Biopreservation: As a Natural Strategy for Enhancing Meat Safety and Shelf Life

VETERINARY TODAY INTERNATIONAL
ISSN 2583-8288

Dr. Shriya Khajuria[3], Dr. Suthar Vishalkumar Shankarji[3], Dr.Shriya Patnaik[2], Dr. Patel Jainam Nanubhai[*1]

[*1]Assistant Professor, Department of Livestock Products Technology, College of Veterinary Science and Animal Husbandry, Kamdhenu University, Anand, Gujarat. jainam.shiv@gmail.com
[2]PhD Scholar, Department of Livestock Products Technology, College of Veterinary Science and Animal Husbandry, Kamdhenu University, Anand, Gujarat.
[3]MVSc Scholar, Department of Livestock Products Technology, College of Veterinary Science and Animal Husbandry, Kamdhenu University, Anand, Gujarat.
doi.org/10.5281/Veterinarytoday.19821037

Abstract

Biopreservation has emerged as an innovative and sustainable approach to improve the safety and shelf life of meat and meat products. It involves the use of beneficial microorganisms and their antimicrobial metabolites to inhibit spoilage organisms and foodborne pathogens. With increasing consumer demand for minimally processed and chemical-free foods, biopreservation offers a sustainable alternative to synthetic preservatives.

Keywords: Biopreservation, Meat Safety, Shelf Life, Lactic Acid Bacteria, Bacteriocins, Natural Preservatives.

Introduction

Meat is a highly perishable commodity due to its rich nutrient composition, which supports microbial growth. Spoilage and contamination by pathogens such as *Salmonella*, *Listeria monocytogenes* and *Escherichia coli* pose significant risks to public health (Barcenilla *et al*., 2022). Conventional preservation methods, including refrigeration and chemical additives, have limitations and may not meet consumer expectations for natural food products. Biopreservation, defined as the use of natural or controlled microbiota and their antimicrobial products, has gained attention as a safe and eco-friendly preservation technique (Stiles, 1996). It primarily utilizes lactic acid bacteria (LAB) and their metabolites such as bacteriocins, organic acids and hydrogen peroxide to enhance meat safety and extend shelf life. In response, biopreservation has gained attention as a natural alternative to chemical preservatives.

Principles of Biopreservation

Biopreservation is based on the ability of protective microorganisms to control undesirable microbes through ecological competition and antimicrobial activity. These microorganisms dominate the food microenvironment and inhibit spoilage and pathogenic bacteria, thereby improving product stability and safety (Cocolin, 2025).

Mechanisms of Biopreservation

Production of Antimicrobial Compounds: Lactic acid bacteria (LAB) produce antimicrobial compounds such as organic acids, hydrogen peroxide, and bacteriocins. Bacteriocins are small antimicrobial peptides that are effective across a wide range of environmental conditions and inhibit foodborne pathogens (Fernandes *et al*., 2024). Lactic acid bacteria produce several antimicrobial substances, including organic acids (lactic acid, acetic acid), hydrogen peroxide, and bacteriocins such as nisin. These compounds inhibit spoilage and pathogenic microorganisms by lowering pH and disrupting cell membranes (Galvez *et al*., 2007).

Competitive Exclusion: Protective cultures suppress spoilage microbes by rapidly colonizing the meat surface, competing for nutrients and attachment sites, and limiting pathogen establishment. This early dominance helps reduce microbial proliferation and supports safer, longer-lasting meat products. (Barcenilla *et al*., 2022).

Reduction of pH: LAB produce lactic acid during fermentation, which lowers the pH of meat products and creates an acidic environment that suppresses spoilage bacteria and pathogens. This acidification also improves product stability and is especially important in fermented meats, where rapid pH decline supports safety and shelf life (Bhattacharya *et al*., 2022).

Disruption of microbial cells: Bacteriocins are antimicrobial peptides that attack target bacteria mainly by damaging cell membranes, causing leakage of cellular contents and loss of membrane potential. In some cases, they also interfere with cell wall synthesis, leading to the death of sensitive microorganisms. Nisin is a classic example used in food preservation (Putri *et al*., 2024).

