www.tufsteam.com
Innovations in STEAM: Research & Education
ISSN (print): 3105-7071; ISSN (online): 3105-708X
Volume 3; Issue 1; Article No. 25030101
https://doi.org/10.63793/ISRE/0021

REVIEW ARTICLE

A Short Review of Multifunctional Roles of Bacteriocins

Abdul Wahab[1], Alina binti Abdul Rahim[2], Muhammad Abdullah Qadri[3]
[1]Institute of Home and Food Sciences, Faculty of Life Sciences, Malaysia
[2]Faculty of Science and Technology, University Sains Islam Malaysia, 71800, Malaysia
[3]Depatment of Botany, Faculty of Life Sciences, University of the Punjab, Lahore, 54000, Pakistan

METADATA

Paper history
Received: 01 May 2025
Revised: 12 April 2025
Accepted: 30 April 2025
Published online: 20 May 2025

Corresponding author
Email: abdul.wahab14670@gmail.com
(Abdul Wahab)

Keywords
Bacteriocins
Innovative
Industrial Perspective
Multidimensional

Citation
Wahab A, Rahim AbA, Qadir MA (2025) A short review on multifunctional roles of bacteriocins. *Innovations in STEAM: Research & Education* 3: 25030101. https://doi.org/10.63793/ISRE/0021

ABSTRACT

Background: Rising demand for healthy food products has created the need for more innovative food preservation methods. One such method involves the use of bacteriocins, which are natural antimicrobial peptides with potential application in the food industry.
Objective: The purpose of this review is to highlight the purification processes of bacteriocins and discuss their multidimensional roles, particularly in controlling harmful pathogens.
Methodology: Information was compiled from relevant scientific literature focusing on the purification methods, properties, and applications of bacteriocins. Emphasis was given to their potential mechanisms of action against foodborne pathogens and their prospective role in food preservation.
Results: Current findings indicate that bacteriocins exhibit promising antimicrobial activity against a wide range of harmful microorganisms and enhance meat shelf-life, improve plant growth, and control skin-related diseases. However, further industrial-scale studies are still needed to fully validate their commercial applications.
Conclusion: Bacteriocins hold significant potential as innovative tools for food preservation and can potentially improve meat shelf-life, enhance plant growth, and control skin-related disease infestation. Their purification and demonstrated antimicrobial roles provide a foundation for future research aimed at integrating them into industrial applications for safer and healthier food production.

INTRODUCTION

Foodborne diseases remain one of the biggest threats to the food industry, and when outbreaks occur, they cause significant losses to a country, as a large portion of the national budget is spent on managing such disasters. To address this, the food industry has upgraded its safety systems to ensure consumer protection. This continuous improvement has also created healthy competition among food industries, driving technological advancements. Nature has blessed us with a wide variety of foods, and food lovers always expect these to be nutritious, wholesome, and safe for consumption. According to Obafemi *et al*. (2025), microbial spoilage is a major factor affecting food quality and safety. When microbes enter food products, they can cause discoloration, destroy flavour compounds, and lead to food toxicity. This not only damages public perception but may also contribute to food scarcity. Preservation is therefore essential to control spoilage-causing pathogens. Bacteriocins, the native antimicrobial peptides of bacteria, are becoming increasingly important tools in contemporary food protection. They inhibit pathogenic and spoilage bacteria quite effectively, providing a biological alternative to conventional preservatives (Le *et al*. 2016; Obafemi *et al*. 2025).

