# Microbial-Derived Bioactive Peptides in Cosmetic Preservation: Antimicrobial Mechanisms, Formulation-Level Efficacy and Standardization Challenges

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## Abstract

Microbial-derived peptides are attracting interest as potential contributors to the preservation of cosmetic products. This group includes bacterial bacteriocins, peptides secreted by yeasts and peptide-containing fractions obtained through microbial fermentation. Although several preparations have shown antimicrobial activity under laboratory conditions, such findings cannot, on their own, establish that a finished cosmetic will remain adequately protected during storage and use. This review considers the microbial sources of these materials, their structural and analytical characterization, reported antimicrobial mechanisms, spectrum of activity and behaviour in cosmetic formulations. It also examines the distinction between postbiotic preparations and purified microbial metabolites, together with the practical requirements for stability, safety assessment and standardization. Published studies provide encouraging examples, including activity in selected cosmetic matrices. However, the evidence remains limited and product-specific. Further progress will depend on reliable ingredient characterization, consistent manufacturing, appropriate organism panels and preservative efficacy testing in the finished formulation.

Keywords: postbiotics; microbial-derived peptides; antimicrobial peptides; bacteriocins; cosmetic preservation; fermentation; preservative efficacy

## 1. Introduction

Water-containing cosmetic products provide conditions in which microorganisms may survive and, depending on the formulation and storage environment, multiply. Contamination can be introduced through raw materials, manufacturing equipment, the production environment, packaging or repeated consumer contact. Preservation is consequently an essential part of product safety and quality. It cannot be judged solely by whether one ingredient inhibits microbial growth in a laboratory assay; protection must be considered in relation to the complete formulation and the conditions under which the product is manufactured, stored and used [1,2].

Antimicrobial peptides (AMPs) are generally short molecules that contribute to host defence in a wide range of organisms [3]. Their potential as anti-infective agents has been studied because some display activity against different microbial groups and act through mechanisms that differ from those of many conventional antibiotics [4]. Microorganisms also produce antimicrobial peptides, including bacteriocins, which have attracted attention as possible ingredients or supporting components in preservation systems. Their incorporation into creams, lotions, shampoos and other topical products is of interest, although activity may be affected by peptide stability, selectivity, toxicity and interactions with the formulation [5].

The skin microbiome adds another dimension to this area of research. The composition of resident skin microorganisms varies with body site and is influenced by environmental and host-related factors [6]. An ingredient intended to protect a cosmetic from contamination should not automatically be assumed to have a beneficial or harmless effect on the skin microbiota. Product preservation and effects following application are separate questions and require different evidence.

Terminology also needs careful attention. The International Scientific Association for Probiotics and Prebiotics (ISAPP) defines a postbiotic as a preparation of inanimate microorganisms and/or their components that confers a health benefit on the host [7]. A purified microbial metabolite does not meet this definition simply because it originated from fermentation. A purified peptide, a cell-free fermentation supernatant and an inactivated microbial preparation are therefore not interchangeable categories. In cosmetic research, the name used for an ingredient should reflect its actual composition, manufacturing history and demonstrated function.

This review examines microbial-derived bioactive peptides in the context of cosmetic preservation and related topical applications. It considers the evidence linking antimicrobial activity to performance in finished products, discusses the analytical approaches needed to characterize peptide-containing ingredients and identifies the formulation and manufacturing issues that must be addressed before wider application can be justified.

## 2. Scope and Review Approach

This article is intended as an evidence-informed narrative review. Before submission, the literature search and screening process should be completed and recorded in sufficient detail for readers to understand how the evidence was selected. Relevant sources include Scopus, PubMed/MEDLINE, Web of Science and publisher databases, together with backward and forward citation searches of key primary studies and standards. Search terms should cover antimicrobial peptides, bacteriocins, microbial fermentation, postbiotics, yeast-derived peptides, cosmetic preservation, topical formulations, minimum inhibitory concentration (MIC) and preservative efficacy testing.

