



## Review article

## Sustainable preservative strategies for food safety and quality enhancements: a review

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### ABSTRACT

This review provides a comprehensive overview of recent advancements in food science, with a particular focus on the impact of novel preservation technologies on the biochemical, nutritional, and sensory integrity of diverse food matrices. Over the past decade, significant progress has been made in enhancing food safety through the development and application of innovative preservation strategies. The review highlights emerging technologies that have improved the efficiency and practicality of bio-preservation methods, including nano-enabled delivery systems for controlled release of bioactive compounds, probiotic-based preservation approaches that utilize beneficial microorganisms, and bioactive packaging systems designed to extend shelf life while maintaining food quality. It further discusses current regulatory considerations and addresses the importance of compliance with global food safety standards. Moreover, the integration of advanced technologies with traditional practices is identified as a key pathway toward achieving a more resilient and efficient food system. Overall, this review emphasizes that continued research and innovation are essential to balance food quality, safety, and sustainability in the evolving landscape of the food industry.

**Keywords:** Bio-preservation, Bacteriocins, Natural preservation, Non-thermal processing, Nutritional quality, VBNC state, Post-harvest physiology, Food safety, Microbial spoilage.

### INTRODUCTION

The global food industry faces a continuous challenge in balancing the rising demand for fresh, nutritious, and minimally processed products with the logistical necessity of extended shelf life. Food preservation and processing serve as the cornerstone of this balance, employing various physical, chemical, and biological mechanisms to inhibit microbial spoilage and oxidative degradation. Traditionally, methods such as cold storage and thermal processing have dominated field; however, modern research is increasingly focused on the biochemical and textural transitions that occur during these periods, particularly in sensitive matrices like edible fungi, aquatic species such as catfish, and fresh cut vegetables like green beans and pears.

As consumer preferences shift away from synthetic additives, there is a burgeoning interest in natural preservation and

bio-preservation strategies. Among these, bacteriocins, antimicrobial peptides produced by bacteria such as *Bacillus amyloliquefaciens*, have emerged as a novel approach to controlling pathogens without compromising food safety.

Similarly, the extraction of bioactive compounds from agricultural by-products, such as polysaccharides from garlic straw, demonstrated a sustainable path forward for meat preservation. these biological methods not only target common spoilage organisms but also address complex microbial behaviours, such as sublethal injury and the “viable but non-culturable” (VBNC) state, which can occur during non-thermal processing.

This review explores the multidimensional aspects of food preservation, from the fundamental biochemical changes in post-harvest produce to the commercial implementation of innovative

microbial metabolites. By examining the influence of storage conditions on the biological activities and sensory attributes of diverse food groups, this enables a deeper understanding of the diverse food preservation techniques required to extend food longevity while maintaining optimal nutritional quality and ensuring the highest standards of consumer safety. It also highlights the importance of selecting appropriate preservation methods based on the type of food matrix and its biochemical composition. Furthermore, it emphasizes the role of innovative and sustainable technologies in minimizing nutrient loss, preventing microbial contamination, and meeting evolving consumer demands for safe, high-quality, and minimally processed foods.

#### **Biochemical and nutritional changes during food processing and storage**

Domestic food processing goes a long way back in time; for example, heat for cooking was used 1.9 million years ago. Nowadays, food and meal preparation seems to be moving out of the home kitchen into factories, and pre-processed or processed/convenience foods are becoming a larger part of the daily diet. In addition, consumers are progressively focusing on the impact of their food on health, and demand foods that have a high nutritional quality, and aroma and natural flavor similar to freshly-made products. Therefore, nutritional quality is concurrent with food safety, and sensory perception is becoming an increasingly important factor in food choices<sup>[13]</sup>. The human digestive tract disintegrates food in order for nutrients to be released and be made available to the body. However, nutrients can undergo unwanted degradation upon processing and subsequent storage, negatively influencing the nutritional value of food and its physiological effects. Different processing techniques will result in different food structures, thereby also affecting bio accessibility, bioavailability, and overall nutritional value. Hence, food scientists and industry have an increased interest in both conventional and innovative processing methods that can provide products with good quality and high nutritional value, along with a stable shelf life. Processing methods significantly improve nutrient bioavailability, making certain compounds easier for the body to absorb. For example, heating tomatoes increases lycopene levels, while milling grains removes anti-nutritional factors like phytates. To ensure products meet label claims, food scientists use fortification strategies, such as adding heat-sensitive Vitamin C after thermal treatments to offset nutrient degradation<sup>[14]</sup>. Furthermore, monitoring biochemical markers such as lipid oxidation in oils or the Maillard reaction in dried fruits allows companies to set accurate shelf-life predictions and "Best Before" dates. In product development, insights into enzyme activity (like polyphenol oxidase) lead to "clean label" methods, such as blanching or acidulation, which prevent browning in pre-cut produce. Finally, controlled biochemical changes

during fermentation or sprouting break down complex proteins and starches, significantly improving the digestibility of foods like sourdough bread and yogurt.

