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Bacteriocins as Food Bio-Preservative

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According to the data published by the World Health Organization (WHO) in 2023, each year approximately 600 million cases and around 420,000 deaths are caused by food-borne diseases (FBDs), causing an estimated economic loss of 110 billion dollars. In 2018, the European Centre for Disease Prevention and Control (ECDC) reported 91,857 human infections in the European Union due to *Salmonella*-contaminated poultry and meat products. More than 200 of these FBDs are caused by bacteria, viruses, parasites or chemical substances, which not only impact health but also reduce productivity. Microbial activity degrades the quality and safety of food products and plays a major role in food spoilage. Bacteria, molds and yeast are the major contributors among microorganisms. The enzymes and metabolic by-products produced by these microorganisms alter the nutritional properties, rendering them unsafe for consumption. *Pseudomonas* sp., *Saccharomyces* sp., *Penicillium* sp., and *Clostridium* sp. are amongst the most common microbes responsible for food spoilage.

Rapid population growth and the expansion of global food trade have necessitated large-scale food production, distribution from centralised facilities, and prolonged storage prior to consumer delivery. This whole process requires food preservation, i.e., maintaining the inherent nutritional value and organoleptic properties by inhibiting the growth of foodborne pathogens and preventing food deterioration. Ensuring food safety and maintaining product quality throughout transportation and the designated shelf life is a significant challenge. Also, the increasing demand for minimally processed, fresh-like food has intensified innovation in food preservation aimed at suppressing foodborne pathogens while ensuring freshness, flavour, and texture. Conventional preservation methods such as thermal processing, drying, salting, and refrigeration remain widely employed. However, modern techniques such as canning, pasteurisation, and incorporation of chemical preservatives are readily utilised to retard spoilage and extend the shelf life of food products. Conventional and modern preservation techniques have been discouraged by stringent food safety laws and standards, as well as consumer demand for preservative-free food products. Certain chemical preservatives may cause allergy and turn nitrites into nitrosamines, which are carcinogenic. Also, harsh physical and chemical treatments alter the nutrient availability and sensory properties of food. Such drawbacks have pushed interest towards natural bio-preservation technology. Non-pathogenic microorganisms and their metabolic products work antagonistically against pathogenic microbes, helping ensure the safety and shelf life of food. Bacteriocins are one such product. These small antimicrobial peptides are synthesised by bacteria and target related and unrelated groups of bacteria. These ribosomally synthesised peptides have multiple modes of action. Both Gram-positive and Gram-negative bacteria can produce bacteriocins, but they are primarily produced by Gram-positive bacteria. Bacteriocins produced by Gram-negative bacteria have a narrow range of antibacterial activity, whereas bacteriocins produced by Gram-positive bacteria have a wider range of antibacterial activity and are effective against some food spoilage microbes. Distinct amino acids present in the bacteriocins confer precise molecular complementarity with the surface

proteins of the target pathogen. This selective binding allows bacteriocins to disrupt essential cellular processes. This mode of action is highly targeted, inhibiting pathogen growth while minimally affecting non-susceptible bacteria. Bacteriocin-producing lactic acid bacteria (LAB) have been recognised with Generally Regarded as Safe (GRAS) status by the US Food and Drug Administration (FDA). Also, most LAB genera, such as *Lactobacillus*, *Leuconostoc*, *Lactococcus*, *Pediococcus*, and some *Streptococcus*, have been granted Qualified Presumption of Safety (QPS) status by the European Food Safety Authority (EFSA). Bacteriocins are among the most sought-after natural preservatives in the food industry. Most bacteriocins are well characterised, non-toxic, and do not cause side effects. In 1925, it was first isolated from the Gram-negative bacterium *E. coli* and named colicin. These antibacterial peptides were found to have bactericidal effects on closely related bacteria by inhibiting cell wall synthesis and RNase/ DNase activity. Later, bacteriocins were discovered from Gram-positive bacteria and found to be effective against broad-spectrum food spoilage bacteria. Unlike bacteriocins from Gram-negative bacteria, those from LAB did not require rigorous purification. Also, these bacteria can be added to fermented foods as a starter culture, or coated on the food matrix as a protective culture (Fig. 1).