The final version should state the date on which each database was searched, provide the search strings and identify any date or language restrictions. Inclusion and exclusion criteria should be defined in advance. The manuscript should also report how many records were screened and retained, how many reviewers were involved and how disagreements were resolved. Studies reporting inhibition in broth or agar assays should be distinguished from those testing a peptide-containing ingredient in a finished or representative cosmetic formulation. Reviews can provide background and conceptual context, but specific claims about efficacy should be supported by primary research.

A narrative synthesis is appropriate where the available studies differ substantially in their materials, methods and test conditions. MIC values obtained using different organisms, media, inoculum sizes and incubation conditions should not be pooled as though they were directly comparable. Where the published information permits, each study should be considered in terms of the producing organism, nature of the tested material, fractionation procedure, test organisms, assay conditions, neutralization controls, formulation type and challenge-test findings. Until the search and screening steps have been completed, the article should be identified as a narrative review rather than a systematic review.

## 3. Microbial Sources and Classes of Bioactive Peptides

Bacteriocins are antimicrobial peptides synthesized ribosomally by bacteria [8]. They include relatively simple linear molecules as well as peptides that undergo extensive post-translational modification. Differences in sequence, structure and biosynthetic pathways contribute to the wide range of activities reported for this group. Microbial AMPs are distinct from host-derived defence peptides, and their production is often associated with specific biosynthetic gene clusters [9]. Despite extensive research, many bacteriocins remain incompletely characterized,

and their development beyond laboratory applications continues to present challenges [8]. For cosmetic use, these limitations underline the need to establish the identity of the active material and to demonstrate that it can be manufactured consistently.

Lactic acid bacteria are among the best studied bacteriocin-producing organisms. Their bacteriocins have been investigated extensively as food-preservation agents, providing useful information about production, activity and the influence of complex product matrices [10,14]. Protective cultures and bacteriocins have, for example, been used in dairy systems, where fat, protein content and pH can alter the amount of antimicrobial activity available [11]. Cosmetic emulsions present comparable formulation questions: surfactants, polymers, electrolytes and oil phases may all influence peptide distribution and activity. Bacteriocins can also shape microbial communities, making their ecological effects relevant when considering products intended for application to skin [12].

Bacteriocin production has been described as one of the traits that may contribute to the ecological function of probiotic organisms [13]. This provides a rationale for investigating selected producing strains, but the presence of a bacteriocin-producing organism does not demonstrate that its peptide will function as a preservative in a cosmetic. The peptide must be recovered or produced in a controlled manner, characterized and tested in the intended formulation.

Yeasts are another potential source of peptide-containing fermentation fractions. A 2024 study examined a 2–10 kDa fraction secreted by Saccharomyces cerevisiae and reported antimicrobial activity against a selection of dermal microorganisms, together with certain in-vitro skin-related activities. The reported MIC values differed between organisms. In the body-milk formulation evaluated in the study, the fraction met the stated ISO 11930:2019 challenge-

test criteria for the organisms tested, with the exception of Aspergillus brasiliensis [15]. This is useful proof-of-concept evidence, but it should be interpreted in the context of the particular fraction, concentrations, formulation and test conditions used. It does not establish equivalent performance for other yeast-derived materials.

Fermentation-derived preparations are often chemically complex. Depending on the organism, substrate and downstream processing, they may contain organic acids, enzymes, polysaccharides, residual nutrients, salts and a range of other metabolites. Research on fermented foods similarly shows that biological effects may arise from interactions among multiple components rather than from one isolated molecule [16]. The terminology used for postbiotic preparations has also developed over time, reinforcing the need to state clearly what a preparation contains and how it was produced [17]. When a crude filtrate or partially purified fraction inhibits microbial growth, the activity cannot be attributed to peptides without appropriate evidence. Fractionation, compositional analysis, peptide-depletion experiments and activity-guided purification can help establish the contribution of individual components. Neutralization controls are particularly important when testing acidic fermentates, since low pH alone may inhibit microbial growth.

Microbial surface structures and secreted products can influence interactions with host tissues and other microorganisms [18]. These effects may not be captured by a simple growth-inhibition assay. For this reason, characterization should extend beyond a nominal molecular-weight range or a general description such as 'ferment filtrate'.

