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The potential of *Lactobacillus* spp. fermented plant extract in modulating collagen and MMPs in photoaging skin : a review

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ABSTRACT: Photoaging poses a significant challenge to skin health, marked by collagen degradation and heightened matrix metalloproteinase (MMP) activity driven by oxidative stress. This review aimed to summarize the role of *Lactobacillus* spp. fermented plant extracts in restoring collagen levels, modulating MMP activity, and highlighting their cellular mechanisms for anti-aging skincare applications. Recent literature on *Lactobacillus* spp. fermentation of plant extracts was synthesized to evaluate its impact on skin rejuvenation, bioactive enhancement, and underlying signaling pathways. Recent evidence suggests that these fermented extracts possess potent antioxidant properties, that counteract oxidative stress (a key factor in photoaging). The fermentation process can modify the structural characteristics of compounds, enhance the bioavailability of beneficial compounds, such as phenolics and flavonoids, which are known for their protective effects on the skin. These fermented extracts can help maintain skin structure and support collagen synthesis by activating the Nrf-2-Keap1 pathway through phenolic acids (for example, salidroside) and inhibiting the activation of MAPK and NF-kB by flavonoids and *Dendrobium officinale* polysaccharides, thereby reducing visible signs of aging. In summary, *Lactobacillus* spp. fermented plant extracts show potential in restoring collagen levels, particularly type I and type III collagen, modulating MMPs, including MMP-1, MMP-2, MMP-3, and MMP-9, in photoaging skin. These findings underscore the promise of using natural fermented extracts as effective strategies for mitigating photoaging and promoting healthier skin. Future research should standardize fermentation methodologies, perform long-term clinical trials with standardization of strain profiles to support the development of safe and effective skin antiaging treatments.

KEYWORDS: Collagen restoration; fermented plant extract; *Lactobacillus* spp.; matrix metalloproteinases; photoaging.

▪ INTRODUCTION

Fermentation is a biological modification method which is promising and widely applied to the structural modification of natural products. Microorganisms like bacteria, fungi, yeast, mold commonly use as a tool for this process. This microorganisms do the biotransformation process triggered by enzymes, leading to structural alteration of the substrates and result in enhanced bioactivity or reduce toxicity. Microbial fermentation has several notable qualities: it can use a variety of raw materials and ferment different substances; it offers the ability to automatically regulate the fermentation process, is user-friendly, and provides strong economic benefits [1]. Traditionally, fermentation was used to preserve perishable foods. But currently, this process being used to produce health promoting components that enhance the nutritional value of foods, transform many medicinal drug, especially those derived from herbal plants, application of probiotics or botanical products in skincare products [2],[3].

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The most commonly used probiotic strains for fermentation are *Lactobacillus* and *Bifidobacterium* genera. Strains belonging to *Lactobacillus* are mostly used include lactic acid bacteria (LAB) [4]. LAB are non spore forming, gram positive and micro aerobic bacteria that produce lactic acid, the main product of carbohydrate fermentation. The use of LAB enhances the regulation of the skin's immune system and aids in maintaining skin balance [5]-[7]. Studies have shown that probiotics, or a combination with active natural ingredients, can offer protection against atopic dermatitis, dry skin, and UV-related skin damage [8]-[10]. Exposure to ultraviolet (UV) radiation can activate MMPs and trigger the degradation of collagen and elastic fibers, leading to disorder in the skin structure [11]. Ultimately resulting in visible signs of photoaging, such as skin laxity, sagging and an increase in wrinkles [12].

Numerous studies have used *Lactobacillus* sp. as fermentation strains to increase polyphenols and other compounds, thereby enhancing biological activity. *Lactobacillus plantarum* is one of the most commonly used LAB species in fermenting plant-based foods to elevate the biological activity of plants by boosting their antioxidant content [13]. This antioxidant activity can offer an anti-aging effect. Study by Kim found that fermented blackberry with *L. plantarum* JBMI F5 can prevent UVB irradiation-induced degradation of type 1 procollagen caused in human foreskin fibroblast Hs68 cells and decrease the expression of matrix metalloproteinase-1 (MMP-1) and matrix metalloproteinase-2 (MMP-2) proteins in UVB-induced Hs68 cells [2]. Although previous reviews have reported the antioxidant, anti-inflammatory, and photoprotective properties of fermented plant extracts, they have generally discussed extracts fermented with diverse microbial strains. In contrast, limited attention has been given to the role of *Lactobacillus* spp. mediated fermentation in enhancing the anti-photoaging properties of plant extracts, particularly its effects on collagen synthesis and matrix metalloproteinase (MMP) expression. Therefore, this review aims to examine the potential anti-photoaging effects of plant extracts fermented with lactic acid bacteria, with a particular focus on *Lactobacillus* spp. and their ability to modulate collagen and MMP expression in photoaged skin.

