The Role of Probiotic and Prebiotics in Maintaining Skin Microbiome: A Dermatological Approach

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Abstract

The skin microbiome harbors various microorganisms and plays a vital part in maintaining skin health with its resilience and homeostasis. It starts from birth and evolves throughout life, playing a vital role in protecting against pathogens and regulating the immune system. Probiotics are live microorganisms primarily belonging to the *Lactobacillus* and *Bifidobacterium* genera. It offers promising alternatives for preventing inflammatory skin conditions, combating aging, moisturizing, and supporting dermatological care. Prebiotics increase hydration, suppleness, and the general health of the skin by feeding beneficial bacteria and creating a thriving microbial ecosystem. The dynamic connection between the skin microbiome and its host is critical and central to driving innovation in microbiome-based cosmetics. The condition and appearance of skin greatly influence self-esteem, underscoring a comprehensive, holistic approach to encountering environmental and intrinsic factors. These are widely used in skincare for restoring skin balance, repairing tissue, antiaging, skin brightening, photoprotection, and treating skin conditions like acne, dermatitis, itching, psoriasis, and eczema. These offer a more sustainable, eco-friendly, biodegradable, nontoxic, and natural alternative to conventional products used in cosmetics. Further investigation and integration of these products with advanced nanotechnology will pave the way for their viable therapeutic potential.

Keywords: Resilience, Homeostasis, Pathogens, Eco-friendly, Nontoxic

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Introduction

Human skin serves as a protective barrier while supporting a broad range of microbiomes, including bacteria, fungi, and viruses, most of which are harmless and contribute to skin health and homeostasis. Although some microbes are pathogenic play a role in causing many infectious conditions while many have a valuable role in health, medicine, and environmental processes. Many site-specific factors such as temperature, moisture, sebum content, and pH influence the composition of the skin microbiome (Oh et al., 2016; Callewaert et al., 2020). The diverse microbes thrive in the dynamic and complex environment of the skin, also referred to as the skin microbiota (Chen et al., 2018). The diversity of skin microbiota could be more extensive than the gut (Boxberger et al., 2021). This variation is owed to diverse anatomical regions of skin that influence the microbial composition as revealed by 16S rRNA gene phylotyping. These microbes interact with the skin, influencing its barrier function (Schommer & Gallo, 2013).

In humans, an infant's skin microbiome rapidly colonizes after its birth but is initially dominated by *staphylococci*. Microbial diversity increases by the end of the first year, resulting in a decline of the *staphylococci* population ensuring a more balanced microbial community. Firmicutes are more prevalent in infants as compared to adults which establishes a healthy microbiome that is crucial for immune function and long-term skin health (Capone et al., 2011). Coagulase-negative *staphylococci* that abundantly thrive on human skin, regulated by the epidermal barrier and immune system within skin layers. Certain species of these microbes produce viable products that support host immunity offering targeted anti-inflammatory, antimicrobial, and antineoplastic potential while boosting both innate and adaptive immunity (Nakatsuji et al., 2021).

The health and appearance of skin significantly impact self-esteem and self-confidence. Disruption or imbalance of the skin microbiome accelerates the aging process, underscoring the importance of maintaining the balance of skin microbiome for youthful skin. To mitigate the harmful impact of various environmental stressors and intrinsic factors, a holistic and tailored strategy is essential. This approach involves lifestyle changes, and customized skin care products using natural ingredients and methods to improve the skin's natural defense, leading to a more sustainable and effective method for maintaining skin aging (Khmaladze et al., 2020).

1.1 Composition of Skin Microbiome

The skin microbiome is made up of many different kinds of microbes that are very important for many metabolic processes such as lipid metabolism, protecting against transient organisms, and regulating immunological balance (Grice, 2015). It includes nearly 19 bacterial phyla, such as Actinobacteria (51.8%), Firmicutes (24.4%), Proteobacteria (16.5%), and Bacteroidetes (6.3%), which are members of the *Staphylococcus, Propionibacterium,* and *Corynebacterium* genera. Other microorganisms that contribute to the skin microbiome include viruses, mites, and fungi. More than 90% of fungal populations are of the Malassezia species (e.g., *M. globosa, M. restricta,* and *M. sympodialis*) that predominate in sebum-rich settings whereas Demodex mites live in lipid-rich environments like sebaceous glands and hair follicles (Findley et al., 2013; Balato et al., 2019)

Its composition varies widely and is influenced by host-specific factors, including demographic variability and site-specific physiological conditions, as well as extrinsic factors, including skincare regimes and lifestyles. For example, in the forehead (oily region) with more sebum production, lipophilic microbes are supported. While in dry regions, i.e., the forearm harbor, diverse communities of microbes reside there (Oh et al., 2014).

