Review Article

Journal of Advanced Veterinary Research
(2026) Volume 16, Issue 1, 187-192

Antimicrobial activity of bacteriocins produced by lactic acid bacteria derived from Indonesian traditional fermented animal products: A review

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ARTICLE INFO

Received: 01 October 2025

Accepted: 14 December 2025

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Keywords:

Antimicrobial activity, Bacteriocins, Fermented animal products, Lactic acid bacteria, Traditional fermented food.

ABSTRACT

Bacteriocins produced by LAB isolated from traditional Indonesian fermented foods like dadih, urutan, bekasam, cangkuk, and bekamal show promising antimicrobial activity against pathogenic and spoilage bacteria. These bacteriocins are effective at inhibiting bacterial growth and maintaining food quality. The review discusses the isolation and characterization of LAB from these fermented products, the properties of the bacteriocins they produce, and their potential applications in food preservation. Bacteriocins from food-grade LAB are considered ideal biopreservatives due to their non-toxic nature, stability under various conditions, and effectiveness at low concentrations. The paper highlights the diversity of LAB strains found in traditional fermented foods and their ability to produce bacteriocins with broad-spectrum antimicrobial activity. Overall, this review emphasizes the potential of bacteriocins from indigenous fermented foods as natural antimicrobial agents for enhancing food safety and quality, aligning with consumer demand for minimally processed foods. Further research is suggested to optimize the production and application of these bacteriocins in food systems.

Introduction

The utilization of Lactic Acid Bacteria (LAB) and their metabolites, particularly bacteriocins, has garnered considerable attention in recent years because of its potential as a natural food preservative and antimicrobial agent, as well as for maintaining the quality of food products (Choi *et al*., 2025). Bacteriocins are peptides synthesized on ribosomes during bacterial metabolism and are predominantly produced by Gram-positive bacteria, with only a minority of Gram-negative bacteria capable of producing them. These antimicrobial compounds have diverse molecular weights and mechanisms of action, rendering them versatile tools for food preservation and safety (Alvarez-Sieiro *et al*., 2016). LAB are particularly noteworthy producers of bacteriocins. These microorganisms are generally classified as Gram-positive, catalase-negative, non-spore-forming, and tolerant to low-oxygen and acidic environments. LAB typically ferment carbohydrates into lactic acid as their primary product and can thrive at a wide range of temperatures and pH levels. This adaptability allows LAB to inhabit various environments (Aguirre-Garcia *et al*., 2024).

The relationship between humans and LAB dates back to the Neolithic period, with evidence of its use in various products. LAB are generally considered safe for human consumption either directly or through fermented food products. These microorganisms have significantly contributed to food safety and biotechnology by providing convenient access to safe and high-quality fermented products (Virdis *et al*., 2021). LAB's proteolytic activity of LAB during fermentation meets their amino acid requirements and contributes to the taste, aroma, and texture of the fermented products. They produce various metabolites that enhance the organoleptic properties and improve product safety and shelf life. LAB can be used for food preservation through three primary mechanisms: employing specific LAB strains with known antibacterial activity, incorporating previously fermented products into new compositions or as starters, and utilizing purified bacteriocins obtained from LAB metabolism (Carneiro *et al*., 2024). Bacteriocins, which are secondary metabolites of LAB, possess remarkable antibacterial properties against both closely related and unrelated bacterial species. They exhibit bacteriostatic and bactericidal mechanisms, and are effective against various pathogenic and spoilage bacteria in food products. Bacteriocins from food-grade LAB are considered ideal biopreservatives because of their non-toxic nature, lack of odor and color, minimal impact on product nutrition, effectiveness at low concentrations, and stability under various storage conditions (Favaro and Todorov, 2017). Several types of bacteriocins, including nisin, pediocin, enterocin, and sakacin have been extensively studied and tested as antibacterial agents (Zendo, 2013).