This review compares the total phenolic content (TPC) and total flavonoid content (TFC) of fermented and non-fermented plant extracts, discusses the possible mechanisms underlying their protective effects against photoaging, and summarizes the current evidence regarding their potential biological activities. By integrating the available findings, this review highlights fermented plant extracts, particularly those produced using *Lactobacillus* spp., as promising materials for further investigation and encourages future studies on the selection of plant substrates, bacterial strains, fermentation conditions, and underlying molecular mechanisms.

▪ METHODS

For this is a narrative literature review, a targeted literature search was conducted on the PubMed, Scopus, ScienceDirect, and Google Scholar databases up to May 2026. Keywords included “fermented plant extract,” “Lactobacillus fermentation,” “lactic acid bacteria,” “skin aging,” “photoaging,” “oxidative stress,” “collagen,” “matrix metalloproteinase.” Clinical studies, randomized controlles trials, recent reviews published in English were prioritized.

Fermented vs. Regular Plant Extracts: what sets them apart?

Extraction is the first step to separate the desired natural products from the raw materials which have bioactive compounds. Alkaloid, anthraquinone, flavonoid, tannin, saponin, steroid and terpenoid are compounds that may contain in extract as the result of extraction. Most herbal plant tissues exist in the form of couplings and mixtures, and traditional processing methods such as decocting, boiling, and steaming are unable to fully extract active substances. When using traditional processing techniques, inactive proteins and polysaccharides are generally produced alongside the active chemical constituents, impacting the extraction efficiency and the application of the active components [14].

Microbial fermentation is recognized as an economically viable and efficient biotechnological approach for enhancing the biological activity of plant-derived natural products [15]. Through specific metabolic pathways operating under appropriate conditions, microorganisms can biotransform raw materials into bioactive target compounds. The process enhances the bioavailability of polyphenols due to enzymes in LAB, which modify the profile and types of bioactive compounds, resulting simpler phenolic compounds [3].

Numerous studies have shown that fermentation with *Lactobacillus* species can enrich the active substance, improve the structural characteristics of the substrates, resulting in either increased biological activity or reduced toxicity of the components. Fermentation involves microorganisms that break down complex compounds in plant materials into simpler, more bioavailable forms. In contrast, regular plant extracts are typically obtained using physical extraction methods, such as solvent extraction, which generally do not alter the chemical structure of the compounds. Although this review focuses on fermentation by *Lactobacillus* spp., selected studies using other LAB are also included to assess changes in TPC and TFC before and after fermentation, observed consistency levels to other LAB genera.

Table 1. Comparison of Total Phenolic Content (TPC), Total Flavonoid Content (TFC) before and after fermentation process.