There are a lot of external factors, such as medication, age and exposure to skincare products, that shape microbial composition as Figure 1 demonstrates The compound, like N-acetylglucosamine, present in many skin care products alters the microbiome by affecting skin properties and also influences pathways like hyaluronic acid biosynthesis pathways and UV-induced aging (Dimitriu et al., 2019). The diversity and distribution of bacteria in the skin microbiome are altered by aging and an array of skin disorders, including dermatitis, acne and rosacea (Howard et al., 2022).

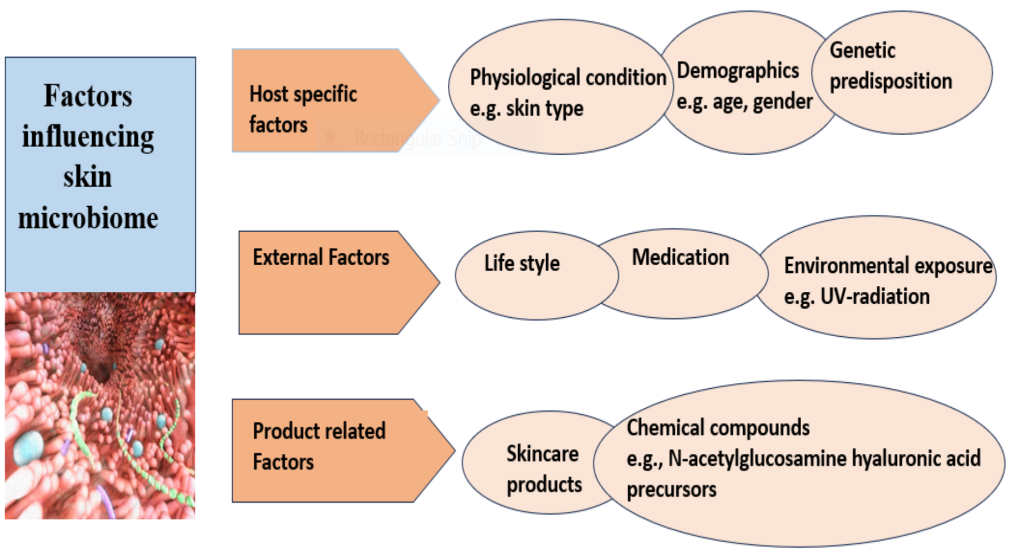

Fig. 1: Factors that influence the composition of skin microbiome (Retrieved from Biorender)

1.2 Mechanism of Action of Skin Microbiome

Microbes that inhabit the skin influence the immune system through various mechanisms.
Staphylococcus epidermidis colonization during the neonatal period promotes immune tolerance by accumulating commensal-specific regulatory T cells which play a crucial role in maintaining immune homeostasis in epithelial tissue; in this way it promotes immunological activity (Scharschmidt et al., 2015; Nakatsuji et al., 2021). *Corynebacterium acnes* produces short-chain free fatty acids, which regulate immune tolerance by inhibition of histone deacetylase activity. The *S. epidermidis* inhibits overactivation of proinflammatory signaling, resulting in controlled wound repair by production of lipoteichoic acid. These microbes also produce lipopeptides that promote the production of antimicrobial peptides in mast cells and keratinocytes, bolstering not only host innate immunity but also providing protection against pathogen infection (Lee & Kim, 2022). *S. epidermidis* acts as physical barrier as it secretes sphingomyelinase which produces ceramide, a vital component of epithelial layer that prevents dehydration and cellular aging. These microbes not only enhance barrier integrity but also play a key role in wound healing. In response to skin damages these microbial metabolites activate AHR (aryl hydrocarbon receptor) that promotes cellular differentiation and adhesion, resulting in restoring skin barrier function (Lewis et al., 2019).

1.3 Probiotics: The Friendly Microbes

In the age of functional foods, probiotics whether in the form of food products or supplements have become the most popular component. Werner Kollath coined the term "probiotic" in 1953. It is derived from the Latin word "pro" and the Greek word "βιο", which means "for life". According to Kollath the probiotics are active substances that play crucial roles in maintaining a number of health aspects (Latif et al., 2023).

Probiotic bacteria have been used in recent years to alter the microbiome for therapeutic purposes and fend off illnesses that endanger the health of both humans and animals. These bacteria have the capacity to colonize the intestine and compete with pathogenic microorganisms (Stavropoulou & Bezirtzoglou, 2020). Probiotics are primarily described as belonging to the genera *Lactobacillus* and *Bifidobacterium* among others. Figure 2 illustrates the key probiotic strains. The primary ways that probiotics work are through improving the function of the mucosal barrier, directly opposing infections, preventing bacterial adhesion and invasion of the intestinal epithelium, strengthening the immune system and regulating the central nervous system (Mazziotta et al., 2023).

