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Natural Strains Producing Unique Bioactive Ingredients and Their Applications in Skincare

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ABSTRACT
With growing insights into the skin microbiome and advances in biotechnology, the application of natural bacterial strains as active ingredients in skincare products is gaining increasing recognition. This article provides a comprehensive review of naturally derived microbial strains from specific environments, focusing on the diverse benefits of their unique bioactive compounds for maintaining skin health. It elaborates on how these strains contribute to skincare by modulating the skin's microbial balance, strengthening the skin barrier, inhibiting pathogenic bacteria, and promoting collagen synthesis. The use of cutting-edge technologies such as fermentation engineering and synthetic biology for efficiently producing these bioactive substances is also discussed. Furthermore, the paper addresses current challenges in strain selection, safety evaluation, and industrial-scale production, while offering perspectives on future developments, aiming to support both scientific research and practical applications in this field.

KEYWORDS
Natural strain; Active ingredient; Skincare

1 Introduction

The surface of human skin hosts a complex and diverse microbial community, collectively forming the skin's micro-ecosystem. Under healthy conditions, a dynamic equilibrium exists between these skin microbes and their host, playing a crucial role in protecting against pathogen invasion, modulating immune responses, and maintaining the integrity of the skin's physical barrier. However, modern lifestyles, environmental stressors, and improper skincare practices can easily disrupt this balance, leading to various issues such as sensitive skin, inflammation, and premature aging. Conventional skincare products typically focus on addressing specific skin concerns using synthetic chemicals or plant extracts, which may come with drawbacks including irritation, environmental impact, or limited efficacy. In recent years, leveraging natural bacterial strains to regulate the skin's microbiome has emerged as a promising strategy for comprehensive skin health management. These naturally derived strains, originating from unique ecological niches, are capable of producing a wide range of bioactive compounds—such as antioxidant enzymes, antimicrobial peptides, and polysaccharides—offering rich potential for developing next-generation skincare solutions that are both highly effective and safe [1]. This article provides a systematic exploration of the innovative applications and mechanisms of action of natural microbial strains producing special active substances in skincare products, along with the challenges they face and future development trends.

2 Diversity of Natural Strains and Their Bioactive Ingredients

In nature, especially in extreme environments such as volcanic vents, hot springs, glaciers, and saline-alkaline lands, a wide range of microorganisms with unique physiological functions and metabolic products can be found. Strains capable of surviving these harsh conditions may produce certain bioactive compounds that help sustain their life processes. These natural microbes and their metabolites have become valuable sources of functional ingredients in cosmetics. For instance, Galactomyces (a yeast-like organism) produces enzymes such as galactosidase, known for its skin-repairing properties, and has been incorporated into SK-II products. Sphingomonas species generate carotenoids with antioxidant effects, and are used in the third-generation serum of L'Oréal's Youth Code line. Bifidobacterium produces reduced glutathione and superoxide dismutase (SOD) [2], which help neutralize free radicals, offering anti-aging and restorative benefits, and is featured in Estée Lauder's Advanced Night Repair serum.

3 Skincare Mechanisms of Active Ingredients Derived from Natural Strains

3.1 Balancing the Skin Microbiome

The skin serves not only as a physical barrier for the human body but also as a dynamic ecosystem teeming with billions of microorganisms—the skin microbiome. Maintaining balance within this ecosystem is essential for healthy skin.

When harmful bacteria proliferate and beneficial microbes decline, microbial imbalance can trigger a range of issues such as dryness, sensitivity, and acne. In recent years, leveraging bioactive compounds derived from natural microbial fermentation to modulate the skin's microbiome has emerged as an innovative frontier in skincare. Rather than introducing live bacteria directly, these solutions harness fermentation byproducts from beneficial strains like lactic acid bacteria and yeast. Rich in amino acids, vitamins, polysaccharides, organic acids, and antimicrobial peptides, these natural ingredients work through a sophisticated mechanism: they nourish and support the growth and colonization of beneficial microbes on the skin's surface, thereby strengthening the skin's primary biological defense layer. For instance, certain probiotics produce prebiotics—substances that play a vital role in maintaining skin health and preventing various skin conditions. Incorporating prebiotics into skincare formulations and therapeutic strategies can significantly enhance overall efficacy [3]. On the other hand, the natural organic acids and antimicrobial peptides they contain selectively inhibit the overgrowth of harmful bacteria (such as Propionibacterium acnes and Staphylococcus aureus), creating a mildly acidic environment that is unfavorable for pathogenic microbes. Through this dual-action approach—supporting beneficial microbes while suppressing harmful ones—bioactive compounds from natural strains help restore microbial diversity and balance. The outcome goes beyond temporary soothing, offering long-term benefits by fundamentally strengthening the skin's resilience, improving barrier function, and promoting a healthy, robust, and naturally radiant complexion—advancing a deeper, more sustainable skincare philosophy.

