Chapter

Bacteriocins: Applications in Food Preservation and Therapeutics

Parul Thapar and Mohinder Kumar Salooja

Abstract

The awareness in preventing the use of chemical preservatives for food has increased. Not only this, but the prevalence of antimicrobial resistance in the food-borne pathogens that can cause infections such as food poisoning is also at a rise. This has led in the growing demand for the safe food. The bacteriocins can be used as an effective alternative in food preservation and safety. Bacteriocins are ribosomally synthesized proteins that possess certain inhibitory activities against diverse group of undesirable microorganisms. These are produced by both Gram-positive and Gram-negative bacteria and some of the archaeal species. Bacteriocins are safe for human consumption, since they can be degraded by proteolytic enzymes in the gastrointestinal tract. In this chapter, focus is made on an alternative and safe approach for food preservation and therapeutics through bacteriocins. The applications of different types of bacteriocins in preserving food are mentioned with regard to increased shelf life, additives, and packaging. Not only this, but also bacteriocins benefit in boosting the immune system and possess certain anticancer properties. Bacteriocins can also be used in controlling the antimicrobial resistance in certain food-borne pathogens. They are the future antimicrobial proteins for the food preservation and therapeutics in a cost-effective manner.

Keywords: bacteriocins, shelf life, food preservation, immune system, *Lactobacillus* spp., therapeutics, antimicrobial resistance

1. Introduction

According to the present scenario, where people have become health and diet conscious, the use of chemical preservatives in foods has become a concern in a healthy lifestyle [1]. Another concern is the antimicrobial resistance of the food-borne pathogens within the food that can lead to spread of infections such as food poisoning [2].

Antimicrobial resistance is the ability of the microorganisms (bacteria, protozoa, fungi, or virus) to continue to grow even when they are exposed to antimicrobial medicines that are meant to kill or inhibit their pathogenic activities. As a result, medicines become ineffective and a person is not cured. It mainly happens due to overuse of the same medicine against a specific disease, which let the genes of the microbes to get adapted to a particular medicine [2]. Antimicrobial resistance is increased in various microorganisms that can lead to food spoilage and cause severe infections. The antimicrobial resistance of these food-borne pathogens in food-producing animals can be spread to humans *via* contaminated food or water and also through direct contact with the animals [3]. This focuses on "One- Health Concept," which is an approach that recognizes "the health of people is closely connected to the health of an animal" [4].

In one of the studies conducted by European Union, it is shown that the *Salmonella* spp. isolated from turkeys, meat, and pork showed antimicrobial resistance to the drugs such as sulfonamides, tetracycline, ampicillin, and fluoroquinolones. Also, the species of *Escherichia coli* isolated from meat and turkey showed antimicrobial resistance to sulfonamides, tetracycline, and ampicillin drugs against the patients suffering from food poisoning after consumption of these animal foods [5].

According to the Centre for Disease Control and Prevention (CDC), the antimicrobial resistance of pathogens from the family Enterobacteriaceae, including *Escherichia coli*, *Shigella,* and *Salmonella* spp., posts a serious threat to the world [4].

The increase in the demand of natural preservatives to be used in food products and natural sources that can inhibit antimicrobial resistance has led the researchers to think about different approaches toward food preservation and safety. Therefore, the application of bacteriocins can be an effective alternative.

Bacteriocins are ribosomally synthesized antimicrobial proteins [6]. These are produced by both Gram-positive and Gram-negative bacteria and some of the archaeal species. They possess certain inhibitory activities against diverse group of undesirable microorganisms [7].

The bacteriocins from Gram-positive bacteria show the following characteristics—antimicrobial in action, narrow spectrum, active against relative species of organisms, and in broad spectrum, active against both Gram-positive and Gram-negative organisms and some fungi [8]. The large group of microbial species producing bacteriocins is mainly the lactic acid bacteria (LAB). These are a group of Gram-positive, non-spore forming, non-motile, non-respiring bacteria, which produce a variety of antimicrobial compounds such as lactic acid, acetic acid, ethanol, formic acid, fatty acids, hydrogen peroxide, and bacteriocins [9]. The genera includes *Lactobacillus*, *Leuconostoc*, *Pediococcus*, *Streptococcus*, *Alloiococcus*, *Carnobacterium*, *Dolosigranulum*, *Enterococcus*, *Oenococcus*, *Tetragenococcus*, *Vagococcus*, *Weissella* [10].

