome) is dynamic and varies among individuals depending on diet, exposure to ingested probiotic bacteria, intestinal environmental conditions, and other host-associated factors that may introduce new strains into the ecosystem transiently. Although gastrointestinal cells are continually exposed to microbial antigens and metabolites, humans live in symbiosis with these microorganisms. This relationship is maintained through various mechanisms. Several reports have demonstrated that manipulating the gut microbiota through probiotics and fecal microbiota transplantation may affect host metabolism (6). Researchers currently focus on the beneficial effects of various probiotic species, including *Lactobacilli*, *Bifidobacteria*, and yeasts. A selection of these probiotics is presented in Figure 1 (1,3). Therefore, this mini-review focuses on several applications of probiotics in health and selected industries.

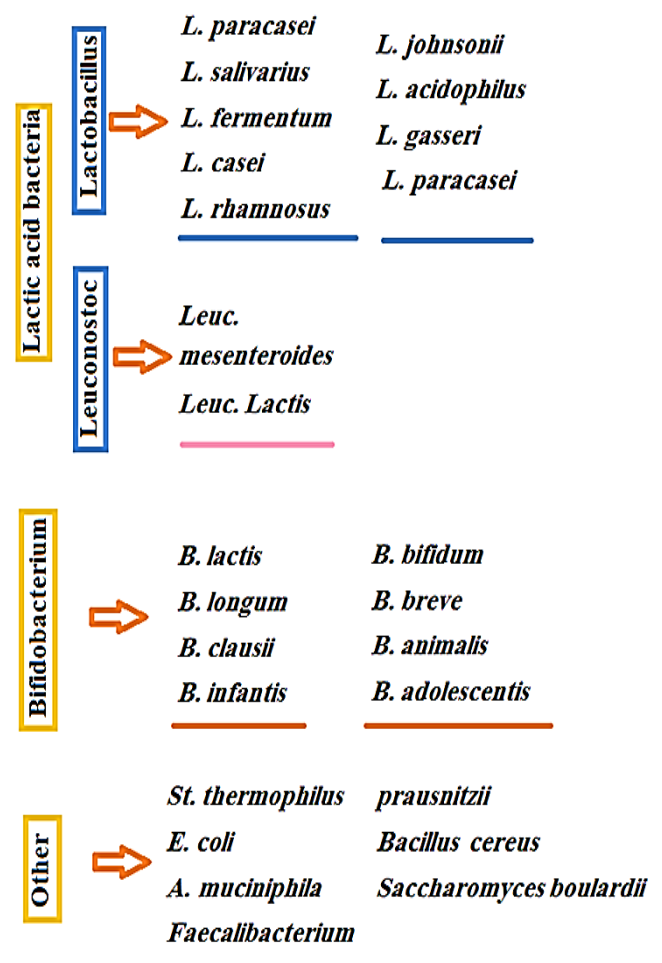


Figure 1. Selected probiotic species

Probiotics in disease prevention and control

Antibacterial effects of probiotics

Several studies have demonstrated the antibacterial and antioxidant effects of probiotics through enhancement of the antioxidant and immune systems. In two separate studies, contamination of hands with *Staphylococcus aureus* and *Pseudomonas aeruginosa* decreased total antioxidant capacity, glutathione levels, and glutathione peroxidase activity. These changes were attenuated in both study groups after treatment with *Saccharomyces boulardii* and *Saccharomyces cerevisiae*, respectively (7,8). Mahpishanian et al. induced osteomyelitis in the thighs of rats by injecting *Staphylococcus aureus*. Radiographic and histopathological images clearly demonstrated the spread of inflammation and infection. However, treatment of the rats with *Lactobacillus plantarum* reduced the severity and extent of the disease and decreased interleukin 6 levels to some extent (9).