It has been reviewed by (Chugh & Kamal-Eldin, 2020), bioactive constituents of probiotics and probiotic food supplements have the ability to synthesize various metabolites that exhibit promising health benefits. Evidence from literature shows that these bacteria synthesize a broad spectrum of bioactive compounds that including short-chain fatty acids (SCFAs), bacteriocins, antioxidants, vitamins, peptides, metabolic enzymes, amino acids, and exopolysaccharides with anti-inflammatory and immunomodulatory agents (Ali et al., 2022).

The efficacy of probiotics depends upon viability, dosage, stability in the acidic environment of the stomach and metabolic stability in food matrices. This is critical, as many microbial cells lose viability during GI transit and storage (Gu et al., 2022).

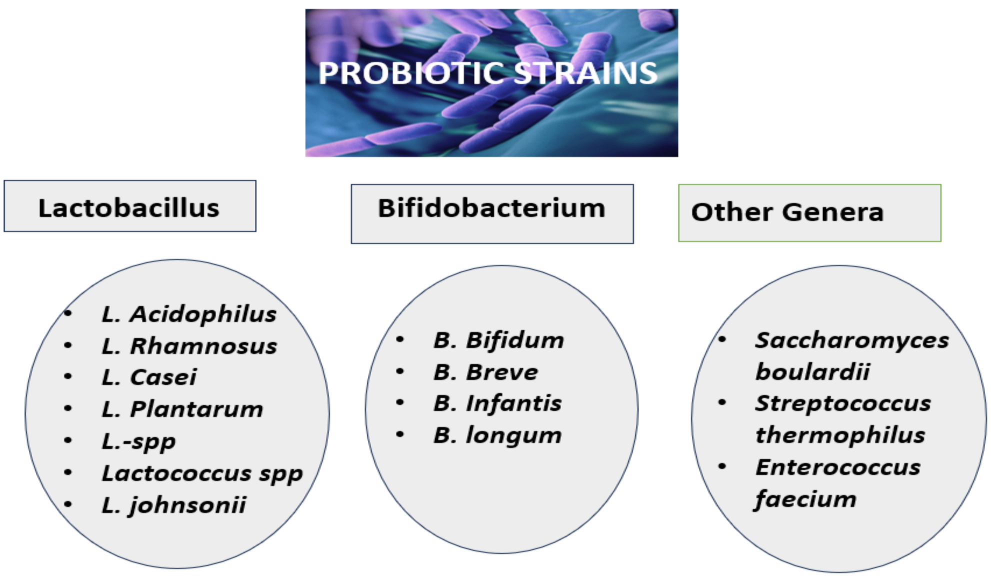

Fig. 2: General classes of Probiotic Strains (Retrieved from Biorender).

In the global market, probiotics are mostly found in three main categories: dietary supplements, foods and medications. Probiotic product quality might fluctuate greatly between product categories and geographical areas (Jan et al., 2023). Inulin, galactofructose, oligofructose, galacto-oligosaccharides (GOS) and xylo-oligosaccharides are examples of short polysaccharides or oligosaccharides that are not digestible carbohydrates that are commonly found in probiotics (Manzoor et al., 2022). Probiotics play a vital role in maintaining overall health, enhancing the digestive process, reducing the risk of toxins, improving gut health, suppressing harmful bacteria and providing defense against various illnesses. Its promising role has been reported in some conditions, including diarrhea, lactose intolerance and inflammatory bowel disease (IBD), malabsorption, allergies and necrotizing enterocolitis (Yousefi et al., 2019). These are widely used in many fields, especially cosmetic products containing probiotics that are now available under a strict regulatory framework to ensure optimum levels of microbes for product safety (Peng et al., 2020). Figure 3 depicts natural probiotic sources.