In the quest for safe, natural, and effective antimicrobial agents, bacteriocins have become a cornerstone of modern biotechnology. These ribosomally synthesized peptides, which are secreted by various strains of bacteria, have strong inhibitory action against other microorganisms, such as foodborne pathogens and spoilage bacteria. Their use includes antimicrobial function to preserve foods, promote animal health, and treat diseases (Ali *et al*. 2020). Food technologists and scientists have increasingly turned to

© 2023 The Authors. Innovations in STEAM: Research & Education published by The University of Faisalabad, Faisalabad, Pakistan
This is an open access article under the terms of the Creative Commons Attribution License, which permits non-commercial use, distribution and reproduction in any medium, provided the original work is properly cited

biopreservatives, among which bacteriocins produced through biotechnology are of particular interest. Bacteriocins show promising antimicrobial effects against food spoilage organisms and are widely considered natural food biopreservatives (Mahindra *et al.* 2015). Bacteriocins play a vital role in overcoming food safety issues, lowering the dependence on chemical preservatives, and minimizing threats of foodborne illness. In the food sector, they provide a reliable solution for shelf-life extension and product safety. Outside of the food sector, they are investigated for their therapeutic applications, such as fighting antibiotic-resistant infections and influencing the gut microbiome (Gu 2023). This review highlights bacteriocins, their classifications, and their importance in the meat sector, plant growth, and skin care products.

BACTERIOCINS

The extensive use of conventional medicines in the treatment of human and animal diseases has become a concern in recent years (Roy 1997; Yoneyama and Katsumata 2006). The emergence of resistant strains has complicated the treatment of many diseases, making the development of new antimicrobial agents an important goal (Kumar and Schweiser 2005; Fisher *et al*. 2005). Bacteriocins have gained attention as alternatives to antibiotics because they are non-toxic, active at nanomolar concentrations, and produced naturally by lactic acid bacteria (Parada *et al.* 2007). They are proteinaceous compounds with antimicrobial activity, produced by bacteria to inhibit or kill other bacterial strains (Parada *et al*. 2007). Although they are bacterial products, they are not classified as antibiotics to avoid confusion with therapeutic drugs (Deraz *et al*. 2005). For the food industry, bacteriocin production is highly beneficial, as it helps inhibit and eliminate pathogens. Many bacteriocins are effective against closely related bacteria, often displaying a narrow host range (Deegan *et al*. 2006). It is used predominantly in canned foods and dairy products and is especially effective when utilized in the production of processed cheese and cheese spreads, where it protects against heat-resistant spore-forming organisms such as those belonging to the genera *Bacillus* and *Clostridium* (Tarelli *et al*. 1994).

CLASSES OF BACTERIOCINS

Bacteriocins are broadly divided into four main classes. Class I includes lantibiotics, which are small peptides of less than 5 kDa in size and are heat-stable. They act mainly by disrupting bacterial membranes, and nisin is the most well-known example (Broadbent *et al*. 1989). Within this class, subclass-Ia- Ia consists of positively charged, elongated, and flexible peptides, while subclass-Ib includes peptides that are more rigid, globular in shape, and either uncharged or negatively charged (Parada *et al*. 2007). Class II bacteriocins, often referred to as non-lantibiotics, are heat-stable peptides composed of amino acids and show variability in molecular weight. This class is further divided into three groups: Class-IIa, which contains peptides active against *Listeria* species and is represented by pediocin PA-1; Class-IIb, which includes bacteriocins that require two different peptides to achieve antimicrobial activity; and Class-IIc, which is characterized by small, heat-stable peptides transported by leader sequences (Venema *et al*. 1997; Holo *et al*. 2002; Mauriello *et al*. 1999; Parada *et al*. 2007). Class-III bacteriocins are larger in size, with molecular weights exceeding 30 kDa, while Class-IV bacteriocins are complex molecules containing carbohydrate or lipid moieties in addition to protein components (Parada *et al*. 2007; Holo *et al*. 2002; Mauriello et al. 1999).

EFFECT OF PURIFICATION METHODS, pH AND TEMPERATURE ON BACTERIOCIN PRODUCTION

Different purification methods have been developed depending on the class of bacteriocin (Table 1). These include protein precipitation, chromatography, and electrophoretic techniques, which allow isolation and characterization of bacteriocins for food and pharmaceutical applications. The production and activity of bacteriocins vary with environmental conditions. Studies have shown that each bacterial strain has an optimum pH range and temperature at which bacteriocin production is maximized (Table 2 and 3).