Many probiotics can produce numerous molecules that resemble antibiotics but differ from them. These molecules are commonly defined as antimicrobial peptides. In particular, *Lactobacilli* produce a broad range of proteins and peptides called lantibiotics, which exhibit variable antimicrobial activity and little or no antibiotic resistance. The principal lantibiotics are grouped under the term bacteriocins. These bioactive peptides, produced by both gram-positive and gram-negative bacteria during the primary growth phase, exert bactericidal activity against strains belonging to the same or related species as their producers. Bacteriocins are rapidly released by bacteria after production and are thought to act primarily by forming pores in the phospholipid layer of the cytoplasmic membrane of the target bacteria, thereby causing bacterial death through disruption of the internal environment (10). The effects of enterocin AS-48, nisin A and V, and pediocin A in ameliorating infections caused by *Lactococcus garvieae* and *Listeria monocytogenes* have been demonstrated in fish and mice, respectively (11,12). Currently, three categories of bacteriocins have been identified, each comprising several subcategories. Figure 2 presents the bacteriocin classes and the molecular characteristics of each class (4).

Probiotics and gastrointestinal diseases

The intestinal mucosal microbiome contributes to the metabolism and digestion of fats, proteins, and carbohydrates. Advances in metabolomics have demonstrated an association between food sources and healthy or diseased mucosal microbiota. Various probiotic strains

are now used clinically to treat complex and inflammatory gastrointestinal diseases (13).

Helicobacter pylori is a common pathogen that causes chronic gastritis and peptic ulcer disease and, if left untreated, may lead to gastric adenocarcinoma and lymphoid tissue lymphoma. Certain probiotic species can survive in the stomach and inhibit *Helicobacter pylori* through mechanisms such as secreting antibacterial substances to inhibit growth, suppressing urease enzyme activity, reducing adhesion to the gastric epithelium, and regulating host immune responses (14).

Irritable bowel syndrome (IBS) is the most common functional disorder of the digestive system. Its treatment largely involves lifestyle modifications, including stress reduction, dietary regulation, and exercise. Probiotics may also be considered a therapeutic approach for IBS because they stimulate the host immune system, increase intestinal permeability to nutrients, and maintain the composition of the intestinal microbiota (14).

Another disease in which microbiome imbalance likely plays an important role is inflammatory bowel disease (IBD) (including Crohn's disease and ulcerative colitis). Significant differences have been observed between the bacterial, fungal, and viral populations in the intestinal microbiota of affected individuals and those of healthy individuals. Probiotics may therefore be suitable candidates for treating IBD by reducing inflammation, improving mucosal barrier function, and strengthening the immune system (15).

Acute gastroenteritis is a common digestive disease, particularly in children, and is often caused by infection. Its symptoms include nausea, vomiting, watery stools, and abdominal pain. Studies have shown that *S. boulardii* significantly reduces disease symptoms, particularly diarrhea, by inhibiting the secretion of pro-inflammatory cytokines (16).

Chronic idiopathic constipation, which affects colonic or anorectal function, occurs in approximately 14% of the global population. Adverse drug effects and gastrointestinal dysfunction related to the enteric nervous system may cause constipation. Although current treatments include lifestyle and dietary modifications, bulking agents, stool softeners, stimulant laxatives, and stimulant medications prescribed by physicians, constipation remains challenging to treat. Several studies have shown that supplements containing *Lactobacilli* and *Bifidobacteria* strains help relieve constipation by increasing bowel movements (16,17). Table 1 presents the beneficial effects of probiotic strains in treating several gastrointestinal diseases (18).

