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Application of *Lactobacillus species* and their bacteriocins in food industry: A descriptive review

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Abstract
Bacteriocins produced by lactic acid bacteria have garnered significant interest in the food industry due to their potential as natural food preservatives. Lactic acid bacteria, particularly those from the Lactobacillus genus, are considered one of the most prolific producers of these antimicrobial compounds. he use of bacteriocin-producing Lactobacillus cultures or directly applied bacteriocins can contribute to improving food safety and quality in several ways. Bacteriocins produced by Lactobacillus species can inhibit the growth of pathogenic and spoilage microorganisms, thereby extending the shelf life of fermented foods and reducing the risk of foodborne illnesses. Consumer demand for safe, fresh, and minimally processed foods has driven the need for alternative preservation methods, and the application of Lactobacillus-derived bacteriocins offers a promising solution. The present review was done to describe of the role of bacteriocin produced from different Lactobacillus species in the food industry. The effectiveness of bacteriocins as food preservatives is influenced by various factors, including the specific target bacteria, the characteristics of the food matrix, and the processing conditions. Careful testing and evaluation are required to ensure the optimal application of Lactobacillus bacteriocins in different food systems.

Keywords: Bacteriocin, LAB, Food industry

Introduction
Consumers today demand safe, fresh, and minimally-processed foods, driving the need for innovative and sustainable food preservation techniques. Lactic acid bacteria have emerged as a promising solution, owing to their ability to produce antimicrobial compounds called bacteriocins (Sidhu & Nehra, 2021;Veskovic-Moracanin *et al*., 2014; O'Sullivan *et al*., 2002) [18, 24]. Bacteriocinogenic Lactobacillus species, in particular, have garnered significant attention for their potential to enhance food safety and quality (Ibrahim, *et al*., 2021) [12]. through the control of pathogenic and spoilage microorganisms. Lactobacillus is a genus of Lactic Acid Bacteria that play a crucial role in the food industry (Bucka-Kolendo & Sokołowska, 2017; Sousa *et al*., 2019; Novik *et al*., 2017) [7, 17, 26]. These bacteria are natural inhabitants of the human gastrointestinal tract and can be applied in various fermented products and probiotic foods (Walter, 2008) [31]. They are present in a wide range of food products, including yogurt, sourdough, fermented vegetables, cheese, wine, and meat, where they contribute to the development of organoleptic and hygienic qualities (Behera, *et al*., 2018) [6].

The technological benefits of *Lactobacillus species* are diverse, as they can enhance the safety, flavor, texture, and nutritional value of food products. *Lactobacillus species* are Gram-positive, non-aerobic, non-sporulating, and acid-tolerant bacteria that are commonly found in a range of fermented food products, as well as on mucosal surfaces of animals (Yadav, *et al*., 2017) [34]. These bacteria are known to produce a diverse array of antimicrobial compounds, including organic acids, hydrogen peroxide, and bacteriocins, which can inhibit the growth of various pathogenic and spoilage micro-organisms (Timothy, *et al*., 2021; Hsiu *et al*., 2016) [11, 28]. The production of bacteriocins by Lactobacillus species has received significant attention in recent years, as these antimicrobial peptides have the potential to serve as natural food preservatives, contributing to the control of food-borne pathogens, extension of product shelf-life, and improvement of sensory qualities (Sidhu & Nehra, 2021; Vesković-Moračanin *et al*., 2014; O'Sullivan *et al*., 2002) [18, 24, 29].

Bacteriocins are ribosomally synthesized antimicrobial peptides produced by a wide range of bacterial species, including many members of the lactic acid bacteria group (Simons, *et al*., 2020) [25]. These potent molecules have the ability to inhibit or kill closely related species, as well as various food-borne pathogens such as *Listeria monocytogenes* (Wu, *et al*., 2022) [33]. The production of bacteriocins is considered a significant advantage for food producers, as they can effectively eliminate or restrict the growth of harmful bacteria competing for the same ecological niche (Meade, *et al*., 2020) [14]. Among the various bacteriocins, nisin is the most extensively studied and has gained widespread application in the food industry (Santos, *et al*., 2018) [23]. Undoubtedly, the discovery of an ever-increasing "arsenal" of these antimicrobial peptides has led to a surge of interest in their use as natural food preservatives, offering an alternative to synthetic additives and reducing the need for harsh thermal treatments.