Bacteriocins can be considered as an alternative in food preservation compared to chemical preservatives. These are safe for human consumption, since they can be degraded by proteolytic enzymes in the gastrointestinal tract [6]. Bacteriocins become inactive when they come in contact with the digestive enzymes in the stomach, as the enzymes such as pepsin denature the bacteriocins [9]. Also, presently, 50 LAB strains have obtained the Qualified Presumption of Safety (QPS) status by the European Food Safety Agency [11].

2. Classification of bacteriocins

Different types of bacteriocins have been classified according to size, inhibitory mechanism, target cells, spectrum of action, interaction with immune system, and biochemical features [12]. The bacteriocins have different mechanisms of action: bactericidal, with or without cell lysis through cell wall, and bacteriostatic, inhibiting the cell growth by inhibiting gene expression or protein production [6]. Accordingly, the types of bacteriocins are represented in **Table 1**.

Class	Typical producing species	Properties	Examples	Mode of action	References
I	*Lactococcus lactis* sub sp. *Lactis*	Contain unique amino acids, that is, lanthionine and methyllanthionine;<5 kDa	Nisin, Lactocin, Mersacidin	Bactericidal; by targeting the peptidoglycan layer of the bacterial cell wall. Except nisin—targets by both mechanisms	[12–14]
			Some novel lanthionines—linardin, azoline, cyanobactin, glycocin, , thiopeptide, and lasso peptide	Bactericidal	[15]
IIa	*Leuconostoc gelidum*	Heat stable, non-modified, cationic, hydrophobic peptides; contain a double–glycine leader peptide; pediocin-like peptides; <10 kDa	Pediocin PA1, Sakacin A, Leucocin A		[13, 16, 17]
IIb	*Enterococcus faecium*	Require synergy of two complementary peptides; mostly cationic peptides	Lactococcin G, Plantaricin A, Enterocin X		[18, 19]
IIc	*Lactobacillus acidophilus*	Affects membrane permeability and cell wall formation	Acidocin B, Enterocin P, Reuterin 6		[20, 21]
III	*Lactobacillus helveticus* from Swiss cheese	Heat-labile; large molecular mass peptides; >30 kDa	Lysostaphin, Enterolysin A, Helveticin J	Bacteriostatic	[13–15, 19, 21]

Table 1.
Classification of bacteriocins.

3. Applications of bacteriocins in food preservation

Bacteriocins have been used in biopreservation of various foods, either alone or in combination with other methods of preservation, such as hurdle technology [19]. The criteria for the bacteriocins to be used for food preservation or food safety are [22, 23]:

- Bacteriocin-producing strains should be food grade (GRAS or QPS).
- Exhibit a broad spectrum of inhibition.

- Show high specific activity.
- Have no health risks.
- Beneficial effects on foods (e.g., improve safety) and do not affect quality and flavor of food.
- They should be heat and pH stable.

Bacteriocins can be incorporated in foods either by inoculating directly into the food or incorporating in food packaging films/coatings, which will improve their activity or stability in complex food systems [24].

To protect the foods from contamination with certain microorganisms such as *Listeria monocytogenes* (pathogens in cheese) and *Streptococcus aureus* in dairy products [25] while in meat and fermented sausages, contamination of *Clostridium botulinum* [26–28] and other bacterial pathogens such as Campylobacter spp.,