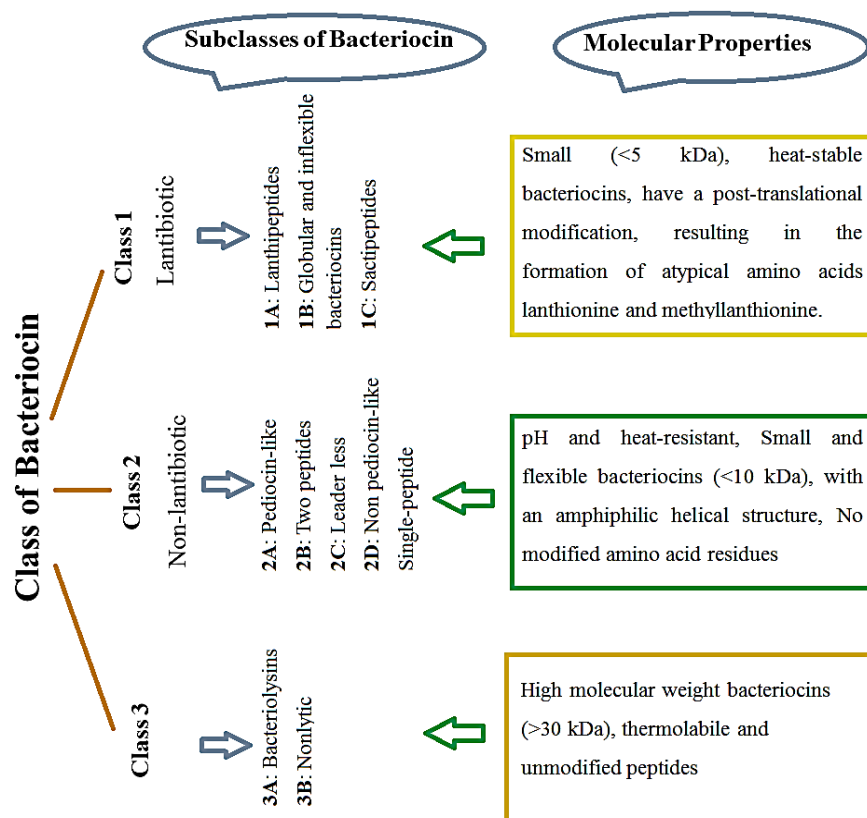


Figure 2. Classification of bacteriocins

Probiotics and skin health

As the body's largest organ, the skin plays an important role in human health by preventing pathogen invasion. Although many microbial species successfully colonize the skin, the skin microbiome consists of diverse microorganisms that interact to maintain skin health. Probiotics are highly beneficial in preventing chronic diseases through their mediating effects. They exert positive effects on skin conditions such as burns, scars, infections, and wounds. They also enhance innate skin immunity and promote the regeneration of healthy skin (19). The skin microbiota act as a defensive barrier and can regulate inflammatory responses to minor epidermal injuries by modulating cytokine production to maintain skin health. Skin injuries disrupt microbiota levels and increase the prevalence of bacteria that adversely affect wounds. Probiotics may exert beneficial effects by directly killing pathogens, strengthening the epithelial barrier, competitively displacing pathogenic bacteria, and inducing fibroblasts (20).

Atopic dermatitis (AD) is a common inflammatory skin disease in early life that is associated with food allergies and asthma. Its symptoms include impaired barrier function and a general decrease in transepidermal water loss (TEWL), leading to dry, itchy skin. An association has been observed between the microbiota and this disease; infants with atopic dermatitis had higher numbers of Clostridia than healthy infants. In this study, combined *Lactobacilli* supplementation reduced eczema severity in affected children (21).

Acne is a skin infection for which *A. vulgaris* and *P. acnes* are common causative pathogens. Several studies have shown that the use of a probiotic mixture (*L. acidophilus*, *B. bifidum*, and *L. delbrueckii*) significantly reduces inflammatory symptoms. In addition, CBT SL-5 (An antimicrobial compound produced by *E. faecalis*) reduced inflammation (22,23). Table 2 also presents the effects of a group of probiotics on the healing of allergic contact dermatitis (ACD), psoriasis, and photoaging (22).

