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(Review Article)

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Formulation and assessment of a probiotic-infused anti-aging cream: Harnessing the synergy of prebiotics and probiotics for skin revitalization

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Abstract

Prebiotics, comprising natural (first generation) and generally modified (second generation) strains, play a crucial role in maintaining health. The gut and skin microbes influence immune balance, and disruptions can lead to dermatological disorders. While oral probiotics show promise in treating inflammatory skin conditions, research on topical probiotics remains limited. This review explores probiotics applications in dermatology, focusing on skin microbiome composition, common disorders, and emerging formulations, including probiotic-infused textiles. Lactic acid essential in food, pharmaceuticals, and bioplastics is predominantly produced by lactic acid bacteria. Lactobacillus sporangium, a promising yet understudied species, demonstrates high yield fermentation potential. This review examines its metabolic pathways, extraction methods, and industrial significance, highlighting the need for optimization in sustainable lactic production

Keywords: Probiotics; Skin microbiome; Topical probiotics; Lactic acid bacteria; Lactobacillus sporangium; Fermentation; Dermatology; Biotechnology

1. Introduction

Probiotics are living microorganisms that, when consumed in appropriate amounts, contribute to overall health and well-being. The naturally occurring strains are classified as first-generation probiotics, whereas genetically modified strains are considered second-generation probiotics. The role of microorganisms in human health was first recognized in the era of Louis Pasteur, who demonstrated the importance of fermentation and suggested that consuming fermented foods could have health benefits and promote longevity. Both oral and topical probiotics have been explored for their therapeutic potential in managing various skin conditions.

Microorganisms inhabit different parts of the human body, including the gut and skin. Commensal bacteria play a crucial role in maintaining human health by supporting a balanced immune system. The skin microbiome consists of diverse microbial species, and any disruption in this balance can lead to dermatological conditions such as acne, atopic dermatitis, psoriasis, and rosacea. Probiotics have gained recognition for their clinical applications in treating certain skin conditions, and probiotic-based therapies are increasingly being investigated for their potential to prevent and manage severe dermatological disorders.

Research has established a link between gut microbiome disturbances and inflammatory skin diseases, highlighting the potential of oral probiotics as a treatment option. However, limited clinical studies have examined the effectiveness of topical probiotic formulations. The application of probiotic bacteria directly to the skin may enhance its natural

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protective barrier by interacting with resident microbiota. This interaction may lead to the production of antimicrobial peptides, which play a role in immune responses and pathogen elimination.

Although topical probiotics have been used to maintain a healthy skin microbiome since the early 20th century, their commercial availability has significantly increased over the last decade. Despite their rising popularity, there remains a scarcity of clinical trials evaluating their efficacy. This review aims to provide an in-depth analysis of the role of topical probiotics in dermatology. It includes discussions on the composition of the normal skin microbiome, common skin disorders, and widely used topical probiotic formulations. Additionally, this article explores the potential of functional clothing infused with probiotics as an innovative approach to preserving the skin microbiome.

2. Lactic Acid Production by *Lactobacillus sporangium*

Lactic acid is a vital metabolite in industrial biotechnology, widely applied in the food, pharmaceutical, and bioplastic sectors. *Lactobacillus sporangium*, though relatively less studied, exhibits significant potential for lactic acid production through fermentation. This review examines its production process, extraction techniques, evolutionary significance, and analytical methods, while also addressing recent research developments, challenges, and future perspectives.(1)

As a key organic acid (As shown in Fig: a), lactic acid is primarily synthesized by lactic acid bacteria (LAB), including various *Lactobacillus* species. Among them, *Lactobacillus sporangium* has demonstrated promising efficiency in high-yield fermentation. The increasing demand for biodegradable plastics, probiotics, and food preservatives has fueled research into optimizing microbial lactic acid production (Sharma et al., 2020). Understanding the metabolic pathways, extraction strategies, and evolutionary traits of *Lactobacillus sporangium* is essential for enhancing its industrial applications. (2)

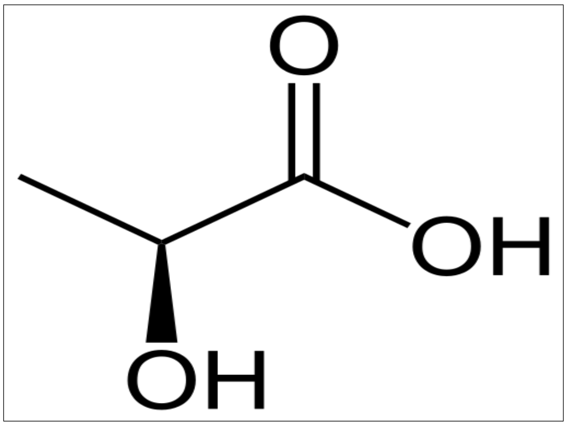

Figure 1 lactic acid chemical Structure

2.1. Metabolic Pathways of Lactic Acid Production

Lactobacillus sporangium utilizes two main fermentation pathways:

- **Homolactic Fermentation**: Converts glucose into lactic acid through glycolysis, achieving a yield of over 85% . (3)(As shown in Fig : b)
- **Heterolactic Fermentation**: Generates lactic acid alongside ethanol, CO_2, and acetic acid via the phosphoketolase pathway (4,5)

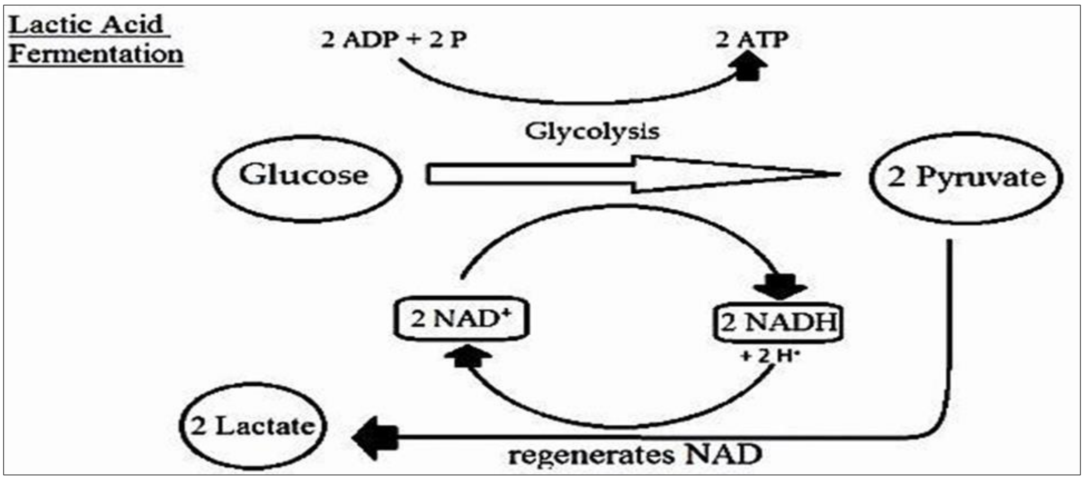

Figure 2 Lactic acid fermentation

2.1.1 *Growth Conditions*

The efficiency of lactic acid production is influenced by several key factors:

- **Temperature:** Optimal range between 30–42°C (6)
- **pH:** Ideal conditions between 5.5–6.5 (7)
- **Nutrient Sources:** Carbohydrates such as glucose, lactose, and sucrose serve as primary substrates (Gómez-Caravaca et al., 2016). (8)

2.2. Factors Influencing Yield

Enhancements in lactic acid productivity have been achieved through strain improvement via genetic engineering and metabolic pathway optimization. Studies indicate that yield is significantly impacted by the selection of carbon sources and bioreactor conditions (Elbagory et al., 2019). (9)

2.2.1 *Lactic Acid Extraction Methods*

- **Precipitation Methods:** Commonly involves calcium lactate precipitation followed by acidification to recover lactic acid from fermentation broth (Duarte et al., 2016). (10)
- **Membrane Filtration:** Techniques like ultrafiltration and nanofiltration enhance purity and recovery efficiency compared to conventional extraction methods (Mandana et al., 2021). (11)
- **Electrodialysis:** Uses an electric field to separate lactic acid, minimizing reliance on chemical reagents (Wang et al., 2020). (12)
- **Solvent Extraction:** Organic solvents, such as ethyl acetate, facilitate the extraction and purification of lactic acid from fermentation media (Carr and Frei, 1999).(13,14)

2.3. Evolutionary Aspects of *Lactobacillus sporangium*

- **Phylogenetic Relationship:** Comparative genomic analyses position *Lactobacillus sporangium* within the *Lactobacillaceae* family, closely related to *Lactobacillus* and *Lactobacillus plantarum* (Nielsen et al., 2010).
- **Genetic Adaptation:** Adaptive mutations in genes related to carbohydrate metabolism have contributed to improved lactic acid production efficiency in *Lactobacillus sporangium* (Bender et al., 2021).
- **Industrial Strain Improvement:** Selective breeding and CRISPR-based genetic modifications have facilitated the development of high-yield strains (Padayatty et al., 2003) (15)