S.No.	Bacteriocin-producing strains	Products incorporated	Active against	References
1.	*Lactococcus lactis* 8L1A and 8L1 B	Starters for cheese	Bacterial pathogens	[29–31]
2.	*Lactobacillus sakei* sub sp. *sakei* 2a	Cheese spread	*Listeria monocytogenes*	[21, 32]
3.	*Lactiplantibacillus plantarum* CCDM1078	Cheese spread	*Listeria monocytogenes*	
4.	*Staphylococcus equorum* SE3	Cheese	*Listeria monocytogenes*	[33]
5.	*Enterococcus faecium*	Fresh cheese whey	*Listeria monocytogenes*	[34]
6.	*Lactococcus lactis* (Nisin producer)	Fresh cheese	*Listeria monocytogenes*	[35]
7.	Enterocin from *Enterococcus faecalis* LBB1K3	Model fresh cheese	*Listeria monocytogenes*	[36]
8.	Lacticin 481 (*Lactococcus lactis*)	Fresh cheese	*Listeria monocytogenes*	
9.	Semi -purified pediocin	Fermented cheese	*Staphylococcus aureus*	[37]
10.	Semi-purified lacticin	Fresh cheese	*Listeria monocytogenes*	
11.	Semi-purified bacteriocin—BacFL31	Turkey meat	*Listeria monocytogenes* and *Salmonella typhi*	
12.	*Enterococcus faecium* KEB2	Raw and sterile milk	*Listeria monocytogenes*	
13.	Aureocin A70 (*Staphylococcus aureus*)	UHT skim milk	*Listeria monocytogenes*	[38]
14.	Lactococcin BZ (*Lactococcus lactis*)	Skim and UHT milk	*Listeria monocytogenes*	[39]
15.	*Leuconostoc mesenteroides*, Leucocin K7	UHT and whole-fat milk	*Listeria monocytogenes*	[40–42]

Table 2.
Bacteriocins-producing strains used as biopreservatives.

S. No.	Bacteriocin-producing strains	Food products	Active against	References
1.	Nisin	Cured meat products	*Listeria monocytogenes*, *Clostridium spp.*, *Bacillus cereus*, *Escherichia coli*, and Salmonella spp.	[43]
2.	Plantaricin 423	Cheese	*Listeria innocua*	[44]
3.	Nisin A, nisin Z and lacticin-481	Cottage cheese	*Listeria monocytogenes*	[45, 46]
4.	Nisin A (Nisapsin^R)	Milk pudding	Spore formers	[47]
5.	Nisin A (Nisapsin^R)	Cheese	*Staphylococcus aureus*	[48]
6.	*Lactococcus lactis* N564, Nisin	Cow milk	*Listeria monocytogenes and Staphylococcus aureus*	[49]

Table 3.
Some commercialized bacteriocins.

Salmonella spp., *Escherichia coli*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Yersinia enterocolitica* [29]; some viral and parasitic species such as *Toxoplasma gondii* and *Taenia solium* [30], certain immobilized form of bacteriocins have been developed as antimicrobial packaging films [26–28].

3.1 Bacteriocins as biopreservatives

Some of the bacteriocin-producing strains are used as biopreservatives in food preservation but not marketed yet. These are shown in **Table 2**. There are other bacteriocins that have been proposed for industrial applications such as Enterocin AS-48 [26] and Lacticin 347 [41].

Till present, there are some bacteriocins that have been commercialized as food additives including nisin, with trade name Nisaplin andDanisco; pediocin A1, with trade name Microgard^{TM} and ALTA2431 [42]. The other commercialized bacteriocins active against certain food spoilage microorganisms are represented in **Table 3**.

3.2 Bacteriocins as food additives

Food additives are the substances added to food to maintain or improve the safety, freshness, taste, texture, or appearance. Food additives need to be checked for potential harmful effects on human health before they can be marketed [50]. Some of the bacteriocins that are applied as food additives are presented in **Table 4**.

S.No.	Bacteriocin-producing strains	Food additives	References
1	Bacteriocin-producer adjunct of *Pediococcus acidilacti*	Cheddar and semi-hard cheeses	[44]
2.	Bacteriocin-producing adjunct of *Lactobacillus acidophilus*	Food fermentation	[49]

Table 4.
Bacteriocins as food additives.