## 4. Antimicrobial Mechanisms and Spectrum of Activity

Many antimicrobial peptides interact with microbial cell envelopes through a combination of electrostatic attraction and hydrophobic association. Cationic peptides can associate with

negatively charged components of bacterial surfaces, while their amphipathic structures may facilitate interaction with lipid membranes [19,20]. Depending on the peptide sequence, conformation, concentration and target organism, this interaction may increase membrane permeability, produce pores, disturb membrane potential or cause leakage of intracellular material [19,20].

Several models have been proposed to explain peptide-induced membrane disruption. In the barrel-stave model, peptides are arranged within the membrane to form a pore, whereas the toroidal model involves both peptides and lipid headgroups in the pore structure. Studies using model membranes have demonstrated that pore organization can vary with the peptide and experimental conditions [21]. Membrane disruption is not the only possible mechanism. Some peptides interfere with essential metabolic processes, while others bind specific cell-wall precursors. Nisin is a well-characterized example: it binds lipid II, thereby interfering with peptidoglycan synthesis, and can also promote pore formation [22,23].

These examples illustrate why antimicrobial peptides should not be treated as a mechanistically uniform group. Bacteriocins differ in their structures and targets [8], while host-defence peptides may also exert immunomodulatory or intracellular effects [24]. A mechanism established for one peptide cannot be assigned to another solely because both belong to the AMP category. Where a cosmetic ingredient is promoted on the basis of a specific antimicrobial mechanism, that claim should be supported by evidence obtained using the actual ingredient or a well-defined active fraction.

The spectrum of activity is equally important when considering preservation. Certain bacteriocins are particularly active against Gram-positive bacteria, while the outer membrane of Gram-negative organisms can restrict access to the cytoplasmic membrane. Yeasts and

moulds differ from bacteria in cell-wall composition and membrane organization and may respond quite differently to the same peptide. The Saccharomyces cerevisiae fraction described above illustrates this organism-dependent response: susceptibility varied across the test panel, and the challenge-test outcome was not uniform [15].

MIC testing provides a useful measure of growth inhibition under defined conditions, and standardized dilution procedures are available for antimicrobial susceptibility testing [25]. Nevertheless, an MIC result does not show whether an organism is killed, whether the ingredient remains active in a cosmetic matrix or whether the product will be protected throughout its shelf life and period of use. Minimum bactericidal or fungicidal concentrations, time-kill studies and viable-count recovery can provide additional information. Reports should describe the test medium, inoculum, incubation conditions, peptide concentration and purity, and the method used to neutralize antimicrobial carry-over. Without these details, comparisons between studies may be misleading.

## 5. From Antimicrobial Screening to Cosmetic Preservation

The ability of a peptide to inhibit microorganisms in a laboratory assay is an early indication of activity, not proof that it can preserve a cosmetic product. Preservative efficacy should be assessed in the finished product or in a formulation that adequately represents the product being developed. ISO 11930:2019 provides a framework for evaluating the antimicrobial protection of cosmetics through preservative efficacy testing and microbiological risk assessment [1]. It includes a reference challenge-test procedure and a risk-based approach for products considered in relation to the low-risk guidance in ISO 29621 [1,26]. Until the intended formulation has demonstrated adequate protection, a peptide-containing material is more accurately described as a candidate preservation ingredient.

The 2024 study of the Saccharomyces cerevisiae peptide fraction is particularly relevant because the investigators evaluated the material in a body-milk formulation using an ISO 11930:2019 challenge-test approach. The authors reported that the fraction, tested at organism-specific MICs, met the stated criteria for the organisms assessed except A. brasiliensis. They also reported synergistic effects against selected fungi when the fraction was combined with a commercial preservation system [15]. These findings support further investigation of peptide-based and combination approaches. At the same time, the organism-specific outcome demonstrates why a single overall statement of 'preservative efficacy' may conceal important differences in performance.

A separate 2024 investigation evaluated a Lactobacillus/radish-root ferment filtrate in an oil-in-water cream. Antimicrobial activity against selected bacteria and fungi and a favourable challenge-test outcome were reported for the tested base [27]. This study is relevant to the broader use of fermentation-derived cosmetic ingredients, but the tested material was a ferment filtrate rather than a purified peptide. Its activity should therefore not be used as direct evidence for a peptide-specific mechanism. Complex fermentates may contain several antimicrobial constituents, including organic acids and other low-molecular-weight metabolites.