#### **Antimicrobial peptides as natural bio-preservative to enhance the shelf-life of food**

Antimicrobial peptides (AMPs) are diverse group of natural proteins present in animals, plants, insects and bacteria<sup>[3]</sup>. These peptides are responsible for defense of host from pathogenic organisms. Chemical, enzymatic and recombinant techniques are used for the synthesis of antimicrobial peptides. These peptides have been found to be an alternative to the chemical preservatives<sup>[4]</sup>. Currently, nisin is the only antimicrobial peptide, which is widely utilized in the preservation of food. Antimicrobial peptides can be used alone or in combination with other antimicrobial, essential oils and polymeric nanoparticles to enhance the shelf-life of food. This review presents an overview on different types of antimicrobial peptides, purification

Antimicrobial peptides (AMPs) are used across various food sectors to prevent microbial spoilage and inhibit foodborne pathogens. In dairy products, they are integrated into cheese, yogurt, and milk to inhibit pathogens such as *Listeria monocytogenes* and *Escherichia coli*<sup>[5]</sup>. For meat and poultry, AMPs are applied to pork, beef, and minced meat to delay rancidity, reduce lipid oxidation, and control the growth of spoilage bacteria like *Staphylococcus aureus*. In the seafood industry, they maintain the freshness of fish fillets and shellfish by reducing microbial loads during refrigerated storage.

Furthermore, AMPs are applied to fruits and vegetables as edible coatings or films—such as on strawberries and mangoes—to maintain texture and inhibit surface-level spoilage. In baked goods and beverages, they control the growth of mold and yeast in products like bread, beer, and fruit juices without altering their sensory properties. Finally, AMPs are often incorporated into biodegradable films or hydrogels to provide a controlled release of antimicrobial agents during storage.

#### **Advanced commercial technologies in food preservation and processing**

Food preservation involves different food processing steps to maintain food quality at a desired level so that maximum benefits and nutrition values can be achieved. Food preservation methods include growing, harvesting, processing, packaging, and distribution of foods<sup>[6]</sup>. The key objectives of food preservation are to overcome inappropriate planning in agriculture, to produce value-added products, and to provide variation in diet. Food spoilage could be caused by a wide range of chemical and biochemical reactions. To impede chemical and microbial deterioration of foods, conventional and primitive techniques of preserving foods like drying, chilling, freezing, and pasteurization have been fostered. In recent years, the

techniques to combat these spoilages are becoming sophisticated and have gradually altered to a highly interdisciplinary science. Highly advanced technologies like irradiation, high-pressure technology, and hurdle technology are used to preserve food items [7]. Commercial food preservation and processing methods are applied across diverse sectors to ensure food security, variety, and safety. Canning and sterilization are used for meat, fish, and vegetables to produce shelf-stable products that can be stored at ambient temperatures for years. Pasteurization is primarily applied to liquid milk and fruit juices to destroy pathogenic bacteria while maintaining flavor and nutritional quality. Low-temperature preservation methods, such as freezing and chilling, are essential for maintaining the "fresh-like" quality of fruits, vegetables, and seafood during short- to long-term storage [8]. Individual Quick Freezing (IQF) allows for the bulk processing of small items like peas or shrimp, ensuring they remain separate and retain their texture. Additionally, dehydration is applied to grains, spices, milk powder, and instant coffee to reduce weight and volume, significantly lowering transportation and storage costs [9]. Advanced non-thermal methods include High Hydrostatic Pressure (HPP), used for premium juices and deli meats to preserve vitamins and taste without heat, and irradiation, which is applied to spices, potatoes, and fruits to eliminate pests and pathogens. Finally, chemical and biological methods such as fermentation enhance flavor and probiotic benefits in dairy and vegetables, while chemical additives like benzoates and nitrates provide low-cost protection against spoilage. This article analyzes the market economy surrounding these preserved and processed foods.

