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Review

Bioactive levan polysaccharides in cosmeceutical applications: A review

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ABSTRACT

Levan, a β-(2,6)-linked fructose homopolysaccharide, has gained increasing attention as a multifunctional biopolymer for cosmetic and cosmeceutical applications. Owing to its distinctive molecular architecture, levan uniquely combines high molecular weight, pronounced bioadhesive capacity, and remarkably low intrinsic viscosity, which facilitates its integration into diverse formulation platforms, including hydrogels, films, emulsions, and self-assembled nanostructures. This review presents a comprehensive overview of levan with a particular emphasis on skin health–related applications. It begins by outlining its physicochemical properties and biological features, followed by a critical examination of its mechanisms of action and translational relevance based on recent scientific studies and patent landscape analyses. Experimental evidence indicates that levan acts as an effective moisturizing agent comparable to hyaluronic acid, while also exhibiting tyrosinase inhibitory activity associated with skin-brightening effects. Additionally, its capacity to enhance collagen synthesis, regulate matrix metalloproteinases, and reduce wrinkle formation underscores its anti-aging potential. Both *in vitro* and *in vivo* studies further demonstrate its ability to stimulate keratinocyte and fibroblast proliferation, supporting tissue regeneration and wound repair. Complementary antioxidant, anti-inflammatory, and antimicrobial activities reinforce its suitability for multifunctional and sustainability-driven cosmetic formulations. Despite its favorable safety profile, biodegradability, and biocompatibility, levan remains underutilized relative to established polysaccharides in the cosmetic sector. By identifying current technological limitations, scalability challenges, and gaps in clinical validation, this review highlights strategic directions for advancing levan towards broader commercial implementation in next-generation skin care and hair-care technologies.

1. Introduction

Cosmetics are substances or preparations intended to improve the appearance of the human body. They can include skin care such as makeup and moisturizers, shampoos, conditioners and dyes for hair care, personal cleaning products, sunscreens, manicure preparations, and fragrances. Cosmetics do not affect bodily structures and functions, so there is no need for pre-market approval although active ingredients are subject to some degree of scrutiny depending on the country [1,2]. This distinction is increasingly challenged by cosmeceuticals, a term extensively employed in scientific literature and the commercial sector to denote topical formulations containing bioactive agents [3]. Although the term lacks a formal regulatory definition within most legal frameworks, it identifies a class of products that exert measurable physiological effects on skin health and morphology. These formulations thus represent a functional bridge between conventional cosmetics and pharmaceutical agents, delivering bioactive compounds to achieve targeted dermato-therapeutic benefits [3,4].

The cosmetics industry has become one of the markets with the greatest potential for expansion. Of the approximately 1000 products registered on the global market, around 13% are classified as cosmetic products [4]. In 2025, the global cosmeceuticals market was estimated at US $74.31 billion. This value is expected to increase to US $80.59 billion in 2026, reaching US $169.02 billion by 2034, with a Compound Annual Growth Rate (CAGR) of 9.7% over the projected period. The Asia-Pacific region led the sector, accounting for 41.31% of the market

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in 2024 [5,6]. One of the principal factors driving this expansion is the growing consumer demand for products that enhance their appearance [6].

A fundamental aspect in the qualitative evaluation of a cosmetic is the maximum reduction of adverse effects on skin. Accordingly, cosmetic manufacturers have directed their attention towards safer products with sustainable, non-toxic, and natural characteristics [7,8]. The global market for natural and organic cosmetics and personal care products was valued at US$37 billion in 2022 and is projected to reach US$58.6 billion by 2031. Within Europe, Germany, representing the largest regional market for cosmetics, has experienced significant growth in this sector, with the market share of natural cosmetics increasing from 6.9% in 2012 to 10% in 2022 [9]. In Brazil the market demand for cosmetics based on natural products is expected to grow by 5 to 10% and reaching US $25.11 billion by 2025 [10]. Over the next ten years, the natural cosmetics market in Japan is expected to grow at a 3.6% CAGR, reaching USD 7.4 billion by 2035 from USD 5.1 billion in 2025 according to Future Market Insights (FMI) [11].

Cosmetics formulated with natural or organic ingredients have become increasingly popular in recent years. Although fruits, flowers, and plants are commonly used as raw resources, production challenges have prompted the development of alternative sources. Biopolymers have emerged as a new trend in the cosmetics industry due to their non-toxic, biocompatible, and biodegradable qualities. Among biotechnologically produced ingredients widely used in cosmetics, proteins such as collagen, elastin, and silk, together with polysaccharides including hyaluronic acid, chitosan, sodium alginate, carrageenan, and starch, play pivotal roles in formulation development and skin health enhancement [12,13].

Functional polysaccharides from natural sources such as plants, marine organisms, animals, and fungi have attracted considerable interest due to their binding, emulsifying, and film-forming capacities, as well as their bioactivity, biocompatibility, and biodegradability. Bacterial exopolysaccharides (EPSs) have added advantages for cosmetics due to their sustainability and economical production [8].

Among EPSs, levan has received particular attention in recent years owing to its unusual combination of strong adhesive activity and low intrinsic viscosity, alongside its capacity for self-assembled nanostructure formation, environmental and user safety, biocompatibility, and biodegradability [10]. This fructose polymer is soluble in water and is a good film former. Levan has become an attractive biomaterial for the food, pharmaceutical, and cosmetics sectors, and its healing and cell-proliferation–promoting properties also support its use in regenerative medicine and tissue engineering. It has additionally been evaluated as a fruit-coating agent and is notable for its antioxidant, anticancer, and anti-inflammatory activities [14,15].

Of all review papers published on levan polysaccharide since 1968, more than 80% have appeared in recent years. These range from its production, characterization, and general applications [15–22] to specific biomedical applications such as its bioadhesivity [23] and immunomodulatory properties [24,25]. Other reviews have covered its hydrogels [26,27], enzymatic degradation [28], nanotechnological applications [29,30] and simultaneous production with other high-value-added products [31–34].

Despite the substantial literature on levan, as far as we know, there is no review article on the use of levan in cosmetics and cosmeceuticals. Consequently, this review offers a systematic overview of the state of the art for levan as an ingredient in these products, identifying gaps in the research and showing new perspectives in this field.

2. Methodology

2.1. Study design

This study is a systematic literature review that allows incorporation of different scientific sources. The approach enables structured gathering of data from multiple investigations, which may present distinct or convergent findings. Its main advantage is the ability to systematically integrate all evidence into a single set of studies.

2.2. Bibliographic search strategy

The work was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [35].

To contextualize the position of levan within the broader landscape of cosmetic polysaccharide research, a preliminary keyword-based search of the Web of Science Core Collection was performed. Using the search term “polysaccharide AND cosmetic”, a total of 2136 publications were retrieved, while individual searches for specific polysaccharides revealed a markedly uneven distribution of research attention. Hyaluronic acid (“hyaluronic acid AND cosmetic”) accounted for 1545 publications, chitosan for 1153, and cellulose and its derivatives for 1187, collectively representing the three most extensively studied polysaccharides in the cosmetic literature. Alginate and dextran occupied an intermediate position with 501 and 108 publications, respectively. In contrast, levan returned only 58 publications under the same search conditions, underscoring its comparatively limited representation in the cosmetic and cosmeceutical literature despite its well-documented biological properties. These quantitative findings highlight that while certain polysaccharides such as hyaluronic acid, chitosan, and cellulose are deeply ingrained in cosmetic research, levan remains relatively underexplored.

To systematically assess the available evidence on the cosmetic and cosmeceutical applications of levan, electronic searches were carried out without language or date restrictions up to May 2026 across Web of Science, Scopus, PubMed, and Google Scholar databases. The final search string combined (“levan” OR “levan polysaccharide”) AND (“cosmetic” OR “cosmeceutical” OR “skincare” OR “skin care”), applied consistently across title, abstract, and author keyword fields. The searches retrieved 63, 70, 38, and 60 records from Web of Science, Scopus, PubMed, and Google Scholar, respectively. After deduplication and removal of theses and conference proceedings, 94 records were screened based on titles and abstracts, and studies without direct cosmetic relevance or skin-related applications were excluded.

A total of 24 studies were included in the qualitative synthesis. From these, five were review articles addressing microbial exopolysaccharides or fructans in general. One of these was a book chapter addressing fructans in a general cosmeceutical context rather than levan-specific applications [36]. The remaining 19 studies were original research articles experimentally investigating levan in skin-related or cosmetic-relevant contexts. Notably, despite the growing body of experimental evidence, no prior systematic review has critically synthesized the cosmetic and cosmeceutical applications of levan polysaccharide. While fructans as a class have received some coverage in the cosmetic literature, a focused and systematic evaluation of levan specifically remains absent. The present review therefore addresses this gap by providing the first systematic integration of available evidence on levan's cosmeceutical potential.

3. General characteristics of levan

Levan is a fructan, a group of carbohydrates in the furanosidic form that also includes inulin and graminans. It is a homopolysaccharide composed almost entirely of fructose residues (with a single glucose molecule at the reducing end) linked by β-(2,6) glycosidic bonds in the main chain (Fig. 1A) and β-(2,1) bonds at branch points on the C-1 carbon [15], as shown in Fig. 1.