Table 1. Probiotics effective against selected gastrointestinal diseases

Gastrointestinal diseases	Probiotics
Acute infectious diarrhea	<i>Lactobacillus rhamnosus</i> GG, <i>Saccharomyces boulardii</i>
Acute pancreatitis	<i>Bifidobacterium animalis subsp lactis</i> , <i>L.casei</i> B. <i>bifidum</i> , <i>B. Jongum</i> , <i>L. delbrueckii</i> , <i>Enterococcus faecalis</i> , <i>L.acidophilus</i> , <i>L.paracasei</i> , <i>Leuconostoc cremoris</i> , <i>Leuconostoc mesenteroides</i> , <i>Pediococcus pentosaceus</i> , <i>Streptococcus salivarius</i> , <i>Streptococcus thermophilus</i>
Antibiotic- associated diarrhea	<i>Bacillus coagulans</i> , <i>Bifidobacterium animalis subsp lactis</i> , <i>B.bifidum</i> , <i>B. longum</i> , <i>Clostridium butyricum</i> , <i>Enterococcus faecium</i> , <i>L. acidophilus</i> , <i>L.casei</i> , <i>L. delbrueckii</i> , <i>L. paracasei</i> , <i>Leuconostoc cremoris</i> <i>Saccharomyces boulardii</i> , <i>Saccharomyces florentinus</i> , <i>Streptococcus thermophilus</i>
<i>C.difficile</i> - associated diarrhea	<i>Bifidobacterium animalis subsp lactis</i> , <i>B. longum</i> , <i>Clostridium butyricum</i> , <i>L.acidophilus</i> , <i>L.casei</i> , <i>L. delbrueckii</i> , <i>L. paracasei</i> , <i>Saccharomyces boulardii</i> , <i>Streptococcus thermophilus</i>
<i>C.difficile</i> infection	<i>Bifidobacterium animalis subsp lactis</i> , <i>B.bifidum</i> , <i>B. longum</i> <i>Clostridium butyricum</i> , <i>Enterococcus faecium</i> , <i>L.acidophil</i> <i>L.casei</i> , <i>L. delbrueckii</i> , <i>L. paracasei</i> , <i>Saccharomyces boulardii</i> <i>Streptococcus thermophilus</i>
Chemotherapy- associated diarrhea	<i>Lactobacillus rhamnosus</i> GG
Colic	<i>Lactobacillus reuteri</i>
Crohn disease	<i>Bifidobacterium animalis subsp lactis</i> , <i>E. coli</i> , <i>B.bifidum</i> , <i>B. Jongum</i> , <i>L.johnsonii</i> , <i>L. acidophilus</i> , <i>L. delbrueckii</i> , <i>L. paracasei</i> , <i>Saccharomyces boulardii</i> <i>Streptococcus thermophilus</i>
Functional abdominal pain	<i>Bifidobacterium animalis subsp lactis</i> , <i>B. longum</i> , <i>L.acidophilus</i> , <i>L.casei</i> , <i>L. delbrueckii</i> , <i>L. paracasei</i> , <i>Streptococcus thermophilus</i>
Functional constipation	<i>Bifidobacterium animalis subsp lactis</i> , <i>B. longum</i> , <i>L.casei</i> , <i>L. delbrueckii</i> , <i>Streptococcus thermophilus</i>
<i>Helicobacter pylori</i> infection	<i>Bifidobacterium animalis subsp lactis</i> , <i>L.gasseri</i> , <i>L.acidophilus</i> , <i>L.casei</i> , <i>L. delbrueckii</i> , <i>L.johnsonii</i> , <i>Streptococcus thermophilus</i>
Hepatic encephalopathy	<i>B. longum</i> , <i>E. coli</i> , <i>L.acidophilus</i> , <i>L.casei</i> , <i>L. delbrueckii</i> , <i>L. [paracasei</i> , <i>Leuconostoc mesenteroides</i> , <i>Pediococcus pentosaceus</i> , <i>Streptococcus thermophilus</i>
Irritable bowel syndrome	<i>Bifidobacterium animalis subsp lactis</i> , <i>Enterococcus faecalis</i> , <i>B.bifidum</i> , <i>B. longum</i> , <i>E. coli</i> , <i>L.acidophilus</i> , <i>L. delbrueckii</i> , <i>L. iparacasei</i> , <i>L.lactis</i> , <i>Streptococcus thermophilus</i>
NAFLD/NASH	<i>Bifidobacterium animalis subsp lactis</i> , <i>B. longum</i> , <i>L.acidophilus</i> , <i>L.casei</i> , <i>Streptococcus thermophilus</i>
Necrotizing enterocolitis	<i>Bacillus cereus</i> , <i>Bacillus subtilis</i> , <i>Bifidobacterium adolescentis</i> , <i>Bifidobacterium animalis subsp lactis</i> , <i>B.bifidum</i> , <i>B. longum</i>