Bacteriocin-producing strains	Food packaging	Features	References
Nisin coated on polyethylene films	Packaging of poultry	Reduced risk of *Salmonella* spp.	[51]
Nisin absorbed onto salinized silica surfaces	Packaging of meat	Inhibited *Listeria monocytogenes*	
Lacticaseibacillus casei producing bacteriocin strain	The bacteriocins adsorbed on the packages on cheese, diffused through the medium, thus, inhibiting the growth of undesirable organisms like *Escherichia coli* and *Staphylococcus aureus*	Reduced the risk of pathogen development and extending the shelf-life of foods.	[21, 52]

Table 5.
Bacteriocins in food packaging.

3.3 Bacteriocins in food packaging

Antimicrobial packaging film prevents microbial growth on food surface by direct contact of the package with food surfaces such as meat and cheese [51]. In one of the studies, bacteriocin-producing lactic acid bacteria were isolated from Yakult (a probiotic drink) to develop an antimicrobial packaging (**Table 5**) [52].

4. Applications of bacteriocins as therapeutics

4.1 Bacteriocins in boosting immune system

Bacteriocins play an important role in boosting the immune system of the human beings. They allow the survival of specific bacterial strains in the

S. No.	Bacteriocins	Immune system, disease prevention, and Anticancer properties	Reference
1.	Bactofencin A or bacteriocin 21 produced by *Enterococcus faecalis*	Kill multidrug-resistant bacteria	[53]
2.	Pyocin	Control *Pseudomonas* lung infections in patients with cystic fibrosis.	
3.	Colicin A and Colicin E1	Inhibitory activity against the growth of eleven different tumor cell lines	
4.	Colicin D and Colicin E2	Inhibitory effect against murine leukemia cells P388	
5.	Colicin E3	Suppressed the malignant transformation of a chicken monoblast line	
6.	Bacteriocins of *Escherichia coli*	Act against human colorectal carcinoma cells	
7.	Nisin (commercial)	Act against human colorectal carcinoma cells	
8.	Bacteriocins from lactic acid bacteria	Inhibits vancomycin-resistant *Enterococci*, *Salmonella enteritidis*, *Clostridium difficile*, and *Listeria monocytogenes*	[54]

Table 6.
Bacteriocins in immune system.

S.No.	Bacteriocins or producer strains	AMR-resistant strains	Reference
1.	Nisin	Methicillin-resistant *Staphylococcus aureus* (MRSA) in goat milk	[55]
2.	Lip A	*Pseudomonas aeruginosa*	[56, 57]
3	BAC-1B-17 from *Bacillus subtilis* (thermostable) and Sonorensin from *Bacillus sonorensis*	Methicillin-resistant *Staphylococcus aureus* (MRSA)	[58, 59]
4.	Strains of *Lactobacillus helveticus*, *Lactobacillus delbreuckii*, *Lactococcus lactis*	Vancomysin-resistant *Salmonella enetritidis*, *Clostridium difficle*, *Listeria monocytogenes*	[60, 61]

Table 7.
Bacteriocins in inhibiting antimicrobial-resistant (AMR) food pathogens.

gastrointestinal tract. For example, some strains of *Lactobacillus* spp. are able to resist modification by the host diet; also inhibit other killing factors and colonization by pathogenic species within the intestine. Hence, they improve the gut barrier function and host immune response. Bacteriocins also possess anticancer properties by inhibiting the growth of the tumor cells in some animals and humans. The examples of bacteriocins in immune system and anticancer properties are mentioned in **Table 6**.

4.2 Bacteriocins in inhibiting antimicrobial-resistant (AMR) food pathogens

The bacteriocins inhibiting the antimicrobial-resistant strains of the microbes present within the food work on the principle of quorum sensing. They inhibit the competitive strains by directly influencing the niche competition [55]. The bacteriocins or producing strains that can inhibit the antimicrobial-resistant food pathogens are mentioned in **Table 7**.