Levan occurs widely in nature, being produced by plants, fungi, yeasts, archaea, and bacteria [15,37]. Bacterial levan is synthesized extracellularly by the enzyme levansucrase (LS), which acts on sucrose by catalyzing transfructosylation reactions (Fig. 2A) to produce the biopolymer (Fig. 2B) [15].

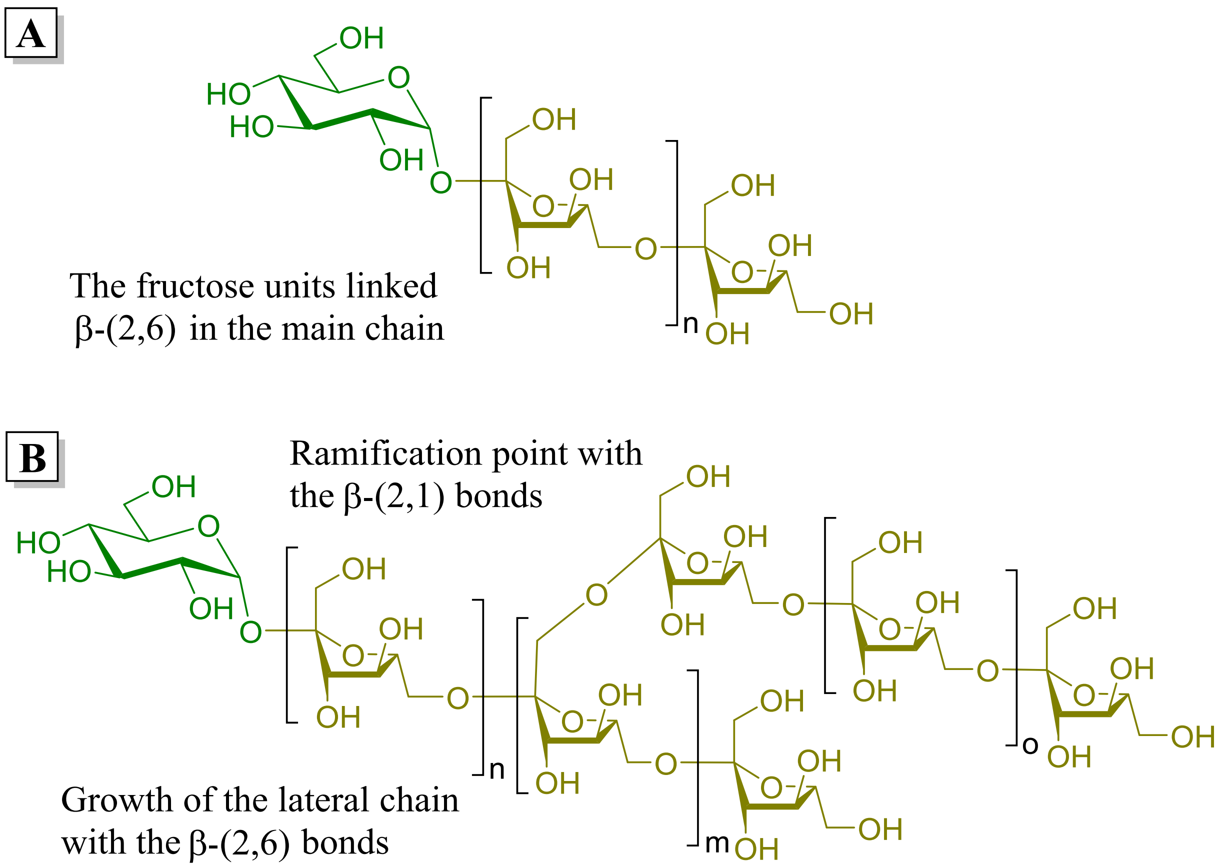

Fig. 1. Molecular structure of the linear levan (A) and of the levan ramified at C-1 (B).

The LS enzyme is quite common in Gram-positive and Gram-negative bacteria, including Pseudomonas, *Bacillus subtilis*, Xanthomonas, *Streptococcus mutans*, *S. salivarius*, *Azotobacter chroococcum*, *Lactobacillus reuteri*, *Leuconostoc citreum*, *Zymomonas mobilis*, Halomonas smyrnensis, *Arthrobacter ureafaciens*, and *Rothia dentocariosa*, among others [16,19,32,38].

Following fermentation, levan is recovered from the supernatant by precipitation, using chilled (4 °C) 70% ethanol as an antisolvent. The levan pellet (Fig. 2B) is usually resuspended three times in distilled water to remove contaminants and converted into powder form, either by freeze-drying or by atomization using a spray dryer [39].

Levan has interesting intrinsic characteristics, such as an amphiphilic character that renders it soluble in water and certain oils [38]. It exhibits low intrinsic viscosity ([η] = 0.07–0.18 dL/g for molecular weights of 16–24 kDa [40]), high thermal stability (degradation temperature 225 °C [41]), and excellent mechanical stability, including resistance to tensile stress and strong adhesiveness. It is also chemically stable across the pH range of 4–11 [13]. Finally, levan forms nanoparticles by self-assembly in aqueous media [29,30,39,42].

4. Levan as a bioactive polysaccharide

Levan is a non-toxic, biocompatible, and biodegradable polymer exhibiting a wide range of biological activities. Among these, the properties most relevant to skin health and cosmeceutical applications are its antioxidant [15,43,44], anti-inflammatory [30,43,44], antimicrobial [46], prebiotic [47] and cell-proliferative/regenerative activities [48], which are discussed in detail below. Additional systemic biological effects including antidiabetic, antihypertensive, immunomodulatory and antiviral activities have recently been documented for further reference [26].

Unlike its analogues, levan is not recognized by mammalian hydrolytic enzymes, which underpins its suitability as a versatile biomaterial for cosmetic and biomedical applications [48]. Accordingly, levan and its chemical derivatives have been incorporated into a wide range of biomedical platforms, including skin regenerative systems [8], immunostimulant [49] and cryoprotectant formulations [50], nano- and microparticulate drug delivery systems [51–53], laser-deposited [54] and layer-by-layer assembled thin films [55], electrospun matrices [56], and three-dimensional bioprinted scaffolds [57].

In parallel, substantial progress has been made in the development of levan-based hydrogels, with both physically and covalently crosslinked systems reported for diverse applications [26]. A variety of covalently crosslinked levan-based hydrogels have been developed, including glutaraldehyde crosslinked *Zymomonas* levan/poly(vinyl alcohol) hydrogels for pathogen capture [58] and chitosan-crosslinked oxidized *Bacillus* levan hydrogels loaded with curcumin for wound dressing applications [59]. Furthermore, 1,4-butanediol diglycidyl ether (BDDE)-crosslinked *Halomonas* levan hydrogels have been extensively investigated for controlled drug release [60–62], cryoprotection of probiotics [63], cultural heritage conservation [64] and, most recently, demonstrated *in vivo* efficacy in guided bone regeneration [65].

Oxidative stress, driven by an imbalance between reactive oxygen species (ROS) generation and the skin's endogenous antioxidant defenses, is a primary driver of cutaneous aging and a key contributor to inflammatory skin conditions such as dermatitis and photoaging [66]. UV radiation, pollution, and metabolic activity trigger ROS accumulation in the skin, which then leads to lipid peroxidation, protein oxidation, and DNA damage in keratinocytes and fibroblasts, ultimately accelerating wrinkle formation, loss of elasticity, and impaired barrier function. Antioxidant ingredients that can neutralize free radicals and reinforce the skin's natural defense mechanisms are therefore of central importance in cosmeceutical formulations.