Table 2. Probiotics and their effects on skin diseases

Probiotics	Disease	Function
<i>L. rhamnosus</i>	Atopic dermatitis (AD)	Improvement of severity of eczema, reduction of risk of AD development in infants
<i>L. reuteri</i>	AD Infections (<i>S. aureus</i>)	Improvement of eczema. Blocks integrin, Reduces cell death due to <i>S. aureus</i> infection
<i>L. delbrueckii</i> <i>Subspecies bulgaricus</i>	Acne	Improvement of Acne symptoms (Acne Vulgaris)
<i>L. sporogenes</i>	Psoriasis	Improvement of symptoms, reduction of blood sugar levels and fever
<i>E. coli</i> Nissle 1917	ACD	Increase of TGF- β , Foxp3, IFN- γ and IL-10 expression
<i>L. fermentum</i>	Infections (Wounds)	Production of nitric oxide, increases productions of Interleukin 1 (IL-1) and Transforming Growth Factor B (TGF- β) cytokines
<i>L. casei</i> <i>L. salivarius</i>	ACD, Infections Methicilin Resistant <i>S. aureus</i> (MRSA)	Reduction of skin inflammation, inhibition of IFN- γ , CD8+ T cells, increase in IL-10 production,
<i>B.bifidum</i>	AD Acne	Reduction of Ig-E, reduction of development of AD in infants, reduction of <i>Acne Vulgaris</i> symptoms
<i>B. lactis</i>	AD	Reduction of Ig-E, Reduction of development of AD in infants
<i>B. breve</i> strain yakult	Photoaging	Prevention of loss of elasticity, suppression of elastase, activation of IL-1
<i>B. infantis</i>	Psoriasis	Reduction of plasma TNF- γ , increase of IL-6
<i>S. epidermidis</i>	Acne	Growth inhibition of <i>P.acnes</i> and <i>Acne Vulgaris</i> by competitive exclusion
<i>E. faecalis</i>	Acne	Reduction of inflammation areas, production of bacteriocins

Probiotics and anticancer effects

Cancer is one of the leading causes of mortality worldwide, and genetic and immune factors play important roles in its development. Because an imbalance in the intestinal microbiota induces pro-inflammatory immune responses and subsequently contributes to the development of various diseases, including cancer, proper microbiota function can help maintain body homeostasis. Probiotics could be used as adjuvants for various cancers because of their potential to modulate the enteric flora and enhance innate and adaptive immunity. They prevent the initiation, progression, and metastasis of transplantable or chemically induced tumors (24,25). Many researchers have demonstrated interactions between probiotics and their metabolites (Bacteriocins, peptides, and organic acids) and critical metabolic pathways, including cell proliferation, inflammation, apoptosis, angiogenesis, and metastasis. Moreover, probiotics inhibit carcinogenesis by competitively excluding pathogens, increasing short-chain fatty acid production, binding carcinogens and mutagens, downregulating NF-kappa B-dependent gene products involved in cell proliferation (Cox-2, cyclin D1) and cell survival (Bcl-3, Bcl-xl), and enhancing apoptosis (26). Probiotics have been shown to inhibit hepatocellular carcinoma progression by reducing liver tumor size and downregulating angiogenic factors. In breast cancer, in addition to immunomodulation, the hypoxia-inducible factor pathway was significantly suppressed by *Lactobacillus* culture supernatant (27). In one study, cell residues and supernatant from *Saccharomyces boulardii* were injected into breast tumors after breast cancer had been induced in rats. After treatment, the resulting changes in hematological factors were attenuated, BAX concentrations increased significantly, and BCL-2 concentrations decreased compared with those in untreated rats with cancer. The researchers suggested that the observed reduction in tumor size was probably attributable to apoptosis in the cancer cells (28). Several clinical studies have demonstrated the effectiveness of probiotics in reducing the progression of various cancers. These findings are presented in Table 3 (25).