5. Conclusion and future scope

Bacteriocins are the antimicrobial proteins, which could be categorized as antibiotics, but they are not. The major difference between bacteriocins and antibiotics is that the bacteriocins are species-specific and their activity is restricted to a particular strain of species; on the other hand, antibiotics have a wider activity spectrum. The bacteriocins are produced by the lactic acid bacterial species. The increased antimicrobial resistance and growing awareness of microbiome for the importance of human health underscore the need of this class of antimicrobials, as an approach for the treatment of infectious diseases spread by the antimicrobial-resistant food-borne pathogens such as *Salmonella* spp., *Listeria* spp. etc. [62]. Thus, these bacteriocins can be a part of sustainable development goals by delivering safe foods with longer shelf life [1]. The bacteriocins are the future antimicrobial proteins for the preservation of food and as therapeutics even in a cost-effective manner. The species of Enterococci have been identified as antimicrobials against vancomycin-resistant pathogens of the food industry [63, 64]. The food and dairy industries and healthcare sector should be more focused on the use of bacteriocins for food preservation and as therapeutics in cancer treatment, respectively.

Author details

Parul Thapar[1*] and Mohinder Kumar Salooja[2]

1 Department of Food Science and Technology, School of Science, Gandhi Institute of Technology and Management (GITAM) Deemed University, Hyderabad, India

2 School of Agriculture, Indira Gandhi National Open University, New Delhi, India

*Address all correspondence to: parul.thapar@yahoo.com

References

[1] Rossi F, Pallotta LM. Bacteriocin producing cultures: A sustainable way for food safety improvement and probiotics with additional health promoting effects. International Journal of Medical Biology Frontiers. 2019;**22**:59-91

[2] World Health Organization. Antibiotic Resistance: Key Facts. 2020. Available from: https://www.who.int/en/news-room/fact-sheets/detail/antibiotic-resistance

[3] Oniciuc EA, Likotrafiti E, Alvarez MA, Prieto M, Lopez M, Alvarez OA. Food processing as a risk factor for antimicrobial resistance spread along the food chain. Current Opinion in Food Science. 2019;**30**:21-26

[4] Centres for Disease Control and Prevention. Available from: https://www.cdc.gov/onehealth/basics/index.html

[5] Dall C. EU Notes Rising Resistance in Common Foodborne Pathogens. News Report. 2020. Available from: https://www.cidrap.umn.edu/news-perspective/2020/03/eu-notes-rising-resistance-common-foodborne-pathogens

[6] Silva CCG, Silva SPM, Ribeiro SC. Application of Bacteriocins and Protective Cultures in Dairy Food Preservation. Frontiers in Microbiology. 2018;**9**:1-15

[7] Lopetuso LR, Giorgio ME, Saviano A, Scaldaferri F, Gasbarrini A, Cammarota G. Antimicrobial activity of bacteriocins of Lactic Acid Bacteria on Listeria monocytogenes, Staphylococcus aureus and Clostridium tyrobutyricum in cheese production. Journal of International Molecular Science. 2019;**20**(183):1-12

[8] Salazar MEL, Galan WLJ, Moreno MVR, Reyes MA, Pereyra AB. Bacteriocins synthesized by Bacillus thuringiensis: Generalities and potential applications. Review in Medical Microbiology. 2016;**27**(3):95-101

[9] Upendra SR, Khandelwal P, Jana K, Kumar AN, Devi G. Bacteriocin Production from Indigenous Strains of Lactic Acid Bacteria Isolated from Selected Fermented Food Sources. International Journal of Pharma Research and Health Sciences. 2016;**4**(1):982-990

[10] Quinto EJ, Jimenez P, Caro I, Tejero J, Mateo J, Girbes T. Probiotic Lactic Acid Bacteria: A Review. Food and Nutrition Science. 2014;**5**:1765-1775

[11] Ricci A, Allende A, Bolton D, Chemaly M, Davies R, Girones R. Listeria monocytogenes contamination of ready-to-eat foods and the risk for human health in the EU. Journal of EFSA. 2017;**1**:15-33

[12] Hegarty JW, Guinane CM, Ross RP, Hill C, Cotter PD. Recent advances in microbial fermentation for dairy and health. Journal of EFSA. 2016;**5**:2587

[13] Parada JL, Caron CR, Medeiros ABP, Soccol CR. Bacteriocins from lactic acid bacteria: purification, properties and use as biopreservatives. Brazilian Archives of Biology and Technology. 2007;**50**:521-542