Antioxidant activity has been consistently reported for levans

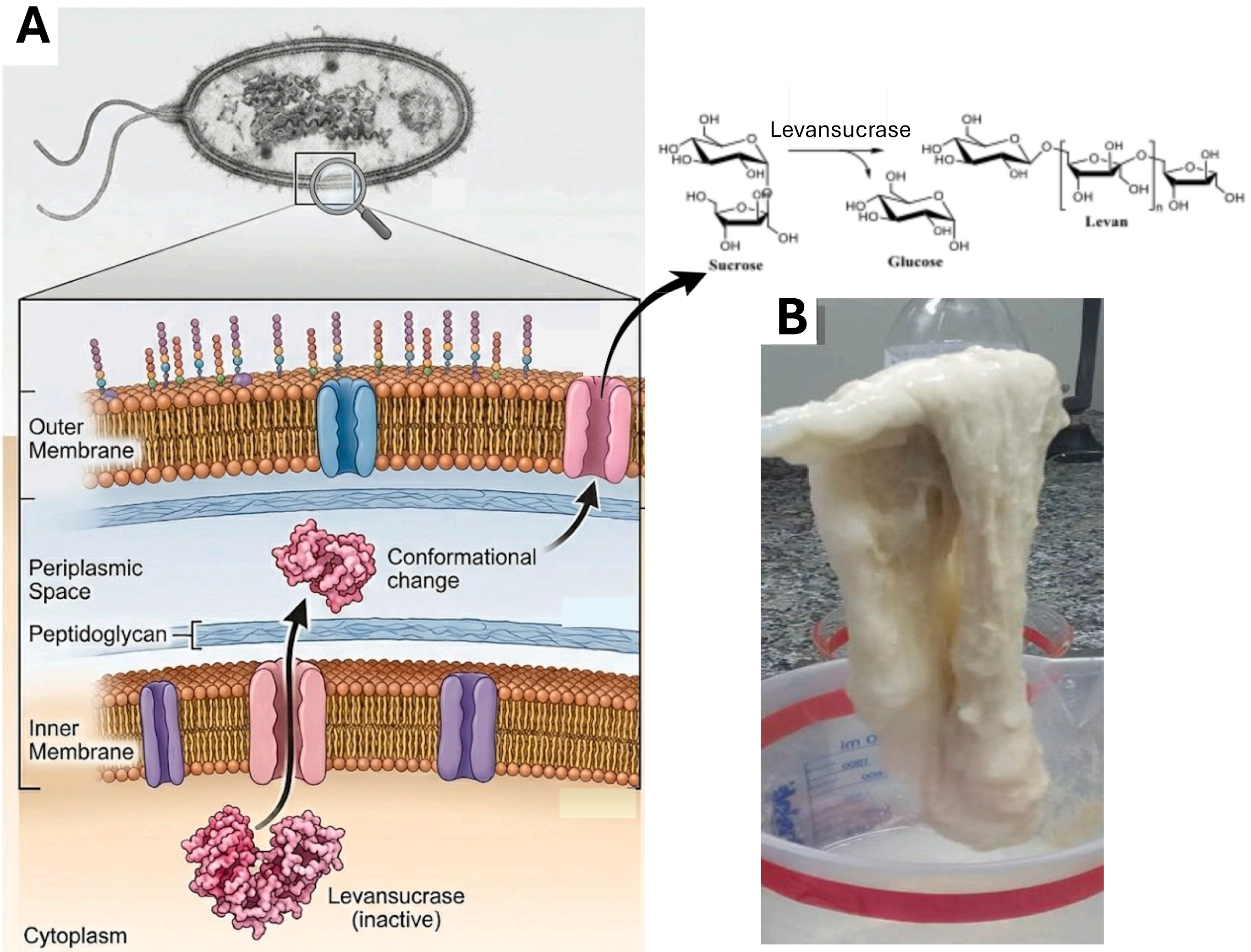

Fig. 2. Activation of the enzyme levansucrase and its action on saccharose to promote transfructosylation (A) to form the levan (B).

produced by a wide range of microbial species, especially for *Bacillus* strains such as *Bacillus subtilis* AF17 isolated from kefir milk [67] or soil bacterium *Bacillus megaterium* PFY-147 [68]. More recently, *Bacillus siamensis* KKSB4, *Bacillus velezensis* KKSB6 and *Bacillus amyloliquefaciens* KKSB7 isolated from traditionally fermented soybean as well as *B. velezensis* strain 5.18 isolated from Jerusalem artichoke were reported to produce levan with effective DPPH radical scavenging activities [69]. The antioxidant activity of levan was also demonstrated *in vivo* using a diabetic rat model, where treatment with *Bacillus licheniformis*–derived levan favorably modulated plasma antioxidant defense by enhancing antioxidant enzyme activities in the heart [70]. Moreover, Abdel-Fattah et al. reported that chemical modification through sulfation significantly improved the antioxidant properties of *B. subtilis*-derived levan, suggesting that structural tailoring can optimize its antioxidant potential for topical applications [45]. Beyond *Bacillus*, strong antioxidant capacity has been reported for levan from *Acetobacter xylinum* [44], *Halomonas elongata* [71] and *Leuconostoc mesenteroides* [72], indicating that this property is broadly distributed across microbial levans rather than species-specific. Notably, Lewińska et al. demonstrated that levan nanoparticle and nanoemulsion systems incorporated into cosmetic cream formulations quenched 88% of DPPH radicals within 5 min and 100% within 30 min, with *in vivo* testing on human volunteers confirming improvements in skin hydration, elasticity, and reduction of wrinkle depth [73]. Collectively, these findings position levan as a promising antioxidant active ingredient capable of mitigating oxidative stress-driven skin aging in cosmeceutical applications.

Cosmetic products require protection against microbial contamination to extend their shelf life, with natural polymers serving as effective antimicrobial agents [74]. Levan has demonstrated strong antimicrobial activity against both Gram-positive and Gram-negative bacteria, particularly *Staphylococcus aureus* and *Escherichia coli* [75,76]. Beyond bacterial strains, levan has also shown efficacy against fungal biofilms, including *Candida albicans* and *Aspergillus niger*, although higher concentrations are typically required for eukaryotic organisms [77,78]. The antimicrobial properties of levan have been further enhanced through nanostructured systems. Levan-based silver nanoparticles (AgNPs) exhibited significant inhibitory effects against various bacterial strains, including multidrug-resistant organisms [79,80]. Additionally, levan-based hydrogels loaded with amphotericin B demonstrated antifungal activity against *C. albicans* [77], while levan/bentonite composite films enhanced with essential oils showed promising antimicrobial properties for various applications [81].

The stability of the ingredients used to create an efficient formulation is a crucial factor in cosmetic applications. Levan is heat-resistant and highly stable under saline, alkaline, and acidic conditions, making it a promising candidate for cosmetic applications [30]. In one study, Helenas et al. used phase separation testing to examine the stability of thirteen distinct formulations that contained levan. No phase separation or discernible changes in the formulations were found after a 24-hour assessment. Additionally, it was discovered that all formulations had pH values near 6.0, suggesting that the biocosmetic products are compatible with the pH range of 4.6–5.8 that is typical of facial skin [10]. In another study, a levan-based formulation exhibited good physicochemical stability over a 90-day storage period under different conditions. No phase separation or significant changes in organoleptic properties were observed, while spreadability remained within acceptable ranges despite minor variations. The formulation maintained consistent density and non-Newtonian viscosity, and although a slight decrease in pH was observed under elevated temperature and light exposure (from 4.5 to approximately 4.2–4.3), it remained within the physiologically acceptable range for skin applications. These findings demonstrated the formulation's strong potential with respect to both physicochemical stability and functional performance [82].

In particular, the incorporation of levan into POLEVAN shampoo formulations has been shown to enhance foam generation and stability, thereby enabling a reduction in surfactant content. This effect is attributed to the film-forming properties of levan, which contribute to the formation of a stable structure at the air–water interface and support foam stabilization. Notably, foam performance was maintained even when the surfactant concentration was reduced from 30% to 20% or 15%, with satisfactory foam stability observed at these lower levels [83].

Similarly, Wasilewski et al. investigated the stability and performance of levan-containing, bio-derived formulations in surfactant systems comparable to shampoos. Foam properties were evaluated based on initial volume following mechanical agitation of a 1% solution and volume retention after 10 min. The results confirmed the formation of stable and persistent foam over time [7]. Collectively, these studies highlight that natural polysaccharides such as levan not only offer biocompatibility and safety advantages but also play a significant role in improving formulation stability and enhancing functional performance, underscoring their value in the development of advanced cosmetic systems.

There is growing interest in bioactive materials and their use in the treatment of wounds, burns, and tissue regeneration [6]. In this context, levan appears to offer significant value in wound healing in dermatology and in subcutaneous filling [15,48]. For example, levan produced by *Z. mobilis* NCIB 11163 has demonstrated proliferative effects in Wistar rat models, where it was shown to modulate metalloproteinase (MMP-2 and MMP-9) activity involved in extracellular matrix remodeling and new tissue formation during wound and burn healing [84]. Similarly, Hamada et al. (2022) reported that levan derived from *B. subtilis* MZ292983.1 significantly accelerated burn wound healing compared to control treatments, further supporting its regenerative potential [76].

Advanced biomaterial approaches have also highlighted levan's versatility in skin-related applications. Matrix-assisted pulsed laser evaporation (MAPLE) and combinatorial MAPLE (C-MAPLE) techniques have been used to fabricate levan and oxidized levan films for osteoblast support, drug delivery, and tissue regeneration, with oxidized derivatives showing enhanced cell proliferation, particularly at interface regions [85]. Likewise, multilayer levan phosphonate–chitosan films demonstrated improved cell adhesion compared to conventional alginate and chitosan polysaccharide-based systems, indicating potential for bioactive coating and dermal scaffold applications in skin regeneration [86].

In soft tissue engineering relevant to dermocosmetic applications, injectable levan-based hydrogels have been developed as dermal fillers, where they enhanced fibroblast proliferation and increased type I collagen expression compared to hyaluronic acid, highlighting their potential as next-generation anti-aging and skin-rejuvenating materials [87]. Furthermore, levan-based hydrogels loaded with resveratrol exhibited high biocompatibility with human keratinocytes, supporting their suitability for controlled release systems in skin care and cosmeceutical delivery platforms [61].