Material	Non Fermented TPC* and TFC* (mg/100 g or mL)	Microorganism	Fermented TPC* and TFC* (mg/100 g or mL)	References
Tumeric (*Curcuma longa* Linn.) beverage	TPC: 39.34 ± 0.33 TFC: 35.05 ± 0.74	*Pediococcus lolii* MH752471, *Pediococcus acidilactici* strain 5560, *Pediococcus acidilactici* MK028218, *Pediococcus pentosaceous* strain L16	TPC: 62.32 ± 0.28 TFC: 54.39 ± 0.59	[16]
Pomegranate juice enriched with Pomegranate seed oil	TPC: 103.88 ± 1.17 TFC: Not available	*Lactiplantibacillus paraplantarum* CRL 2051	TPC: 112.15 ± 2.62 TFC: Not available	[17]
Ginger (*Zingiber officinale Roscoe*)	TPC: 11362 TFC: 4142	*Bifidobacterium adolescentis*	TPC: 12400 TFC: 4500	[18]
Ginger (*Zingiber officinale Roscoe*)	TPC: 11362 TFC: 4142	*Monascus purpureus*	TPC: 13200 TFC: 4600	[18]
Quinoa	TPC: 201.76 TFC: 185.15	*Lactobacillus kisonensis*	TPC: 268.84 ± 10.89 TFC: 210.30 ± 2.37	[19]
Black Barley	TPC: 203.02 TFC: 187.06	*Lactobacillus kisonensis*	TPC: 271.53 ± 2.70 TFC: 217.16 ± 0.82	[19]
Quinoa + Black Barley	TPC: 161.83 TFC: 195.88	*Lactobacillus kisonensis*	TPC: 364.90 ± 1.78 TFC: 264.35 ± 18.20	[19]
Codonopsis lanceolata	TPC: 260 ± 127 TFC: Not available	*Lactobacillus acidophilus* (KACC 12419)	TPC: 2430 ± 15 TFC: Not available	[20]
Honeysuckle (*Lonicera japonica* Thunb.)	TPC: 11.995 TFC: 8.723	*Lacticaseibacillus rhamnosus* L08	TPC: 16.431 TFC: 14.300	[21]
Tartary Buckwheat	TPC: 261.19 ± 16.1 TFC: 534.97 ± 39.92	*Ganoderma lucidum* (G10)	TPC: 558.17 ± 15.69 TFC: 1624.89 ± 48.62	[22]
Yogurt	TPC: 1.52 ± 0.08 TFC: Not available	*Lactobacillus plantarum* ATCC 14917	TPC: 1.62 ± 0.05 TFC: Not available	[23]

*Values are expressed per 100 g for solid samples and per 100 mL for liquid samples. TPC is reported as Gallic Acid Equivalent (GAE), while TFC is reportes as Quercetin Equivalent (QE) or Rutin Equivalent (RE), as per original literature.

On skin aging, phenolics and flavonoids are important to neutralize the free radical and inhibit molecular signaling pathways that can prevent degradation of collagen. Flavonoids suppress the formation of reactive oxygen species (ROS) by inhibiting enzymes such as microsomal monooxygenase and NADH oxidase, and by chelating trace metals that facilitate free radical production [24],[25] . Additionally, flavonoids scavenge ROS by donating hydrogen atoms, effectively neutralizing highly reactive species like superoxide and hydroxyl radicals [26]. Besides that, polyphenolic compounds readily oxidize and play a crucial role in scavenging free radicals. During this process, they donate a proton from the hydroxyl (OH) group of the phenolic structure, leading to the formation of a relatively stable phenoxyl [27]. This stabilization helps prevent further oxidative damage, as the phenoxyl radical is less reactive than the original free radical. By neutralizing these free radicals, polyphenols effectively reduce oxidative stress and protect cells from damage, contributing to various health benefits. In plant extracts or foods fermented by bacteria, the total phenolic content (TPC) and total flavonoid content (TFC) have been elevated, indicating a potential for antioxidant activity, listed in Table 1.

The increase in TPC and TFC may be attributed to microbial enzymatic activity during fermentation, which releases bound phenolic and flavonoid compounds or converts them into more readily detectable forms. Additionally, microbial metabolites such as bacteriocins, vitamins, and exopolysaccharides may contribute to the enhanced biological activity of the fermented extract. LAB like *Lactobacillus* have capability to generate esterases that break down ester bonds in glycosides, thereby releasing soluble conjugated or insoluble bound phenolic compounds from plant cell wall [16]. During fermentation, microorganisms transform phenolic compounds in plant materials through the action of various enzymes. Enzymes such ad β-glucosidase, decarboxylases, esterases, hydrolases and reductases catalyze reactions including hydrolysis, deglycosylation, decarboxylation, and reduction, leading to structural modifications that can enhance the bioavailability and biological activity of phenolic compounds. This enhancement can be attributed to the β-glycosidase enzyme produced by the bacteria, which facilitates the hydrolysis of β-glycosides into isoflavone aglycones [28]. As a result, polyphenols associated with sugars can be released during fermentation, breaking down into their components, and can also be altered into different metabolites through the action of tannase [29]. Consequently, the metabolism of polyphenols by LAB can result in either an increase or decrease in TPC after fermentation [17].

Temperature and pH play significant roles in the metabolic processes of materials. As the temperature increases, there is a notable increase in the growth rate of LAB, leading to greater flavonoid production. Additionally, the interaction between pH and turmeric concentration may explain the stability of flavonoids at lower pH levels, as these compounds are metabolized by *Lactobacillus plantarum*. As a result, this metabolic activity contributes to an increase in TFC [16].