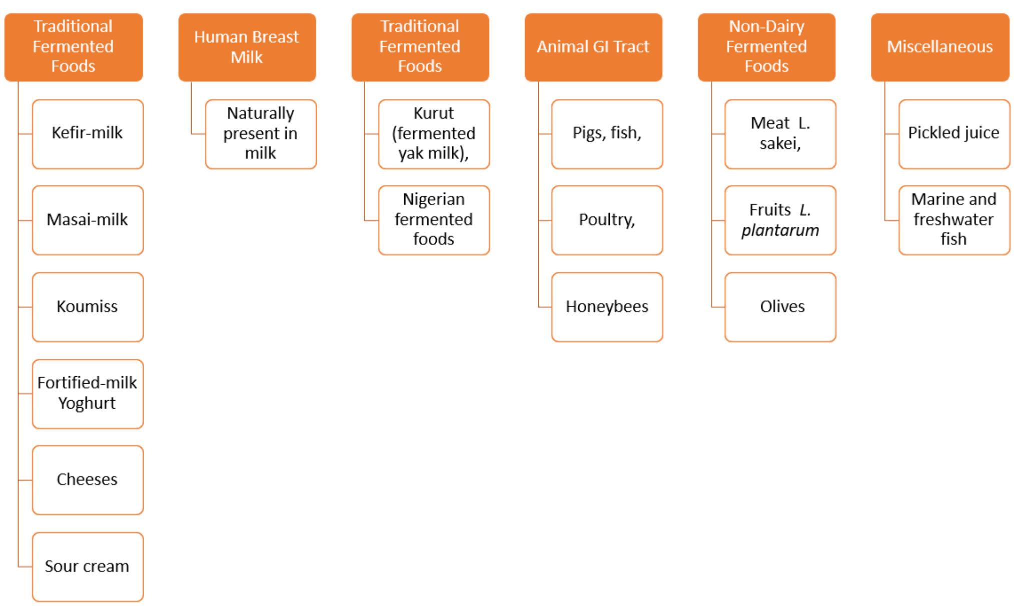

Fig. 3: Fundamental Natural sources of Probiotics (Retrieved from Biorender).

1.3.1 Role of Probiotics in Dermatology

Probiotics play a vital role in improving the skin's barrier function by strengthening the connections between skin cells and accelerating skin renewal. By replenishing the skin microbiome with beneficial microorganism's probiotics help maintain a balanced micro-ecological environment. This reduces trans-epidermal water loss, enhances skin hydration and promotes healthier, more resilient skin (Yu et al., 2022).

Probiotic use for skin care and improvement is a compelling substitute for inflammatory disease prevention and skin issues. Non-oral topical probiotic products are designed to speed up and enhance skin health, help with skin-related problems (atopic dermatitis (AD), psoriasis, rosacea, acne and wounds), improve the appearance of skin (anti-wrinkles, antiaging, moisturizing and skin treatment) or prevent dermatological problems (Vargason & Anselmo, 2021; Gao et al., 2023).

Human skin is frequently exposed to external factors that can cause skin damage and imbalance in gut microbiome. The gut-skin axis, influenced by factors like diet, UVB radiation and local allergens that is critical in maintaining skin health. So, probiotics serve as a natural remedy for strengthening the skin microbiome (De Pessemier et al., 2021; Shirkhan et al., 2024).

These living microorganisms act as promising anti-aging agents, whether applied topically or taken orally. Oral probiotics enhance skin resilience by modulating gut microbiome, enhancing immune response, reducing inflammatory cytokines, and increasing SCFAs levels with provision and protection against photoaging. Topical probiotics restore the skin microbiome, reduce oxidative stress and support treatments of skin disorders rosacea and dermatitis (Patra et al., 2020; Teng et al., 2022). Additionally, these microbes act as a promising alternative to antibiotics for the treatment of chronic inflammatory skin disorders and are highly protective against various pathogens like *Staphylococcus aureus* and *Pseudomonas aeruginosa,* which form antibiotic-resistant biofilms (Rawal & Ali, 2023). Topical probiotics are considered safe with fewer side effects as compared to conventional skin treatment (Habeebuddin et al., 2022).

Studies on the beneficial effects of probiotics on skin health indicate that supplementation with *Lactococcus lactis* H61 for eight consecutive weeks improved skin elasticity, hydration and the condition of hair follicles in middle-aged women. Similar outcomes have been reported by oral intake of probiotics *Lactobacillus plantarum* HY7714 strain in subjects aged 41-59, enhancing skin moisture content, improving gloss and elasticity and reducing wrinkle depth. Furthermore, administration of *Lactobacillus reuteri* for 12 weeks not only increased melanin production but also reduced trans-epidermal water loss. Other probiotics, including the *Bifidobacterium breve* strain Yakult, *L. lactis*, *L. rhamnosus* and *Streptococcus thermophilus,* have reportedly similar potential, including improved skin hydration, skin barrier function, and reduced toxic by-products formed by gut bacteria (Lee et al., 2018; Lolou & Panayiotidis, 2019).