2.3.1 *Assay Methods for Lactic Acid*

- **High-Performance Liquid Chromatography (HPLC):** Recognized as the most precise method for lactic acid quantification (Eitenmiller et al., 2016).
- **Spectrophotometric Methods:** Enzymatic colorimetric assays offer a rapid alternative to HPLC, though with slightly lower accuracy (Arya et al., 2017).
- **Titration Methods:** Cost-effective acid-base titration techniques are widely used in industrial settings for lactic acid estimation and reaction (as shown in Fig :3)

- (Telang, 2013). (16)

$$C_2H_5OCOOH + NaOH \leftrightharpoons NaC_2H_5OCOO + H_20$$

lactic acid caustic sodium lactate water

Figure 3 Titrimetric reaction of lactic acid

2.3.2 *Industrial Applications*

- **Food Industry:** Functions as a preservative and acidifier in dairy and fermented products.
- **Pharmaceuticals:** Plays a role as a probiotic component supporting gut health (Carr and Maggini, 2017).
- **Bioplastics:** Serves as a key precursor in the production of biodegradable polylactic acid (PLA) (Moyo et al., 2018). (16)

2.3.3 *Challenges and Future Directions*

- **Yield Optimization:** Requires advanced genetic and metabolic engineering strategies.
- **Cost-Effective Extraction:** Innovative separation techniques are needed to reduce processing costs.
- **Industrial Scale-Up:** Enhanced bioreactor designs can improve commercial viability (Sharma et al., 2020).

Lactobacillus sporangium holds promise for sustainable lactic acid production. Continued advancements in metabolic engineering, extraction techniques, and analytical methods will expand its industrial potential. Future research should prioritize strain optimization and eco-friendly extraction technologies. (17)

3. Skin Benefits of Citrus Fruits

Citrus fruits, rich in vitamin C, citric acid, and antioxidants, promote skin health by brightening, exfoliating, and providing hydration.

- **Brightening and Even Tone:** Vitamin C reduces dark spots, sun damage, and boosts collagen for firmer skin.
- **Exfoliation and Texture Improvement:** Citric acid gently removes dead skin cells, enhancing smoothness and radiance.
- **Hydration and Nourishment:** Oranges and grapefruits supply moisture and essential nutrients like vitamin A and potassium.
- **Antioxidant and Anti-Inflammatory Protection:** Citrus shields against free radicals and UV damage while reducing redness and irritation (18,19)

3.1. Lactic Acid in Skincare

- **Exfoliation and Brightening:** Dissolves dead skin cells, improving tone and texture.
- **Acne Prevention:** Keeps pores clear while maintaining hydration.
- **Hydration Boost:** Acts as a humectant, drawing in moisture to support skin softness.
- **Strengthening Skin Barrier:** Enhances ceramide production, preventing dryness and irritation.

Lactobacillus-fermented plant extracts in skincare improve hydration, exfoliation, and skin barrier function, offering promising cosmetic benefits. (20)

3.1.1 *Corrects Skin Discoloration*

Lactic acid, especially in high concentrations like chemical peels, helps lighten hyperpigmentation by inhibiting tyrosinase, the enzyme responsible for melanin production. This reduces dark spots and uneven skin tone caused by aging and UV exposure.

3.1.2 *Fights Signs of Aging*

Lactic acid boosts collagen production, improving skin elasticity and reducing wrinkles. While aging is inevitable, growing consumer awareness has driven interest in anti-aging skincare, particularly probiotics. Fermented, probiotic-rich products support gut health, immunity, and longevity.

Aging theories fall into **programmed aging** (genetic regulation) and **damage-based aging** (cellular deterioration over time). Gut microbiota play a key role in longevity, and lactic acid bacteria (LAB) have been linked to extended lifespan and skin health. Research continues to explore microbiome influence on aging and probiotics' role in skincare. (13,21)

3.2. Lactic Acid Production by Lactobacillus

3.2.1 Characteristics of Lactobacillus

Lactobacillus sporangium is a gram-positive, facultative anaerobe known for efficient lactic acid production in dairy and fermented foods. It follows homofermentative or heterofermentative pathways depending on substrate availability.