Enzymatic activity: Some protective cultures produce enzymes such as nitrite reductase and catalase, which can reduce unwanted compounds and limit microbial metabolism. These activities may help lower nitrite residues, reduce formation of harmful metabolites, and improve the overall safety and stability of meat products without compromising sensory quality (Leroy & De Vuyst, 2004).

Microorganisms Used in Biopreservation

Lactic acid bacteria (LAB) are the most important biopreservative cultures in meat products because they are generally safe and produce lactic acid, hydrogen peroxide, diacetyl, and antimicrobial peptides that suppress spoilage and pathogenic microbes (Barcenilla *et al*., 2022). Common LAB used in meat systems include *Lactiplantibacillus plantarum*, *Lactobacillus sakei*, *Pediococcus acidilactici*, *Pediococcus pentosaceus*, *Lactococcus lactis*, and *Enterococcus faecium*. Many of these strains also act through competitive exclusion and by lowering pH, thereby improving shelf life without harming sensory quality.

Bacteriocin – producing cultures are especially valuable against Gram - positive pathogens such as *Listeria monocytogenes*. Important bacteriocins include **nisin** from *Lactococcus lactis*, **pediocin** from *Pediococcus* spp., **enterocin** from *Enterococcus* spp., **sakacin** from *Lactobacillus sakei*, **lacticin**, and **pentocin**. Protective cultures are carefully selected strains added to meat products to control undesirable microbes while maintaining flavour, colour, and texture. Examples include *L. sakei*, *L. plantarum*, and *P. acidilactici*, which are widely explored in fermented and ready-to-eat meats (Bhattacharya *et al*., 2022).

Protective cultures, such as *Lactobacillus sakei*, *Lactiplantibacillus plantarum*, and *Pediococcus acidilactici*, are added to meat products to suppress spoilage and pathogenic microbes through acidification, competition for nutrients, and bacteriocin production. They help maintain microbial stability, extend shelf life, and preserve the sensory quality of the final product.

Application in Meat and Meat Products

Biopreservation has wide applications across different meat systems because it helps control spoilage organisms and foodborne pathogens while supporting product quality and shelf life. In **fresh meat**, biopreservatives can be applied to slow microbial growth, reduce surface contamination, and delay rancidity and spoilage during chilled storage, thereby maintaining freshness for a longer period (Fernandes *et al*., 2024).

In **processed and fermented meat products**, LAB such as *Lactiplantibacillus plantarum*, *Lactobacillus sakei*, and *Pediococcus acidilactici* are commonly used because they contribute not only to safety but also to acid development, flavour formation, and texture improvement (Bhattacharya *et al*., 2022).

In **ready-to-eat meat products**, biopreservation is especially valuable because these foods may be contaminated after heat processing during slicing, packaging, or handling. Protective cultures and bacteriocin-producing strains help suppress *Listeria monocytogenes* and other contaminants without affecting product acceptability. (Barcenilla *et al*., 2022).

In **edible coatings and active packaging**, bioactive compounds such as bacteriocins can be incorporated into films or coatings to create an extra antimicrobial barrier on the product surface, improving safety and extending shelf life. This approach is particularly useful for high-moisture meat products that are prone to rapid surface spoilage.(Sharma *et al*., 2017).

Advantages of biopreservation

Biopreservation is increasingly valued because it offers a natural, chemical-free way to extend the keeping quality of meat and meat products while supporting consumer demand for minimally processed foods. By slowing the growth of spoilage organisms and foodborne pathogens, it helps improve shelf life, enhance microbial safety, and maintain product quality. It is also considered a sustainable approach because it can reduce reliance on synthetic preservatives and aligns well with clean-label food trends (Cocolin, 2025).

Limitations and challenges

Despite its potential, biopreservation faces certain limitations. The antimicrobial action of bacteriocins is often narrow, making them effective against only selected target organisms, and their performance may decline in complex food matrices such as meat, where fats, proteins, and salts can reduce activity. Their effectiveness may also be influenced by the native microflora already present in the product. In addition, regulatory approval, large-scale standardization, and commercialization remain important challenges for wider adoption (Fernandes *et al*., 2024).