Fermented plant extract with *Lactobacillus* spp. and mechanisms in repairing damaged skin

Lactobacillus sp. are known for producing a range of beneficial compounds, including enzymes, extracellular polysaccharides, organic acids, and amino acids. After fermentation, the levels of functional active components and antioxidant activity were significantly enhanced. The macromolecules were broken down into smaller free molecules by the enzymes produced by LAB. These small molecules have been identified in antioxidant studies as providing hydrogen or electrons to stabilize free radicals [18]. According to Table 1, fermentation enhances the levels of TPC and TFC. These compounds, which include phenolics and flavonoids, help reduce the generation of free radicals and ROS during metabolism. This reduction can potentially lower the risk of aging related to oxidative stress caused by UV radiation. These antioxidant and anti-aging effects are mediated through key signaling pathways, particularly Nrf2/Keap1 and MAPK/NF-kB, which regulate MMP expression and collagen degradation.

Table 2. Mechanism of action of compounds resulting from fermentation process.

Compounds	Material	Mechanism	References
Polysaccharide	*Dendrobium officinale* with *Lactobacillus plantarum* GT-17F	- Decrease the gene expression level of MMPs in skin cells by affecting various signaling pathways - Decrease the degradation of Type I and Type III Collagen and elastin	[30],[31]

Compounds	Material	Mechanism	References
Phenolic acids – the top three significantly up-regulated; 2-Hydroxy-3-(4-hydrozyphenyl) propanoic acid (PubChem CID 9378), methyl 2,4-dihydroxyphenylacetate (PubChem CID 105727) and homogenitisic acid (PubChem, CID 521612), protocatechuic acid (PubChem CID 72), 4-hydroxybenzoic acid (PubChem, CID135), vanillic acid (PubChem CID 8468)	Mulberry with *Lactobacillus plantarum* SC-5	Increase the T-SOD, GSH and CAT enzyme activity	[32]
Phenolic – Salidroside	*Rhodiola rosea* with *Lactobacillus plantarum*	– Activated the Nrf-2-Keap-1 pathway – Increase the levels of CAT, GSH-Px, GCLC, HO-1 and NQO1 proteins – Inhibit the activities of MMP-1 and MMP3 – Increase the content of Type I and Type III Collagen, ELN and hyaluronic acid (HA)	[33]
Flavonoids	– Blackberry with *Lactobacillus plantarum* JBMI F5 – Pomegranate (*Punica granatum*) with *Lactobacillus plantarum* and *Saccharomyces cerevisiae*	– Restore COLs degradation and decrease in MMP-1 protein levels – Inhibit UVB-induces phosphorylation of ERK1/2 (p44 and p42), JNK1/2 (p54 and p46) and p38 – Inhibit MAPK and NF-kB activation – Increase collagen density	[2],[34]

Phenolic compounds identified in fermentation products activate the Nrf2/Keap1 antioxidant pathway. Phenolic compounds were identified in the fermentation products of mulberry with *Lactobacillus plantarum SC-5*, including 2-hydroxy-3-(4-hydroxyphenyl) propanoic acid, methyl 2,4-dihydroxyphenylacetate, homogentisic acid, protocatechuic acid, 4-hydroxybenzoic acid, and vanillic acid. These phenolic acids significantly increased T-SOD, GSH, and CAT levels ($p < 0.05$) [32]. This indicates that the fermentation reduces oxidative stress by enhancing the dismutation of superoxide anions ($O_2\bullet-$) into hydrogen peroxide (H_2O_2) and oxygen (O_2) through SOD. Meanwhile, CAT further catalyzes the breakdown of H_2O_2 into O_2 without consuming endogenous reducing agents, and GSH removes $O_2\bullet-$ while supplying electrons to enzymes like GPx, which also aids in converting H_2O_2 into O_2 [35]-[37]. Salidroside, in particular, fermentation product of *Rhodiola rosea* with *Lactobacillus plantarum*, exhibits scavenging activity against hydroxyl radicals and DPPH and has been reported that this phenolic compound dissociates the Nrf2 (NF-E2-related factor 2)-Keap1 complex in the cytoplasm, leading to Keap1 degradation [38]. This allows Nrf2 to translocate into the nucleus, where it activates downstream antioxidant pathways and promote the expression of antioxidant genes such as CAT, GSH-Px, GCLC, HO-1, and NQO1, which help scavenge reactive oxygen species (ROS) and protect cells from oxidative damage. Nrf2 is a key transcription factor that regulates the cellular antioxidant response by inducing the expression of antioxidant enzymes, and its activity is modulated by the cytoplasmic protein Keap1 [39]-[41].