The bacteriocins produced by LAB offer several desirable properties that make them suitable for food preservation (Johnson, et.al., 2018) [13]: (1) are generally recognized as safe substances, (2) are not active and nontoxic on eukaryotic cells, (3) become inactivated by digestive proteases, having little influence on the gut microbiota, (4) are usually pH and heat-tolerant, (5) they have a relatively broad antimicrobial spectrum, against many food-borne pathogen and spoilage bacteria, (6) they show a bactericidal mode of action, usually acting on the bacterial cytoplasm membrane: no cross resistance with antibiotics, and (7) their genetic determinants are usually plasmid-encoded, facilitating genetic manipulation(Anupad,2007). The properties of bacteriocins produced from different Lactobacillus species have enhanced its applications in food industry (And and Hoover, 2003) [2]. In the present investigation we will review the application of different bacteriocins produced from *Lactobacillus species* in the food industry. The results of this investigation will be adapted by different food sectors for the preservation, protection and storage of foods.

Material and Methodology

The present review is descriptive in nature. A descriptive review is a systematic process that summarizes existing research and presents it in an organized way. Key topics, trends, and gaps can be found with the use of descriptive reviews, which can then guide more concentrated research efforts. Determining the degree to which a body of information in a certain study area displays any interpretable pattern or trend with regard to prior hypotheses, theories, techniques, or conclusions is the main objective of a descriptive review (King and He, 2005; Paré, *et al*., 2015). The author has worked on the isolation of *Lactobacillus species* from homemade cheese, raw milk, dosa paste, sauce, and curd. Four species of Lactobacillus *viz*; *L.plantarum*(P2), *L. brevis, L.plantarum*(P1), *L. casei,* and *L. fermentum* have been isolated from sampled source (Table-1). The author have also reported the antimicrobial activities of *L.plantarum*(P2), *L. brevis*, *L.plantarum*(P1), *L. casei,* and *L. fermentum* against *Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa* and *Bacillus cereus.*

Table 1: Morphological characteristics of the bacterial strain isolated from homemade cheese, raw milk, dosa paste, sauce, and curd

Strain code	Cell's form	Type	Colour	Motility test	Gram staining
L. brevis	Rod shaped	Bacilli	Yellow	Non-motile	Gram positive
L.plantarum	Slender rods	Coccobacilli	Yellow	Non-Motile	Gram positive
L.fermentum	Rod Shaped	Cocci	Creamy White	Non-Motile	Gram positive
L. casei	Rod-shaped	Smooth	Opaque with pigment	Non-Motile	Gram positive

Different bacteriocin produced by the *L. brevis, L.plantarum(P1), L. casei, and L. fermentum* was analysed. It was reported that across different bacterial strains, *L. plantarum*(P2) reported maximum bacteriocins activity followed by *L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum*. In the present study the characteristics of bacteriocin produced by the *L. brevis, L.plantarum(P1), L. casei, and L. fermentum* was analysed and its application in the food industry was reviewed. Systematic and cross-sectional review in context to the isolation of *Lactobacillus species* and application in the food industry was reported and presented in results section of this review.

Results and Discussion

Lactobacillus Acid Bacteria (LAB) plays a significant role in the food, agriculture and pharmaceutical industry (Abedin, *et.al.,* 2023) [1]. We have observed that production of lactic acid, hydroperoxide,bacteriocins and organic acids from different strains of *Lactobacillus species viz L.plantarum* (P2), *L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* were the most significant in terms of stability, storage and antimicrobial activity. The antimicrobial activity of different strains of *Lactobacillus species* against different pathogenic and food spoilage bacteria has gained a wide attention from researchers, scientific community, and food industrialists. The antimicrobial activity of *L.plantarum* (P2), *L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* towards different pathogenic and food spoilage bacteria *viz; Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa,* and *Bacillus cereus.* The results were very significant and their applications in food industry are fruitful. In addition to the antimicrobial activity of different strains of *Lactobacillus species,* they are also associated with some elite functions in food industry they include food preservation, adjunct cultures, bio-preservative functions, and probiotic culture. The different strains of *Lactobacillus species viz*; *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* isolated from curd, raw milk, cheese, dosa batter and sauce have following application in the food industry;