#### **Recent approaches in food bio-preservation**

Bio-preservation is a technique of extending the shelf life of food by using natural or controlled microbiota or antimicrobials. The fermentation products as well as beneficial bacteria are generally selected in this process to control spoilage and render pathogen inactive [10]. The special interest organism or central organism used for this purpose is lactic acid bacteria (LAB) and their metabolites. They are capable to exhibit antimicrobial properties and helpful in imparting unique flavor and texture to the food products [11]. The major compounds produced by LAB are bacteriocin, organic acids and hydrogen peroxide. Bacteriocin is peptides or proteins with antimicrobial activity. On the basis of size, structure and post-translational modification, bacteriocin is divided into four different classes. Due to non-toxic, non-immunogenic, thermo-resistance characteristics and broad bactericidal activity, LAB bacteriocins are considered good bio-preservative agents [12]. The most common LAB bacteriocin is nisin which has wider applications in food industry and has been Food and Drug Administration (FDA) approved. Nisin and other bacteriocin are being used in vegetables products, dairy and meat industries. Apart from LAB metabolites, bacteriophages and

endolysins has promising role in food processing, preservation and safety. Bacteriocins and endolysins are more suitable for DNA shuffling and protein engineering to generate highly potent variants with expanded activity spectrum. Genetically modified bacteriophages may also be helpful in bio-preservation, however; their safety issues must be addressed properly before selection as bio-preservative agent.

#### **Food preservation techniques and nanotechnology for increased shelf life of fruits, vegetables, beverages and spices**

Food wastage is a major issue impacting public health, the environment and the economy in the context of rising population and decreasing natural resources [15]. Wastage occurs at all stages from harvesting to the consumer, calling for advanced techniques of food preservation. Wastage is mainly due to presence of moisture and microbial organisms present in food. Microbes can be killed or deactivated, and cross-contamination by microbes such as the coronavirus disease 2019 (COVID-19) should be avoided. Moisture removal may not be feasible in all cases. Preservation methods include thermal, electrical, chemical and radiation techniques. We emphasize electrothermal, freezing and pulse electric field methods because they allow both pathogen reduction and improvement of nutritional and physicochemical properties. Ultrasound technology and ozone treatment are suitable to preserve heat sensitive foods. Finally, nanotechnology in food preservation is discussed.

Nanotechnology offers several innovative applications in food preservation, ranging from nanocoatings and edible films such as those made from chitosan or essential oils to active nanopackaging [15]. By applying these films to fruits like strawberries or mangoes, producers create a gas barrier that slows respiration and moisture loss. Furthermore, incorporating silver (Ag) or zinc oxide (ZnO) nanoparticles into plastic films provides strong antibacterial and antifungal protection for fresh produce. In the beverage industry, nanocarriers like liposomes protect heat-sensitive vitamins and antioxidants from degradation during storage. Additionally, smart packaging uses integrated nanosensors to provide real-time freshness indicators by changing color when they detect ethylene gas or microbial by-products. Finally, nano-milling techniques for spices increase the bioavailability of active compounds, such as curcumin, while significantly enhancing their natural antimicrobial strength.

#### **Bacteriophages are sustainable preservation options for food safety**

Food safety and sustainable food production is an important part of the Sustainable Development goals aiming to safeguard the health and wellbeing of humans, animals and the environment. Foodborne illness is a major cause of morbidity and mortality, particularly as the global crisis of antimicrobial resistance proliferates. In order to actively move towards sustainable food

production, it is imperative that green biocontrol options are implemented to prevent and mitigate infectious disease in food production (Gravery, 2022). Replacing current chemical pesticides, antimicrobials and disinfectants with green, organic options such as biopesticides is a step towards a sustainable future. Bacteriophages, virus which infect and kill bacteria are an area of great potential as biocontrol agents in agriculture and aquaculture. Lytic bacteriophages offer many advantages over traditional chemical-based solutions to control microbiological contamination in the food industry. The innate specificity for target bacterial species, their natural presence in the environment and biocompatibility with animal and humans means phages are a practical biocontrol candidate at all stages of food production, from farm-to-fork. Phages have demonstrated efficacy as bio-sanitisation and bio-preservation agents against many foodborne pathogens, with activity against biofilm communities also evident. Additionally, phages have long been recognised for their potential as therapeutics, prophylactically and metaphylactically. Further investigation is warranted however, to overcome their limitations such as formulation and stability issues, phage resistance mechanisms and transmission of bacterial virulence factors.