From a delivery system perspective, carboxymethyl levan nanoparticles have been used to encapsulate human epidermal growth factor (hEGF), significantly improving its stability and maintaining keratinocyte proliferation over extended periods compared to free hEGF. This prolonged bioactivity is particularly relevant for advanced cosmeceutical formulations targeting skin renewal and repair [88].

More recently, Erginer et al. investigated levan and its derivatives as active ingredients in cosmeceutical and skin regenerating formulations. Levan produced by *Halomonas smyrnensis* cultures (HL) and its hydrolyzed (hHL) and sulfonated (ShHL) derivatives, as well as enzymatically produced branched levan (EL) demonstrated increased proliferation of keratinocytes and fibroblasts (113–118%), improved skin barrier function through induced expression of involucrin genes (2.0 and 6.43-fold changes for HL and EL), filaggrin (1.74 and 3.89-fold changes for hHL and ShHL), and increased type I collagen (2.63 for ShHL) and hyaluronan synthase 3 (1.41 for HL), along with the ability for rapid wound healing within 24 h (100%, HL) in 2D wound models [8]. These combined biological effects strongly support their potential use in bioactive cosmeceutical formulations aimed at skin rejuvenation and barrier restoration.

In addition, hydrogels of levan from *Halomonas elongata* 153B supplemented with liposomes containing *Plantago lanceolata L* plant extracts have shown high biocompatibility and wound-healing performance in fibroblast models, highlighting their applicability in both pharmaceutical and cosmetic industries [62]. Similarly, levan–catechol iron oxide nanoclusters have demonstrated strong tissue adhesion and accelerated wound closure in diabetic mouse models, achieving up to 92% healing within 14 days, further reinforcing their translational potential for advanced dermal repair and cosmeceutical applications [89].

Biological properties attributed to levan from different microbial origins as well as levan based biomaterials are shown in Table 1.

As shown in Table 1, levan has various biological properties. Due to its intrinsic characteristics and biological properties, levan has several applications in cosmetics and cosmeceuticals.

5. Cosmetic and cosmeceutical applications of levan

Bacterial polysaccharides have physicochemical and biological properties that have led to their use in cosmetic products [2]. As mentioned earlier, levan has remarkable characteristics in many aspects, making it a promising biomaterial for the cosmetic and cosmeceutical industries.

Fig. 3 below shows some of the intrinsic properties of levan and its potential applications in cosmetics.

5.1. Levan as a skin whitener (anti-tyrosinase)

Excessive production of dark brown melanin leads to darkening of the skin, *i.e.* hyperpigmentation. Melanogenesis begins with the oxidation of tyrosine, first into L-DOPA and then into L-dopaquinone, followed by polymerization. These two initial stages are catalyzed by tyrosinase (Fig. 4).

Considerable research has been dedicated to identifying tyrosinase inhibitors as a strategy for reducing excessive melanin production. Many compounds have been tested on hyperpigmented areas of the skin, but due to their low stability in water, oxidation by light and irritation, the search for new candidates continues [15].

The use of levan as an inhibitor of melanin production was first described in a 2006 patent application, which reported that levan significantly decreased tyrosinase activity, producing a skin-whitening effect [90]. A second patent application presented a combination of levan and ascorbic acid. The authors claim that the binding of ascorbic acid to the furanosyl residue makes the compound more stable to oxidation [91].

Recently, levan from *B. subtilis* natto was used in formulations of skin tonics and gels. The results showed that both formulations improved skin discoloration [92].

Table 1
Biological properties of levan produced by different microorganisms.

Biological property	Relevance to skin/cosmeceutical applications	Microbial source	References
Antioxidant	ROS accumulation from UV, pollution, and metabolic activity causes lipid peroxidation, protein oxidation, and DNA damage in skin cells, driving wrinkle formation, loss of elasticity, and barrier impairment; antioxidant ingredients that neutralize free radicals are therefore essential in cosmeceutical formulations.	Acetobacter xylinum	[44]
		Bacillus licheniformis	[70]
		Bacillus megaterium PFY-147	[68]
		Bacillus siamensis KKSB4, *Bacillus velezensis* KKSB6, *B. velezensis* 5.18 and *Bacillus amyloliquefaciens* KKSB7	[69]
		Bacillus subtilis AF17	[67]
		Bacillus subtilis natto KB1	[73]
		Bacillus subtilis	[45]
		Halomonas elongata	[71]
		Leuconostoc mesenteroides	[72]
Antimicrobial	Microbial contamination compromises both the safety and shelf life of cosmetic products, while skin pathogens such as *S. aureus* contribute to acne, dermatitis, and wound infections. Broad-spectrum antimicrobial activity against bacteria and fungi positions levan as both a natural preservative extending cosmetic shelf life and a bioactive ingredient targeting skin-associated pathogens implicated in acne, dermatitis, and infection.	*Bacillus subtilis*	[76]
		Halomonas smyrnensis	[77]
		Pseudomonas mandelii	[75]
		Pseudomonas putida	[78]
Cell proliferation/ wound healing	Keratinocyte and fibroblast proliferation, upregulation of structural proteins (filaggrin, involucrin, collagen I), and ECM remodeling are fundamental to skin renewal, barrier repair, and anti-aging.	*Bacillus subtilis* MZ292983.1	[76]
		Halomonas elongata 153B	[62]
		Halomonas smyrnensis	[8]
		Zymomonas mobilis	[89]
		Z. mobilis NCIB 11163	[84]
Prebiotic	Prebiotics can be applied topically or consumed to promote microbiome balance and skin health. The overgrowth of bacteria like *Cutibacterium acne*, which cause skin acne, is suppressed by the use of prebiotics. Furthermore, the gut microbiota influences the skin through activities that strengthen overall immunity.	*Bacillus subtilis*	[47]
Skin regeneration	Skin regeneration encompasses re-epithelialization, collagen deposition, ECM remodeling, and endogenous hyaluronic acid synthesis — processes central to anti-aging, barrier restoration, and post-procedure recovery. Levan-based formulations control these mechanisms to deliver regenerative actives and stimulate dermal remodeling.	*Halomonas smyrnensis*	[61,85,86]
		Zymomonas mobilis	[87,88]

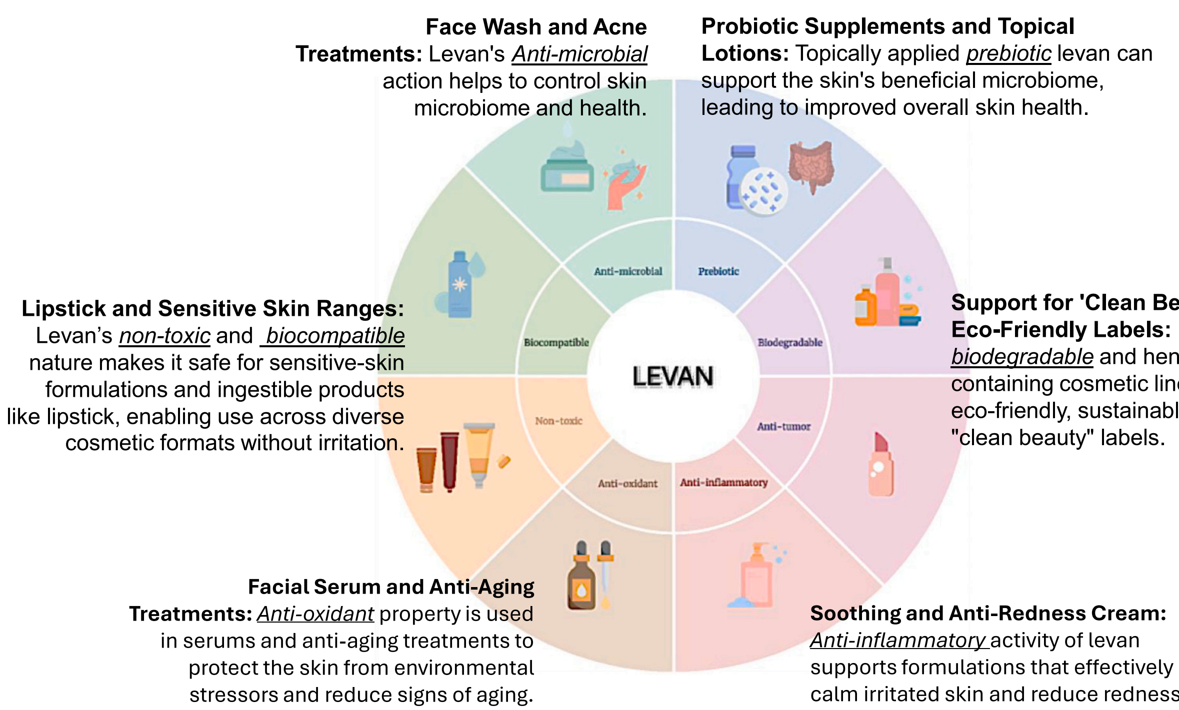

Fig. 3. Biological properties of levan and its cosmetics applications.

5.2. Hair-care products

Levan has been tested as an ingredient in hair fixatives. The low intrinsic viscosity of levan in aqueous solutions is an attractive property for formulators of hair gels, creams, and lotions. As a non-ionic polymer, levan has broad chemical compatibility with other ingredients and polymers. Solutions of levan in water and/or water/ethanol have potential use in hair fixative sprays in the form of aerosols [93].