Bacteriocins are categorized into four distinct classes based on their molecular weights, thermal stabilities, and compositions. Their resilience to extreme temperatures and low pH levels, coupled with their susceptibility to degradation by proteolytic enzymes, renders them a promising alternative to conventional preservatives (Tumbarski *et al*., 2018). Isolation of LAB from diverse sources, particularly traditional fermented products of animal origin, is essential for obtaining effective bacteriocins. After isolation, the LAB isolates were collected, identified, and characterized to acquire strains with enhanced properties. Further investigation is required to characterize the bacteriocins produced by promising LAB isolates and assess their antibacterial efficacy (Grosu-Tudor *et al*., 2014). The use of bacteriocins as biopreservatives aligns with increasing consumer demand for natural and minimally processed foods. As research in this domain progresses, the potential applications of bacteriocins in food preservation and safety are anticipated to expand, presenting new opportunities for enhancing food quality and prolonging shelf life (De Vuyst, 2007).

This review examines the antimicrobial properties of bacteriocins produced by LAB isolated from traditional Indonesian fermented animal products. It delves into the characteristics and classification of bacteriocins, their modes of action, and their use in food preservation. LAB derived from native fermented foods such as dadih, urutan, bekasam, cangkuk, and bekamal are highlighted. By showcasing the potential of these traditional products as sources of new antimicrobial compounds, this study aims to aid in the development of natural preservatives to improve food safety and quality.

Indonesian traditional fermented animal products

Dadih

Dadih, also known as dadiah, is a traditional fermented buffalo milk obtained from the Minangkabau tribe in West Sumatra, Indonesia. It is a yogurt-like product with a distinctively thicker consistency, smooth texture, and pleasant flavor (Herlina and Setiarto, 2024). The traditional method of preparing dadih involves fermenting buffalo milk at room temperature for 24-48 hours in bamboo containers, without the need for additional inoculation (Alzahra *et al*., 2021; Pramana *et al*., 2025; Surono, 2015). The fermentation process contributes to the taste and texture of dadih, resulting in a smooth and shiny surface, thick bodies, creamy color, and pleasant flavor (Herlina and Setiarto, 2024). The microbes involved in dadih fermentation, particularly lactic acid bacteria (LAB), provide functional value, including antimicrobial, antioxidant, antimutagenic, hypocholesterolemic, and immunomodulatory properties (Alzahra *et al*., 2024; Herlina and Setiarto, 2024; Pramana *et al*., 2025). Additionally, dadih has been found to have significant nutritional content, with protein content ranging from 6.83% to 8.92%, fat content ranging from 5.11% to 6.18%, and water content ranging from 72.43% to 75.71% (Putri *et al*., 2021; Surono, 2015). Indigenous dadih LAB have been shown to have several advantages, including immunomodulatory, antioxidant, antimutagenic, hypocholesterolemic, and antimicrobial properties. Furthermore, dadih offers health benefits, such as promoting digestive health and enhancing the body's resilience (Pramana *et al*., 2025). The nutritional composition of dadih, including protein, fat, and water contents, varies slightly depending on the specific region of production (Putri *et al*., 2021; Surono, 2015).

Urutan

Urutan is a traditional Balinese dry-fermented sausage made from pork, lard, and various of spices. Unlike European sausages, urutan is fermented under warm conditions, with temperatures fluctuating between approximately 25°C at night and 50°C during sun drying. The fermentation process involves the use of LAB, with *Lactobacillus plantarum* and *Pediococcus acidilactici* being the significant contributors. These bacteria help in lowering the pH and coagulating soluble proteins, which are crucial for the texture and safety of sausages. The use of these LAB strains as starter cultures can effectively eliminate harmful bacteria, such as *Enterobacteriaceae* and Micrococci during fermentation (Antara *et al*., 2002). The bacterial diversity in urutan can vary significantly, depending on the species and raw materials used. A study using metagenomic analysis revealed that Bacillota is the most abundant phylum in the urutan, with *Staphylococcus*, *Weissella*, and *Lactococcus* being the predominant genera. This diversity is influenced by the specific conditions and ingredients used in different household industries, which can affect the pH, water activity, and overall acidity of sausages. The unique fermentation process and microbial interactions not only contribute to the distinctive flavor and texture of urutan but also ensure its safety and nutritional value (Yogeswara *et al*., 2024).