Industrial applications of probiotics

Probiotics in the food industry

Growing public awareness of diet-related issues and increasing evidence of the health benefits of probiotics have heightened consumer interest in probiotic foods. Numerous foods, including yogurt, powdered milk, frozen fermented dairy desserts, cheese and cheese products, ice cream, infant foods, cereals, and fruit juices, contain probiotics (29). The principal barriers to using probiotics in the food industry are their sensitivity to heat treatment during processing, vulnerability to gastric acid and digestive enzymes, and the difficulty of delivering sufficient quantities of viable probiotics to the intestine. The most widely used technique for preserving probiotics in various foods is encapsulation in biopolymeric materials (30). Carrier particles in these systems can be designed in several ways to improve probiotic viability. First, they may

form a physical barrier that protects probiotics from harmful components in the surrounding environment, such as gastric acids, bile salts, or digestive enzymes. Second, microparticles may retain specific components excreted by probiotics that promote their survival. Third, they may contain additives, such as antacids that regulate local pH, to create a favorable local environment for probiotics. Finally, they may microencapsulate probiotics with specific nutrients that promote survival, including digestible carbohydrates, dietary fibers, proteins, lipids, or minerals (31).

Various materials are used to encapsulate probiotics in the food industry. These materials include the following: 1. Whey protein: This protein-rich material can form intermolecular cross-links with carbohydrate biopolymers, thereby increasing microcapsule stability. Adding lignin to whey protein not only helps preserve probiotic viability but also promotes their gradual release in the digestive system. 2. Soybean protein: Because whey protein causes allergic reactions in some individuals, plant-derived soybean protein is another candidate for microcapsule production. Its characteristics include availability, utility, similarity to the extracellular matrix, and low immunogenicity. 3. Alginates: These natural polysaccharides contain mannuronic and guluronic acid residues. Because they are negatively charged in aqueous solutions, they can form complexes with positively charged gelatin polymers. 4. Gum Arabic: This plant gum is prepared from *Acacia branches*. Its high-water solubility, emulsifying properties, and low viscosity have led to its widespread use in the food and pharmaceutical industries. 5. Chitosan: This natural polysaccharide forms an encapsulation system with xanthan that is resistant to digestive enzymes and low pH (32).

Probiotics in the cosmetic industry

Aging and exposure to ultraviolet radiation increase skin pH, decrease collagen and elastin levels, alter immune and inflammatory responses, reduce antioxidant levels, increase the production of reactive oxygen species (ROS), and change the skin microbiome. These effects are major contributors to skin aging (33).

Dry skin is an important sign of skin aging and is associated with surface evaporation caused by weakened epidermal barrier function and degradation of the sebaceous membrane. Certain microorganisms, such as *Streptococcus thermophilus* S244 and *Streptococcus salivarius* spp., possess hydrating enzymes and are therefore used in cosmetic formulations to reduce skin dryness (34). Nakai et al., 2019, showed that *Lactobacillus plantarum* L-137 cell fluid activates the NFkB signaling pathway by producing the cytokine IFN. By increasing fibroblast expression of hyaluronate synthase mRNA through this cytokine, it increases hyaluronic acid production and maintains skin moisture (35). Another study reported that *Streptococcus thermophilus* maintains the flexibility of the stratum corneum by increasing its ceramide content (36).

Table 3. Clinical studies of the use of probiotics in cancer prevention and treatment