Formulation composition can substantially change the performance of antimicrobial peptides. Relevant variables include pH, water activity, surfactant type, emulsifier system, polymer content, electrolyte concentration and the distribution of the peptide between aqueous and oil phases. Cationic peptides may interact with anionic surfactants or polymers, reducing the freely available concentration. Adsorption to packaging or interfaces, aggregation and proteolytic degradation may also reduce activity during storage. Consequently, promising

results in broth should be followed by compatibility studies, stability testing and a challenge test in the intended product.

The microbiological risk category of the product should be considered early in development. ISO 29621 provides guidance for identifying cosmetic products that may be regarded as microbiologically low risk [26]. Products that do not meet the relevant low-risk considerations require an appropriate preservation strategy and evaluation in line with ISO 11930 [1]. The suitability of a peptide ingredient will therefore depend not only on its intrinsic antimicrobial activity but also on the product category, packaging, manufacturing controls and expected conditions of use.

## 6. Analytical Characterization and Standardization

Characterization of a peptide-containing ingredient should go beyond reporting a broad molecular-weight range. Depending on the nature of the material, useful approaches may include total peptide or protein estimation, size-exclusion or reversed-phase chromatography, electrophoretic profiling, LC-MS/MS analysis, amino-acid composition and sequence confirmation. The analytical plan should be appropriate to the claim being made. A purified peptide can be described in terms of sequence and purity, whereas a complex fermentation-derived preparation may require a combination of compositional fingerprinting and functional assays.

A raw-material specification intended for cosmetic development should identify the producing microorganism and strain, fermentation substrate, key process parameters, clarification and concentration steps, and any inactivation procedure. It should also address residual microbial burden, peptide-content assay, chromatographic fingerprint, pH, dry matter, microbiological limits and recommended storage conditions. Where the ingredient is derived from an

inactivated microbial preparation, the inactivation status and evidence supporting it should be documented. These controls are consistent with the broader quality principles applied to cosmetic manufacturing and good manufacturing practice [28].

Batch consistency is a central requirement. Differences in substrate composition, temperature, aeration, fermentation time and downstream processing may alter the peptide profile even when the same production strain is used. Multiple independent batches should therefore be assessed before a material is considered reproducible. Strain identity should also be authenticated at appropriate intervals, since contamination or changes in the production culture can affect the final composition.

Standardization requires more than a specification sheet. Analytical methods used to quantify a claimed active peptide should be evaluated for specificity, linearity, accuracy and precision. For complex preparations in which the active constituents are not fully identified, a chemical fingerprint can be combined with a defined bioactivity assay. Such an approach does not replace identification of the active molecules, but it can provide evidence that successive batches have comparable composition and performance.

## 7. Safety, Skin Compatibility and Regulatory Considerations

The intended function of a peptide-containing ingredient should be stated clearly. Antimicrobial protection within the package is different from an effect on microorganisms present on the skin after application. An ingredient with broad antimicrobial activity may also influence resident skin organisms, and the consequences of repeated exposure to many candidate peptides have not been adequately established [6,29]. Since the skin microbiome contributes to barrier function and host interactions, selectivity and exposure deserve attention during safety assessment [29,30].

Safety evaluation should take account of the intended concentration, route and frequency of exposure, together with irritation, sensitization, cytotoxicity, impurities and residual fermentation components. In-vitro testing can contribute to this assessment. OECD Test Guideline 439, for example, describes a reconstructed human epidermis method for evaluating skin irritation potential [31]. The choice of tests should be justified by the ingredient's composition and intended use rather than relying on a single assay.

For cosmetics placed on the European Union market, Regulation (EC) No 1223/2009 establishes requirements for product safety and the safety assessment of cosmetic ingredients [32]. Guidance from the Scientific Committee on Consumer Safety outlines the types of information considered in the evaluation of cosmetic ingredient safety [33]. Other markets may apply different regulatory frameworks, and these should be considered when the ingredient is intended for international use. Claims that imply treatment or prevention of disease require separate regulatory consideration; antimicrobial activity in a preservation test does not establish a therapeutic benefit on skin.