Bekasam

Bekasam is a traditional Indonesian fermented food, typically made from freshwater fish or any kind of meat, salt, steamed rice, and garlic, undergoing spontaneous fermentation for about one week to a month. This process imparts a distinctive scent and flavor to the product (Suharto *et al*., 2024). The fermentation process involves LAB, which play a crucial role in enhancing the nutritional and sensory properties of bekasam. For instance, the addition of *Pediococcus acidilactici* as a starter culture has been shown to increase protein content and improve the overall quality of bekasam by promoting proteolytic activity and reducing the total plate count of harmful bacteria (Suharto *et al*., 2024). Fermentation also results in a decrease in pH and an increase in lactic acid content, contributing to the sour taste of bekasam (Wulandari *et al*., 2020). Bekasam is not only valued for its unique taste but also for its potential health benefits. The LAB present in bekasam, such as *Lactobacillus plantarum* and *Pediococcus pentosaceus*, have been identified for their probiotic properties, including inhibition of pathogenic bacteria such as *Escherichia coli* and *Staphylococcus aureus* (Desniar *et al*., 2013; 2023). Fermentation enhances the nutritional profile of bekasam by increasing its protein content and reducing fat and carbohydrate levels (Wulandari *et al*., 2020). The use of different fish types and fermentation conditions can further influence the quality and characteristics of bekasam, making it a versatile and culturally significant food product in Indonesia (Azara *et al*., 2019; Lestari *et al*., 2018).

Cangkuk

Cangkuk is a traditional Indonesian fermented beef product that is particularly popular in the Riau Province. The fermentation process of cangkuk involves various ingredients, formulations, and incubation times, with one notable ingredient being the kepayang (*Pangium edule*) endosperm, which contains organic acids, tannins, and polyphenols (Mirdhayati *et al*., 2024). The fermentation process can last for up to 28 days, during which the nutritional content and populations of LAB remain stable. However, sensory properties such as color, aroma, texture, and taste improve significantly, while pH and total titratable acidity (TTA) decrease, enhancing the overall acceptance by panelists (Mirdhayati *et al*., 2024). The fermentation of cangkuk is characterized by LAB activity, which is crucial for the development of unique properties of the product. LAB are known for their probiotic potential and ability to produce lactic acid and other metabolites that lower the pH and inhibit the growth of pathogenic microorganisms (Antara *et al*., 2019; Mirdhayati *et al*., 2024). This microbial activity is essential to ensure the safety and quality of fermented beef. Additionally, the presence of the kepayang endosperm contributes to the chemical complexity of cangkuk, adding beneficial compounds such as tannins and polyphenols, which may have health-promoting properties (Mirdhayati *et al*., 2024).

Bekamal

Bekamal is a traditional fermented meat product from Banyuwangi Regency, Indonesia, known for its unique taste and preservation qualities. The traditional preparation of bekamal involves fermenting meat with the addition of sugar and salt, which act as preservatives and flavor enhancers. This process typically takes three to six months, resulting in a product that is juicy, slightly sour, and salty, which is highly favored by consumers (Prastujati *et al*., 2024). The fermentation process is facilitated by LAB, including genera such as Lactobacillus, Streptococcus, and Leuconostoc, which contribute to the safety and sensory properties of the product (Prastujati *et al*., 2022). The fermentation of bekamal not only enhances its flavor but also significantly improves its safety and shelf life. Studies have shown that the fermentation process effectively eliminates pathogenic microorganisms, such as *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella* sp., making the product safe for consumption (Prastujati *et al*., 2023). LAB involved in the fermentation process produce lactic acid, which lowers the pH and inhibits the growth of harmful bacteria, thus preserving meat and enhancing its nutritional value (Prastujati *et al*., 2022; 2023). Additionally, the fermentation process increases protein content and reduces moisture, fat, and carbohydrate content, contributing to the overall quality and health benefits of bekamal (Wulandari *et al*., 2020).

