Bacteriocins as Sustainable Biotherapeutics for the Control of Aquatic Bacterial Pathogens

Chandru Govindan[1] and Arun Sharma[1*]

[1]*Department of Aquatic Animal Health Management, ICAR-Central Institute of Fisheries Education, Off Yari Road, Versova, Andheri West, Mumbai- 400061, Maharashtra, India.*

Corresponding Author
Arun Sharma
Email: arunsharma@cife.edu.in

OPEN ACCESS

Keywords

Bacteriocins, Aquaculture, Aquatic pathogens, Probiotics, Antimicrobial resistance

How to cite this article:

Govindan, C. and Sharma, A. 2026. Bacteriocins as Sustainable Biotherapeutics for the Control of Aquatic Bacterial Pathogens. *Vigyan Varta* 7 (09): 61-65.

ABSTRACT

The increasing occurrence of bacterial diseases in freshwater aquaculture has become a major concern due to the substantial economic losses affecting the fisheries sector. Bacteriocin-producing probiotics have emerged as a promising approach for reducing fish mortality and disease incidence, as they are generally regarded as safe and produce fewer side effects compared to conventional treatments. In aquaculture, it is crucial to understand the mode of action by which bacteriocins are effective against pathogens in order to utilize them as a biopesticide, particularly as a prophylactic biopesticide. Antibiotics, chemotherapy and vaccination are usually the techniques used, but they may have negative effects on cultured organisms and the aquatic environment and are not often used in field conditions. These bacteriocins are environmentally friendly alternative to chemical treatment in the freshwater aquaculture industry for bacterial disease management if properly up used. Bacteriocins and their modes of action against the major pathogens of the aquaculture industry are emphasized.

INTRODUCTION:

Aquaculture now ranks among the world's fastest-growing food production sectors and fish is an important source of high-quality protein contributing to food and nutritional security worldwide. Production through capture fisheries has grown steadily over the decades, while aquaculture production has grown spectacularly, and thus plays a significant role in food security and economic development. At the same time, a large number of cultured aquatic species have also increased (FAO, 2026).

However, even with these advances, it is possible for intensive aquaculture to be linked to high densities that can cause stress to the cultured fish and lead to increased risk of disease. Antibiotics and chemotherapeutic agents are used extensively in aquaculture to reduce losses due to diseases. Overuse and inappropriate application of such chemicals, however, have resulted in multi-antibiotic resistance of fish pathogens to several commonly used antibiotics. Vaccination is an effective, prophylactic method, but there are only a few commercially available fish vaccines and vaccination may not be feasible for certain immature fish. Therefore, other methods to control the disease that are not only effective and sustainable, but also environmentally friendly, should be developed. Considering their spectrum of activity, which includes pathogens but excludes the host and aquatic environment, and their eco-friendly, degradable, and pathogen-antagonistic properties, bacteriocins are regarded as potential biotherapeutic agents for aquaculture, where they would not cause any pathogenic effect.

Bacteriocins

Bacteriocins are antimicrobial peptides or proteins synthesized in the ribosome by some bacteria, particularly bacteria belonging to Bifidobacteriaceae family. This usually occurs during bacteria's early phases of growth and has a variety of health-promoting properties, such as strong antimicrobial activity against pathogenic microorganisms. Unlike classical antibiotics, the antimicrobial spectrum of action of the bacteriocins is generally quite restricted, targeting generally close bacterial species. Antibiotics generally have a broad spectrum of activity, while not being species-specific. Microorganisms have multiple defence mechanisms such as classical broad-spectrum antibiotics, metabolic by-products, lytic enzymes, exotoxins and biologically active proteinaceous compounds with bactericidal effects (bacteriocins). Of these defence molecules, the most important ones are the bacteriocins, which have a wide variety of structure, and also exist in many natural products. Many studies have shown that for almost all the bacterial species tested so far, at least one of the synthesized bacteriocins was found, and in one bacterial species different and distinct bacteriocins are synthesized.

Classification of bacteriocins

Bacteriocins are highly structurally and functionally diverse, leading to the creation of several classification methods. The most widely-used system, especially for the production of bacteriocins by Gram-positive bacteria like lactic acid bacteria (LAB), classifies all these into three main groups based on their biochemical and genetic characteristics. Gram-negative bacterial bacteriocins are mainly classified into two groups: colicins and microcins. Colicins are protein bacteriocins with high molecular weight that are primarily produced by *Escherichia coli*, while microcins are small heat-stable antimicrobial peptides produced by members of the Enterobacteriaceae family (Marković *et al*., 2022).