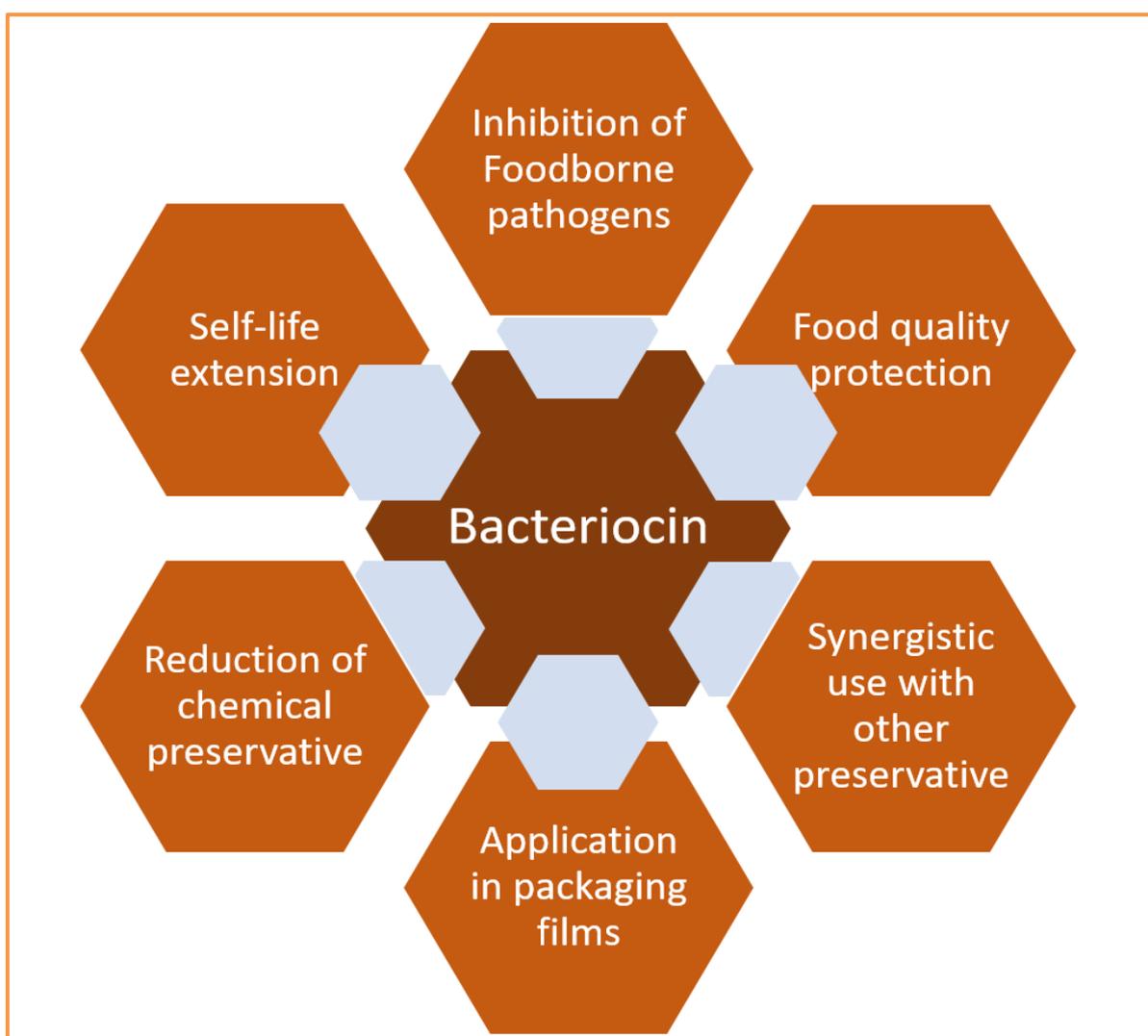


Fig. 1: Application of bacteriocin as a food preservative

Classification of Bacteriocins

Bacteriocins have been classified and reclassified from 1993 to 2024 based on physical properties, molecular size, chemical structures, mode of action, and the organisms that produce them. In 2016, Alvarez-Sieiro et al. categorised bacteriocins into three classes based on their biosynthesis mechanisms, genetic features, and structural characteristics. Classes I and II are heat-stable and smaller peptides, less than 10 kDa, whereas class III bacteriocins