Rhodia Inc. developed a levan-based surfactant with cationic substituents for a conditioning shampoo [94]. Levan in the carboxymethylated form (CML) was found to increase the tensile strength of chemically damaged hair. Scanning electron micrograph analysis of

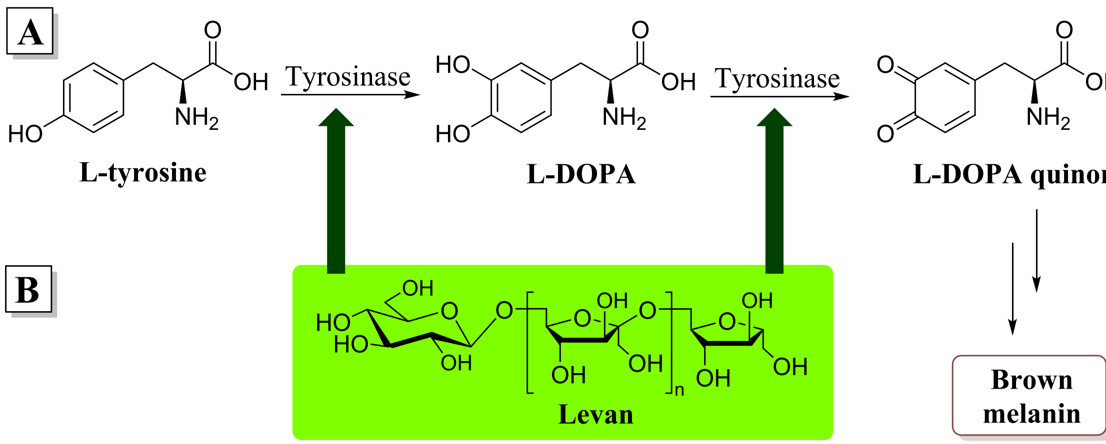

Fig. 4. Initial stages of formation of brown melanin catalyzed by the tyrosinase (A). Inhibitory effect of levan on tyrosinase (B).

damaged hair showed a decline in the lifting of the cuticle layers caused by bleaching after the hair was treated with CML [95].

The use of levan in hair care cosmetics was examined in a study by Budman et al. POLEVAN, a novel shampoo component, was created to lower surfactant concentration, boost shine, and hydrate hair. According to *in vitro* evaluation, a shampoo containing 2% levan enhanced hair shine by 24%. Twenty two healthy female volunteers aged 40–70 participated in a four-week *in vivo* assessment of the shampoo's moisturizing properties. The study indicated no statistically significant difference and comparable effectiveness between POLEVAN and HA, which is well-known for its moisturizing qualities. Lastly, POLEVAN was added at various surfactant doses to examine foam volume and stability. Foam volume and stability were preserved with the proper amount of POLEVAN when the surfactant concentration was cut in half from 30% to lower values, like 15%. This novel levan-containing shampoo can be useful for hydrating, boosting shine, and lowering the formulation's surfactant content [83].

5.3. Anti-wrinkle formulations

Levan's ability to induce collagen production suggests its potential as a polymer suitable for use in anti-aging and anti-wrinkle formulations [8]. The anti-aging properties of levan were evaluated for the first time using *Saccharomyces cerevisiae* as a model microorganism. According to this study by Alugoju et al., levan treatment extended the chronological lifespan of yeast cells by lowering oxidative and apoptotic stress. For larger model organisms like humans or animals, the anti-aging effect of levan on *S. cerevisiae* serves as an initial investigation [96].

Levan-based hydrogels have better anti-wrinkle effects than those produced with other materials. For example, Choi et al. developed and evaluated several injectable hydrogels based on levan, Pluronic F127, and carboxymethyl cellulose. Hydrogels containing levan proved to be more biocompatible and stable over a period of two weeks *in vivo*. More importantly, levan hydrogels showed greater anti-wrinkle efficacy compared to HA hydrogels in a rat model [87].

Levan from *B. subtilis* natto, in the form of a nanoemulsion, was used in the composition of anti-wrinkle creams, tonics, and gels. Analysis of the results showed that the formulations reduced the depth of wrinkles on the skin [92].

Lewińska et al. introduced the levan nanoparticle system and the surfactin-stabilized nanoemulsion system to three distinct cosmetic compositions, such as serums, toners, and creams. DPPH radical scavenging and EPR spectroscopy were used to measure the system's antioxidant activity. A cream formulation combining these two nanosystems was tested on ten women between the ages of 42 and 54. It was discovered that this formulation reduced the area and depth of wrinkles while also improving hydration, elasticity, smoothness, and discoloration [73].

Hwang et al. prepared a hydrogel composed of levan and hydroxyapatite (HAp) with the aim of increasing collagen production and anti-wrinkle efficacy. The *in vivo* stability tests showed greater longevity than the *in vitro* tests. The hydrogels were stable for 8 weeks. Furthermore, the excellent anti-wrinkle efficacy of the hydrogel composed of 1% by weight of HAp was maintained during the same period and showed the highest collagen production [97].

5.4. Antiallergenic formulations

Cosmetic formulations based on levan have shown promise for improving skin conditions. For example, levan produced by *Aerobacter* sp., *B. subtilis*, *Rahnella aquatilis*, and *Z. mobilis* have immunomodulatory properties, to inhibit allergenic reactions [98]. These properties are generally mediated through the stimulation of mononuclear cells, an increase in peripheral leukocytes, macrophage activation, induction of interleukins, and regulation of immunoglobulin levels [98–100].

Levan obtained as a product of *B. subtilis* fermentation process has immunostimulatory properties and can be used to prevent allergic disorders. In this study, it was found that oral doses (120–600 mg) of levan provided allergy-inhibiting effects, reducing the production of IgE and IL-4. In addition, this fructan promoted production of IL-12, inhibiting the differentiation of Th2 cells [101].

In a similar study, Xu et al. studied the *in vivo* effect of levan on the ovalbumin (OVA)-specific T-helper type 2 (Th2) response. Levan was administered intragastrically and IgE production was examined in BALB/c mice immunized with OVA. Levan was found to induce the production of IL-12 p40 and TNF-a *in vitro* (in macrophages) and to inhibit the Th2 response with IgE production *in vivo*. Both studies concluded that levan may be useful for preventing allergic responses [98,101].

Wasilewski et al. used levan from *B. subtilis* to make a shower gel. The gel provided a reduction in the skin irritation effect, which was seen from the decrease in the zein number. The reduction in skin irritation was attributed to the formation of a levan-surfactant complex [7].

Xu et al. demonstrated that levan can act as an immunomodulator through activation of Toll-like receptor 4 (TLR4), promoting increased production of interleukin-12 (IL-12) and subsequent suppression of the Th2 response, in addition to reducing IgE production. This finding is particularly relevant in the context of allergic conditions, as the pathophysiology of type I hypersensitivity reactions is strongly associated with Th2 polarization and IgE overproduction. However, this same signaling pathway raises an important concern: TLR4 activation may, depending on biological context and concentration, trigger undesirable pro-inflammatory responses, suggesting that levan's effect may be biphasic (immunoregulatory *versus* pro-inflammatory), particularly when applied topically to sensitive or compromised skin.

Additionally, studies show that the biological activity of levan, including its antitumor and immunological effects, is strongly associated with its molecular weight and branching structure [48]. This structural dependence is a critical issue for cosmetic applications, as commercial formulations rarely contain levan with a standardized molecular profile. Consequently, variations in microbial production processes can yield different levan fractions with distinct biological activities, compromising the reproducibility of antiallergic effects and raising important regulatory concerns.

Hence the main limitations of levan use in anti-allergy cosmetics include the lack of structural standardization, the scarcity of controlled clinical trials, and the insufficiency of long-term toxicological studies specifically addressing topical application. Although *in vitro* and *in vivo* data indicate relevant immunomodulatory potential, the threshold between therapeutic effects and the risk of unwanted immune activation has not yet been clearly established.

5.5. Bath gels and lotions

The development of innovative and sustainable cosmetics formulations based on non-toxic natural molecules is of value to the cosmetics industry [9]. In this context, ingredients derived from fermentation processes have gained popularity in body care cosmetics, including shower gels [6,7].

Fermented *B. subtilis* extract rich in levan was used to make a shower gel, which resulted in a significant reduction in negative impacts on the skin. A reduction of more than 40% in the emulsifying capacity of hydrophobic substances on the skin after the washing process was demonstrated, reducing dryness. In this work, levan was shown to be a suitable ingredient in cosmetic body wash formulations and safe for the skin [7].

Using levan from *Bacillus subtilis*, Berg et al. synthesized hydrogels with levan functionalized with methacrylate groups. The hydrogels were investigated for mechanical behavior, hydrolytic degradability, and cytocompatibility. The results showed relative stability against hydrolytic degradation in aqueous media over a period of 8 days. The hydrogels showed no cytotoxic effects on fibroblast cells during the test period [102].

The levan produced by various sources showed a series of acceptable physicochemical properties, indicating a potential application for levan as a water-soluble microgel. The findings of this study support the exploration for the use of more hydrogels in the food, medicinal, and cosmetics industries [26].