Class	Type of Bacteriocin	Main Characteristics	Examples
Class I	Lantibiotics	Small, heat-stable peptides with unusual amino acids formed by post-translational modification	Nisin, Lacticin
Class II	Non-lanthionine	Small, heat-stable, unmodified peptides	Pediocin, Plantaricin

Class	Type of Bacteriocin	Main Characteristics	Examples
	bacteriocins		
Class IIa	Pediocin-like bacteriocins	Active mainly against *Listeria* species	Pediocin PA-1
Class IIb	Two-peptide bacteriocins	Require two peptides for antimicrobial activity	Lactococcin G
Class IIc	Circular bacteriocins	Peptides with circular structure	Enterocin AS-48
Class IId	Other linear bacteriocins	Linear, non-pediocin-like peptides	Bactofencin A
Class III	Large bacteriocins	Large, heat-labile proteins	Helveticin J
Class IV	Complex bacteriocins	Contain lipid or carbohydrate moieties	Glycocin F

Table 1. Classification of bacteriocins produced by Gram-positive bacteria

Group	Characteristics	Examples
Colicins	High molecular weight proteins produced by *Escherichia coli*	Colicin E1
Microcins	Small, low molecular weight peptides	Microcin J25

Table 2. Classification of bacteriocins produced by Gram-negative bacteria

Mechanism of Action of Bacteriocins

Bacteriocins are antimicrobial peptides that are synthesized by bacteria and kill or inhibit the growth of other bacteria in the environment via other mechanisms. They mostly act on bacterial cell membrane, cell wall or on critical intracellular processes.

1. **Pore formation in Cell Membrane**: There are lots of bacteriocins that bind to the bacterial cell membrane and form pores/ channels. These pores allow cellular components, such as ions, amino acids and ATP to leak out, and the cell will die as a result of the loss of membrane integrity (e.g. Nisin).

2. **Inhibition of Cell Wall Synthesis:** There are some bacteria that produce bacteriocins which inhibit peptidoglycan synthesis, which is an important component of the outer cell-wall of the bacteria. For example, nisin binds to the Lipid II molecule in the process of cell wall formation, blocking normal cell wall formation and killing bacteria.

3. **De-polarization of the membrane potential:** Some bacteriocins disrupt the proton motive force/membrane potential for energy production and transport. Eventually, this upset in the normal metabolism of the cells will destroy the bacteria.

4. **Degradation of Cell Wall:** Some of the high molecular weight bacteriocins, called bacteriolysins, hydrolyse or degrade the cell wall which results in the rupture and killing of the target bacterium.

5. **Inhibition DNA Replication:** Some bacteriocins inhibit enzymes involved in the replication of DNA such as DNA gyrase in the bacterial cytoplasm. This does not permit the bacteria to multiply and results in cell death.

6. **Inhibition of RNA Synthesis (Transcription):** Some bacteriocins inhibit transcription (RNA polymerase) and prevent the formation of important molecules of RNA which are required for protein synthesis.

7. **Inhibition of Protein Synthesis:** Some bacteriocins bind to the bacterial ribosome or transfer RNA and inhibit the translation process which in turn prevents the synthesis of necessary proteins important for bacterial survival.

8. **Disruption of the nutrient uptake:** Some bacteriocins interfere with the glucose and other nutrient transport system, which leads

to the prevention of bacterial cells from uptake of nutrients and hence their growth.

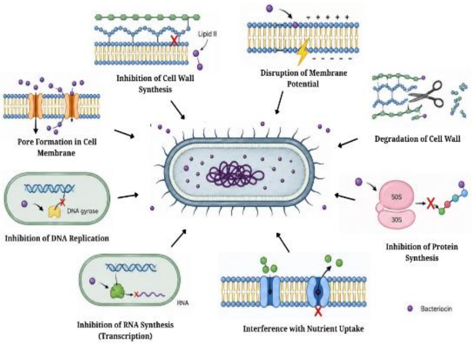

Figure 1. Mechanism of action of bacteriocins

Bacteriocins in Aquaculture

Several of the bacteriocins have been shown to be effective against important aquatics pathogens like *Aeromonas hydrophila, Vibrio* spp., *Lactococcus garvieae, Pseudomonas aeruginosa, Shewanella putrefaciens* and *Listeria monocytogenes.* (Sahoo *et al.*, 2016). The antimicrobial peptides can decrease the number of pathogens, enhance the survival rate of cultured aquatic animals and raise the general health condition of cultured aquatic animals. Bacteriocins may be used directly as a purified antimicrobial compound or indirectly by feeding probiotic bacteria which produce the compound.