BENEFITS OF BACTERIOCINS

The application of bacteriocins in the food industry is valuable for extending shelf life and protecting against harmful pathogens. Their use reduces the risk of disease transmission and economic losses associated with food spoilage. Growing consumer demand for natural, minimally processed foods further supports the role of bacteriocins as natural antimicrobial agents (Soltani *et al*. 2021). When tested individually or in combination, bacteriocins show promising results against foodborne pathogens (Rendueles *et al*. 2022). In the dairy and poultry sectors, they have been applied successfully to control *Clostridium* spp. (Arqués *et al*. 2015; Le *et al*. 2016). However, bacteriocins that are applied commercially as biopreservatives must fulfill specific requirements (Holo *et al*. 2002; Mauriello *et al*. 1999), such as being non-toxic, accepted by recognized authorities, remaining sufficiently stable during storage, and not negatively affecting the quality of the product to which they are applied.

APPLICATIONS OF BACTERIOCINS

Table 1: Purification of bacteriocins according to their classes

Class	**Purification Method**	**Procedure**	**Result**	**Reference**
Class I Bacteriocins	Expanded bed ion exchange chromatography	Through processing of the *Lactococcus lactis* subsp diluted culture broth of A164 obtained, and further, this broth was processed by using this method	31-fold purification was achieved with a yield of 90%	Cheigh *et al.* 2004
	Ion exchange, Hydrophobic Interaction	20% of ammonium sulphate was used with the precipitate of the cell-free supernatant	Through the use of *Lactobacillus sake* L45, its strain Lactocin S, a 3,7 kDa bacteriocin, was created and then refined to uniformity	Mørtvedt *et al*. 1991
	Combinations of different chromatographic methods	Hydrophobic and Cation exchange principles were applied during the use of these methods	Purification of Acidocin CH5 manufactured by using *L. acidophilus* in lab	Chumchalova *et al.* 2004
Class II Bacteriocins	Ethanol precipitation	In the first step, ampholytes, Tween 20, and glycine were mixed, followed by ultrafiltration to achieve a pure sample. Lastly, the sample was moved to tricine SDS-PAGE	*Pediococcus acidilactici* was used to produce purified pediocin PA-1, with a yield between 30 and 40%	Venema *etal.* 2004
	Saturation with ammonium sulfate (35%)	In an FPLC system, purification includes Gel filtration chromatography, and then is moved to methanol-chloroform extraction, followed by three methods. Firstly by ion-exchange, then by hydrophobic interaction, and lastly through reverse-phase chromatography	Lactobin A, produced by *L. amylovorus,* was purified	Contreras *et al.* 1997
	ion-exchange chromatography, ultrafiltration, and successive gel filtrations	One of these methods can be used in the presence of two experimental consituents, 8 M urea followed by sodium dodecyl sulfate 0,1% sodium dodecyl sulfate	Lactacin B produced from *L. acidophilus* was purified	Barefoot *et al*. 1984
Class III Bacteriocins	Ammonium sulfate precipitation	In sodium acetate buffer, the pellet was placed and then dialysed against sodium acetate buffer.	*Lactobacillus helveticus* 481 produced Helveticin J, a peptide was purified	Joerger and Klaenhammer 1986

Table 2: Effect of pH on bacteriocin

Bacteriocin producing strain	Optimum pH	Reference
Leuconostoc MF215B	pH 6.0	Blom *et al*. 1999
L. gelidin	pH 6.5	Stiles and Hasting 1991
amylovorin L471	pH 6.5	Callewaert *et al*. 1999)
C. piscicola	7.0	Herbin et al. 1997

Table 3: Effect of temperature on bacteriocin

Bacteriocin /Strain	Suitable Temperature for Bacteriocin Production	Observation	Reference
Strain D53	10°C to 37°C	--------	Uhlman *et al.* 1992
Brevibacterium linens	25°C	No growth found at 37°C	Diep *et al*. 2000
L. sake	25–30°C	At 33.5°C decline in production occurs, and zero production is observed at 34.5°C	Diep *et al*. 2000
L. plantarumY21	30°C	At 37°C, especially in milk products, bacteriocin was produced during incubation	Tarelli *et al*. 1994

Metal industry

Several bacteriocins have been applied in the meat sector to control pathogens, thereby improving food safety and extending shelf life. Classes of meat-preservation bacteriocins are present in Table 4. Partially purified or purified bacteriocins may be applied as a food additive and for active packaging. Moreover, bacteriocin-producing cells may be incorporated as starter or protective cultures for meat fermentation.