The application of bacteriophages serves as a powerful tool for biocontrol in livestock, as they can be administered to live animals like poultry or cattle to reduce pathogen colonization before slaughter [17]. On the production line, phages are used for surface decontamination, sprayed onto raw meats or fresh-cut produce to eliminate threats like *Listeria monocytogenes* without altering the food's flavor. For bio-preservation, they are added directly to brine or packaging to suppress spoilage bacteria and extend shelf life. Beyond direct food contact, these agents are used for bio-sanitisation to clean equipment, effectively breaking down bacterial biofilms that traditional chemicals often miss. Finally, modified phages act as "reporter" molecules for rapid detection, allowing for the identification of specific bacteria in food samples much faster than traditional culture methods. Consumers and industry experts frequently have negative perceptions of most chemical preservatives. Although most people concede that they cannot resolve global food waste issues without preservatives, they prefer products without chemical preservatives [18]. Numerous emerging technologies is now surpassing conventional methods for mitigating microbial food deterioration in response to consumer demand and fundamental health and safety considerations, including biological antimicrobial systems such as using food-grade microorganisms and their metabolites primarily originating from microorganisms, plants, and animals. Microbial compounds, including bacteriocins, bacteriophages, and anti-fungal agents, plant extracts such as flavonoids and essential oils; and animal-originated compounds, such

as lysozyme, chitosan, and lactoferrin, are considered some of the major bio-preservatives. These natural compounds can be used alone or with other preservatives to improve food safety. Hence, the use of microbes or their metabolic byproducts to extend the shelf life of foods while maintaining safety standards is known as bio-preservation. To manufacture and consume foods in a safe condition, this review primarily aims to broaden knowledge amongst industry professionals and consumers regarding bio-preservation techniques, bio-preservatives, their classifications, and distinctive mechanisms to enhance food safety.

### **Italian microbial culture collections of conserved biological resources**

Microorganisms, microbiomes, and their products (e.g., enzymes, metabolites, antibiotics, etc.) are key players in the functioning of both natural and anthropized Earth ecosystems; they can be exploited for both research purposes and biotechnological applications, including fighting the big challenges of our era, such as climate change. Culture collections (CCs) and microbial Biological Resource Centres (mBRCs) are repositories of microorganisms that investigate and safeguard biodiversity and facilitate the scientific and industrial communities' access to microbial strains and related know-how by providing external users with skills and services [19]. Considering this, CCs and mBRCs are pivotal. Italy is, indeed, a hotspot of microbial biodiversity with a high rate of endemism and incredible potential, not only for the food and beverage sector (i.e., "Made in Italy" products), where microorganisms can have a beneficial or a spoiling function, but also to guarantee environmental sustainability and foster the bioeconomy through the design of new bioprocesses and products. However, weaknesses, such as the lack of management rules in accordance with international quality standards, are also analysed, and ways of overcoming them are discussed. In food and beverage innovation, these methods provide authentic "starter cultures" for traditional Italian products such as DOP cheeses (Parmigiano Reggiano), cured meats, and regional wines to ensure both consistency and historical accuracy [20]. Beyond food, these cultures are vital for pharmaceutical discovery, where rare microbial strains are screened for secondary metabolites that could lead to new antibiotics or anti-cancer drugs. In agriculture and biocontrol, specific soil microbes (PGPR) are utilized to enhance crop growth and develop bio-pesticides, reducing the reliance on synthetic chemicals. Furthermore, these resources aid in bioremediation by identifying "extremophile" bacteria capable of breaking down pollutants and plastics at industrial sites. Finally, they serve as essential reference standards, supplying certified, high-quality strains for diagnostic labs to ensure that experimental results remain reproducible globally.

### New advances in biological preservation technology for aquatic products

Aquatic products, characterized by their high moisture content, abundant nutrients, and neutral pH, create an optimal environment for the rapid proliferation of spoilage organisms, lipid oxidation, and autolytic degradation. These factors collectively expedite the spoilage and deterioration of aquatic products during storage and transportation within the supply chain [21]. To maintain the quality and extend the shelf-life of aquatic products, appropriate preservation methods must be implemented. The growing consumer preference for bio-preservatives is primarily driven by consumer demands for naturalness and concerns about environmental sustainability. Moreover, the preservation mechanisms of bio-preservatives, including antioxidant activity, inhibition of spoilage bacteria and enzyme activity, and the formation of protective films are reviewed. Integration of bio-preservation techniques with other methods, such as nanotechnology, ozone technology, and coating technology that enhance the fresh-keeping effect are discussed. Importantly, the principal issues in the application of bio-preservation technology for aquatic products and their countermeasures are presented [21].