Terminology should remain consistent with the composition of the material. The ISAPP definition does not support describing purified microbial metabolites as postbiotics solely because they were produced during fermentation [7]. Depending on the evidence, terms such as bacteriocin, antimicrobial peptide, yeast-derived peptide fraction, cell-free fermentate or inactivated microbial preparation may be more accurate. This distinction is not merely semantic: it affects how the ingredient is characterized, how its activity is interpreted and what evidence is needed to support its proposed use.

## 8. Research Gaps and Future Directions

Published studies provide a basis for further work on microbial-derived peptides in cosmetic preservation, but they do not support the general conclusion that these materials can replace conventional preservatives across product categories. The most immediate research needs include identification of active sequences in complex fractions, confirmation of mechanisms, testing against a suitably broad range of bacteria, yeasts and moulds, and evaluation of compatibility across different cosmetic bases. Stability during manufacture and storage, as well as reproducibility across independent production batches, also remain important gaps.

A practical development pathway should begin with authentication of the producing microorganism and documentation of the fermentation process. The resulting material should then be characterized chemically and microbiologically before antimicrobial activity is investigated using suitable controls. MIC and time-kill data can help establish activity under defined conditions, while cytotoxicity and skin-compatibility studies address selected safety questions. The ingredient should next be incorporated into representative cosmetic formulations, followed by stability studies and preservative efficacy testing using an appropriate standard and organism panel. Combination with established preservatives may be worth exploring, but claims of synergy should be based on experimental evidence.

Further insight could be gained by comparing purified peptides, crude fermentates and peptide-depleted fractions prepared from the same fermentation material. This design would help determine whether observed activity is attributable primarily to peptides, to other metabolites or to interactions among several components. Such work is particularly important when the ingredient is marketed or described as a postbiotic peptide preparation.

The terminology surrounding postbiotics and related concepts has developed over time, and consensus statements have helped clarify the use of these terms [7,34,35]. Cosmetic research would benefit from applying the same care to ingredient naming and characterization. A consistent vocabulary, combined with transparent reporting of composition and efficacy, would make it easier to compare studies and assess whether findings can be translated into practical formulation development.

## 9. Conclusion

Microbial-derived peptides represent an interesting area of research for cosmetic preservation. Selected bacterial and yeast-derived materials have demonstrated antimicrobial activity, and a limited number of studies have examined their performance in finished or representative cosmetic formulations [15,27]. The available evidence nevertheless remains dependent on the organism tested, the composition of the ingredient and the formulation in which it is used. Laboratory inhibition should not be equated with validated product preservation. Progress towards practical application will require reliable ingredient characterization, reproducible production, appropriate antimicrobial spectrum testing, finished-product challenge studies, stability assessment and safety evaluation. Clear distinctions between postbiotic preparations, purified peptides and complex fermentates are essential if the evidence is to be interpreted accurately and claims are to remain proportionate to the data.

## Tables

**Table 1. Evidence categories for microbial-derived peptide ingredients**

| Evidence category | Typical method | What it can establish |
|---|---|---|
| Composition and identity | LC-MS/MS, chromatography, electrophoresis | Whether a peptide or peptide-rich fraction is present and how consistently it is produced |
| In-vitro antimicrobial activity | MIC, MBC/MFC and time-kill assays | Growth inhibition or killing under defined assay conditions [25] |
| Formulation compatibility | pH, viscosity, appearance, stability and activity retention | Whether the material remains compatible and active in a selected base |
| Preservative efficacy | Finished-product challenge test, e.g. ISO 11930 | Antimicrobial protection of the tested cosmetic formulation [1] |
| Safety and skin compatibility | Cytotoxicity, irritation and sensitization assessment | Selected safety endpoints relevant to intended exposure [31,33] |