3.2.2 Biochemical Pathway for Lactic Acid Synthesis

The primary pathway is the Embden-Meyerhof-Parnas (EMP) pathway (as shown in Fig: d) where glucose is converted into pyruvate and then lactic acid. Some strains also produce acetic acid and ethanol through mixed acid fermentation.

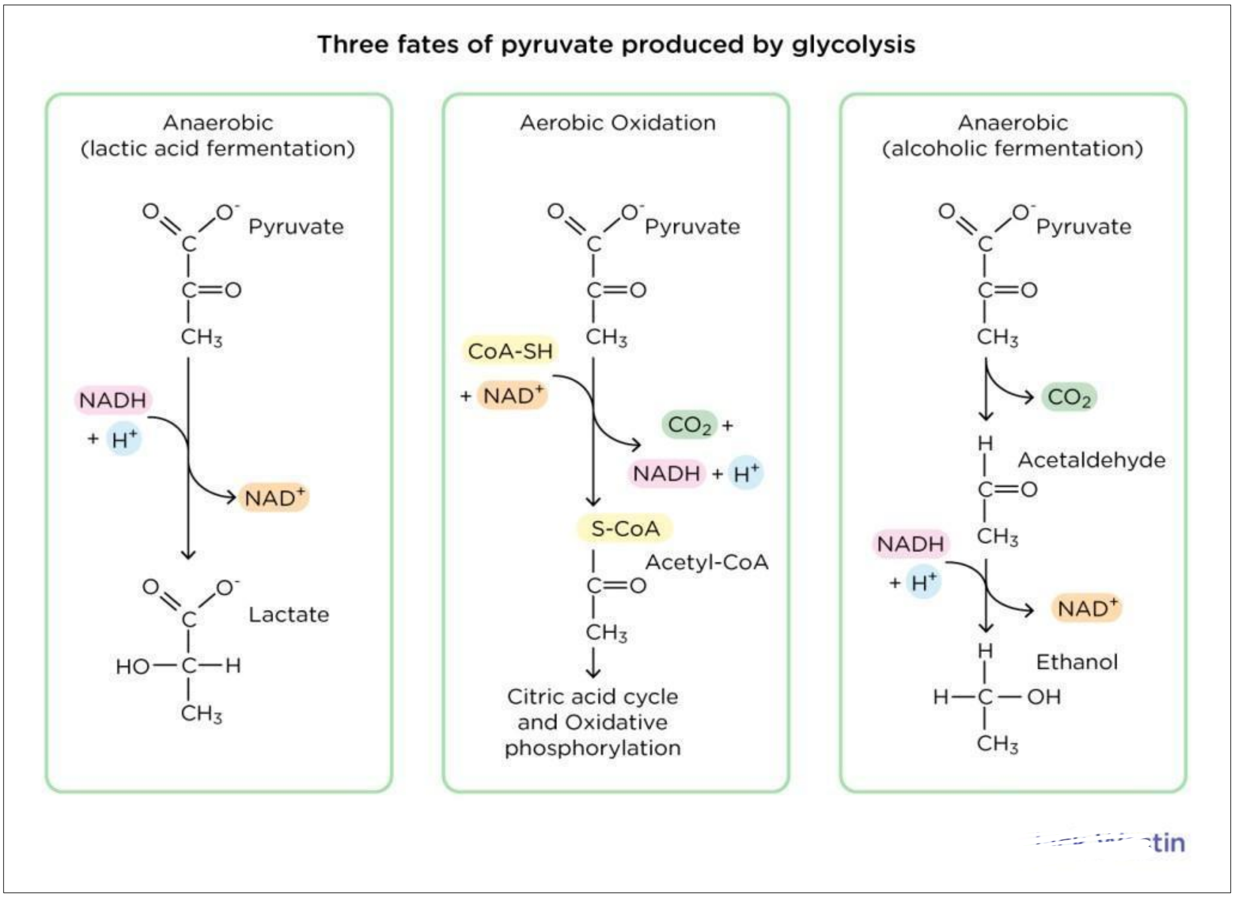

Figure 4 Biochemical Pathway for Lactic Acid Synthesis

3.2.3 Factors Influencing Lactic Acid Production

- **Substrate Availability:** Glucose, lactose, and starch impact yield.
- **pH and Temperature:** Optimal conditions: pH 5.5–6.5, temperature 30–40°C.
- **Oxygen Levels:** Anaerobic conditions maximize lactic acid yield; controlled aeration affects byproduct formation (15)

3.2.4 Evaluation of Lactic Acid Production

- **HPLC:** Measures lactic acid concentration. (22)
- **GC-MS:** Identifies metabolic byproducts for purity.
- **Titration Methods:** Cost-effective lactic acid quantification (19)