Isolation of LAB and bacteriocins

LAB isolation

Lactic acid bacteria (LAB) are a diverse group of bacteria that play significant roles in food fermentation, bioremediation, and probiotics. Isolation of LAB is a crucial step in the study of their properties and potential applications. LAB strains were selected based on their growth characteristics and antimicrobial activity. Molecular identification, such as 16S rRNA gene sequencing, is commonly used to confirm the identity of isolates (Kaur and Tiwari, 2016; Sariri *et al*., 2025). LAB can be isolated from diverse environments including fermented animal products. The diversity of LAB suggests their potential for various industrial applications (Bakar *et al*., 2017; Kaur and Tiwari, 2016). Isolated LAB strains were characterized using morphological, biochemical, and molecular techniques. This includes Gram staining, catalase testing, and 16S rRNA gene sequencing to ensure accurate identification (Bakar *et al*., 2017; Sanam *et al*., 2022; Sariri *et al*., 2025). LAB isolated from different environments have shown potential for bioremediation, food preservation, and use as probiotics. For example, LAB isolated from buffalo milk demonstrated good probiotic properties, including resistance to low pH and bile salts and antimicrobial activity against pathogenic bacteria (Melia *et al*., 2018).

Bacteriocin isolation

Bacteriocins are antimicrobial peptides produced by bacteria, including LAB, and have potential applications in food preservation and as alternatives to antibiotics. Bacteriocins can be isolated using various methods such as ammonium sulfate precipitation, dialysis, and chromatographic techniques. These methods help purify bacteriocins and enhance their antimicrobial activity (Cheikhyoussef *et al*., 2009; Ovchinnikov *et al*., 2022). Ultrafiltration and nanofiltration offer high recovery yields and enhanced bacteriocin activities. For instance, ultrafiltration and nanofiltration have been used to isolate bacteriocins from LAB, resulting in a high recovery performance and increased antimicrobial activity (Zacharof *et al*., 2013). Isolated bacteriocins are characterized by their antimicrobial activity, stability under different conditions (e.g., pH, temperature), and resistance to proteolytic enzymes. Techniques such as SDS-PAGE and mass spectrometry have been used to determine the molecular weight and purity of bacteriocins (Elamathy and Kanchana, 2013; Shokri *et al*., 2013). Bacteriocins are effective against a range of pathogenic bacteria and fungi, making them valuable for food preservation and as therapeutic agents. For example, bacteriocins from LAB have been used to inhibit the growth of *Listeria monocytogenes*, a common foodborne pathogen (Elamathy and Kanchana, 2013; Shokri *et al*., 2013).

LAB isolated from Indonesian traditional fermented animal products

Traditional Indonesian fermented foods such as dadih, urutan, bekasam, cangkuk, and bekamal are rich sources of lactic acid bacteria (LAB) and bacteriocins, which have significant potential as natural preservatives and probiotics. Dadih contains various LAB strains, including *Lactobacillus pentosus* 124-2 and *Lactiplantibacillus pentosus* DHS6. These strains produce bacteriocins with antimicrobial properties that are effective against pathogens, such as *Salmonella* and *Staphylococcus aureus* (Hayati *et al*., 2021; Susmiati *et al*., 2024; Yuliana *et al*., 2023). Bacteriocins from *L. pentosus* 124-2 are stable across a range of pH levels, temperatures, and salt concentrations, making them suitable for food preservation (Yuliana *et al*., 2023). Additionally, *Lactobacillus plantarum* strains from dadih exhibit probiotic properties, including bile salt resistance and low pH tolerance (Jatmiko *et al*., 2017).