**Table 2. Key interpretation limits in the evidence base**

| Reported evidence | Interpretive limitation |
|---|---|
| Positive MIC result | Does not demonstrate preservation in a finished cosmetic. |
| Peptide fraction active in one emulsion [15] | Cannot be generalized to all formulations or product categories. |
| Activity in a crude fermentate [27] | Does not prove that peptides are the active constituents. |
| Challenge-test pass in one product | Applies to the tested formulation, test conditions and organism panel. |
| In-vitro skin-related bioactivity | Does not establish clinical benefit in consumers. |

## References

1. International Organization for Standardization. ISO 11930:2019. Cosmetics: Microbiology: Evaluation of the antimicrobial protection of a cosmetic product. Geneva: ISO; 2019. Includes Amendment 1:2022. https://www.iso.org/standard/75058.html

2. Alshehrei FM. Microbiological quality assessment of skin and body care cosmetics by using challenge test. Saudi J Biol Sci. 2024;31(4):103965. doi:10.1016/j.sjbs.2024.103965.

3. Zasloff M. Antimicrobial peptides of multicellular organisms. Nature. 2002;415:389–395. doi:10.1038/415389a.

4. Hancock REW, Sahl HG. Antimicrobial and host-defense peptides as new anti-infective therapeutic strategies. Nat Biotechnol. 2006;24:1551–1557. doi:10.1038/nbt1267.

5. Rahnamaeian M, Vilcinskas A. Short antimicrobial peptides as cosmetic ingredients to deter dermatological pathogens. Appl Microbiol Biotechnol. 2015;99:8847–8855. doi:10.1007/s00253-015-6926-1.

6. Byrd AL, Belkaid Y, Segre JA. The human skin microbiome. Nat Rev Microbiol. 2018;16:143–155. doi:10.1038/nrmicro.2017.157.

7. Salminen S, Collado MC, Endo A, Hill C, Lebeer S, Quigley EMM, et al. The International Scientific Association of Probiotics and Prebiotics (ISAPP) consensus statement on the definition and scope of postbiotics. Nat Rev Gastroenterol Hepatol. 2021;18:649–667. doi:10.1038/s41575-021-00440-6.

8. Sugrue I, Ross RP, Hill C. Bacteriocin diversity, function, discovery and application as antimicrobials. Nat Rev Microbiol. 2024;22:556–571. doi:10.1038/s41579-024-01045-x.

9. Cotter PD, Ross RP, Hill C. Bacteriocins: a viable alternative to antibiotics? Nat Rev Microbiol. 2013;11:95–105. doi:10.1038/nrmicro2937.
10. Papagianni M. Ribosomally synthesized peptides with antimicrobial properties: biosynthesis, structure, function, and applications. Biotechnol Adv. 2003;21:465–499. doi:10.1016/S0734-9750(03)00078-5.
11. Silva CCG, Silva SPM, Ribeiro SC. Application of bacteriocins and protective cultures in dairy food preservation. Front Microbiol. 2018;9:594. doi:10.3389/fmicb.2018.00594.
12. Heilbronner S, Krismer B, Brötz-Oesterhelt H, Peschel A. The microbiome-shaping roles of bacteriocins. Nat Rev Microbiol. 2021;19:726–739. doi:10.1038/s41579-021-00569-0.
13. Dobson A, Cotter PD, Ross RP, Hill C. Bacteriocin production: a probiotic trait? Appl Environ Microbiol. 2012;78:1–6. doi:10.1128/AEM.06169-11.
14. Cotter PD, Hill C, Ross RP. Bacteriocins: developing innate immunity for food. Nat Rev Microbiol. 2005;3:777–788. doi:10.1038/nrmicro1273.
15. Maurício EM, Branco P, Araújo ALB, Roma-Rodrigues C, Lima K, Duarte MP, et al. Evaluation of biotechnological active peptides secreted by Saccharomyces cerevisiae with potential skin benefits. Antibiotics. 2024;13(9):881. doi:10.3390/antibiotics13090881.
16. Marco ML, Heeney D, Binda S, Cifelli CJ, Cotter PD, Foligné B, et al. Health benefits of fermented foods: microbiota and beyond. Curr Opin Biotechnol. 2017;44:94–102. doi:10.1016/j.copbio.2016.11.010.
17. Aguilar-Toalá JE, Garcia-Varela R, Garcia HS, Mata-Haro V, González-Córdova AF, Vallejo-Cordoba B, Hernández-Mendoza A. Postbiotics: an evolving term within the

functional foods field. Trends Food Sci Technol. 2018;75:105–114. doi:10.1016/j.tifs.2018.03.009.