Veterinary use

Table 4: Role of different bacteriocins against different pathogens in meat sector

Type of meat	Meat product	Strains of bacteriocin	Action against pathogens	Other changes	References
Meat Salami	Ostrich meat salami	Lactobacillus curvatus DF126	Anti-Listeria activity	-----	Dicks *et al*. 2004
	Salami from ostrich, beef, mutton	Lactobacillus plantarum 423		----	Dicks *et al*. 2004; Todorov *et al*. 2007
		Lactobacillus curvatus DF38		----	Todorov *et al*. 2007
Fermented Meat	Fermented pork sausage	Pediococcus pentosaceus BCC 3772	Anti-Listeria activity	No changes in sensory properties, as well as in consumer acceptability of the product	Kingcha *et al.* 2012
	Fermented pork sausage	Lactobacillus sakei C2	nti-Listeria and Anti-Enterobacteriacae activity,	Both the ratio of malondialdehyde and The nitrite content in the product was reduced	Gao *et al.* 2014
Raw Meat	Raw beef	Lactobacillus curvatus CWBI-B28	Anti-Listeria activity	--------	Dortu *et al.* 2008
Packed Meat	Vacuum-packed fresh beef	Lactobacillus curvatus CRL705	Anti-Listeria activity	-------	Castellano *et al.* 2010; Castellano and Vignolo *et al.* 2006

Nisin has been investigated for the prevention of bovine mastitis caused by *Staphylococcus aureus* and Streptococcus agalactiae. Injectable formulations containing nisin have shown up to 99.9% effectiveness in controlling these pathogens. If these pathogens are not controlled, they cause significant economic losses in the livestock industry (Perez *et al*. 2014; Le *et al*. 2016).

Skincare

Scientific evidence suggests that certain probiotics help maintain the skin's lipid barrier and microflora, supporting skin immunity and homeostasis (Munir *et al*. 2025). In one study, a lotion containing ESL5, a bacteriocin from *Enterococcus faecalis* SL-5, significantly reduced pimples and inflammatory acne lesions caused by *Propionibacterium acnes* (Kang *et al*. 2009), suggesting their potential role in skin care products.

Plant growth promotion

Bacteriocins such as thuricin 17, bacthuricin F4, and bacteriocin C85 have been shown to enhance plant growth. When applied with their producing bacteria on tomato, soybean, and corn, they improved leaf area, increased photosynthesis rates by up to 6%, and raised plant dry weight by 15%. Additionally, root nodulation increased by 21% compared to control plants (Smith *et al*. 2008).

CONCLUSIONS

In the 21st century, the preparation of various food products requires knowledge and integration of multiple scientific fields, with the primary objective of ensuring food safety. Bacteriocins are associated with the control of harmful pathogens in the food and pharmaceutical industries, although further research is needed to fully understand their hidden roles in food safety. At present, consumers are paying greater attention to food safety, and to address their concerns, so industries are developing strong research-based models that ensure food safety. However, more research is needed to explore the use of bacteriocins in food and other industries.

AUTHOR CONTRIBUTIONS

Conceptualization and data collection were carried out by AW; manuscript drafting was performed by AbAR; review and editing were undertaken by MAQ. All authors read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors affirm that they possess no conflicts of interest.

DATA AVAILABILITY

The data will be made available on a fair request to the corresponding author

ETHICS APPROVAL

Not applicable to this paper

FUNDING SOURCE

This project is not funded by any agency.

REFERENCES

Ali A, Parisi A, Conversano MC, Iannacci A, D'Emilio F, Mercurio V, Normanno G (2020) Food-borne bacteria associated with seafoods: A brief review. *Journal of Food Quality and Hazards Control* 7: 4–10. https://doi.org/10.18502/jfqhc.7.1.2446.