5.6. Facial creams

Levan has been shown to promote cell proliferation and to exert soothing and skin-moisturizing effects when incorporated into cosmetic formulations [8]. Levan's capacity to preserve and improve the skin's natural conditions has been extensively studied, supporting its proposed use in facial cosmetic applications.

The development of a model cream from levan nanosystems, nanoparticles, and nanoemulsion stabilized with surfactin was investigated [20,103]. The cream was evaluated *in vivo* for hydration, elasticity, smoothness, wrinkles, vascular lesions, and discoloration. It was observed that the cream improved skin condition in all the parameters tested in at least 50% of the volunteers. The addition of tonic and gel reduced previously existing skin discoloration by 10%.

Silva et al. developed a biocosmetic facial formulation based on *B. subtilis* levan, containing almond and cinnamon oils. As it was a facial cosmetic, the formulation was optimized to have an intermediate viscosity. The ideal formulation was 75% (0.75 g) levan and 25% (2 mL) almond oil, without the addition of cinnamon oil. After 90 days of exposure to different conditions, the formulation showed a spreadability of 805 mm^2, ideal pH and density for the facial area, and a hydration capacity of 100.3%. Overall, the formulation showed high moisturizing capacity and stability [82].

Helenas et al. developed a new type of anionic gel containing 1% levan and other plant compounds, such as *Aloe vera* extract, avocado oil, and vitamin E. Using statistical modelling design, they arrived at a multifunctional biocosmetic with a composition of 1% levan, 10% (0.1 mL) *A. vera*, and 90% (0.9 mL) avocado oil. The biocosmetic showed maximum antioxidant activity, moisturizing capacity, and spreadability of 76%, 98.37%, and 767.30 mm^2, respectively. The cosmeceutical formulation showed good stability and was classified as normal for use [10].

5.7. Skin moisturizers

In addition to protecting the skin against irritants, levan-based cosmeceutical formulations reduce transepidermal water loss, maintaining skin hydration [2].

The moisturizing effect of levan is largely due to its ability to stimulate collagen synthesis by fibroblast cells [8,87]. For example, Kim et al. observed that levan, in addition to stimulating the proliferation of human fibroblasts and keratinocytes, manifested a moisturizing effect highly reminiscent of that of hyaluronic acid [104].

Dahmer et al. created a biotechnological moisturizer formulation with multiple uses for lip care. The stability, spreadability, moisture retention capacity, and antioxidant activities of several formulations containing levan produced from *Bacillus subtilis*, sophorolipids (SOP), and grapefruit (*Citrus paradisi*) essential oil (OCP) were examined. In terms of spreadability (1135.6 mm^2), antioxidant activity (53.41%), and moisture retention capacity (95.49%), the formulation with 0.4% levan and 0.8% SOP was found to be the most appropriate. 85% of the 61 healthy female participants in an *in vivo* research who used the improved mixture reported having more moisture and less dry lips. The study presented an innovative approach for demonstrating the usability of levan in lip care [105].

Levan hydrogels are also reported to increase the collagen synthesis capacity of dermal fibroblasts [26,87]. Nair and Choudhury (2020) produced a levan-gellan hydrogel and evaluated its behavior. The hydrogel showed high stability and elasticity, confirming its potential as an injectable material [106].

Due to its ability to penetrate the skin, levan has become an effective excipient for nanoparticles carrying substances intended for the skin. Levan from *B. subtilis* (natto) was used in the production of nanoparticles to make up a nanoemulsion cream stabilized with surfactin. The cream was found to improve skin hydration and elasticity [92]. Also recently, nano-assembly of *Halomonas* levan was systematically studied and surfactant-free encapsulation of active compounds were demonstrated by an easy protocol [42].

Ko et al. synthesized CML (carboxymethyl levan) nanoparticles containing hEGF with dual biological functions. The CML-hEGF nanoparticles had a significant effect on skin hydration. This result was confirmed by analyzing collagen synthesis and the expression level of aquaporin 3 [88].

Levan nanoparticles and nanoemulsions have also been investigated for their ability to encapsulate and carry hydrophobic compounds against the *Stratum corneum*. Raman spectroscopic analysis showed that the nanoparticles increased hydration in the deeper layers of the skin. In short, levan exhibits a substantial moisturizing effect, significantly reducing transepidermal water loss [7]. It is likely that this characteristic is related to its water solubility, high adhesion strength, and ability to form films, which makes it an excellent skin conditioner.

Levan stands out in the field of cosmetics for its unique characteristics overcoming shortcomings of many traditional ingredients. It acts similarly to hyaluronic acid but offers a lighter texture and greater breathability, providing hydration without the sticky sensation. Due to its neutral charge, levan easily interacts with the cellular lipid bilayer. Flexibility of the furanose rings and their smaller size stabilize the cellular membranes better than glucans [8,17].

Levan-based skin moisturizers have gained prominence in the cosmetics and cosmeceuticals fields due to their combined humectant, film-forming, and rheological properties. However, evidence indicates that these properties are strongly influenced by cultivation conditions, which modulate molecular weight and degree of branching, directly affecting viscosity, stability, and moisturizing performance [8,17,92]. In topical formulations, levan demonstrates benefits such as increased hydration of the stratum corneum and an occlusive effect. However, these properties can be compromised during storage, particularly under variations in pH and temperature, which may promote rheological instability and polymer degradation [2,104].

In more advanced systems, such as hydrogels and responsive polymer networks, improvements in stability and controlled release of active ingredients have been observed, although these advantages still depend on rigorously controlled conditions, with a gradual loss of performance under thermal stress or humidity fluctuations [106]. More recent studies on cosmetic formulations report good moisturizing efficacy and sensory acceptance, although changes in viscosity over storage time may affect applicability and consumer perception [105]. Furthermore, nanotechnology-based approaches and encapsulation systems expand the potential for stabilizing bioactive compounds but still face limitations regarding stability under real-world market conditions [42,88].

5.8. Prebiotics in skin health

The skin presents a unique barrier environment (saline, acidic, and low in humidity) that has driven the evolution of a diverse community of resident microorganisms collectively termed the skin microbiome. This microbiome serves vital functions for immunity and barrier integrity, but its dysfunction (dysbiosis) can contribute to various skin diseases, pointing to the therapeutic potential of the microbiome for skin health. Microbiome-targeted approaches that enable the skin to strengthen its natural function and increase the potential of the skin microbiome against diseases are an alternative to traditional treatments. Most importantly, prebiotics and probiotics are examples of microbiome-targeted approaches [107]. Prebiotics are substrates that are selectively utilized by host microorganisms conferring health benefits according to International Scientific Association for Probiotics and Prebiotics (ISAPP). The other term is probiotics which are living microorganisms conferring health benefits [108]. Nutricosmetic-based treatment strategies are a new generation approach that focuses on probiotic and prebiotic effects, allowing the selective proliferation of beneficial bacteria by balancing them with natural polysaccharides, whether consumed or applied topically [109]. Levan exhibits prebiotic properties by supporting beneficial gut bacteria growth and being resistant to breakdown in the gastrointestinal system, levan fructooligosaccharides lower the environmental pH, thereby providing protection against pathogens (*Salmonella* spp., *Escherichia coli*, *Campylobacter* spp.) [20]. Applications for levan's nutritional supplements are based on Natto, a food with great cultural significance in Japan. This traditional food's constituent, levan, has drawn significant attention from researchers looking for organically derived health supplements [14]. A recent study showed that levan derived from *Lactobacillus reuteri* increased the viability of damaged HT-29 intestinal epithelial cells, decreased the oxidative stress and showed antioxidant effects. Additionally, levan supplementation improved metabolic health in mice by lowering blood sugar, serum cholesterol, and weight gain [110]. Similarly, another study examined the prebiotic impact of levan at different doses (2–10%) on Wistar Albino rats. The outcomes confirmed the bifidogenic impact of 5% levan supplementation by showing an increase in bifidobacteria abundance in the gut microbiota. These results show that levan has high prebiotic properties [111]. In summary, the skin microbiota, the second largest microbial community after the gut, plays a crucial role in skin health and research demonstrates that prebiotics can improve dermatological conditions by modulating gut microbiota through the gut-skin axis [112].

6. Levan in cosmetic market

In nature, levan is a polysaccharide produced by plants living in cold regions and microorganisms living in areas with high salt concentrations to protect cells from harsh external stimuli. This inherent property of “protection from extreme conditions” is a compelling narrative that resonates with the skin-barrier needs of modern consumers exposed to environmental stress. In addition, levan is a viscous component contained in natto, a traditional food that has been popular in Japan for a long time and is therefore expected to have health effects as a component. As shown in Table 2, levan-containing products have been emerging in the market. However, broader market diffusion has been hindered by production challenges and limited supply. However, recent developments in production technology have finally enabled its industrial implementation in society.