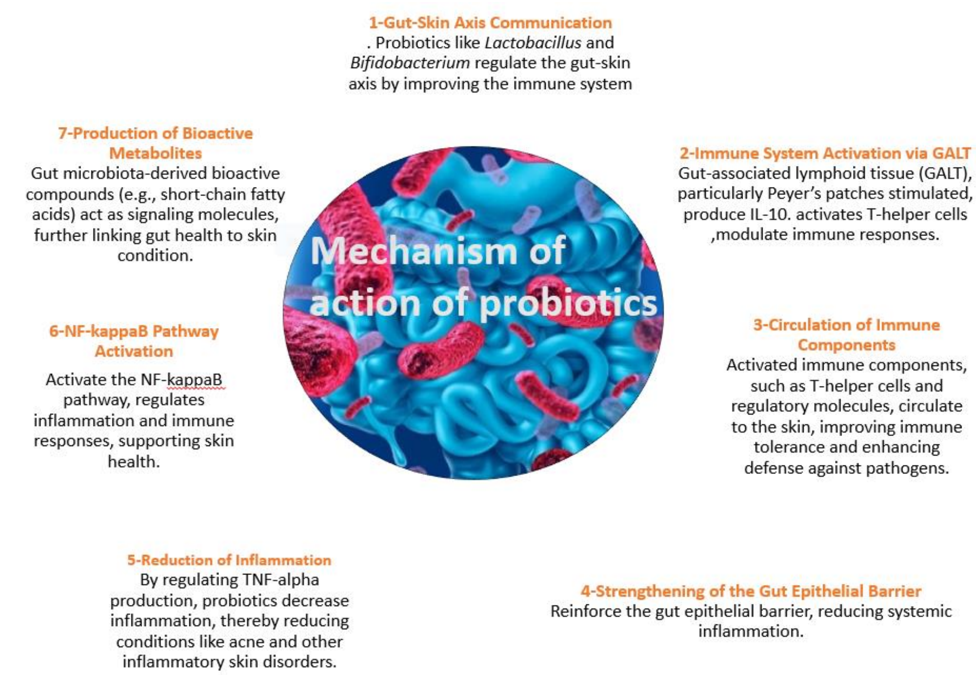

Fig. 4: Mechanism of action of probiotics (Retrieved from Biorender).

1.3.2 Mechanism of Action of Probiotics

The human skin harbors over 1000 bacterial species primarily commensals, contributing to microbiome balance and preventing pathogen colonization (Yu et al., 2020). Probiotics have gained attention for their potential to modulate the skin microbiome indirectly via the gut axis in gut-targeted probiotics, promoting healthier skin by combating inflammation and dryness (McLoughlin et al., 2022). These also support skin health by producing antimicrobial compounds, preventing pathogen adherence and offering a natural approach to acne and many other skin conditions via topical or oral administration (Cristofori et al., 2021; Sharma et al., 2022). Their antimicrobial and anti-inflammatory potential has been validated in many in vitro analyses using *Lactobacillus* species, *Bifidobacterium adolescentis* and *Streptococcus salivarius* strains that results in reduced inflammation and the effects become more pronounced when used in combination with other drugs or antibiotics (Deng et al., 2018; Sánchez-Pellicer et al., 2022). Another probiotic strain, *L. plantarum*-GMNL6, has reportedly enhanced collagen production stimulated by the gene expression of SPTSSA, which is a key enzyme in ceramide biosynthesis, promoting skin rejuvenation by increasing moisture content and lipid integrity (Tsai et al., 2021).

Most probiotics enhance skin health by modulating gut-skin communication and activating T helper cells. These mainly strengthen the gut epithelial barrier, reducing inflammation by activating the NF-kappa B pathway through TNF alpha production as presented in Figure 4 (Szántó et al., 2019).

1.4 Prebiotics

As per the International Society of Prebiotics and Probiotics (ISAPP) "dietary prebiotics" are "selectively fermented ingredients that change the composition and/or activity of the gastrointestinal microbiota in ways that are beneficial for host health" (Gibson et al., 2010; Davani-Davari et al., 2019). This leads to the promotion of the growth of beneficial bacteria. Inulin, fructo-oligosaccharides, and GOS are generally accepted prebiotics.

As a functional food component, these are found in various fruits and vegetables naturally with notable technological benefits. Table 1 elucidates the natural vegetable and food as source of prebiotics. The integration of prebiotics into various foods and beverages, i.e., dairy products, cereals and bread allows the consumer not only to enjoy favorable food with reaping health benefits. These are reported to improve colon health by increasing minerals (calcium and magnesium) absorption, preventing obesity and constipation and reducing the risk of cancer (Al-Sheraji et al., 2013). Additionally, these support starter culture formulation, positively regulating the immune system, which makes them highly sought after by food as well as pharmaceutical industries (Figure: 5)(Rolim, 2015).