are larger than 10 kDa and thermo-labile peptides. All three classes can be further classified into three sub-classes. These ribosomally synthesised peptides are biologically inactive and need post-translational modifications. It is composed of an N-terminal leader peptide attached to a C-terminal pre-peptide. The leader peptide helps guide the pre-peptide to maturation and transport proteins. It keeps the bacteriocin inactive within the cell and protects the secreting bacteria.

- Class I (lantibiotics) bacteriocins are resistant to extreme pH and heat, immune to certain proteases and have a molecular weight of less than 5 kDa. Nisin (Fig. 2) is one of the most well-known lantibiotics, produced by *Lactococcus lactis*. It consists of 34 amino acids.
- Class II bacteriocins are less than 10 kDa in size (37-48 amino acids) and do not undergo post-translational modifications. It is a cationic, hydrophobic and thermo-stable peptide. For full antimicrobial activity, it may require two distinct peptides.
- Class III bacteriocins are larger than 30 kDa, thermo-labile and either lytic or non-lytic in nature. Because of thermos instability, it is poorly utilised for food preservation. It has enzymatic activity, including an endopeptidase that targets and disrupts the bacterial cell wall. Class III bacteriocins-secreting bacteria produce autoimmune proteins to protect themselves from their own bacteriocins.

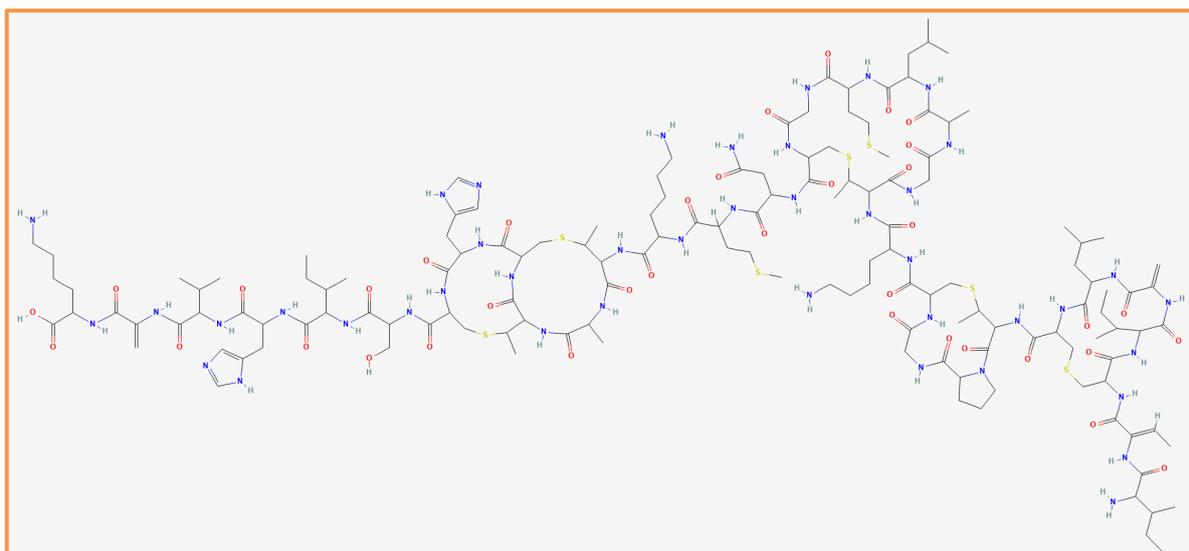


Fig. 2: Two-dimensional structure of Nisin

- In 2024, DA Putri et al. added two more classes to the previous classification: Class IV and V. Class IV bacteriocins are complex mixtures of carbohydrates, proteins, and lipids. It can act on both Gram-positive and Gram-negative bacteria. On the one hand, colicin peptides have molecular weights of 30-80 kDa, whereas microcin ranges from 1 to 10 kDa. Apart from temperature and extreme pH, microcin is resistant to protease enzymes.
- Class V bacteriocins are circular in shape as peptide bond forms between the N and C termini through enzymatic reactions. It is highly thermostable and does not require posttranslational modifications. Amylocyclicin is an example of Class V bacteriocin.

