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Advances in the Research of Natural Preservatives

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Abstract: With growing consumer awareness of safety and health in food, dietary supplements, and cosmetics, the development and application of natural preservatives have become a research hotspot. This paper provides a systematic review of the main sources, classifications, mechanisms of action, and current applications of natural preservatives, with a focus on the antimicrobial properties of plant-derived extracts, antimicrobial peptides, and microbial metabolites, as well as their effectiveness in the food, dietary supplement, and cosmetic industries. The article also examines the safety evaluation and regulatory landscape of natural preservatives and offers insights into future development trends. Research indicates that natural preservatives not only exhibit strong antimicrobial and antioxidant activities but also meet consumer demand for "clean label" products, demonstrating broad application potential.

Keywords: Natural preservatives; Antibacterial; Food; Dietary supplements; Cosmetics

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1. Introduction

Natural preservatives refer to substances derived from plants, animals, or microorganisms that exhibit antimicrobial and antioxidant properties, primarily used to delay or inhibit the spoilage of food, dietary supplements, cosmetics, and other products. These preservatives are generally regarded as safe, non-toxic, and free from adverse effects. Although traditional chemical preservatives are highly effective, they may pose potential health risks, raising consumer concerns. With increasing demand for safety, health, and "green products," research into natural alternatives has become a key focus. In recent years, extensive experimental studies—both domestically and internationally—have been conducted on the synthesis, screening, antimicrobial performance, and mechanisms of natural preservatives, leading to significant advancements. This article aims to review the current state of research on natural preservatives, analyze their mechanisms of action and practical efficacy, and discuss future development trends, providing a reference for further exploration and innovation in this field.

2. Classification and Sources of Natural Preservatives

2.1. Plant-Based Preservatives

Plant-based preservatives are bioactive compounds derived from plants, including essential oils, plant extracts, and polyphenolic substances. For instance, rosemary extract (ARLE) contains nine active components—such as thujanol, camphor, and eucalyptol—that effectively extend product shelf life by reducing microbial counts to safe levels while enhancing sensory qualities. Essential oils from bay, clove, and cinnamon also demonstrate strong antimicrobial and antioxidant properties. Cinnamon oil is particularly potent, containing (E)-cinnamaldehyde (77.93%), eugenol (4.34%), trans-caryophyllene (3.68%), and linalool (2.79%). Barbosa et al. successfully used leaf extracts from cardoon (Cynara cardunculus L.) as a natural preservative, markedly prolonging the shelf life of poultry meat[1].

2.2. Animal-Derived Preservatives

Animal-derived preservatives are primarily obtained from secretions or tissue extracts of animals. Lysozyme, a hydrolytic enzyme that specifically targets bacterial cell walls, is found in human saliva, tears, egg whites, mammalian milk, as well as in plants and microorganisms. Insect antimicrobial peptides represent another crucial category of animal-derived preservatives. Based on their molecular structure and compositional characteristics, these peptides can be classified into four main types: cecropins, insect defensins, proline-rich peptides, and glycine-rich peptides. For instance, Pektaş et al. found that the defensive peptide from the four-spotted blister beetle (MqDef) exhibits strong activity against Staphylococcus aureus and methicillin-resistant Staphylococcus aureus (MRSA), while defensins from the bordered earwig (SmDef) and the red-legged black beetle (HrDef) effectively inhibit Candida tropicalis[2].

2.3. Microbial Preservatives

Microbial-derived preservatives are substances produced by microorganisms through metabolism or the microorganisms themselves that exhibit antimicrobial activity. Natamycin, polylysine, and nisin are all important examples of such preservatives. Natamycin effectively inhibits the growth of yeasts and molds, while polylysine demonstrates broad-spectrum antimicrobial properties. Nisin is a small peptide produced by Lactococcus lactis during fermentation in a denatured milk medium, consisting of 34 amino acid residues. Guo et al. found that nisin can effectively suppress the foodborne pathogen Staphylococcus aureus[3].

3. Mechanisms of Action of Major Natural Preservatives

3.1. Mechanisms of Membrane Disruption

Active components in plant essential oils, such as eucalyptol, can enhance membrane permeability, leading to leakage of cellular contents and eventual cell death. Potassium cinnamate effectively disrupts bacterial metabolism by breaking down biofilm structures, elevating intracellular reactive oxygen species, and compromising membrane integrity, ultimately causing cytoplasmic leakage and cell demise. Most amino acids in insect antimicrobial peptides carry a positive charge, enabling them to interact with the negatively charged phospholipids on bacterial membranes. This interaction results in significant ion efflux from the bacterial cells, disrupting osmotic balance and inducing cell death[4].