3.2 Antioxidant Effects

Oxidative stress is a major contributor to skin aging. External aggressors such as UV radiation and pollution generate reactive oxygen species (ROS) that attack skin cells, leading to collagen degradation and lipid peroxidation—ultimately resulting in wrinkles, sagging, and dullness. Natural microbial strains are emerging as a promising new force in antioxidant defense. These beneficial microbes can produce endogenous antioxidant enzymes, such as superoxide dismutase (SOD) and glutathione peroxidase, which act like molecular scissors to directly break down and neutralize excess free radicals. In addition, they synthesize small-molecule antioxidants, including various organic acids, peptides, polysaccharides, and phenolic compounds. These molecules halt oxidative chain reactions by donating electrons to stabilize free radicals. Shao et al. found that the cell-free supernatant of *Cutibacterium acnes* strain CCSM0331 contains multiple short-chain fatty acids (SCFAs), glutathione peroxidase (GSH-Px), and total superoxide dismutase (T-SOD), all of which exhibit strong DPPH and ABTS radical-scavenging activity, demonstrating significant antioxidant potential [4].

3.3 Anti-inflammatory Effects

Skin inflammation lies at the heart of many dermatological concerns, with conditions such as allergies and acne closely linked to dysregulated inflammatory responses. Natural microbial active compounds offer a gentle yet highly effective solution for calming skin inflammation through a unique multi-target mechanism. These compounds work by directly suppressing key inflammatory signaling pathways—acting as "switches" to downregulate factors like NF-κB—thereby reducing the production of pro-inflammatory cytokines such as tumor necrosis factor (TNF-α) and interleukins (IL-1β, IL-6). This approach effectively dampens redness, heat, and swelling at their source. Additionally, these bioactive substances function as immune modulators. In cases where immune cells—such as Langerhans cells—are overactivated due to compromised barrier function or microbial imbalance, they help restore immune homeostasis, preventing exaggerated reactions to minor stimuli and thereby alleviating skin sensitivity. For instance, Hilaire et al. isolated a strain of *Sphingomonas xenophaga* whose fermentation extract was found to inhibit the generation of inflammatory vasoactive bradykinin. This highlights its potential in precisely targeting skin inflammatory pathways and improving vascular-related skin issues [5].

3.4 Skin Barrier Repair

A healthy skin barrier is the foundation for maintaining both internal skin health and external radiance. Its structure resembles a "brick-and-mortar" wall, where corneocytes act as the "bricks" and intercellular lipids serve as the "mortar" holding them together. When this barrier is compromised, the "wall" becomes unstable, leading to dryness, sensitivity, redness, and other issues. Natural microbial active ingredients can effectively restore this core structure from multiple angles. First, fermentation byproducts are rich in small-molecule nutrients such as amino acids and ceramide precursors. These components support corneocytes in producing essential structural proteins (like filaggrin) and accelerate the synthesis of intercellular lipids such as ceramides—strengthening the "brick-and-mortar" framework and minimizing moisture loss. Second, these bioactive compounds quickly calm micro-inflammation caused by barrier damage and reduce oxidative stress on repair cells, creating a stable, favorable environment for the skin's self-repair processes. Additionally, certain active ingredients can activate specific signaling pathways within skin cells, essentially sending an

"accelerate repair" signal that enhances the proliferation and differentiation of keratinocytes. This boosts the skin's intrinsic renewal capacity, driving the regeneration and reconstruction of the protective barrier from within [6].

3.5 Skin Brightening

Metabolites produced by natural microbial fermentation, such as organic acids and peptides, effectively suppress the activity of tyrosinase—the key enzyme responsible for melanin synthesis—thereby reducing the "production signals" at the source. Certain active ingredients interfere with the transfer of melanin, limiting its distribution to the epidermis and helping to prevent the appearance of dark spots. Additionally, some compounds promote normal keratinocyte turnover, accelerating the shedding of pigmented skin cells and supporting a more even, brighter complexion [7].

4 Conclusion

Natural microbial strains, serving as a treasure trove of bioactive compounds, hold immense and far-reaching potential in the skincare industry. By modulating the skin microbiome, offering antioxidant and anti-inflammatory benefits, and reinforcing the skin's barrier function, they provide innovative solutions for developing safe and highly effective products that address a wide range of skin concerns. These natural strains are driving a profound transformation in skincare, offering consumers worldwide a more scientific, health-oriented, and sustainable approach to beauty. Expanding investment and research in this field not only promises significant commercial opportunities but also plays a vital role in advancing global skin health.

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