Arqués JL, Rodríguez E, Langa S, Landete JM, Medina M (2015) Antimicrobial activity of lactic acid bacteria in dairy products and gut: Effect on pathogens. *BioMed Research International* 2015: 584183. https://10.1155/2015/584183.

Broadbent JR, Chou C, Guillies K, Kondo JK (1989) Nisin inhibits several gram-positive, mastitis-causing pathogens. *Journal of Dairy Science* 72: 3342–3345. https://10.3168/jds.S0022-0302(89)79496-0.

Barefoot SF, Klaenhammer TR (1984) Purification and characterization of the *Lactobacillus acidophilus* bacteriocin lactacin B. *Antimicrobial Agents and Chemotherapy* 26: 328–334. https://doi.org/10.1128/aac.26.3.328.

Blom H, Katla T, Holck A, Sletten K, Axelsson L, Holo H (1999) Characterization, production and purification of leucocin H, a two-peptide bacteriocin from Leuconostoc MF215B. *Current Microbiology* 39: 43–48. https://doi.org/10.1007/pl00006825.

Cheigh C, Kook M, Kim S, Hong Y, Pyun Y (2004). Simple one-step purification of nisin Z from unclarified culture broth of Lactococcus lactis subsp. lactis A164 using expanded bed ion exchange chromatography. *Biotechnology Letters* 26: 1341–1345. https://10.1023/B:BILE.0000045630.29494.45.

Chumchalova J, Stiles J, Josephsen J, Plocková M (2004) Characterization and purification of acidocin CH5, a bacteriocin produced by *Lactobacillus acidophilus* CH5. *Applied Microbiology* 96: 1082–1089. https://doi.org/10.1111/j.1365-2672.2004.02237.x.

Contreras BGL, De Vuyst L, Devreese B, Busanyova K, Raymaeckers J, Bosman F, Sablon E, Vandamme EJ (1997) Isolation, purification, and amino acid sequence of lactobin A, one of the two bacteriocins produced by *Lactobacillus amylovorus* LMG P-13139. *Applied and Environmental Microbiology* 63: 13–20. https://doi.org/10.1128/aem.63.1.13-20.1997.

Callewaert R, Holo H, Devresse B, Beeumen JV, Nes I, Vuyst LD (1999) Characterization and production of amylovorin L471, a bacteriocin purified from *Lactobacillus amylovorus* DCE 471 by a novel three-step method. *Microbiology* 145: 2559–2568. https://10.1099/00221287-145-9-2559.

Castellano P, Vignolo G (2006) Inhibition of Listeria innocua and *Brochothrix thermosphacta* in vacuum-packaged meat by addition of bacteriocinogenic *Lactobacillus curvatu*s CRL705 and its bacteriocins. *Letters in Applied Microbiology* 43: 194–199. https://10.1111/j.1472-765X.2006.01933.x.

Castellano P, González C, Carduza F, Vignolo G (2010) Protective action of *Lactobacillus curvatus* CRL705 on vacuum-packaged raw beef: Effect on sensory and structural characteristics. *Meat Science* 85: 394–401. https://doi.org/10.1016/j.meatsci.2010.02.007.

Deraz SF, Karlsson EN, Hedstrom M, Andersson MM, Mattiasson B (2005) Purification and characterisation of acidocin D20079, a bacteriocin produced by *Lactobacillus acidophilus* DSM 20079. *Biotechnology* 117: 343–354. https://doi.org/10.1016/j.jbiotec.2005.02.005.

Deegan LH, Cotter PD, Hill C, Ross P (2006) Bacteriocins: Biological tools for biopreservation and shelf-life extension. *International Dairy Journal* 16: 1058–1071. https://doi.org/10.1016/j.idairyj.2005.10.026.

Diep BD, Axelsson L, Grefsli C, Nes IF (2000) The synthesis of bacteriocin sakasin A is a temperature-sensitive process regulated by a pheromone peptide through a three-component regulatory system. *Microbiology* 146: 2155–2160. https://doi.org/10.1099/00221287-146-9-2155.