Probiotic strain	Subject	Time treatment	Effect
<i>Bifidobacterium breve yakult</i>	42 patients during chemotherapy	6 weeks	Reduce the incidence of fever Reduce the need for intravenous antibiotics using compared to the control group
<i>Bifidobacterium longum</i>	60 patients with colorectal cancer undergoing colon resection	3 days	Increase the count of bacteria of the Bifidobacterium genus. Reduce the count of bacteria of Escherichia genus
<i>L.plantarum CGMCC, L. acidophilus-11, Bifidobacterium</i>	150 patients with colorectal cancer	6-10 days	Reduce the serum zonulin concentration, reduce duration of postoperative pyrexia, reduce duration of antibiotic therapy Inhibited the p38 (Mitogen-activated protein kinase)
<i>L.acidophilus, L.plantarum, B. lactis, S. boulardii</i>	164 patients with colorectal cancer undergoing surgery	4 weeks	Reduce the risk of postoperative complications A positive correlation was observed between the expression of the SOCS3 gene and the expression of the TNF gene and IL-6.
<i>Lactobacillus acidophilus L1</i>	180 people with bladder cancer and 445 controls	10 weeks	Reduce the risk of bladder cancer correlated with habitual intake of lactic acid bacteria
<i>L. rhamnosus LC 705, P.freudereichii subsp. shermanii</i>	90 male students with high aflatoxin level in urine	5 weeks	61.5% reduce a liver cancer biomarker which leads to reduced urinary excretion of aflatoxin B1-N7guanine (AFB-N7- guanine)
<i>Lactobacillus gasseri OLL2716 (LG21)</i>	10 people with colorectal cancer and 20 controls	12 weeks	Increase the number of <i>Lactobacillus</i> genus Increase synthesis of isobutyric acid, Increase NK cell activity. Reduce the amount of <i>Clostridium perfringens</i> .
<i>Lactobacillus casei shirota (LsC)</i>	54 women with an HPV-positive intraepithelial lesion	6 months	60 % reduce in human papilloma virus (HPV) associated infection and cervical cancer precursors
<i>Streptococcus thermophiles and L.delberuckii</i>	Bulgarius 45241 healthy people	12 years	Reduce the risk of colorectal cancer correlated with increased consumption of yogurt (Especially in men).

An excessive increase in free radicals in skin cells exposed to UV light leads to lipid peroxidation and, ultimately, the production of lipofuscin, an indicator of cellular aging. Therefore, eliminating excess ROS is necessary to prevent aging (37). Research has shown that creams containing *Lactobacillus fermentum* TKSNO41 and heat-inactivated *Lactobacillus acidophilus* can prevent wrinkles by strengthening the skin's antioxidant system, producing anti-inflammatory cytokines (such as IL-10), regulating ROS levels, and inhibiting MMP (38,39). Lipopolysaccharides and lipoteichoic acid extracted from bacterial extracellular vesicles increase skin elasticity and maintain cell shape by inhibiting MMP-1 and elastase activity (40,41). In addition, lactic acid from *Lactobacilli* inhibits tyrosinase, reduces melanin formation in cells, and alleviates skin darkening (42). The use of probiotics in cosmetics and skin-care products has increased because of their antiaging, antiwrinkle, antioxidant, and hydrating properties. Table 4 presents the beneficial effects of several probiotics used in cosmetic products (42).

Table 4. Selected cosmetic products containing probiotics

Probiotics and their products	Type of cosmetic product	Cosmetic effects
<i>Lactobacillus ferment</i> extract	Lotion	Skin feels soft, moisturized, and revitalized. Restores skin barrier function and seal in moisture on the skin's surface.
A lysate from <i>Bifidobacterium longum</i>	Toner	Maintain the balance between the skin's water and oil content. Improved skin stability. Revitalize and repair skin.
<i>Alteromonas baumann</i> ferment extract	Cream	Multidimensional repair of skin fragility and relieving skin discomfort.
<i>Lactobacillus</i> /Soymilk ferment filtrate	Cream	Intensive moisture lock water and reduce skin moisture loss. Balance skin flora and improve skin health.
<i>Vitreoscilla</i> ferment	Mask	Repair skin barrier, and relieve redness and discomfort.
<i>Lactobacillus</i> /Soymilk ferment filtrate, <i>Bifidobacterium longum</i> lysate	Lotion	Regulate skin flora, strengthen the micro-ecological barrier, and improve skin condition.
<i>Lactobacillus</i> ferment extract	Gel	Balance the micro-ecological barrier to help reduce repeated breakouts.
<i>Bifidobacterium</i> /Soybean ferment/ <i>Lactococcus</i> /Milk ferment	Cream cleansing	Maintain skin elasticity and permeability.
<i>Lactobacillus</i> / Soy milk ferment filtrate	Cleaning serum	Help restore the dynamic balance of bacteria on the skin surface and create a stable skin microenvironment.
<i>Lactococcus lactis</i> fermentation lysate	Serum	Reduce skin redness, acne, and sunburn. Restore skin elasticity.
<i>B. longum</i> /L. ferment lysate, <i>Streptococcus thermophilus</i> ferment	Cleaning	Regulate skin pH.
<i>Bifidobacterium longum</i> lysate	Cream	Accelerate collagen regeneration and effectively improve skin fullness.
<i>Lactobacillus</i>	Mask	Enhance the outer strength of the skin.
<i>Lactococcus</i> ferment extract Yeast cytolytic extract	Lotion	Enhance wrinkles, unwind, and keep skin looking young.