Mode of action of Bacteriocin

Bacteriocins employ various modes of action, including pore formation, inhibition of peptidoglycan synthesis, degradation of cellular DNA, cleavage of 16S rRNA, autolytic enzymatic activity, and inhibition of spore formation. Nisin is a surface-active molecule with cationic detergent-like action. It is adsorbed to the bacterial cell membrane and anchors to the lipid II component. The anionic lipids present in the cytoplasmic membrane act as the primary receptor of nisin. Upon binding to the receptor, the poration complex is stabilised, causing degradation of the sulphhydryl group. It causes pore formation and efflux of ions and other molecules from the membrane, leading to permanent damage and cell death.

Application of Bacteriocin in Food Preservation

Nisin and pediocin PA-1 are both GRAS-designated, but Nisin is the only bacteriocin with FDA approval and licenced as a food preservative (E234). *Lactococcus lactis* produces Nisin A, Z, F and Q, while some *Streptococcus* strains produce Nisin U, U2, P and H. Nisaplin is a commercially available bacteriocin, containing nisin A, NaCl, non-fatty dry milk and other ingredients. It utilises hurdle technology, i.e., the use of nisin alongside other hurdles to prevent the growth of foodborne pathogens. Bacteriocins can be incorporated into food in three main ways: by adding purified or semi-purified bacteriocins as preservatives, by adding an ingredient previously fermented with a bacteriocin-producing starter culture, or by directly inoculating the food with a bacteriocin-producing strain. The use of purified bacteriocin must be labelled as an additive and requires regulatory approval, which is neither pleasing to the food industry nor to consumers who demand clean, additive-free products. Also, regulatory approvals are complex and expensive, which limits widespread adoption. In contrast, incorporating fermented ingredients or live starter cultures typically avoids labelling as preservatives and the need for regulatory approvals. Bactoform F-Lc is a commercially available bio-protective culture containing *L. curvatus* and *P. acidilactici*, producing sakacin A and pediocin, respectively and is used in fermented sausages. HOLDBAC is another protective culture, consisting of a mixture of several bacteria, and is used to protect poultry, meat, dairy products, and seafood.

Nisin, pediocin PA-1 and microcin effectively inhibit the growth of *Clostridium botulinum*, *Staphylococcus aureus* and *Listeria monocytogenes*. *L. monocytogenes* are very stubborn and resistant to refrigeration and high salt concentrations. These species are a major threat to older adults, pregnant women, infants and immunocompromised individuals. Bacteriocins are predominantly used in dairy products such as milk, cheese, and yoghurt, as well as in canned foods, including meat, vegetables, fruits, seafood, and soups. They prevent the growth of heat-resistant, spore-forming bacteria such as *Clostridium botulinum*, *Bacillus subtilis*, and *Bacillus cereus*. Adding bacteriocins to fruit juices either prevents or slows down the growth of *Salmonella typhimurium* and *E. coli*. Nisin was found to be effective against the growth of *L. monocytogenes* in milk and cheese (cottage cheese, cheddar, and ricotta-type cheese). Pediocin is commercially available under the names Micrograde and Alta 2341 (Table 1). It was more effective than nisin against *L. monocytogenes* and *S. aureus*. Bacteriocins, being tasteless, odourless and colourless, retain the original attribute of food products. Thus, their use reduces the need for intensive processing and helps preserve nutritional value and quality.