Dicks LMT, Mellett FD, Hoffman LC (2004) Use of bacteriocin-producing starter cultures of *Lactobacillus plantarum* and *Lactobacillus curvatus* in production of ostrich meat salami. *Meat Science* 66: 703–708. https://doi.org/10.1016/j.meatsci.2003.07.002.

Dortu C, Huch M, Holzapfel WH, Franz CMAP, Thonart P (2008) Anti-listerial activity of bacteriocin-producing *Lactobacillus curvatus* CWBI-B28 and *Lactobacillus sakei* CWBI-B1365 on raw beef and poultry meat. *Letters in Applied Microbiology* 47: 581–586. https://doi.org/10.1111/j.1472-765X.2008.02468.x.

Fisher JF, Meroueh SO, Mobashery S (2005) Bacterial resistance to beta-lactam antibiotics: Compelling opportunism, compelling opportunity. *Chemical Reviews* 105: 395–424. https://doi.org/10.1021/cr030102i.

Gao Y, Li B, Liu X (2014) Bacteriocin-producing *Lactobacillus sakei* C2 as starter culture in fermented sausages. *Food Control* 35: 1–6. https://doi.org/10.3390/foods11050736.

Gu Q (2023) Application of bacteriocins in the food industry. *Bacteriocins* 26: 63–83. https://doi.org/10.1007/978-981-99-2661-9_4.

Holo H, Fye T, Brede DA, Nilsen T, Odegard I, Langsrud T, Brendehaug J, Nes IF (2002) Bacteriocin of propionic acid bacteria. *Institut National de la Recherche Agronomique* 82: 59–68. https://doi.10.1051/lait : 2001005.

Herbin S, Mathien F, Brule F, Branlant C, Lefebvre G, Lebrihi A (1997) Characteristics and genetic determinants of bacteriocin activities produced by *C. piscicola* CP5 isolated from cheese. *Current Microbiology* 35: 319–326. https://doi.org/10.1007/s002849900262.

Joerger MC, Klaenhammer TR (1986) Characterization and purification of helveticin J and evidence for a chromosomally determined bacteriocin produced by *Lactobacillus helveticus* 481. *Journal of Bacteriology* 167: 439–446. https://doi.org/10.1128/jb.167.2.439-446.1986.

Kumar A, Schweiser HP (2005) Bacterial resistance to antibiotics: Active efflux and reduced uptake. *Advanced Drug Delivery Reviews* 57: 1486–1513. https://doi.org/10.1016/j.addr.2005.04.004.

Kingcha Y, Tosukhowong A, Zendo T, Roytrakul S, Luxananil P, Chareonpornsook K, Visessanguan W (2012) Anti-listeria activity of *Pediococcus pentosaceus* BCC 3772 and application as starter culture for Nham, a traditional fermented pork sausage. *Food Control* 25: 190–196.

Kang BS, Seo JG, Lee GS et al. (2009) Antimicrobial activity of enterocins from *Enterococcus faecalis* SL-5 against Propionibacterium acnes, the causative agent in acne vulgaris, and its therapeutic effect. *The Journal of Microbiology* 47: 101–109. https://doi.org/10.1007/s12275-008-0179-y.

Le LC, Dridi L, Bergeron MG, Ouellette M, Fliss I (2016) Nisin is an effective inhibitor of *Clostridium difficile* vegetative cells and spore germination. *Journal of Medical Microbiology* 65: 169–175. https://doi.org/10.1099/jmm.0.000202.

Mauriello G, Aponte M, Andolfi R, Moschetti G, Villani F (1999) Spray drying of bacteriocin-producing lactic acid bacteria. *Food Protection* 62: 773–777. https://doi.org/10.4315/0362-028x-62.7.773.

Mørtvedt CI, Nissen-Meyer J, Sletten K, Nes IF (1991) Purification and amino acid sequence of lactocin S, a bacteriocin produced by *Lactobacillus sake* L45. *Applied and Environmental Microbiology* 57: 1829–1834. https://doi.org/10.1128/aem.57.6.1829-1834.1991.