[14] Todorov SD. Bacteriocins from Lactobacillus plantarum – production, genetic organization and mode of action. Journal of Brazilian Microbiology. 2009;**40**:209-221

[15] Mahrous H, Mohamed A, El-Mongy MA, El-Batal AI, Hamza HA. Effect of Probiotic Chocolate in the Reduction of Streptococcus Mutans Count. Food and Nutrition Sciences. 2013;**4**:342-356

[16] Umu OC, Bauerl C, Oostindjer M, Pope PB, Hernandez PE, Perez-Martinez G, et al. Lactic acid bacteria. PLoS One. 2016;**1**:11-13

[17] Zacharof MP, Lovitt RW. Bacteriocins produced by Lactic acid bacteria. APCBEE Procedia. 2012;**2**:50-56

[18] Hu CB, Malaphan W, Zendo T, Nakayama J, Sonomoto K. Enterocin X, a novel two-peptide bacteriocin from enterococcus faecium. Applied and Environmental Microbiology. 2010;**76**:4542-4545

[19] Perez RH, Zendo T, Sonomoto K. Novel bacteriocins from lactic acid bacteria (LAB): Various structures and applications. Microbial Cell Factories. 2014;**13**:3-6

[20] Suskovic J, Kos B, Beganovic J, Pavunc AL, Habjanic K, Matosic S. Antimicrobial Activity – The Most Important Property of Probiotic and Starter Lactic Acid Bacteria. Food Technology and Biotechnology. 2010;**48**:296-307

[21] Zheng J, Salvetti E, Franz MAPC, Mattarelli P. A taxonomic note on the genus Lactobacillus: Description of 23 novel genera, emended description of the genus Lactobacillus Beijerinck 1901, and union of Lactobacillaceae and Leuconostocaceae. International Journal of System Evolution and Microbiology. 2020;**70**:2782-2858

[22] Cotter PD, Hill C, Ross RP. Nature Reviews. Microbiology. 2005;**3**:777-788

[23] Leroy F, De Vuyst L. Bacteriocins of lactic acid bacteria to combat undesirable bacteria in dairy products. Journal of Australian Dairy Technology. 2010;**65**:143-149

[24] Salgado PR, Ortiz CM, Musso YS, Di GL, Mauri AN. Edible films and coatings containing bioactives. Current Opinion in Food Science. 2015;**5**:86-92

[25] Melo J, Andrew P, Faleiro M. Listeria monocytogenes in cheese and the dairy environment remains a food safety challenge: The role of stress responses. Bacteriocins: developing innate immunity for food. Journal of International Food and Research. 2015;**67**:75-90

[26] Sanchez HM, Montalban LM, Cebrian R, Valdivia E, Martinez BM, Maqueda M. AS-48 bacteriocin: Close to perfection. Cellular and Molecular Life Sciences. 2011;**68**:2845-2857

[27] Ibarguren C, Celiz G, Diaz AS, Bertuzzi MA, Daz M, Audisio MC. Gelatine based films added with bacteriocins and a flavonoid ester active against food-borne pathogens. Innovative Food Science and Emerging Technologies. 2015;**28**:66-72

[28] Narsaiah K, Wilson RA, Gokul K, Mandge H, Jha S, Bhadwal S. Effect of bacteriocin-incorporated alginate coating on shelf-life of minimally processed papaya (Carica papaya L.). Postharvest Biology and Technology. 2015;**100**:212-218

[29] Tack D, Ray L, Griffin P. Preliminary Incidence and Trends of Infections with Pathogens Transmitted Commonly Through Food – Foodborne Diseases Active Surveillance Network, 10 U.S. Sites, 2016-2019. Morbility Mortalality Weekly Report. 2020;**69**:509-514

[30] Franssen F, Gerard C, Cozma-PetruÛ A, Vieira-Pinto M, Jambrak AR, Rowan N, et al. Inactivation of parasite transmission stages: Efficacy of treatments on food of animal origin. Trends in Food Science and Technology. 2019;**83**:114-128