Similarly, *Dendrobium officinale* fermented with *Lactobacillus plantarum* GT-17F contain polysaccharides (*D. officinale* polysaccharides /DOP) that possess significant antioxidant properties, including scavenging hydroxyl radicals, O_2-, and 1,1-diphenyl-2-picrylhydrazyl (DPPH) radicals [30],[42],[43]. DOP enhances the activities of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GSH-Px) in the serum, liver, and thymus, also decrease the p-NF-κB p65/NF-κB p65 protein levels after H_2O_2 exposure [44]. Inhibition of the MAPK signaling pathway and NF-κB transcriptional activity suppresses the expression of MMPs, thereby limiting collagen degradation.

Flavonoids and phenolics formed or increased during fermentation suppress the MPAK and NF-kB signaling pathways, thereby reducing inflammation and MMP expression. Flavonoids such as quercetin, kaempferol, apigenin, and wogonin exhibit anti-inflammatory effects by suppressing AP-1, MAPK, and NF-kB signaling, leading to reduced expression of pro-inflammatory cytokines and MMP-1 [45]. Similarly, fisetin and myricetin inhibit NF-kB and MAPK activation by suppressing the phosphorylation of IkBα, p65, JNK, ERK, p38, and MEK, and by reducing the nuclear translocation of NF-kB p65. The antioxidant potency of dietary flavonoids is closely associated with the position and number of hydroxyl groups on the A and B rings. Phosphorylation of MAPK activates the transcription factor AP-1, which translocates to the nucleus and induces pro-inflammatory genes such as TNF-α [46]. Inhibition of MAPK is crucial for suppressing MMP activity and collagen degradation.

Kim H reported that NF-kB is activated by UV radiation in Hs68 cells [2]. Oral treatment with fermented blackberry reduce protein expression of p-IkBα and NF-kB. UV irradiation can activate and translocate NF-kB into the nucleus, contributing to skin aging and collagen degradation. However, flavonoids inhibit UVB-induced phosphorylation of MAPKs and NF-kB in Hs68 cells [47]. Activation of MAPKs leads to activation of several transcription factors, including NF-kB. A critical event in NF-kB activation is the dissociation and subsequent degradation of the inhibitory protein IkBα through phosphorylation. The MAPK signal transduction pathway is essential for regulating immune responses and inflammation, including the expression of MMPs [48]. Another cell model conducted by Xiang showed that DOP suppress the translocation of NF-κB p65 subunits to the nucleus in a cell model and inhibit the phosphorylation of p38, JNK, and ERK1/2, which are part of the MAPK family [49]. Fu H found that fermentation inhibited the production and gene expression of MMP-1 and MMP-3 while significantly increasing the levels of type I collagen, type III collagen, and elastin (ELN) in human immortalized fibroblasts (HDF) cells [33]. Fermentation also suppresses the activation of ERK1/2, as indicated by a reduction in the phosphorylation levels of ERK1/2 and an increase in non-phosphorylated ERK1/2 in a dose-dependent manner [50].

Through coordinated activation of Nrf2/Keap1 and inhibition of NF-kB pathways, fermentation-derived polysaccharides, phenolics, and flavonoids downregulate MMPs expression and activity. Inhibition of MAPK signaling and NF-kB transcriptional activity suppresses MMP expression, thereby limiting collagen degradation. Fei's findings on fermented D. *officinale*, Fu H's results on fermented substrates in HDF cells, and Kim H's work on fermented blackberry collectively demonstrate that fermentation reduces MMP-1 and MMP-2, increases type I collagen, type III collagen, and protects against UV-induced skin aging [2],[30],[33].

Advantages of fermentation in increasing efficacy

Enchancement of bioactive compounds

Fermentation can alter the polyphenols content and activity in plant-based foods. Microorganisms produce enzymes like tannase and glycosidase during this process, which break down complex polyphenol structures into simpler, more bioavailable forms [51]. This transformation enhances the potency of polyphenols, increasing their bioactivity. Fermentation also enhances the antioxidant properties of plant extracts by increasing levels of phytochemicals, including antioxidant polysaccharides and peptides produced via microbial hydrolysis or biotransformation [52]. These compounds are essential for countering oxidative stress, a major contributor to ageing and related diseases. For example, fermenting soybeans raises the concentration of bioactive aglycones such as daidzein and genistein, which are known for their antioxidant and health benefits [53]. Fermenting pumpkin juice with five species of *Lactobacillus* led to a high production of organic acids from *Lactobacillus casei paracasei*, *Lactobacillus plantarum*, *Lactobacillus acidophilus*, and *Lactobacillus swissii* demonstrated strong capabilities in scavenging DPPH and hydroxyl radicals. A positive correlation was found between these scavenging abilities and levels of vanillic acid and erucic acid [54].