3.2.5 Lactic Acid Yield and Extraction

Certain *Lactobacillus* strains produce high lactic acid yields, enhanced by genetic engineering (Kang et al., 2019). Efficient extraction methods include **membrane filtration, solvent extraction,** (19) and **electrodialysis** (15) while purification relies on **crystallization** and **ion exchange resins** (Zheng et al., 2021) (14)

3.2.6 Vitamin C Extraction from Orange (Citrus sinensis) Peels

Citrus sinensis (as shown in Fig:5) peels, rich in ascorbic acid, flavonoids, and polyphenols, offer a sustainable source of vitamin C. Extraction techniques include solvent extraction, ultrasound-assisted (UAE), microwave-assisted (MAE), enzyme-assisted, and supercritical fluid extraction (SFE). (23,24)

Figure 5 Citrus sinensis

3.2.7 Vitamin C Stability and Health Benefits

Vitamin C also known as Ascorbic Acid (as shown in Fig: 6) degrades with heat, light, and oxygen but can be stabilized via encapsulation (23). Its benefits include antioxidant protection, immune support, skin health, (22) cardiovascular benefits, and neuroprotection. (25,26)

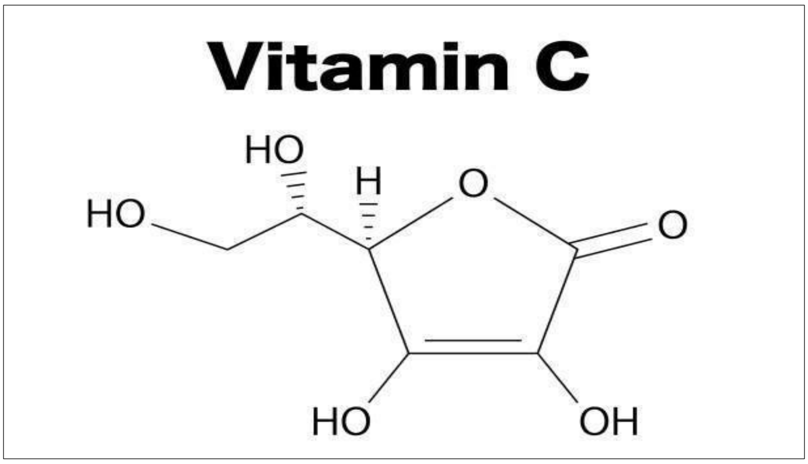

Figure 6 L - Ascorbic Acid (Vitamin - C)

3.2.8 Applications

- **Food and Pharma:** Used in supplements, fortifiers, and preservatives (26)
- **Cosmetics:** Brightening and anti-aging ingredient.
- **Agriculture:** Natural biopesticide and plant growth enhancer.

These advancements promote sustainability and enhance industrial applications of lactic acid and vitamin C.

3.2.9 Challenges and Future Prospects of Vitamin C Extraction

Key challenges include stability issues, low extraction efficiency, and scalability for industrial use. Future research should enhance extraction and stabilization techniques to promote sustainability and reduce citrus waste.

3.2.10 Anti-Aging Skin Cream Formulation

- **Key Ingredients:** Retinoids, peptides, antioxidants, hyaluronic acid, botanical extracts, and sunscreen.
- **Formulation Methods:** Emulsions, liposomes, nanotechnology, and hydrogels enhance ingredient delivery and stability.
- **Evaluation Techniques:** Cell studies, antioxidant assays, and physicochemical tests ensure efficacy.

3.2.11 Future Trends

- **Stability Enhancements**: Preventing ingredient degradation.
- **Personalized Skin Care**: AI-driven formulations.
- **Sustainable Innovation**: Eco-friendly bioactive compounds and emulsions.

Advancements in formulation and evaluation will drive the future of effective and sustainable anti-aging skincare.

4. Conclusion

The present study demonstrates that the probiotic-infused anti-aging cream, enriched with *Lactobacillus sporangium*, lactic acid, and vitamin C, offers a natural, effective approach to enhancing skin health by improving hydration, collagen synthesis, and microbiome balance. This formulation not only addresses visible signs of aging but also promotes sustainable practices by utilizing microbial fermentation and citrus waste valorization. By integrating biotechnology with skincare, this research supports the development of safe, eco-friendly, and microbiome-friendly products, paving the way for future innovations in personalized and sustainable dermatological solutions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest

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