[31] Cotelo MF, Schein KP, Salvo SSG, Abirad PMZ, Techera SBC. Antimicrobial properties of lactic acid bacteria isolated

from uruguayan artisan cheese. Food Science and Technology. 2013;**33**(4):1-3

[32] Patrovsky M, Kourimska L, Havlikova S, Markova J, Pechar R, Rada V. Utilization of bacteriocin-producing bacteria in dairy products. Mljekarstvo. 2016;**66**:215-224

[33] Bockelmann W, Koslowsky M, Goerges S, Scherer S, Franz C, Heller KJ. Growth inhibition of Listeria monocytogenes by bacteriocin-producing Staphylococcus equorum SE3 in cheese models. Food Control. 2017;**71**:50-56

[34] Aspri M, Oconnor PM, Field D, Cotter PD, Ross P, Hill C. Application of bacteriocin-producing Enterococcus faecium isolated from donkey milk, in the bio-control of Listeria monocytogenes in fresh whey cheese. Journal of International Dairy Research. 2017;**73**:1-9

[35] Khan I, Oh DH. Integration of nisin into nanoparticles for application in foods. Innovative Food Science & Emerging Technologies. 2016;**34**:376-384

[36] Ribeiro SC, Ross RP, Stanton C, Silva CC. Characterization and application of antilisterial enterocins on model fresh cheese. Journal of Food Proteins. 2017;**80**:1303-1316

[37] Vandera E, Lianou A, Kakouri A, Feng J, Koukkou AI, Samelis J. Enhanced control of Listeria monocytogenes by Enterococcus faecium KE82, a multiple enterocin–producing strain, in different milk environments. Journal of Food Proteins. 2017;**80**:74-85

[38] Fagundes PC, De FFM, Da Silva SOC, Da Paz JAS, Ceotto VH, Alviano DS. The four-component aureocin A70 as a promising agent for food biopreservation. Journal of International Food Microbiology. 2016;**237**:39-46

[39] Yildirim Z, Oncul N, Yildirim M, Karabiyikli S. Application of lactococcin BZ and enterocin KP against Listeria monocytogenes in milk as biopreservation agents. Acta Alimentaria. 2016;**45**:486-492

[40] Shi F, Wang YW, Li YF, Wang XY. Mode of action of leucocin K7 produced by Leuconostoc mesenteroides K7 against Listeria monocytogenes and its potential in milk preservation. Biotechnology Letters. 2016;**38**:1551-1557

[41] Suda S, Cotter PD, Hill C, Paul RR. Lacticin 3147-biosynthesis, molecular analysis, immunity, bioengineering and applications. Current Protein & Peptide Science. 2012;**13**:193-204

[42] Simha BV, Sood S, Kumariya R, Garsa AK. Simple and rapid purification of pediocin PA-1 from Pediococcus pentosaceous NCDC 273 suitable for industrial application. Microbiological Research. 2012;**167**:544-549

[43] Fraqueza MJ, Patarata L. Laukova A. Fermented meat products health aspects. Fermented Meat Products: Health Aspects. 2017;**572**

[44] Mills S, Serrano LM, Griffin C. Inhibitory activity of Lactobacillus plantarum LMG P-26358 against Listeria innocua when used as an adjunct starter in the manufacture of cheese. Microbial Cell Factories. 2011;**10**:1-5

[45] Dal BB, Cocolin L, Zeppa G, Field D, Cotter PD, Hill C. Technological characterization of bacteriocin producing Lactococcus lactis strains employed to control Listeria monocytogenes in cottage cheese. Journal of International Food Microbiology. 2012;**153**:58-65

[46] Arques JL, Rodríguez E, Langa S, Landete JM, Medina M. Antimicrobial activity of lactic acid bacteria in dairy

products and gut: effect on pathogens. Journal of International Biomedical Research. 2015;**1**:1-5

[47] Oshima S, Hirano A, Kamikado H, Nishimura J, Kawai Y, Saito T. Nisin A extends the shelf life of high-fat chilled dairy dessert, a milk based pudding. Journal of Applied Microbiology. 2014;**116**:1218-1228