18. Lebeer S, Vanderleyden J, De Keersmaecker SCJ. Host interactions of probiotic bacterial surface molecules: comparison with commensals and pathogens. Nat Rev Microbiol. 2010;8:171–184. doi:10.1038/nrmicro2297.
19. Shai Y. Mode of action of membrane active antimicrobial peptides. Biopolymers. 2002;66:236–248. doi:10.1002/bip.10260.
20. Matsuzaki K. Why and how are peptide–lipid interactions utilized for self-defense? Magainins and tachyplesins as archetypes. Biochim Biophys Acta. 1999;1462:1–10. doi:10.1016/S0005-2736(99)00197-2.
21. Yang L, Harroun TA, Weiss TM, Ding L, Huang HW. Barrel-stave model or toroidal model? A case study on melittin pores. Biophys J. 2001;81:1475–1485. doi:10.1016/S0006-3495(01)75802-X.
22. Brogden KA. Antimicrobial peptides: pore formers or metabolic inhibitors in bacteria? Nat Rev Microbiol. 2005;3:238–250. doi:10.1038/nrmicro1098.
23. Wiedemann I, Breukink E, van Kraaij C, Kuipers OP, Bierbaum G, de Kruijff B, Sahl HG. Specific binding of nisin to the peptidoglycan precursor lipid II combines pore formation and inhibition of cell wall biosynthesis for potent antibiotic activity. J Biol Chem. 2001;276:1772–1779. doi:10.1074/jbc.M006770200.
24. Hancock REW, Diamond G. The role of cationic antimicrobial peptides in innate host defences. Trends Microbiol. 2000;8:402–410. doi:10.1016/S0966-842X(00)01823-0.

25. Clinical and Laboratory Standards Institute. Methods for Dilution Antimicrobial Susceptibility Tests for Bacteria That Grow Aerobically. 11th ed. CLSI standard M07. Wayne (PA): CLSI; 2018.
26. International Organization for Standardization. ISO 29621:2017. Cosmetics: Microbiology: Guidelines for the risk assessment and identification of microbiologically low-risk products. Geneva: ISO; 2017.
27. Juliano CCA, Magrini GA. A radish root ferment filtrate for cosmetic preservation: a study of efficacy of Kopraphinol. Appl Sci. 2024;14(17):7761. doi:10.3390/app14177761.
28. International Organization for Standardization. ISO 22716:2007. Cosmetics: Good manufacturing practices (GMP): Guidelines on good manufacturing practices. Geneva: ISO; 2007.
29. Grice EA, Segre JA. The skin microbiome. Nat Rev Microbiol. 2011;9:244–253. doi:10.1038/nrmicro2537.
30. Kong HH, Segre JA. Skin microbiome: looking back to move forward. J Invest Dermatol. 2012;132:933–939. doi:10.1038/jid.2011.408.
31. Organisation for Economic Co-operation and Development. Test No. 439: In Vitro Skin Irritation: Reconstructed Human Epidermis Test Method. OECD Guidelines for the Testing of Chemicals, Section 4. Paris: OECD; 2022.
32. European Parliament and Council. Regulation (EC) No 1223/2009 on cosmetic products. Official Journal of the European Union. 2009;L342:59–209.

33. Scientific Committee on Consumer Safety (SCCS). Notes of Guidance for the Testing of Cosmetic Ingredients and their Safety Evaluation. 12th revision. Brussels: European Commission; 2023.
34. Tsilingiri K, Rescigno M. Postbiotics: what else? Benef Microbes. 2013;4:101–107. doi:10.3920/BM2012.0046.
35. Sanders ME, Merenstein DJ, Reid G, Gibson GR, Rastall RA. Probiotics and prebiotics in intestinal health and disease: from biology to the clinic. Nat Rev Gastroenterol Hepatol. 2019;16:605–616. doi:10.1038/s41575-019-0173-3.