Biological preservation in aquatic products is often implemented as part of a hurdle technology strategy, where multiple mild treatments are combined to ensure safety and quality. Edible coatings and films, such as those derived from chitosan or algal polysaccharides (like sodium alginate), create physical barriers on fillets that reduce moisture loss, block oxygen, and inhibit spoilage bacteria like *Pseudomonas*. These systems are further enhanced by natural antimicrobials, including plant essential oils and bacteriocins (such as Nisin), which disrupt pathogen cell membranes and extend the shelf life of vacuum-packed fish. On a microbial level, lactic acid bacteria (LAB) are used as protective cultures to outcompete spoilage organisms, while bacteriophage therapy provides a targeted "biological spray" to eliminate *Listeria* or *Vibrio* in raw seafood. Finally, nanotechnology integration—specifically nano-encapsulation—allows for the slow, controlled release of essential oils. This innovation not only doubles the shelf life of fillets like *Huso huso* but also masks the pungent aromas of the oils, preserving the product's sensory appeal.

### CONCLUSION

The food industry is progressively moving toward a precision-based preservation approach that strategically combines traditional storage practices with modern, natural bio-preservation technologies. Conventional methods, such as harvesting crops at optimal physiological maturity, controlled atmosphere storage, and temperature management, continue to play a vital role in extending shelf life and maintaining post-harvest quality. However, with

growing consumer awareness and demand for minimally processed, chemical-free foods, there has been a significant shift toward the use of natural bio-preservatives. Among these, antimicrobial peptides (AMPs) have emerged as highly promising agents due to their broad-spectrum activity against foodborne pathogens and spoilage microorganisms. These peptides often derived from plants, animals, or microorganisms, function by disrupting microbial cell membranes, thereby enhancing food safety without compromising nutritional and sensory attributes. In addition to improving microbial stability, the incorporation of AMPs and other natural preservatives supports the clean-label movement, which emphasizes transparency and the reduction of synthetic additives in food products. This transition is further supported by advances in biotechnology, nanotechnology, and encapsulation techniques that aim to improve the stability, controlled release, and effectiveness of these bioactive compounds within diverse food matrices. Despite these advantages, several challenges hinder their widespread industrial application. High production and purification costs, potential degradation during processing and storage, interactions with complex food components, and regulatory constraints pose significant barriers to commercialization. Furthermore, ensuring consistent efficacy across different food systems remains a critical concern. To fully realize the potential of precision preservation, ongoing research is focused on developing cost-effective production methods, enhancing peptide stability through innovative delivery systems, and optimizing their integration into existing food processing frameworks. Collaborative efforts between academia, industry, and regulatory bodies will be essential to overcome these challenges. Ultimately, the successful adoption of such integrated preservation strategies will not only extend shelf life and improve food safety but also contribute to sustainability, reduced food waste, and enhanced consumer trust in food products.

### Conflicts of interest

The authors declare no conflicts of interest.

### REFERENCES

1. Kaur K, Dhillon W S, 2015. Influence of maturity and storage period on physical and biochemical characteristics of pear during post cold storage at ambient conditions. *Journal of Food Science and Technology*. 52(8), Pages 5352-5356. Doi: 10.1007/s13197-014-1620-3.
2. Bouzo C A, 2017. Effect of different packaging materials on post-harvest quality parameters of pear under zero energy chamber storage condition. *International Journal of Current Microbiology and Applied Science*. Doi: 10.20546/IJCMAS.2017.609.141.
3. Li J, Hu S, Jian W, 2021. Plant antimicrobial peptides: structures, functions, and applications. *Botanical Studies*. 62(1), Page 5. Doi: 10.1186/s40529-021-00312-4.
4. Rai M, Pandit R, Gaikwad S, 2016. Antimicrobial peptides as natural bio-preservative to enhance the shelf-life of food.