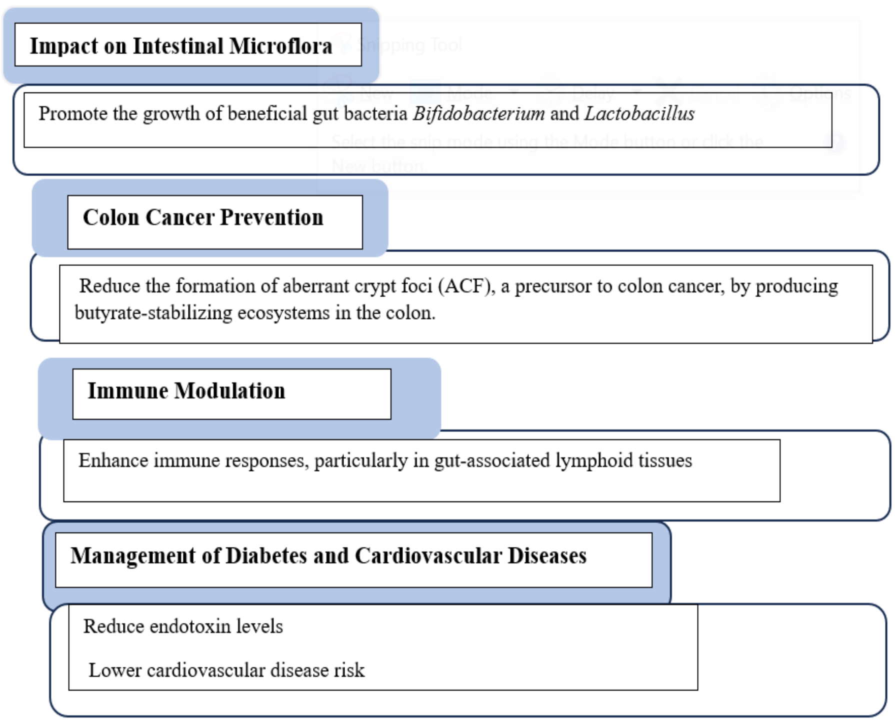

Fig. 5: Therapeutic potential of prebiotics (Retrieved from Biorender).

1.4.1 Mechanism of Action of Prebiotics

Prebiotics influence the host's health through two primary mechanisms: indirect and direct actions. In the indirect mechanism, prebiotics that serve as fermentable substrates for gut-specific commensal bacteria promote the growth of beneficial taxa, including *Bifidobacteria* and *Lactobacilli.* These microbes modulate gut microbiota, which results in increased production of SCFAs, such as acetate, butyrate, and propionate, that improve host health by inhibiting the proliferation of pathogenic bacteria (C. difficile), strengthen gut barriers by reducing pathogen translocation, modulate cellular activities via G-protein-coupled receptors, and support various metabolic pathways. While in direct mechanisms, prebiotics act directly on gut compartments and host cells, including epithelial and immune cells. These stimulate the production of anti-inflammatory cytokines IL-10 by specific bacteria*, Faecalibacterium prausnitzii* and *Eubacterium eligens,* that modulate gene expression, differentiation, and apoptosis through SCFA-induced signaling pathways including AMPK, MAPK, mTOR, STAT3, and NFκB. Prebiotics are essential for preserving intestinal and systemic health because they improve gut flora and stimulate the generation of SCFA(Brosseau et al., 2019).

1.4.2 Role of Prebiotic in Dermatology

Prebiotics such as GOS serve as selective substrates for beneficial bacteria particularly those belonging to Bifidobacterium and Lactobacillus species stimulating their growth to enhance host health. These live microbes release bioactive molecules that activate key signaling pathways, including NF-κB (nuclear factor kappa-light-chain-enhancer of activated B cells) and MAPK (mitogen-activated protein kinase) pathways. Both these pathways modulate immune response by maintaining skin homeostasis. These have demonstrated potential benefits in managing skin conditions like acne, rosacea and apoptotic dermatitis (Ramsey et al., 2016; Maguire & Maguire, 2017).

Another study on prebiotic oligosaccharides (e.g., FOS, GOS) has demonstrated their protective potential against AD, particularly in the infants. It is reported that supplementation of prebiotics in formula-fed infants has declined the prevalence of AD and its long-term benefits have been observed up to 5 years of age (Jun et al., 2017; Lee et al., 2021). In psoriasis treatments (chronic inflammatory skin disease), pre- and probiotics supplementation along with anti-psoriatic drugs showed promising outcomes (Buhaș et al., 2023). These also play crucial role in managing skin allergies particularly eczema (Wopereis et al., 2018).