Urutan, a traditional Balinese sausage, is another fermented product that likely contains LAB; however, specific studies on its LAB content and bacteriocin production are limited. Generally, fermented sausages are known to harbor LAB, such as Lactobacillus curvatus and *Weissella viridescens*, which produce bacteriocins with broad inhibitory spectra (Castilho *et al*., 2019). Bekasam, a fermented fish product, contains LAB strains like *Pediococcus pentosaceus* and *Lactobacillus plantarum* subsp. plantarum. These strains produce organic acids and bacteriocins that inhibit pathogens, such as *Listeria monocytogenes*, *Staphylococcus aureus*, and *Escherichia coli*. Bacteriocins from these strains are effective in reducing spoilage and enhancing the safety of fermented fish products (Desniar *et al*., 2020). Specific studies on LAB isolated from cangkuk and bekamal have not yet been conducted. However, it can be inferred that these traditional fermented products, like other Indonesian fermented foods, likely contain LAB with potential bacteriocin-production capabilities. LAB, such as *Lactobacillus plantarum* and *Pediococcus acidilactici* are common in various fermented foods and are known for their antimicrobial properties (Jawan *et al*., 2019; Todorov *et al*., 2023).

Potential of lactic acid bacteria from food products

Lactic acid bacteria (LAB) are generally classified as Gram-positive, catalase-negative, non-spore-tolerant, tolerant to low-oxygen conditions, tolerant to acidic atmospheres, and rod-shaped or coccus, with very high fermentation properties. LAB generally ferment carbohydrates to lactic acid as the main product (W. Chen and Narbad, 2018; Hugenholtz *et al*., 2002). LAB can grow well in the temperature range of 15-45°C and pH 3-11. This shows that LAB have a high adaptability to the environment, so that they can be found and widespread in nature, such as in plants and their products, various fermented products, fruits, soil, water, cavities in the human and animal bodies (mouth, intestines, genital organs, etc.), and in other natural habitats. LAB include several bacterial genera, including *Lactobacillus, Lactococcus, Leuconostoc, Pediococcus, Streptococcus*, and *Bifidobacterium*. However, it should be emphasized that the term LAB is not fixed on one particular taxonomy but can be heterogeneous. Based on the results of phylogenetic proximity analysis, LAB can be classified into two phyla: Actinobacteria and Firmicutes (W. Chen and Narbad, 2018; Obis *et al*., 2019).

The use of LAB in fermented products was the result of human discovery and domestication during the Neolithic period. Archaeological evidence from dairy, wine, beer, and bread production has been found in Asia and Europe. A biomolecular archaeological approach has been reported to successfully identify DNA from yeast and proteins from LAB on artifacts from food and cooking utensils. This provides evidence of a direct relationship between humans, microorganisms, and LAB (Douglas and Klaenhammer, 2010; Salque *et al*., 2013; Y. Yang *et al*., 2014).

So far, in the scientific literature, there have been no reports of side effects seen after consuming foods containing LAB or its metabolites. LAB are microorganisms that are safe for human consumption, either directly or through their metabolites, resulting in fermented food products (Obis *et al*., 2019). LAB have contributed significantly to the sustainability of the food industry, especially in terms of food safety and biotechnology, which provide convenience to consumers in consuming food products (O'Bryan *et al*., 2015b).

Empirical selection of LAB has been performed worldwide for a long time to produce safe and high-quality fermentation of both plant and animal foods (Obis *et al*., 2019). Currently, consumers can easily enjoy fermented food products that are safe, healthy, and have a delicious taste with various types and sources. This causes humans to consume food containing significant amounts of LAB and their metabolites (Bell *et al*., 2017; Chilton *et al*., 2015; Şanlier *et al*., 2019).