As illustrated in Fig. 5, levan can be incorporated into a wide range of cosmetic formulations. Due to its high water solubility and high biocompatibility, it is an ingredient that is relatively easy to incorporate into various formulations regardless of the dosage form. In addition, it has two aspects as a cosmetic material: as an active agent providing anti-inflammatory effects, melanin inhibition, and promotion of collagen synthesis, and as a formulation base material with adhesive properties and film-forming ability despite low viscosity. Taking advantage of these characteristics, the use of levan in cosmetics is being investigated, such as for the recovery of skin barrier function after cosmetic laser treatment or as a base material to reduce stickiness derived from glycerin, which is often used as a moisturizer in cosmetics. As shown in Table 3, the status of patent applications shows the potential of levan as a cosmetic material. In addition, the production process by microbial fermentation is clean and has a low environmental impact, which is suitable for the modern market seeking sustainable materials.

Despite its widespread scientific and commercial use, the term “cosmeceutical” lacks formal recognition by most regulatory authorities, resulting in the absence of a unified regulatory classification and continuing to challenge global regulatory systems [113,114].

Table 2
Commercial products containing Levan.

Product	Supplier/Brand	Country
Fructan™	SK Bio	South Korea
MoistPlus	BlueSun	Mexico
Nonomist	SK Bio	South Korea
PoLevanS	GREENTECH	France
PROTEOLEA	Rahn	Switzerland
SLIMEXIR	Rahn	Switzerland
SoyPol	SK Bioland	South Korea
POLEVAN®	Gan Shmuel Group	Israel
Hydra Mocktail	ONLYBIO	Poland
Hydroactive Cleanse	HydroPeptide	Us
Snail Gel Facial Serum	dr.organic	Uk
Synbiotic Defense Mist	VENN	South Korea
Synbiotic Polyamine Shampoo	VENN	South Korea
Probiotic-Tensive Hydro Firming Body Cream	VENN	South Korea
Hypercharged Glass Skin Serum	BYNACHT	Germany
20% Vitamin C + Hyaluronic Acid Glow Serum	goop beauty	Us
15% Glycolic Acid Overnight Glow Peel	goop beauty	Us
Microderm Instant Glow Exfoliator	goop beauty	Us
Vitamin C Elixir	CLE Cosmetics	Us
Serumide	CLE Cosmetics	Us
Pure Vitamin C 15% + Marigold Brightening Serum	Wildfleur	Us
Brightening Eye Serum	Aurelia Cellular Vitality	Uk
Centella Ferment Serum	ZYMOGEN	Singapore
Honey Glow Cream	I'm From	South Korea

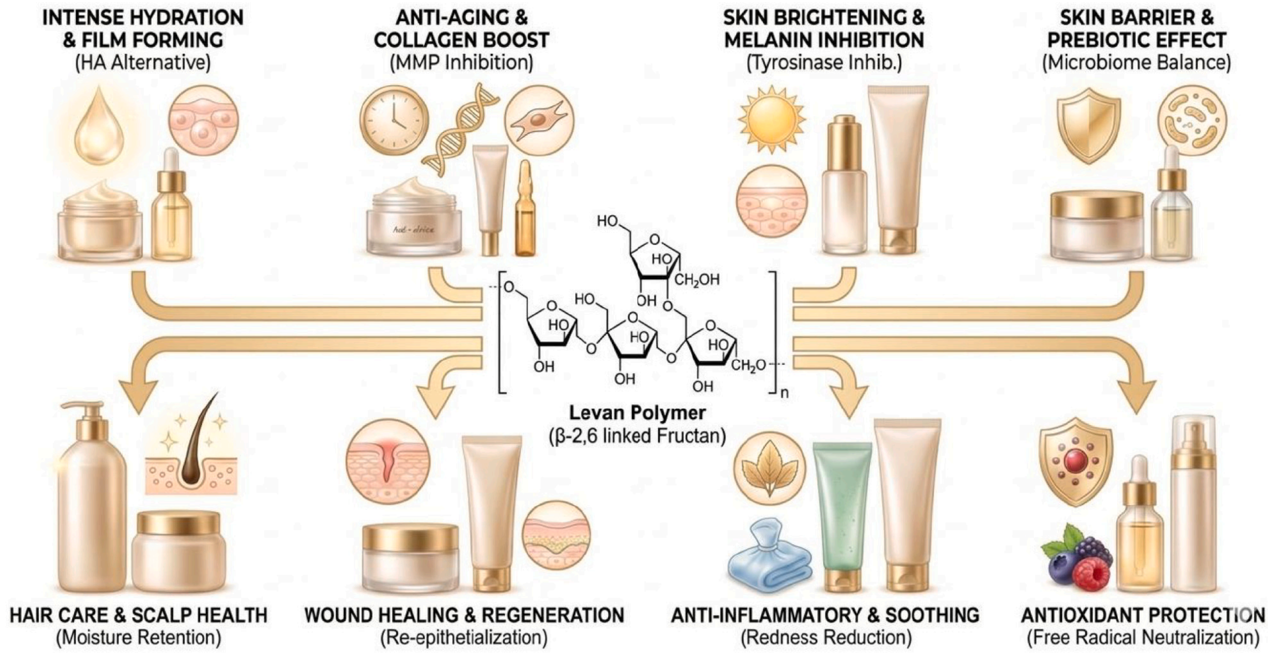

Fig. 5. Applications of levan in cosmetic formulations.

Importantly, regulatory classification is primarily determined not by composition but by intended use and product claims, which creates ambiguity in categorizing these products across jurisdictions [115]. Globally, regulatory approaches to cosmeceuticals vary significantly. In the United States (US), the Federal Food, Drug, and Cosmetic Act (FD&C Act) does not recognize the term "cosmeceutical." Instead, products are classified as either cosmetics or drugs under the supervision of the U.S. Food and Drug Administration (FDA) [116]. Products making therapeutic claims, such as sunscreens or anti-dandruff shampoos, are regulated as over-the-counter (OTC) drugs. In Japan, specific regulations apply to skin care products that do not strictly fall within the categories of conventional drugs or cosmetics and are instead classified as an intermediate category known as "quasi-drugs" [117]. Similarly, the European Union (EU) regulates such products under Regulation (EC) No. 1223/2009, which treats them as cosmetics provided they do not claim to treat or prevent disease. This framework emphasizes product safety, requiring a comprehensive technical dossier and post-market surveillance mechanisms [118]. Turkey largely follows the European Union model while maintaining its own legal framework under the Cosmetics Law No. 5324, which clearly separates cosmetics from pharmaceuticals and prohibits therapeutic claims for cosmetic products [119]. Other countries, including Canada, China, India, and Brazil, adopt hybrid or evolving regulatory approaches, reflecting differences in legal traditions, market priorities, and public health strategies.

Regarding its safety for cosmetic use, evaluations of levan have been positive. The Cosmetic Ingredient Review (CIR) panel assessed the safety of 34 microbial polysaccharides used in cosmetics, including levan. The panel based its conclusions on available animal and clinical data. Minimum safety requirements considered in the evaluation included acute toxicity, corrosivity and irritation, skin sensitization, dermal/percutaneous absorption, repeated dose toxicity, and mutagenicity/genotoxicity [120]. Levan was classified as a microbial polysaccharide gum and deemed safe under current conditions of use and concentration in cosmetics [121]. Additionally, a 2020 reference on cosmetic ingredients also listed levan as safe [122].

As for the future outlook, the market will be driven by its development as a highly functional active ingredient at first, but the market scale will expand dramatically as the utilization of levan as a base material for products expands with the stabilization of the supply system. This combination of "bioactivity" and "base material properties" strongly suggests the expansion of levan beyond the framework of the cosmetics field to adjacent huge markets such as functional foods, medicine, and environmental materials. While levan is a familiar component with a long history of research—notably found in traditional foods like natto—it is now emerging as a new industrial biomaterial. It is expected that its applications will spread across many markets, starting with the cosmetics industry as a springboard.

7. Future prospects and research gaps

Despite the promising biological activities and formulation versatility of levan documented in this review, several critical gaps remain that must be addressed before its full cosmeceutical potential can be realized. One of the most significant limitations is the near-complete absence of well-designed clinical trials. The majority of studies reviewed relied on *in vitro* cell models or small-scale *in vivo* experiments in rodent models, with only a handful of studies involving human volunteers. Rigorous randomised controlled trials evaluating the efficacy, safety, and tolerability of levan-based formulations in target populations, including those with aging, sensitive, or compromised skin, are therefore a priority for advancing its regulatory and commercial standing.

A further gap concerns the sourcing and scalability of levan production. While levan can be produced by a wide range of microbial species, the majority of cosmeceutically relevant studies have focused on a limited number of strains, particularly within the genera *Bacillus*, *Halomonas*, and *Zymomonas*. Systematic comparative studies evaluating how microbial origin, fermentation conditions, and post-processing influence the structural, rheological, and biological properties of levan are largely lacking. Such studies are essential for establishing structure–activity relationships that would guide rational selection of levan variants for specific cosmeceutical applications. In parallel, the industrial-scale production of levan with consistent quality and purity remains a challenge, and advances in bioprocess engineering, including the development of cost-effective fermentation strategies and downstream purification protocols, will be critical for enabling commercial implementation.

The cosmeceutical potential of levan derivatives remains

Table 3
Patents on cosmetic applications of levan.