Integration with Other Preservation Techniques

Biopreservation is often most effective when used as part of **hurdle technology**, where it works alongside refrigeration, vacuum packaging, or modified atmosphere packaging (MAP) to slow microbial growth more efficiently than any single method alone (Barcenilla *et al*., 2022). For example, LAB cultures have been combined with chilled storage in fresh meat to reduce spoilage during distribution; bacteriocin-producing starter cultures have been used in fermented sausages to improve control of *Listeria monocytogenes*; and biopreservatives in MAP-packaged ready-to-eat meat help maintain safety under low-oxygen conditions (Barcenilla et al., 2022; Fernandes *et al*., 2024). Vacuum packaging also supports biopreservation by limiting oxygen availability, which helps suppress aerobic spoilage bacteria and extends refrigerated shelf life (Fernandes et al., 2024). One of the relevant company is **Linde**, which offers MAPAX modified atmosphere packaging solutions that can be combined with chilling to help inhibit microbial growth and extend shelf life in meat and poultry products. **Kerry Group**, which develops clean-label antimicrobial and fermentation-based preservation systems that can be combined with chilled storage or packaging to improve meat safety and shelf life. **Godavari Biorefineries Ltd.**, is a major Indian bio-based company known for producing ethanol and other bio-based chemicals; in a biopreservation context. It can be mentioned as an Indian **bio-solutions** company relevant to sustainable preservation and clean-label processing.

Future Perspectives

Recent research focuses on developing novel bacteriocins, bioengineered strains, and advanced delivery systems such as active packaging. Sustainable bioprotection strategies are expected to play a key role in future meat processing systems (Cocolin, 2025). Adopting integrated approaches combining microbiology, food technology, and sustainability will strengthen the application of biopreservation in ensuring safe meat products.

Conclusion

Biopreservation represents a promising natural strategy for enhancing meat safety and extending shelf life. By utilizing beneficial microorganisms and their antimicrobial compounds, it provides an effective alternative to synthetic preservatives. Continued research and technological advancements will further improve its application and contribute to safer, high-quality, and sustainable meat products.

References

Barcenilla, C., Ducic, M., Lopez, M., Prieto, M., & Alvarez-Ordonez, A. (2022). Application of lactic acid bacteria for the biopreservation of meat products: A systematic review. *Meat Science, 183*, 108661. https://doi.org/10.1016/j.meatsci.2021.108661

Bhattacharya, D., Nanda, P. K., Pateiro, M., Lorenzo, J. M., Dhar, P., & Das, A. K. (2022). Lactic acid bacteria and bacteriocins: Novel biotechnological approach for biopreservation of meat and meat products. *Microorganisms, 10*(10), 2058. https://doi.org/10.3390/microorganisms10102058

Cocolin, L. (2025). Microbial bioprospection: An opportunity to improve safety and quality of meat products in a sustainable way. *Meat Science, 219*, 109576. https://doi.org/10.1016/j.meatsci.2024.109576

Fernandes, N., Achemchem, F., Gonzales-Barron, U., & Cadavez, V. (2024). Biopreservation strategies using bacteriocins to control meat spoilage and foodborne outbreaks. *Italian Journal of Food Safety, 13*, 12558. https://doi.org/10.4081/ijfs.2024.12558

Galvez, A., Abriouel, H., Lopez, R. L., & Omar, N. B. (2007). Bacteriocin-based strategies for food biopreservation. *International Journal of Food Microbiology, 120*(1–2), 51–70. https://doi.org/10.1016/j.ijfoodmicro.2007.06.001

Leroy, F., & De Vuyst, L. (2004). Lactic acid bacteria as functional starter cultures for the food fermentation industry. *Trends in Food Science & Technology, 15*(2), 67–78. https://doi.org/10.1016/j.tifs.2003.09.004

Putri, D. A., Lei, J., Rossiana, N., & Syaputri, Y. (2024). Biopreservation of food using bacteriocins from lactic acid bacteria: Classification, mechanisms, and commercial applications. *International Journal of Microbiology, 2024*, Article 8723968.

Sharma, H., Mendiratta, S. K., Agarwal, R. K., Kumar, S., & Soni, A. (2017). Evaluation of antioxidant and antimicrobial activity of various essential oils in fresh chicken sausages. *Journal of Food Science and Technology, 54*(2), 279–292. https://doi.org/10.1007/s13197-016-2461-5

Stiles, M. E. (1996). Biopreservation by lactic acid bacteria. *Antonie van Leeuwenhoek, 70*(2–4), 331–345. https://doi.org/10.1007/BF00395940