3.2. Mechanism of Cell Wall Hydrolysis

Lysozyme is a hydrolytic enzyme specifically targeting bacterial cell walls by breaking the β-1, 4-glycosidic bonds in peptidoglycan, leading to cell wall disruption and subsequent cell lysis. It exhibits particularly strong activity against Gram-positive bacteria due to their thick peptidoglycan layer. In contrast, its effectiveness against Gram-negative bacteria is limited by the presence of an outer membrane. However, its lytic action can be enhanced when combined with agents such as glycine, phytic acid, or polyphosphates[5].

3.3. Mechanism of Enzyme Activity Inhibition

Certain natural preservatives exert antimicrobial effects by inhibiting the activity of key enzymes. Sarcotoxin II disrupts bacterial cell wall synthesis, preventing bacteria from maintaining normal cell morphology and thereby hindering their growth. Attacin interferes with the transcription of outer membrane protein genes—Omp C, Omp F, Omp A, and LamB—in Escherichia coli, reducing the production of these proteins. This leads to increased membrane permeability and ultimately suppresses bacterial growth[6].

4. Advances in Applied Research

4.1. Applications in the Food and Health Product Industry

Natural preservatives are gaining increasing popularity in the food and health product industries. In meat preservation, rosemary extract (ARLE) has demonstrated strong inhibitory effects against common foodborne pathogens such as B. cereus, E. coli, P. aeruginosa, and S. aureus in beef burgers and luncheon meat. For fruits and vegetables, essential oils derived from bay, clove, and cinnamon have shown promising preservation performance. In bakery products, Angel Yeast has developed a natural biopreservative containing lactic acid bacteria and fermented rice culture, significantly extending shelf life. Chen et al. found that phenolic compounds in flaxseed oil can suppress the growth of E. coli and S. aureus, highlighting its potential for use in food and health-related applications[7].

4.2. Applications in Cosmetics

Amid the growing trend toward “clean beauty,” many cosmetic brands are turning to naturally derived preservatives to replace traditional synthetic ingredients. Tea tree essential oil, known for its strong antibacterial and antifungal properties, is commonly used in acne treatments and cleansing products. Anisic acid (derived from anise) and white willow bark extract—a natural source of salicylic acid—are frequently found in serums and moisturizers. Some well-known brands incorporate rosemary leaf extract as part of their preservation systems. Although sodium benzoate and potassium sorbate are often synthetically produced, they occur naturally in berries and fruits and are widely regarded as safe and effective nature-identical preservatives, commonly used in aqueous formulations such as toners and serums. Caprylyl glycol, derived from coconut oil, is another effective antimicrobial agent. Lactic acid and nisin, both natural byproducts of sugar fermentation, exhibit excellent antibacterial activity. Their gentle nature makes them ideal for skincare products designed for sensitive skin, as well as for baby and maternal care items. Naturally sourced polyols such as pentylene glycol and hexylene glycol help preserve products by reducing water activity, and are often combined with other preservatives to minimize overall usage. These are widely used in various creams and lotions. Studies have also found that Opuntia ficus-indica (EFOS) is rich in polyphenols, flavonoids, quinic acid, and hyperoside, demonstrating strong antimicrobial activity against Staphylococcus aureus and Fusarium solani, making it a promising natural preservative for cosmetic applications[8].

5. Challenges and Future Prospects

5.1. Current Challenges

Although natural preservatives offer numerous advantages, their complex extraction and purification processes, along with high costs, limit widespread application. Moreover, they are sensitive to environmental factors such as pH, temperature, and light, leading to stability issues. Some natural preservatives have a narrow antimicrobial spectrum, making them effective only against specific microorganisms. In addition, higher concentrations are often required to achieve preservation effects comparable to synthetic alternatives, increasing costs and potentially affecting product flavor.

5.2. Future Development Trends

Future research and development of natural preservatives may focus on efficient extraction, structural modification, and combination strategies. Advanced extraction techniques can enhance the efficiency of obtaining active compounds. Structural modification and chemical alteration of natural preservatives can improve their stability, solubility, and antimicrobial activity. In-depth exploration of synergistic effects among different natural preservatives could lead to the creation of highly effective composite preservation systems. Furthermore, the application of nanotechnology and microencapsulation can significantly enhance the stability and efficacy of natural preservatives.

6. Conclusion

As alternatives to traditional chemical preservatives, natural preservatives offer advantages such as safety, non-toxicity, and minimal side effects. Preservatives derived from plant, animal, and microbial sources exhibit strong antimicrobial activity and significant application potential. These natural agents work by disrupting cell membrane integrity, inhibiting cell wall synthesis, interfering with energy metabolism, and suppressing enzyme activity. They have been widely used in food, health supplements, and cosmetics. However, challenges remain, including high extraction costs, poor stability, and narrow antimicrobial spectra. Future advancements will rely on innovative technologies, structural modifications, combination strategies, and the development of novel formulations to overcome these limitations.

Disclosure statement

The author declares no conflict of interest.

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