Patent publication number	Patent title	Country, year
JP2003277225A	Cosmetic composition containing levan having cell growth action, skin moisturizing and irritation alleviating effects	Japan, 2004
KR100440357B1	Cosmetic compositions containing levan	South Korea, 2004
KR20080102486A	Cosmetic soap composition containing palm activated charcoal powder and levan powder	South Korea, 2007
US20110311463A1	Hair spray and hair mousse with natural ingredients	United States, 2010
WO2014164463A1	Natural hairstyle holding product containing levan as a film-former	WIPO (PCT), 2013
CN103961360A	Pharmaceutical composition for skin whitening	China, 2014
CN106176569A	A kind of prevent haze weather to the compositions of skin damage and application thereof	China, 2016
KR101938994B1	Functional Mask Pack Containing Natural Polymer levan	South Korea, 2017
JP6912772B2	Hyaluronic acid production promoter and cosmetics containing it	Japan, 2017
CN108113914B	Essence cream without essence and preservative and preparation method thereof	China, 2018
US11975092B2	Hair treatment compositions, methods, and kits for treating hair	United States, 2018
JP7366376B2	Epidermal cell differentiation promoter	Japan, 2019
US11964041B2	Compositions comprising levan and use thereof	United States, 2019
CN112386511A	Carrier-free facial mask and preparation method and application thereof	China, 2019
CN112741789A	Anti-aging composition, preparation method and application	China, 2020
CN112618431A	Novel whitening composition, preparation method and application	China, 2020
BR102020018762A2	Multifunctional facial biocosmetic with levan and cinnamon oil	Brazil, 2020
BR102020018678A2	Antioxidant cosmetic with levan, avocado oil and *aloe vera* extract	Brazil, 2020
KR102884057B1	Composition for preventing hair loss or promoting hair growth comprising a culture of *Bacillus subtilis* containing levan	South Korea, 2020
JP2023065179A	Film-forming agent and cosmetic blended with the same	Japan, 2021
CN113786379A	Lactic acid bacteria whitening and repairing essence and preparation method thereof	China, 2021
JP2023179392A	Hair cosmetic	Japan, 2023
JP2025076175A	Cosmetics or skin preparations containing levan and glycerin	Japan, 2023
KR102700139B1	Functional composition comprising synbiotics fermented composition and method for manufacturing the same	South Korea, 2023
CN117462447A	Cosmetic composition for skin regeneration comprising sucralfate	China, 2023
US20250360064A1	Compositions and methods for moisturizing a skin region	United States, 2024

substantially underexplored. Chemical and enzymatic modifications such as sulfation, carboxymethylation, hydrolysis, and phosphonation have been shown to modulate biological activity including antioxidant, cell-proliferative, and barrier-enhancing effects, yet only a limited number of derivatives have been systematically investigated in skin-relevant contexts. Future research should focus on establishing comprehensive structure–function profiles for levan and its derivatives, with particular attention to molecular weight, degree of branching, and the nature and degree of chemical substitution as determinants of cosmeceutical efficacy.

From a formulation perspective, the integration of levan into advanced delivery platforms including stimuli-responsive hydrogels, layer-by-layer assemblies, and nanostructured carriers, represents a promising avenue for improving the bioavailability and targeting of both levan itself and co-delivered active compounds. The demonstrated capacity of levan nanoparticles and nanoemulsions to enhance skin penetration and sustain active release underscores the value of nanotechnology-assisted formulation strategies, yet these systems have rarely been evaluated beyond laboratory-scale proof-of-concept studies. Translation of these platforms into stable, scalable, and regulatory-compliant cosmeceutical products represents a substantial opportunity for future development.

The prebiotic activity of levan and its implications for the skin microbiome constitute another underexplored dimension. Given the growing evidence linking gut and skin microbiome composition to inflammatory skin conditions, acne, atopic dermatitis, and skin aging, the potential of topically applied levan to selectively modulate the skin microbiota in favour of beneficial commensals warrants dedicated investigation. Mechanistic studies clarifying how levan interacts with skin-resident microbial communities, and whether these interactions translate into measurable improvements in skin barrier function or inflammatory status, would significantly strengthen the rationale for its inclusion in microbiome-targeted cosmeceutical formulations.

Finally, sustainability considerations should be integrated into future research agendas. As the cosmetics industry moves towards greener and more circular production models, the use of agricultural or industrial by-products as fermentation substrates for levan production, the development of biodegradable levan-based packaging materials, and life cycle assessment of levan-containing formulations are all areas deserving attention. Addressing these dimensions collectively will be essential for positioning levan not merely as a scientifically interesting biopolymer, but as a commercially viable, sustainable, and clinically validated active ingredient in next-generation cosmeceutical applications.

8. Conclusions

The cosmetics industry has become one of the largest and fastest-growing global markets, driven in large part by increasing consumer demand for safer, renewable, and biocompatible natural ingredients. In this context, levan polysaccharide has emerged as a compelling multifunctional candidate for cosmetic and cosmeceutical applications, offering a distinctive combination of biological activity and favorable physicochemical properties that distinguish it from more established polysaccharides such as hyaluronic acid and chitosan.

The evidence reviewed here demonstrates that levan possesses a broad and well-documented spectrum of biological activities relevant to skin health. Its antioxidant capacity has been consistently demonstrated across multiple assay systems, while repeated evidence of TNF-α suppression supports its anti-inflammatory potential. Its ability to inhibit tyrosinase activity positions it as a skin-brightening agent, and its modulation of MMP-2 and MMP-9 activity underpins its regenerative effects in wound and burn healing models. Levan's capacity to stimulate fibroblast and keratinocyte proliferation, upregulate structural proteins including collagen I, filaggrin, and involucrin, and enhance hyaluronic acid synthesis further reinforces its anti-aging and barrier-restoring potential. Complementary antimicrobial and immunomodulatory properties extend its utility to formulation preservation and the management of allergic and inflammatory skin conditions.

In fact, levan has been successfully incorporated into a wide range of cosmetic platforms including hydrogels, nanoparticles, nanoemulsions, films, foams, facial creams, shower gels, and hair care products. Its film-forming ability, low intrinsic viscosity, strong bioadhesivity, and physicochemical stability across a broad pH range make it a versatile and technically attractive base material, in addition to its role as a bioactive ingredient. Notably, its moisturizing performance has been shown to be comparable to hyaluronic acid, while its neutral charge and furanose ring flexibility confer additional sensory and functional advantages.

Despite these strengths, levan remains underutilized in the commercial cosmetics sector, primarily due to limited production scalability and restricted availability as a research and industrial ingredient. Growing demand for novel, sustainable, and clinically validated natural ingredients is expected to accelerate its entry into the cosmetic and cosmeceutical markets, provided that advances in bioprocess engineering reduce production costs and improve supply consistency.

While levan as an ingredient is considered as safe, regulatory strategies for cosmeceuticals vary considerably across countries, influencing not only consumer protection but also the sector's competitiveness and economic sustainability. At the regulatory level, the absence of a universally accepted definition for "cosmeceuticals," combined with substantial variability in ingredient safety assessment and adverse event reporting across jurisdictions, continues to present significant challenges for the global development of bioactive cosmetic ingredients. In response to these discrepancies, international initiatives such as the International Cooperation on Cosmetics Regulation (ICCR), which brings together regulatory authorities from countries including Brazil, Canada, Taiwan, the EU, Japan, South Korea, and the US, facilitate dialogue on safety and regulatory practices. Complementary harmonization efforts by the Organization for Economic Co-operation and Development (OECD) and the International Organization for Standardization (ISO) contribute to the standardization of testing methodologies and the development of internationally accepted frameworks. Nevertheless, despite these advances, only partial progress has been achieved, particularly in areas related to ingredient safety evaluation and adverse event reporting. Consequently, the sustainable growth of the cosmeceutical sector will depend on the establishment of more agile, evidence-based, and globally harmonized regulatory frameworks capable of balancing innovation with consumer safety.

In conclusion, levan stands at an important juncture, as supported by a growing body of scientific evidence, yet still awaiting the clinical validation, production scale-up, and regulatory clarity needed for broad commercial adoption. Addressing these gaps through coordinated multidisciplinary research will be decisive in realizing the full potential of levan as a next-generation active ingredient in advanced skin care and cosmeceutical formulations.

Abbreviations

DPPH	2,2-diphenyl-1-picrylhydrazyl
CAGR	Compound Annual Growth Rate
EPSs	exopolysaccharides
LS	levansucrase

CRediT authorship contribution statement

Edmilson Clarindo de Siqueira: Writing – review & editing, Formal analysis. **Bogdan Doboszewski:** Writing – review & editing, Writing – original draft. **Lütfiye Biçer:** Writing – review & editing, Writing – original draft, Formal analysis. **Kazuyuki Kimura:** Writing – review & editing. **Ebru Toksoy Oner:** Writing – review & editing, Formal analysis.

Consent for publication

Not applicable.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used a generative AI tool to assist with language editing and improving the clarity of the text. The authors reviewed and edited the output as necessary and take full responsibility for the content of this publication.

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