Table 1: Commercially available bacteriocins and their target micro-organisms

Bacteriocin	Commercial Name	Target Micro-organism
Nisin A	Nisaplin	<i>Bacillus</i> sp. <i>Clostridium</i> sp. <i>Listeria</i> sp.
Nisin Z	Nisin Z	<i>Clostridium</i> spp. <i>Bacillus cereus</i>
Nisin	Danisco	<i>E. Coli</i> <i>Salmonella</i> <i>Listeria</i>
Nisin	Chrisin	<i>Clostridium botulinum</i> <i>Listeria monocytogenes</i>
Natamycin	Natamx	Yeast Moulds
Microcin	Microcin	<i>Listeria monocytogenes</i>
Pediocin	ALTA 2351–2341	<i>Listeria monocytogenes</i>
Pediocin	Micrograd	<i>Listeria monocytogenes</i>
Pediocin	Fargo 23	<i>Listeria monocytogenes</i>
Pediocin	Bactoform P-LC	<i>Listeria monocytogenes</i>

Current trends in the application of Bacteriocin

Hurdle technology combines bacteriocins with various barriers, such as high pressure, chemical additives, and heat treatment, to enhance antimicrobial activity. This method is cost-effective as it allows for lower treatment levels to achieve optimal antimicrobial activity. Antimicrobial packaging films have been designed for highly perishable foods such as fish, meat, and fresh produce. It contains lactic acid bacteria (LAB) that continuously interact with the food matrix, and bacteriocins are slowly released into the food, creating a barrier against spoilage microbes. Incorporating bacteriocin into edible coatings not only enhances safety but also preserves the organoleptic properties of minimally processed or raw foods. Challenges related to post-processing contamination of meat and cheese are effectively dealt with by bioactive packaging films. Hydrocolloids (proteins and polysaccharides) are the preferred edible biopolymer coatings for cheese. Microencapsulation is another interesting method of applying bacteriocin. Bacteriocin is enclosed within small capsules ranging in size from 0.2 to 5000 μm , depending on the type of encapsulating material and preparation techniques. These microcapsules are prepared using proteins, polysaccharides and lipids. These materials are non-toxic, affordable, biocompatible and biodegradable.

Conclusion

Bacteriocins are a sustainable and innovative approach towards food preservation. Some bacteriocins, such as nisin and pediocin PA-1, are safe for human consumption. It can easily be degraded by the mammalian gastrointestinal tract. It was found that nisin cannot be detected in human saliva 10 minutes after consuming a liquid containing it. It is a safe, natural peptide and not a chemical food preservative. Beyond food preservation, bacteriocins have potential in other industries, such as pharmaceuticals, cosmetics, and animal feed; however, bacteriocin production and purification remain costly. *In situ* production of bacteriocins and their heterologous expression in bacterial hosts with minimal nutritional requirements can reduce production costs and open new horizons for natural food preservatives.

References

1. Alvarez-Sieiro, P., Montalbán-López, M., Mu, D. and Kuipers, O.P., 2016. Bacteriocins of lactic acid bacteria: extending the family. *Applied microbiology and biotechnology*, 100(7), pp.2939-2951.
2. Johnson, E.M., Jung, D.Y.G., Jin, D.Y.Y., Jayabalan, D.R., Yang, D.S.H. and Suh, J.W., 2018. Bacteriocins as food preservatives: Challenges and emerging horizons. *Critical reviews in food science and nutrition*, 58(16), pp.2743-2767.
3. Obafemi, Y.D., Obiukwu, A.C. and Oranusi, S.U., 2025. Revisiting the application, current trends, and prospect of bacteriocins in food preservation. *Discover Food*, 5(1), p.165.
4. Parada Fabián, J.C., Álvarez Contreras, A.K., Natividad Bonifacio, I., Hernández Robles, M.F., Vázquez Quiñones, C.R., Quiñones Ramírez, E.I. and Vázquez Salinas, C., 2025. Toward safer and sustainable food preservation: a comprehensive review of bacteriocins in the food industry. *Bioscience Reports*, 45(04), pp.277-302.
5. Putri, D.A., Lei, J., Rossiana, N. and Syaputri, Y., 2024. Biopreservation of food using bacteriocins from lactic acid bacteria: Classification, mechanisms, and commercial applications. *International Journal of Microbiology*, 2024(1), p.8723968.
6. Silva, C.C., Silva, S.P. and Ribeiro, S.C., 2018. Application of bacteriocins and protective cultures in dairy food preservation. *Frontiers in microbiology*, 9, p.594.