Furthermore, studies on red seaweed (*Bangia fusco-purpurea*) fermentation show similar results. In one study, total polyphenols increased over time when fermented with *Lactobacillus* [55]. This matches the findings presented in Table 1. This increase probably happen because bacterial enzymes break the bonds holding polyphenols, thereby releasing them from the plant material during the fermentation process [56]. Total flavonoids also increased in the first 36 hours as complex compounds were broken into simpler ones [56]. However, after 36 hours, flavonoids levels dropped, might be due to the depolymerization of high molecular weight phenolic structure in flavonoids by phenol-oxidases od *Lactobacillus* [57]. These higher levels of polyphenols and flavonoids led to real health benefits. The fermented seaweed liquid was able to block pancreatic lipase, an enzyme involved in fat digestion [58]. This blocking effect was stronger in samples with higher polyphenol and flavonoids content. For instance, fermentation with *L. delbrueckii* produced more polyphenols and blockes lipase better than *L. plantarum* [55]. This underscores that fermentation not only boosts the quantity of bioactive compounds but also enhances their enzyme activities.

Promotion of skin health

Compounds produced during fermentation, such as lactic acid and various peptides, help protect skin cells from oxidative stress and promote collagen production. This process improves skin firmness and elasticity, which are essential for maintaining a youthful appearance and slowing down the aging process [59]. The antityrosinase and anti-wrinkle effects of *Citrus aurantium* flowers fermented with *Lactobacillus brevis* were found to be 5.2-fold and 4.29-fold greater, respectively, compared to the unfermented group. The fermented extract of *L. brevis* showed considerable inhibitory activity against enzymes linked to wrinkles [60]. Fermented Research has demonstrated that fermented *Angelica tenuissima* can reduce UVB-induced damage to the extracellular matrix by increasing procollagen type-1 production and release, as well as decreasing the expression of MMP-1 and elastase in HaCaT and Hs68 cells [61]. Researchers found that the secretion of the inflammatory mediator nitric oxide was significantly lower in fermented extracts of *Lepidium meyenii* obtained by fermenting the extract with L. *plantarum*, L. *rhamnosus*, L. *casei*, L. *gattii*, and other *Lactobacillus* strains, compared to the unfermented extracts in RAW264.7 cells. Fermented L. *meyenii* has effective anti-inflammatory properties, along with the ability to inhibit tyrosinase activity, melanin synthesis, and melanogenesis [51].

Potential clinical applications

Several clinical trials have evaluated the potential of *Lactobacillus* spp. fermented plant extracts in treating skin aging. A randomized, double-blind, placebo-controlled study by Fei investigated the effects of a *Dendrobium officinale* extract fermented with *Lactobacillus plantarum* GT-17F (FDO) on 99 volunteers with visible wrinkles over a 56-day period [62]. Participants were randomly assigned to three groups: FDO (containing 0.5% fermented extract), DO (unfermented *Dendrobium officinale* extract, 0.5%), and placebo (basic formulation without active ingredients). Each participant applied 0.5g of the essence twice daily for 8 weeks. The FDO group demonstrated significant improvements in skin elasticity, with a 9.27% increase ($p < 0.001$) after 56 days, compared to no significant changes in the placebo group. Additionally, the wrinkle area in the FDO group decreased by 22.86% ($p < 0.001$), while the DO group showed only a 6.32% reduction ($p = 0.188$), which was not statistically significant. The erythema index in the FDO group decreased by 13.59% ($p < 0.001$), further highlighting its anti-aging potential. These results suggest that FDO significantly improves skin elasticity, reduces wrinkles, and alleviates erythema compared to the placebo and unfermented extract.