[48] Felicio BA, Pinto MS, Oliveira FS, Lempk MW, Pires ACS, Lelis CA. Effects of nisin on Staphylococcus aureus count and physicochemical properties of Minas Frescal cheese. Journal of Dairy Science. 2015;**98**:4364-4369

[49] Alves FCB, Barbosa LN, Andrade B, Albano M, Furtado FB, Pereira AFM. Short communication: inhibitory activities of the lantibiotic nisin combined with phenolic compounds against Staphylococcus aureus and Listeria monocytogenes in cow milk. Journal of Dairy Science. 2016;**99**:1831-1836

[50] World Health Organization. Food Additives. 2018. Fact Sheet. Available from: https://www.who.int/news-room/fact-sheets/detail/food-additives

[51] Deshmukh PV, Thorat PR. Bacteriocins: a new trend in antimicrobial food packaging. International Journal of Advanced Research in Engineering and Applied Science. 2013;**2**(1):1-12

[52] Damania P, Patel R, Shaw R, Kataria RP, Wadia A. Development of antimicrobial packaging materials for food preservation using bacteriocin from Lactobacillus casei. Microbiological Research. 2016;**7**(1):19-22

[53] Yang SC, Lin CH, Sung CT, Fang JY. Antibacterial activities of bacteriocins: Application in foods and pharmaceuticals. Frontiers in Microbiology. 2014;**5**:241

[54] Joo NE, Ritchie K, Kamarajan P, Miao D, Kapila YL. Nisin, an apoptogenic bacteriocin and food preservative, attenuates HNSCC tumorigenesis via CHAC1. Cancer Medicine. 2012;**1**:295-305

[55] Kommineni S, Bretl DJ, Lam V, Chakraborty R, Hayward M, Simpson P, et al. Bacteriocin production augments niche competition by enterococci in the mammalian gastrointestinal tract. International Journal of Food Microbiology. 2015;**526**:719-722

[56] Perales AJ, Rubino S, Martinez M. LAB bacteriocins controlling the food isolated (drug-resistant) staphylococci. Frontiers in Microbiology. 2018;**9**:1143

[57] Escolanoa MR, Cebrianb R, Escolanoa JM, Rosalesa MJ, Maquedab M, Morenoa SM, et al. Insights into Chagas treatment based on the potential of bacteriocin AS-48. Drugs Drug Resist. 2019;**10**:1-8

[58] Ansari A, Zohra RR, Tarar OM, Qader SAU, Aman A. Characterization, Cytotoxic Analysis and Action Mechanism of Antilisterial Bacteriocin Produced by Lactobacillus plantarum Isolated from Cheddar Cheese. BMC Microbiology. 2018;**18**(1):1-10

[59] Chopra L, Singh G, Jena KK, Sahoo DK. Sonorensin: A new bacteriocin with potential of an anti-biofilm agent and a food biopreservative. Scientific Reports. 2015;**5**:13412

[60] Umu OCO, Rudi K. Diep DB. Modulation of the gut microbiota by prebiotic fibres and bacteriocins. Microbial Ecology in Health and Disease. 2019;**28**

[61] Rea MC, Alemayehu D, Ross RP, Hill C. Gut solutions to a gut problem: bacteriocins, probiotics and bacteriophage for control of Clostridium

difficile infection. Journal of Medical Microbiology. 2013;**62**(9):1369-1378

[62] Laranjo M, Potes EM, Elias M. Role of Starter Cultures on the Safety of Fermented Meat Products. Frontiers in Microbiology. 2019;**10**(853):1-11

[63] Grujovic M, Mladenovic K, Petrovic TZ. Comic, L. Assessment of the antagonistic potential and ability of biofilm formation of Enterococcus spp. isolated from Serbian cheese. Veterinarski arhiv. 2019;**89**(5):653-667

[64] Suarez N, Weckx S, Minahk C, Hebert EM. Saavedra L. Metagenomics-based approach for studying and selecting bioprotective strains from the bacterial community of artisanal cheeses. International Journal of Food Microbiology. 2020;**335**:108894