In its metabolic process, most LAB cannot synthesize amino acids using inorganic nitrogen. Amino acids cannot be obtained in sufficient quantities from living LAB environments. To meet the needs of amino acids, LAB exhibit proteolytic activity, which is the ability to hydrolyze proteins and peptides in their environment into amino acids (Fernández and Zúñiga, 2006; O'Bryan *et al*., 2015b). In addition to meeting the needs of amino acids, proteolytic activity during fermentation contributes to the taste, aroma, and texture of fermented products (Fernández and Zúñiga, 2006).

During fermentation, LAB produce organic acids, alcohols, and carbon dioxide as primary products or metabolites (Ray and Daeschel, 2019). In addition, LAB produce secondary metabolites, such as aromatic molecules, vitamins, diacetyls, hydrogen peroxide, and bioactive peptides (Lindgren, 1990; O'Bryan *et al*., 2015b; Paul Ross *et al*., 2002). In general, metabolites produced during LAB fermentation can enhance organoleptic properties and improve the safety and shelf life of fermented products (O'Bryan *et al*., 2015a; Stiles, 1996). To increase the safety and shelf life of the product, LAB can be used by three mechanisms: using a type of LAB that has been known to have direct antibacterial activity, adding fermented products that have been previously made into the product composition or as a starter, and using bacteriocin from the results of LAB metabolism that has gone through the purification process (O'Bryan *et al*., 2015a; Stiles, 1996). Several studies about potential of LAB and bacteriocin from Indonesian traditional fermented animal products was shown in Table 1.

Characteristics of Bacteriocins and Anti-Bacterial Activity

Bacteriocins are peptides synthesized on ribosomes during bacterial metabolism (Mauriello, 2016; S. C. Yang *et al*., 2014). Bacteriocins are mostly produced by bacteria that belong to Gram-positive bacteria and only a small percentage of Gram-negative bacteria can produce bacteriocins (Hanen *et al*., 2014). Bacteriocins consisting of 30-60 amino acids with diverse molecular weights and mechanisms of action (Baindara *et al*., 2018). Bacteriocins can be classified into four classes.

Class I (Lantibiotics)

Lantibiotics are bacteriocins that are stable to heat changes, have a molecular weight of less than 5 kDa, and are composed of 19-38 amino acids. The active part of this bacteriocin molecule usually contains rare amino acids such as lanthionine, beta-methyllanthionine, dehydroalanine, and dehydrobutyrine. Based on the structure and mode of action, antibiotics are grouped into three types: Type A slenderly structured, positively charged, amphiphilic, and works by perforating the plasma membrane of bacteria; Type B, which is round, uncharged, or negatively charged, and works by damaging the enzyme function of bacteria; and Type C, which has a combination structure and contains two polypeptides with synergistic antibacterial action (Meade *et al*., 2020; Zhang, 2019).

Class II (Unmodified Peptide)

Class II bacteriocins are the largest class of bacteriocins and have been studied extensively. Class II bacteriocins generally have a molecular weight of <10 kDa, are stable against heat changes, and do not contain lanthionine. Class II bacteriocins are grouped into four subtypes: subtype IIa (pediocin-like peptides), subtype IIb (two peptides), subtype IIc (circular), and subtype IId (pediocine-like linear) (Meade *et al*., 2020).

Class III (Large Protein)

Class III bacteriocins have a molecular weight of >10 kDa, are heat-sensitive, and are hydrophilic peptides (Meade *et al*., 2020). Class III bacteriocins consist of lysozyme-like bacteriocins that inhibit bacteria by lysizing their cells, whereas non-lysozyme bacterial proteins inhibit bacteria by disrupting the supply of glucose to the cell (Ge *et al*., 2019; Zhang, 2019).

Class IV (Circular Protein)

Class IV bacteriocins are bacteriocins that are stable to heat changes, hydrophobic, have a protein structure that is conjugated with carbohydrates or fats, and have a molecular weight of 5.5-7.5 kDa (Meade *et al*., 2020). Class IV bacteriocins generally have a broad spectrum of antibacterial activity and can partially inhibit fungal growth (Zhang, 2019).