- Journal of food science and technology, 53(9), Pages 3381-3394. Doi: 10.1007/s13197-016-2258-2.
5. Benkerroum N, 2010. Antimicrobial peptides generated from milk proteins: a survey and prospects for application in the food industry. A review. *International Journal of Dairy Technology*. 63(3), Pages 320-338. Doi: 10.1111/j.1471-0307.2010.00615.x.
  6. Amit S K, Uddin M M, Rahman R, et al, 2017. A review on mechanisms and commercial aspects of food preservation and processing. *Agriculture & Food Security*. 6(1), Pages 51. Doi: 10.1186/s40066-017-0130-8.
  7. Priyanka S, Kumar E A, Moses J A, et al, 2024. Food preservation and Hurdle Technology. In *Emerging Technologies for the Food Industry*. Apple Academic Press. Pages 39-84.
  8. Leng D, Zhang H, Tian C, 2022. Low temperature preservation developed for special foods in East Asia: A review. *Journal of Food Processing and Preservation*. 46(1), Apple Academic Press. Doi: e16176. 10.1111/jfpp.16176.
  9. Vaishali H P S, Dholu U, Sharma S, et al, 2020. Effect of freezing systems and storage temperatures on overall quality of perishable food commodities. *The Pharma Innovation Journal*, 9(9), Pages 114-122.
  10. Mokoena M P, Omatola C A, Olaniran A O, 2021. Applications of lactic acid bacteria and their bacteriocins against food spoilage microorganisms and foodborne pathogens. *Molecules*. 26(22), Page 7055. Doi: 10.3390/molecules26227055.
  11. Punia Bangar S, Chaudhary V, Thakur N, et al, 2021. Natural antimicrobials as additives for edible food packaging applications: A review. *Foods*. 10(10), Page 2282. Doi: 10.3390/foods10102282.
  12. Rahmani M, Saffari F, Domann E, et al, 2022. Enterococci as intestinal microbiota: investigation of characteristics and probiotic potential in isolates from adults and breast-fed infants. *Probiotics and Antimicrobial Proteins*. 14(6), Pages 1139-1150. Doi: 10.1007/s12602-021-09856-8.
  13. Röhr A, Lüddecke K, Drusch S, et al, 2005. Food quality and safety—consumer perception and public health concern. *Food control*. 16(8), Pages 649-655. Doi: 10.1016/j.foodcont.2005.02.003.
  14. Ağagündüz, D, Ayakdaş G, Katircioğlu B, et al, 2025. Advances in non-thermal food processing: a comprehensive approach to nutrient retention, food quality, and safety. *Sustainable Food Technology*. 3(5), Pages 1284-1308. Doi: 10.1039/D5FB00136F.
  15. Wani N R, Rather R A, Farooq A, et al, 2024. New insights in food security and environmental sustainability through waste food management. *Environmental Science and Pollution Research*. 31(12), Pages 17835-17857. Doi: 10.1007/s11356-023-31528-7.
  16. Wang X, Wang Y, Zhu H, et al, 2025. Emerging strategies for food preservation: recent advances and challenges in nanotechnology for edible coatings. *Agricultural Products Processing and Storage*. 1(1), Page 13. Doi: 10.1007/s44462-025-00015-7.
  17. Gildea L, Ayariga J A, Robertson B K, 2022. Bacteriophages as biocontrol agents in livestock food production. *Microorganisms*. 10(11), Pages 2126. Doi: 10.3390/microorganisms10112126.
  18. Obahiagbon E G, Ogwu M C, 2024. Organic food preservatives: The shift towards natural alternatives and sustainability in the global south's markets. In *Food safety and quality in the global south*. Singapore: Springer Nature Singapore. Pages 299-329. Doi: 10.1007/978-981-97-2428-4\_10.
  19. Moretti M, Tartaglia J, Accotto G P, et al, 2024. Treasures of Italian microbial culture collections: an overview of preserved biological resources, offered services and know-how, and management. *Sustainability*. 16(9), Page 3777. Doi: 10.3390/su16093777.
  20. Li S, Du D, Wang J, 2024. Application progress of intelligent flavor sensing system in the production process of fermented foods based on the flavor properties. *Critical reviews in food science and nutrition*. 64(12), Pages 3764-3793. 10.1080/10408398.2022.2156057.
  21. Nie X, Zuo Z, Zhang R, et al, 2025. New advances in biological preservation technology for aquatic products. *npj Science of Food*. 9(1), Page 15. Doi: 10.1038/s41538-025-00385-6.