In a separate study, Chan explored the clinical applications of fermented pomegranate extracts (*Saccharomyces cerevisiae* and *Lactobacillus plantarum*) as both a dietary supplement and a topical cosmetic ingredient [34]. This randomized, double-blind study included 40 participants with visible black spots, dry skin (moisture content <75), and visible wrinkles. Participants split into two groups: one group received the FPE-D drink (50 mL daily for 8 weeks), and the other applied FPE-S serum (3 mL nightly for 4 weeks). In the FPE-D group, the skin elasticity increased by 7.8% ($p < 0.001$) and collagen density by 14.5% ($p < 0.001$) after 8 weeks. The FPE-S group (cosmetic serum) showed even more pronounced effects, with a 10.8% increase in skin elasticity ($p < 0.001$) and a 41.5% increase in collagen density ($p < 0.001$) after 4 weeks. These results confirm the efficacy of fermented pomegranate extracts in improving skin elasticity, collagen synthesis, and overall skin health, supporting their potential as both a supplement and a topical cosmetic treatment for aging skin.

Both studies underscore the promising clinical applications of fermented plant extracts, particularly *Lactobacillus* spp. fermented formulations in enhancing skin elasticity, reducing wrinkles, and promoting collagen production. Moreover, the products were reported to be safe and well tolerated, with no serious adverse events when used as topical formulations and also oral supplements (in this case of pomegranate). To provide more systematic overview of the clinical evidence, Table 3 summarizes the plant substrates, *Lactobacillus* sp. used, key biotransformed metabolites, and major outcomes.

Table 3. Summary substrates, *Lactobacillus* strains, key biotransformed metabolites, and clinical outcomes.

Plant substrate	Fermenting micoorganisms	Key biotransformed metabolites	Clinical outcomes
Dendrobium officinale	*Lactobacillus plantarum* GT-17F	Low molecular weight polysaccharides, hydrolyzed polyphenols	- Skin elasticity increase 9.27% ($p < 0.001$) - Wrinkle area decrease 22.86% ($p < 0.001$) - Erythema index decrease 13.59% ($p < 0.001$)
Punica granatum (pomegranate)	*Saccharomyces cerevisiae* and *Lactobacillus plantarum*	Gallic Acid and Ellagitannins/Ellagic Acid derivatives	FPE-D - Skin elasticity increase 7.8% ($p < 0.001$) - Collagen density increase 14.5% ($p < 0.001$) FPE-S - Skin elasticity increase 10.8% ($p < 0.001$) - Collagen density increase 41.5% ($p < 0.001$)

Research challenges and limitations

Although *Lactobacillus* spp. fermented plant extracts show promise for modulating collagen and MMPs in photoaging skin, their potential remains limited by the availability of clinical evidence. To date, recent clinical studies have used different *Lactobacillus* strains with short observation periods of approximately to 4-8 weeks and limited information regarding long-term safety. In addition, the absence of standardized fermentation protocols covering specific bacterial strains and fermentation parameters creates variability that may hamper reproducibility across studies. Addressing these gaps, future work should standardize fermentation methodologies, perform long-term clinical trials with standardization of strain profiles to support the development of safe and effective skin antiaging treatments.

▪ CONCLUSION

In summary, *Lactobacillus* spp. fermented plant extracts show significant potential in restoring collagen levels, particularly type I and type III collagen, while modulating matrix MMPs, including MMP-1, MMP-2, MMP-3, and MMP-9, in photoaged skin. These fermented extracts can enhance the structural characteristics of bioactive compounds, thereby increasing the content of phenolic and flavonoids. This boost helps combat oxidative stress and promotes skin rejuvenation by activate the Nrf-2-Keap1 pathway via phenolic acids (for example, salidroside) and inhibit MAPK and NF-kB activation through flavonoids and D. *officinale* polysaccharides. Positive results from clinical trials further validate the efficacy of these natural extracts, highlighting their practical applications in skincare products aimed at reducing the signs of aging. The findings of this review underscore the importance of integrating *Lactobacillus* spp. fermented plant extracts into cosmetic formulations, as they not only support collagen synthesis but also enhance skin resilience against environmental stressors. Additionally, the ability of these extracts to inhibit MMPs activity suggests a protective role in maintaining skin structure and function over time.

Future research should continue to investigate different plant materials, *Lactobacillus* strains, fermentation conditions, and extract concentrations to clarify and optimize their anti-photoaging potential. Exploring their interactions with other bioactive compounds may provide further insight into their biological effects. Moreover, long-term studies are needed to better understand the durability, safety, and molecular mechanisms underlying their effects on collagen restoration and MMP regulation.

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