Bacteriocins can be produced continuously in the gastrointestinal tract by consuming probiotics, thus preventing pathogenic bacteria from colonizing. Purified bacteriocins can also be used as a fast acting against microbes in feed formulations or aquaculture water systems. These methods have gained importance in biofloc systems, recirculating aquaculture systems (RAS), and in intensive aquaculture production systems, such as fish and shrimp farming (Nayak *et al.*, 2022).

Aquatic Species	Bacteriocins	Target Pathogen(s)
Labeo rohita	Bacteriocin from *Bacillus subtilis* LR1	*Aeromonas hydrophila*, *A. salmonicida*, *Bacillus mycoides*, *Pseudomonas fluorescens*
Oncorhynchus tshawytscha	Enterocin AS-48	*Lactococcus garvieae*
Penaeus monodon	Bacillus-derived bacteriocin	*Vibrio alginolyticus*, *Aeromonas hydrophila*, *Pseudomonas stutzeri*
Litopenaeus vannamei	Bacteriocin from *Lactobacillus plantarum* FGC-12	*Vibrio parahaemolyticus*
Odontesthes platensis	Nisin Z	*Lactococcus garvieae*
Tilapia, *Catla catla*, *Cyprinus carpio*	Bacteriocin from *Pediococcus acidilactici*	*Listeria monocytogenes*
Oxyeleotris lineolata	L49	*Streptococcus iniae*

Table 3. Bacteriocins in aquaculture

Challenges and Limitations

One of the main problems is that some of the bacteria that are responsible for the production of the bacteriocins can be pathogenic and/or opportunistic pathogens of fish. The direct use of the microorganisms producing the bacteriocin can then result in major disease problems with cultured microorganisms. In a few cases, however, the crude extracts of the bacteriocins were also shown to have detrimental effects on fish's indigenous gut flora.

Another limitation is the delivery of the bacteriocins into the feed. If the fish are stressed by being affected by illness, they may refuse to eat or eat less of a feed, which may decrease their intake of the bacteriocin in the feed so that the fish may not benefit from the feed's bacteriocin properties. This could result in the underestimation of the effectiveness of the bacteriocin in the field. Another limitation in the application of large scale is economic feasibility. The production, purification and

E-ISSN: 2582-9467
Popular Article
Govindan and Sharma (2026)

cost of production of bacteriocins such as nisin are expensive, and they are not very stable under environmental conditions, limiting their commercial applications. Also, most of the bacteria which produce bacteriocin are narrow-spectrum, which means that they are only effective against closely related species of bacteria. In aquaculture systems where several pathogens may be involved in polymicrobial infections this specificity may be less than desired.

CONCLUSION AND FUTURE PERSPECTIVES

Due to the emergence of bacterial diseases in aquaculture and the prohibition of antibiotic usage, there is a growing interest in alternative disease management strategies in aquaculture that is sustainable. Probiotics and bacteriocins in this sense have emerged as useful biotherapeutic tools that can positively modulate the health status of fish, improve their immune system and control the pathogenic bacteria in aquaculture facilities. With their application, they can help to decrease production losses and encourage sustainable and eco-friendly aquaculture. With ongoing research into the applications of bacteriocins in aquaculture, future advancements are likely to improve their antimicrobial activity, broaden their scope of activity and reduce the cost of production, paving the way for the future of aquaculture.

REFERENCES

FAO. 2026. The State of World Fisheries and Aquaculture 2026 – Blue Transformation: turning vision into impact. Rome.

Marković, K. G., Grujović, M. Ž., Koraćević, M. G., Nikodijević, D. D., Milutinović, M. G., Semedo-Lemsaddek, T., & Djilas, M. D. (2022). Colicins and microcins produced by Enterobacteriaceae: characterization, mode of action, and putative applications. *International Journal of Environmental Research and Public Health*, *19*(18), 11825.

Nayak, A., Karunasagar, I., Chakraborty, A., & Maiti, B. (2022). Potential application of bacteriocins for sustainable aquaculture. *Reviews in Aquaculture*, *14*(3), 1234-1248.

Sahoo, T. K., Jena, P. K., Patel, A. K., & Seshadri, S. (2016). Bacteriocins and their applications for the treatment of bacterial diseases in aquaculture: a review. *Aquaculture Research*, *47*(4), 1013-1027.