1. Culture for Fermented Foods

The history of fermented foods, which are made by LAB through the fermentation of certain sugars, is lost in antiquity (Ray and Joshi, 2014) [22]. *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* are used as starting cultures in food fermentations (Cornea, *et.al.,* 2016 [8]; Angmo, *et.al.,* 2016 [3]; Suwannaphan,2021; [27]. It is commonly known that the majority of them fall into the category of dairy products, which includes cheese, yoghurt, and fermented milks. On the other hand, starter cultures are now used in the production of fermented meat, fish, pickled vegetables, olives, and a wide range of cereal products. The earliest productions of these products were based on spontaneous fermentation, which was the result of the development of the microflora naturally present in the raw material and its environment. These products were previously produced through back slopping, and the characteristics of the final product depended on the dominance of the best-adapted strains. Most fermented foods produced today are made with the inclusion of specialized, well-defined starter cultures that have characteristics that are well-defined and unique to each product. Its observed that the *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* are used for the fermentation of various products. We can observe that the selected stains of *Lactobacillus species* have a great potential in fermentation of food products. Furthermore these application of *Lactobacillus species* could be used for widening the scope of food industry.

2. Adjunct Culture from *Lactobacillus species*

Secondary cultures, or adjunct cultures or adjuncts, are defined as any cultures that are deliberately added at some point of the manufacture of fermented foods, but whose primary role is not acid production (Parente, *et.al.,* 2017) [19]. Adjunct cultures are used in cheese manufacture to balance some of the biodiversity removed by pasteurisation, improved hygiene and the addition of defined-strain starter culture(Powel, 2023). These are mainly non-starter LAB which have a significant impact on flavour and accelerate the maturation process. *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* are widely used for adjunct culture of various foods.

Many types of *Lactobacillus species* create extracellular polysaccharides (EPSs), which are either discharged into the growth media or exist as capsular polysaccharides attached to the cell surface (Rajoka, *et.al.,* 2020) [21]. These polymers are essential to the creation of yogurt, cheese, fermented cream, and milk-based sweets because they improve the end product's mouthfeel, texture, flavor, and stability. It has also been proposed that these EPSs, or fermented milks containing them, have immunomodulatory, cholesterol-lowering, and prebiotic properties. It has been demonstrated that EPS-producing strains of *Lactobacillus species* improve yogurt's smoothness and viscosity while lowering syneresis. The secondary fermentation process known as malolactic fermentation, which involves the conversion of L-malate to L-lactate and CO_2 by the enzyme malate decarboxylase, also referred to as the malolactic enzyme, is how wine is made. This process lowers the acidity of the wine, stabilizes the microbiota, and modifies the aroma of the wine.

3. Bi-protective cultures by *Lactobacillus species*

Bacteriocins are polypeptides generated ribosomally by *Lactobacillus* bacteria that can have bacteriocidal or bacteriostatic effects on other bacteria. It has been shown that some LAB manufacture these compounds (Veskovic, *et.al.,* 2014). Bacteriocins often cause cell death by preventing the manufacture of cell walls or by rupturing the membrane through the creation of pores (Meade, *et.al.,* 2020) [14]. Therefore, bacteriocins play a crucial role in food preservation since they can suppress food pathogens or stop food from spoiling. The bacteriocin produced by *Lactobacillus* bacteria are used as a food preservative in at least 50 countries and has acquired extensive use in the food business, especially in processed cheese, dairy products, and canned goods.

The antimicrobial and antifungal activities of *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* have been widely used for presevation of various foods (Figueroa, *et.al.,* 2024) [10]. Furthermore, these LAB strains can decrease fungal mycotoxins by absorption or the production of metabolites that are anti-mycotoxinogenic. In order to be employed as bio-protective starting cultures, LAB must meet a number of physical and biochemical requirements, but above all, they must be able to grow and produce enough antimicrobial and antifungal metabolites, a capability that must be shown in the particular food environment. The selected LAB strains *viz*; *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* witnessed the antimicrobial and antifungal properties. This property of these bacterial strains can be exploited for the preservation of foods from pathogenic and food spoilage bacteria and fungus.