Probiotics in the agricultural industry

Modern agricultural practices have adversely affected soil ecosystems through intensive tillage and the use of commercial fertilizers and chemical pesticides. Microorganisms break down organic and inorganic waste in soil through bioremediation. Fungi are dominant species in soil ecosystems and remove carbon sources and bioabsorbable heavy metals from contaminated soils (43). Heavy metals are nondegradable compounds that persist in numerous organic and inorganic forms. Some heavy metals, such as Fe, Cu, and Zn, are essential trace elements, whereas others, such as cadmium, lead, and mercury, are toxic even at trace levels. The accumulation of heavy metals in human organs adversely affects human health (44). The use of heavy metals in various industries, particularly agriculture, can release them into the soil, air, and water. When humans ingest food or water contaminated with heavy metals, the acidic gastric environment acidifies these metals. They are subsequently oxidized to various oxidation states. These radicals can bind to different molecules in biological systems, such as proteins and enzymes, forming strong, stable bonds (45). Probiotics have been reported to adhere strongly to the intestinal mucosa, exhibit strong antioxidant and immunoregulatory activity, tolerate gastrointestinal fluids, and suppress pathogen growth (46). In one study, a group of rats was poisoned with aluminum. Treatment with *Saccharomyces boulardii* and selenium-enriched *Saccharomyces boulardii* reduced the disorders caused by aluminum poisoning. Consequently, total iron-binding capacity and total antioxidant capacity returned to normal levels. In this study, the decrease in malondialdehyde concentration suggested that strengthening the antioxidant system with the probiotic treatment probably prevented an increase in oxidative stress in this group of rats (47). Previous studies indicate that the negative charge on probiotic cell walls can bind positively charged heavy metals and remove them from the environment. Accordingly, several studies have evaluated the possibility of removing heavy metals from living organisms. The kidneys are among the most important organs involved in heavy-metal excretion. In research conducted by Fatemi et al., numerous abnormalities were observed in hematological factors, histopathological findings, and kidney function parameters, including uric acid, creatinine, and urea. Analyses of antioxidant factors also showed disturbances in catalase and glutathione peroxidase activities and glutathione concentrations, indicating increased oxidative stress caused solely by lead poisoning. After treatment of the poisoned rats with *Lactobacillus fermentum*, improvements in kidney tissue structure and the measured factors were evident. After observing decreased blood lead levels and increased fecal lead levels in the group of mice treated with probiotics, the researchers suggested that lead binding to probiotic cell walls may have helped remove lead from the animals' bodies (48,49).

Conclusion

Probiotics help regulate the intestinal microbiome by strengthening innate and adaptive immunity through the production of antioxidant and anti-inflammatory compounds and the competitive elimination of pathogens. An imbalance in the intestinal flora contributes to a wide range of diseases, from digestive disorders to cancer. Consequently, substantial research has examined the effects of probiotics on human health in medicine and various industries, including the food and pharmaceutical industries. The principal challenge in these fields has been the instability and sensitivity of these microorganisms to heat and pH. Currently, the most widely used method of protecting probiotics is their encapsulation in biopolymers, such as whey protein, gum Arabic, soybean protein, alginates, and chitosan, to form microcapsules.

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Ethical Statement

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Conflicts of Interest

The authors report no conflicts of interest.

Author Contributions

Mahnoosh Fatemi contributed to the conception of the manuscript; all authors performed the literature search and critically revised the work. Mahnoosh Fatemi edited the final draft.

Data Availability Statement

Not applicable.

Use of Artificial Intelligence

No artificial intelligence (AI) tools were used in the preparation of this manuscript.

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