Table 1: Natural Source of Prebiotics and their Health Impact

Source of Prebiotic	Type of Prebiotic	Health Impact	Key Components	Role in Skin Health	References
Asparagus	Inulin FOS	Enhance-SCFA production, improve gut health.	Soluble dietary fiber	Supports skin barrier function and hydration.	(Bishnoi, 2016)
Chicory Root	Inulin	Enhances mineral absorption, intestinal regularity Proliferation-of bifidobacteria.	Soluble dietary fiber	Improve skin elasticity and reduce redness.	
Garlic	Inulin FOS	Reduce inflammation	Non-digestible carbohydrates	Potential anti-inflammatory agent	
Onions	Inulin FOS	Improves mineral absorption, promotes bifidobacteria.	Non-digestible carbohydrates	Reducing inflammation. Skin brightening	(Bhawana & Neetu, 2015)
Leeks	Inulin	supports digestive health	Soluble dietary fiber	enhances the gut-skin axis to promote skin health.	
Bananas	FOS, Inulin	Boosts bifidobacteria activity improves digestive health.	Soluble dietary fiber	skin hydration.	
Barley	Beta-glucan	Lowers cholesterol, promotes healthy gut bacteria.	Soluble fiber	Enhance skin moisture content	(Otles & Nakilcioglu-Tas, 2022)
Oats	Beta-glucan	Supports gut health, reduces LDL cholesterol.	Soluble fiber	soothing skin improving moisture retention.	
Flaxseeds	Mucilage	Promotes gut health, improves bowel regularity.	Soluble fiber	Skin hydration and reduces inflammation.	
Seaweed	Inulin	Supports gut health	Prebiotic fiber	skin hydration and elasticity.	(Pierezan et al., 2024)

1.5 Probiotics and Prebiotics Cosmeceuticals

Cosmetics products are used to clean, beautify or change the overall appearance of the human body (Hill et al., 2014). Probiotics and prebiotics play essential roles in cosmetics. Prebiotics alter the microbiota of the skin (Simmering & Breves, 2010), whereas probiotics use live microorganisms or usually inactivated microbial biomass to stimulate the skin's natural antimicrobial peptide, which has been suggested to play a role in skin disorders like acne and seborrhea since 1912. Probiotics have now been used in many common care products, including moisturizers, face creams, body washes, beauty masks and tonics. These products contain constituents of cell walls and inert bacteria. Probiotic-based skin care products are gaining popularity that are driven by positive outcomes and the reliance and trust of consumers on natural products instead of synthetic ones (Arora et al., 2024). Several companies are using prebiotics in skin care products in order to support the growth of live probiotics and prevent microbes from readjusting the makeup of the skin microbiome (Dou et al., 2023). Regular consumption of fermented dairy food not only improves skin's natural barrier, reduces skin wrinkles and acne, but also improves its cosmetic appearance and function. It is reported that oral administration of GOS 2g/day improved skin hydration and reduced wrinkles by reducing the trans epidermal water loss (Hong et al., 2020).

Prebiotics and probiotics have wide applications in cosmetics:

- Restoring the balance of sensitive skin
- Repairing and regenerating skin tissues
- Acting as an anti-aging product
- Acting as skin whitening and brightening agent
- Acting as skin's photoprotector
- Treating acne
- Treating itching

The sensitive skin characterized by disrupted skin barrier and neurogenic inflammation could be alleviated by microbiome-targeted ingredients (Fluhr et al., 2024). Recent studies highlight that using a lotion containing fermented lysates of *Lacticasei bacillus* and *L. paracasei* has improved skin hydration and reduced skin sensitivity. Similarly, *Bifidobacterium longum* lysate has reduced neurogenic inflammation and bolstered the skin barrier in a randomized controlled trial (Cui et al., 2023).

Both oral and topical probiotics have been reported to play a promising role in skin tissue regeneration (Canchy et al., 2023). Topical administration of probiotics *L. plantarum*, *Lactobacillus bulgaricus*, and *Bifidobacterium longum* in animal models has accelerated wound healing by enhancing re-epithelialization and reducing inflammation (Mohtashami et al., 2021). While oral intake of probiotics, including *L. delbrueckii*, *Lactobacillus fermentum*, and *Bifidobacterium bifidum*, has demonstrated improved healing in burns and ulcers, reducing the grafting needs and enhancing the chances of recovery in clinical trials (Mohseni et al., 2018). Studies on antiaging potential showed that *Epidermidibacterium keratini* EPI-7 ferment filtrate has been reported to enhance the skin's hydration and elasticity in women aged 19-69. While oral intake of lysate of *Lactobacillus plantarum* increases hyaluronic acid and reduces wrinkles (Kim et al., 2023).

Lactobacillus plantarum GT-17F along with *Dendrobium officinale* extracts restored the function of the epidermal barrier, diminished damage to barrier proteins, and blocked UV-mediated collagen degradation (Dou et al., 2023). After eight weeks of ingestion, prebiotic GOS decreased melanin and erythema indices and inhibited melanin in cell investigations, resulting in skin brightening and lightening. During acne treatments, extracts from *Vitreoscilla filiformis* reduce inflammation and promote microbial equilibrium. The severity of apoptotic dermatitis has been diminished by bacterial extracts from *Lactobacillus johnsonii, Streptococcus thermophilus*, and *Vitreoscilla filiformis*. These findings suggest that microbiome-based dermatocosmetics hold potential for addressing many skin conditions (Han & Kim, 2024).