4. Probiotic Culture by *Lactobacillus species*

A probiotic is described as "a live microbial feed supplement which beneficially affects the host animal by improving its intestinal microbial balance." LAB are regarded as a prominent type of probiotic bacteria (Naidu, *et.al.,* 1999) [16]. Microbial cell preparations or parts of microbial cells that are good for the host's health and wellbeing are called probiotics (Mishra and Acharya, 2021) [15]. Commercial strains of Lactobacillus, Bifidobacterium, and Propionibacterium are the most common types utilized in food applications. The most common LABs found in probiotic-containing functional foods are *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* (Wang, *et.al.,* 2023) [32]. Among the cheeses that use probiotic LAB in conjunction with bifidobacteria are Argentinean Fresco, Cheddar, and Gouda (Balthazar, *et.al.,* 2023) [5].

The probiotic strains produced of LAB are directly added to different food products to enhance their dietary supplements (Evive, *et.al.,* 2017). Because of these natural qualities, probiotic strains are most suited for use in milk and goods connected to milk. Many commercial dairy products, including fresh milk, yogurt, and cheese, include probiotics. Before probiotic bacteria are introduced into the human body, they need an appropriate environment, which is why most milk and milk products are chilled for storage. Probiotics have demonstrated high potential for application in the fermentation of fruit and vegetable goods as well as cereal products, given the rise in consumer vegetarianism in industrialized nations. Additionally, the food industry and customers now have access to a wide variety of tasty and healthy meals thanks to the use of probiotics in the brewing and meat product fermentation processes.

5. The Future Prospects of LAB and Bacteriocins in the Food Industry

The field of food science and technology has witnessed a significant surge of interest in the utilization of Lactic Acid Bacteria and their antimicrobial compounds, known as bacteriocins, within the food industry. Lactic acid bacteria are a diverse group of Gram-positive, non-spore-forming, catalase-negative, and acid-tolerant microorganisms that are widely recognized for their ability to produce a variety of metabolic products with antimicrobial properties (Sidhu & Nehra, 2021) [24]. These bacteria are commonly found in a range of food sources, including meat, dairy products, vegetables, grains, and fermented foods, among others.

One of the primary advantages of utilizing Lactic Acid Bacteria and their bacteriocins in the food industry is their potential to enhance food safety and quality. Bacteriocins produced by lactic acid bacteria have demonstrated the ability to inhibit the growth of various food-borne pathogens, such as Listeria monocytogenes, as well as spoilage microorganisms (O'Sullivan *et al*., 2002; Sidhu & Nehra, 2021;Hsiu *et al*., 2016) [11, 18, 24]. This antimicrobial activity can contribute to the control of pathogens, the extension of shelf life, and the improvement of sensory qualities in fermented foods. The most extensively studied bacteriocin, nisin, has already gained widespread application in the food industry as a natural food preservative.

The composition of the food matrix, as well as the technological processes involved in food production, can influence the stability and activity of added bacteriocins. Therefore, it is crucial to carefully test the effectiveness of bacteriocins against specific target bacteria in the type of food for which they are intended to be applied. (Vignolo *et al*., 2012) [30] With the growing consumer demand for safer, fresher, and minimally processed foods, the utilization of lactic acid bacteria and their bacteriocins as natural preservatives holds significant promise for the future of the food industry. (Vignolo *et al*., 2012) [30].

Conclusion

The aim of the present study was to review the role of bacteriocinogenic *Lactobacillus species* in food industry.

Detailed review was collected to determine the application of some *Lactobacillus species* like *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* in the food industry. The results reveal that *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* are used as starting cultures in food fermentations. These *Lactobacillus species* have a significant impact on flavour and accelerate the maturation process. The bacteriocins produced from *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* are used for preparation of yogurt, cheese, fermented cream, and milk-based sweets because they improve the end product's mouthfeel, texture, flavor, and stability. The antimicrobial and antifungal activities of *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum* have been widely used for presevation of various foods. The most common LABs found in probiotic-containing functional foods are *L.plantarum (P2), L. brevis, L.plantarum(P1), L. casei,* and *L. fermentum.* This antimicrobial activity can contribute to the control of pathogens, the extension of shelf life, and the improvement of sensory qualities in fermented foods. The most extensively studied bacteriocin, nisin, has already gained widespread application in the food industry as a natural food preservative.

Conflict of Interest

The author would like to undertake that the above mentioned manuscript has not been published elsewhere, accepted for publication elsewhere or under editorial review for publication elsewhere. The authors declare that they do not have any conflict of interest with the submission of this manuscript.

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