Bacteriocins are secondary metabolites that possess antibacterial properties. Bacteriocins can kill or suppress the growth of bacteria that have species proximity (narrow spectrum) and no species proximity (broad spectrum) to bacteriocin-producing bacteria (Ameen and Caruso, 2017; Mauriello, 2016; S.C. Yang *et al*., 2014). The antibacterial properties of bacteriocins are a manifestation of the ability of LAB to compete with other microbes and survive in nature (Ameen and Caruso, 2017). Bacteriocins have antibacterial activity via two different types of working mechanisms: bacteriostatic and bactericidal. Bacteriocins can be used as

Table 1. Potential of LAB and bacteriocin from Indonesian traditional fermented animal products.

Sources	BAL	Bacteriocins	Pathogens	References
Dadih	*L casei* strain HDS-01	Caseicin	- *E. coli* 0157 - *S. aureus*	(Aritonang *et al*., 2022)
	L. brevis IS-26958	BLIS	- *E. coli* 3301 - *L. monocytogenes* ATCC 19112 - *S. aureus* IFO 3060	(Surono, 2003)
	L. pentosus DK8	BLIS	- *Salmonella Sp.* - *E. coli* - *S. aureus*	(Hayati *et al*., 2021)
	L. pentosus DHS6	BLIS	- *Listeria innocua* - *Propionibacterium acnes*	(Susmiati *et al*., 2024)
	L. pentosus 124-2	Bacteriocin (17.15 kDa)	- *Salmonella sp.* - *S. aureus*	(Yuliana *et al*., 2023)
Pork Urutan	- *P. acidilactici* U318 - *L. plantarum* U201	-	*Enterobacteriaceae*	(Antara *et al*., 2004)
Rabbit meat Bekasam	- *W. paramesenteroides* 7.1 - *L. buchneri* 6.1 - *L. buchneri* E3	Bacteriocin and Buchnericin	- *S.* Typhimurium - *S. aureus* - *L. monocytogenes* - *E. coli*	(Wulandari *et al*., 2020, 2022)

biopreservatives or natural preservatives to prevent food spoilage (Sari *et al*., 2018).

The use of bacteriocins as antibacterial substances in food products is in high demand because of their resistance to extreme temperatures and low pH levels. In addition, bacteriocins can be degraded by proteolytic enzymes both in the environment and in the gastrointestinal tract; therefore, the possibility of residues in the body or the risk of resistance formation is very low (Ameen and Caruso, 2017; H. Chen and Narbad, 2018). The effectiveness of bacteriocins as antibacterial substances has been proven to inhibit most disease-carrying bacteria and cause damage to food products. Bacteriocins of LAB Food Grade Considered ideal biopreservative substances in foodstuffs because they are non-toxic, odorless, colorless, do not alter the nutrition of the product, are effective at low concentrations, and are still active under storage conditions at low temperatures (Ahmad *et al*., 2017; H. Chen and Narbad, 2018).

Various activity of bacteriocins

Commonly used bacteriocins that have been tested as antibacterial substances are nisin, pediocin, enterocin, and sakacin (Miranda *et al*., 2016; Sung *et al*., 2013). The use of bacteriocin as an antibacterial substance has the advantages of resistance to high temperature and low pH (Miranda *et al*., 2016). Bacteriocins from lactic acid bacteria (LAB) are the most widely used type of bacteriocins in food products. This is because it is non-toxic, does not affect the nutritional and organoleptic composition of the product, is effective at low concentrations, is stable during storage, and is accepted by most authorities because it has clear regulations in its use (Mauriello, 2016).