1.6 Perspective on Sustainable Development Goals (SDGs)

Sustainable developmental goals (SDGs) are a set of globally accepted sustainable objectives and targets that are intended to implement predetermined agendas and policies. In the context of the integration of prebiotic and probiotic cosmetics, these serve to align with several SDG goals, including SDG 3 (Good Health and Well-being), SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). Various studies have indicated microbial or fermented food results in healthy gut microbiota, and it also supports dietary intervention and contributes to significant progress toward 2030 SDGs targets (Ballet et al., 2023). Prebiotics also contribute to global health by promoting sustainable agricultural practices, reducing reliance on synthetic additives and encouraging eco-friendly practices. Reliance on natural, renewable, and biodegradable sources results in decreasing carbon footprints and greenhouse gas emissions and results in a more sustainable environment (Houngbédji et al., 2024).

1.7 Perspective on Holistic Health Approach

Both prebiotics and probiotics have gained popularity as vital components in dermatology that emphasize a holistic approach to skin health. This approach suggests skin as a part of the body defense system, a large interconnected system in which the gut-skin axis plays a pivotal role. Prebiotics foster the beneficial bacteria and probiotics introduce live microbes, which collectively contribute to restoring the skin microbiome balance, thus enhancing skin health, function, and overall well-being. Several studies have revealed their efficacy in many skin conditions like acne, rosacea, eczema, and skin sensitivity by mitigating inflammation, restoring the immune system and strengthening the skin. This holistic dermatological approach also aligns with more sustainable and synergetic health practices, offering nontoxic and noninvasive alternatives to conventional treatment. These foster a synergy between skin health and gut axis by addressing intrinsic and extrinsic factors that contribute to radiant, resilient, brighter and healthier skin (Bhatt et al., 2024).

1.8 Current Challenges

The modulation of skin microbiota is definitely a promising strategy in skincare and managing skin disorders, but the integration of prebiotics and probiotics still has some challenges. In cosmetics, defining the benefits of prebiotics is challenging. Further research is required to acquire optimal dosage; the full response of the skin microbiome to probiotics is still not clear. A major challenge in using probiotics is to ensure their survival in skincare products, which require encapsulation techniques that improve their viability. For this purpose, the selection of suitable material, particle size, and development of effective coating are significant. Its efficacy is highly influenced by the type of strain, mode of application, duration of use, environmental factors, and exposure to clothing. Transparency in product information is still another concern, and regulatory framework is essential to ensure product efficacy and safety (Chauhan & Kumar, 2023).

1.9 Future Prospects

In dermatology, cosmetics and skin microbiome science, prebiotics and probiotics hold promising futures. With the rising focus on regulation of skin microbiomes, these live microorganisms and bioactive compounds are destined to redefine dermatological practices and emphasize more sustainable, eco-friendly, natural, non-toxic and more personalized solutions. Probiotics not only show great efficacy in treating chronic skin disorders but also play a significant role in modulating inflammatory pathways, enhancing skin barrier function and hydration and paving the way for their integration into advanced therapeutic treatment. Prebiotics not only foster beneficial bacteria but also prevent dysbiosis-driven skin disorders. In cosmetics, these infused formulations are becoming the cornerstone of biocompatible skincare. These products are not only designed to rejuvenate the skin but also act as anti-aging, antimicrobial and anti-inflammatory agents and serve as effective agents in skin whitening and UV protection. The gut-skin axis, where systemic and skin-specific health interact critically it is another area highlighted by the holistic health approach, and it also aligns with SDGs. The integration of nanotechnology is anticipated to enhance product safety, efficacy and stability that meet consumer demand and provide them with sustainable skincare (Alemzadeh & Oryan, 2020 ; Tran & Li, 2022; Zhang et al., 2022).

Conclusion

The revolutionary step toward healthier skin is provided by the integration of probiotics and prebiotics in dermatology, and more specifically in cosmetics. The fostering of microorganisms rejuvenates the skin by modulating the microbiome, enhancing immune response, and bridging towards more sustainable and holistic skin formulations. Probiotics offer targeted anti-inflammatory and antimicrobial responses, and prebiotics prevent dysbiosis-related issues, both collectively addressing skin-related disorders, itching, acne, dermatitis, and UV protection. Their holistic impact extends to systemic benefits via the gut-skin axis. These innovations not only address skin conditions like aging, eczema, and rosacea but also provide sustainable and eco-friendly alternatives, aligning with SDGs. Although challenges regarding its implication, regulation, and stability persist, advancements in biotechnology are poised to refine these products, ensuring broader stability and efficacy. It would undoubtedly become the forefront of personalized and sustainable skincare with further investigation on its applicability, advancing the transition to natural, nontoxic, sustainable, and noninvasive formulations.

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