Munir A, Janbey A, Sajjad B et al. (2025) Bioinformatics-driven discovery of skin microbiota bacteriocins as potential antibiotics and probiotics. *Journal of Antibiotics* 1–15. https://doi.org/10.1038/s41429-025-00847-2.

Obafemi YD, Obiukwu AC, Oranusi SU (2025) Revisiting the application, current trends, and prospect of bacteriocins in food preservation. *Discover Food* 5: 165. https://doi.org/10.1007/s44187-025-00472-w.

Parada JL, Caron CR, Mediros ABP, Soccol CR (2007) Bacteriocin from lactic acid bacteria: Purification, properties and use as biopreservatives. *Brazilian Archives of Biology and Technology* 50: 521–542. https://doi.org/10.1590/S1516-89132007000300018.

Perez RH, Zendo T, Sonomoto K (2014) Novel bacteriocins from lactic acid bacteria (LAB): Various structures and applications. *Microbial Cell Factories* 13: 1. https://doi.org/10.1186/1475-2859-13-s1-s3.

Roy PH (1997) Dissemination of antibiotic resistance. Medical Science 13: 927–933. https://doi.org/10.1086/321877.

Rendueles C, Duarte AC, Escobedo S, Fernández L, Rodríguez A, García P, Martínez B (2022) Combined use of bacteriocins and bacteriophages as food biopreservatives: A review. *International Journal of Food Microbiology* 368: 109611. https://doi.org/10.1016/j.ijfoodmicro.2022.109611.

Stiles ME, Hasting JW (1991) Bacteriocin production by lactic acid bacteria: Potential for use in meat preservation. *Trends in Food Science and Technology* 2: 247–251. https://doi.org/10.1016/0924-2244(91)90706-O.

Soltani S, Hammami R, Cotter PD, Rebuffat S, Said LB, Gaudreau H, Bédard F, Biron E, Drider D, Fliss I (2021) Bacteriocins as a new generation of antimicrobials: Toxicity aspects and regulations. *FEMS Microbiology Reviews* 45: fuaa039. https://doi.org/10.1093/femsre/fuaa039.

Smith D, Lee KD, Gray E, Souleimanov A, Zhou X (2008) Use of bacteriocins for promoting plant growth and disease resistance. *US Patent* 20080248953.

Tarelli TG, Carminati D, Giraffa G (1994) Production of bacteriocin active against *Listeria monocytogenes* and *Listeria innocua* from dairy enterococci. *Food Microbiology* 11: 243–252. https://doi.10.1006/fmic.1994.1027.

Todorov SD, Koep KSC, Van Reenen CA, Hoffman LC, Slinde E, Dicks LMT (2007) Production of salami from beef, horse, mutton, blesbok (*Damaliscus dorcas phillipsi*) and springbok (*Antidorcas marsupialis*) with bacteriocinogenic strains of *Lactobacillus plantarum* and *Lactobacillus curvatus*. Meat Science 77: 405–412. https://doi.org/10.1016/j.meatsci.2007.04.007.

Uhlman L, Schrillinger U, Rupnew J, Holzapfel WH (1992) Identification and characterization of two bacteriocin-producing strains of *Lactococcus lactis* isolated from vegetables. *International Journal of Food Microbiology* 2: 141–151. https://doi.org/10.1016/0168-1605(92)90007-p.

Venema K, Chikindas ML, Seegers JFMI, Haandrikman AJ, Leenhouts KJ, Venema G, Kok J (1997) Rapid and efficient purification method for small, hydrophobic, cationic bacteriocins: Purification of lactococcin B and pediocin PA-1. *Applied and Environmental Microbiology* 63: 305–309. https://doi.org/10.1128/aem.63.1.305-309.1997.

Yoneyama H, Katsumata R (2006) Antibiotic resistance in bacteria and its future for novel antibiotic development. *Bioscience, Biotechnology and Biochemistry* 70: 1060–1075. https://doi.org/10.1271/bbb.70.1060.