Bacteriocins are antimicrobial peptides produced by bacteria that exhibit bactericidal or bacteriostatic action against other bacteria. These actions are crucial for their potential applications in food preservation and medical treatment. Bactericidal bacteriocins kill target bacteria by disrupting cellular processes. One common mechanism involves the formation of pores in the bacterial cell membrane, leading to dissipation of the transmembrane electrical potential and ultimately cell death (Bahrami *et al*., 2024; Ríos Colombo *et al*., 2018; Tymoszewska and Aleksandrzak-Piekarczyk, 2024). For instance, class IIa bacteriocins act on the cytoplasmic membrane of Gram-positive bacteria by forming pores, which disrupt the membrane potential (Ríos Colombo *et al*., 2018). This pore formation is facilitated by the mannose phosphotransferase system (man-PTS) acting as a receptor (Ríos Colombo *et al*., 2018; Tymoszewska and Aleksandrzak-Piekarczyk, 2024). Additionally, bacteriocins, such as pediocin AcH and plantaricin, when combined with nanotechnology, have shown enhanced bactericidal activity against pathogens such as *Staphylococcus aureus* (Correia *et al*., 2024).

Bacteriostatic bacteriocins inhibit bacterial growth without necessarily killing them. This is achieved by interfering with essential bacterial processes such as protein synthesis, DNA replication, or cell wall synthesis (Bernatová *et al*., 2013; Kumariya *et al*., 2019). For example, bacteriostatic agents maintain bacteria in the stationary phase of growth, preventing their proliferation. This mode of action is particularly useful in controlling bacterial populations without exerting selective pressure, which may lead to the development of resistance (Bernatová *et al*., 2013).

Some bacteriocins exhibit both bactericidal and bacteriostatic properties depending on the concentration and environmental conditions (Heizmann and Heizmann, 2007; Ishak *et al*., 2025). The combination of bacteriostatic and bactericidal agents can sometimes be more effective than either agent alone. For instance, sequential treatment with a bacteriostatic agent followed by a bactericidal antibiotic has been shown to be more effective than using a bactericidal agent alone (Gil-Gil and Berryhill, 2025; Ishak *et al*., 2025). This synergy can be crucial in developing new therapeutic strategies, especially against multidrug-resistant bacteria. The mechanisms of action of bacteriocins are diverse and depend on their structure and target bacteria. Bacteriocins exhibit a range of antimicrobial activities, primarily categorized as bactericidal or bacteriostatic. Their ability to kill or inhibit bacterial growth makes them promising candidates for food preservation and medical applications, especially in the context of increasing antibiotic resistance. Understanding their mechanisms of action and potential synergies with other antimicrobial agents is crucial for developing effective bacteriocin-based therapies (Ríos Colombo *et al*., 2018).

Conclusion

This review highlights the significant potential of lactic acid bacteria (LAB) and bacteriocins isolated from traditional Indonesian fermented animal products as natural food preservatives and antimicrobial agents. Diverse LAB strains found in products such as dadih, urutan, bekasam, cangkuk, and bekamal demonstrate promising antibacterial properties against various pathogenic and spoilage microorganisms. The bacteriocins produced by these LAB are stable across a range of pH levels and temperatures, making them suitable for food preservation applications. Isolation and characterization of LAB and bacteriocins from these traditional fermented foods not only contributes to the preservation of cultural food heritage but also opens up new avenues for the development of natural food preservatives. These biopreservatives align with growing consumer demand for clean and minimally processed foods.

Further research is needed to fully elucidate the mechanisms of action of these bacteriocins and to optimize their production and application in food systems. More studies on the probiotic potential of isolated LAB strains could reveal additional health benefits. The continued exploration of traditional fermented foods as sources of novel antimicrobial compounds has the potential to significantly enhance food safety and quality, while preserving cultural food practices.

Acknowledgment

The authors acknowledge the financial support and sponsoring for this research by the Padjadjaran Doctoral Program Scholarship (BPDP), Universitas Padjadjaran (grant number: 1595/UN6.3.1/PT.00/2021). We would like to thank the Livestock Products Processing Technology Laboratory, Department of Livestock Products Technology, Faculty of Animal Husbandry, Universitas Padjadjaran, Bandung, Indonesia.

Conflict of interest

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work reported in this study.

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