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Bacteriocin producing lactic acid bacteria from camel milk and its fermented products: A review

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Abstract

Addressing global hunger is a critical 21st-century challenge. Ensuring food security is essential due to growing food demand. Concerns about chemical preservatives' impact on health have led to exploring alternative ways to extend shelf-life. Fresh preservation techniques and new preservatives are being developed to meet prolonged shelf-life needs and prevent dairy product spoilage. Bacteriocins are natural antimicrobial peptides with several functional qualities that can improve the safety, shelf-life, and quality of dairy products. Bacteriocins can withstand heat processing, pH changes, and enzymes, which are commonly used in the food industry. Nisin is one of the important bacteriocins widely studied in the preservation of dairy and food products. Camel milk closely resembles a human mother's milk and has low lactose and cholesterol content but is rich in minerals (sodium, potassium, iron, copper, zinc, magnesium) and vitamin C. It is known for its unique nutritional composition and potential health benefits and offers an intriguing context for exploring the presence of nisin-producing lactic acid bacteria (LAB). By isolating these LAB, the dairy industry could introduce improvements such as extended product shelf-life, heightened food safety, and the creation of novel dairy items. However, the complexity of isolating suitable LAB strains, optimizing bacteriocin production, and addressing regulatory and consumer considerations underscore the need for comprehensive research and evaluation. This paper reviews the isolation and characterization of bacteriocin-producing LAB from camel milk, emphasizing their functional features and possible dairy industry advantages. The paper also explores the problems and potential for using these distinct microbial resources.

1. Introduction

Lactic acid bacteria (LAB) are non-sporulating, gram-positive, anaerobic, or facultative aerobic cocci or rods, as one of the main fermentation products of carbohydrate metabolism, produce lactic acid (Quinto *et al.*, 2014). LAB produces fragrance components, modifies or produces proteins and exopolysaccharides, and produces nutritional components, improve the texture, nutritional value, and flavor of fermented foods (Meena *et al.*, 2008; Ngene *et al.*, 2019). It is commonly used in traditional fermented foods, including dahi, yoghurt, cheese, lassi, butter milk, sourdough, wine, sausage, sauerkraut, olives, natto, raabadi, and tempeh, *etc.* LAB have substantial impacts on human health and are GRAS (Generally Recognized As Safe) (Meena *et al.*, 2022). Camel milk is a highly nutritive nutritious medium supporting the growth of many type of bacterial species, many of which are capable of producing antimicrobials that might be utilized as food preservatives and have essential technological properties (Swelum *et al.*, 2021; Muthukumaran *et al.*, 2022). Camel milk reported to cure various diseases such as tuberculosis, asthma, dropsy, jaundice, and leishmaniasis or kala-azar (Solanki and Hati, 2018). Furthermore, camel milk possesses additional health advantages, functioning as a glycemia regulator (Agrawal *et al.*, 2007), demonstrating potential anti-carcinogenic properties (Khan *et al.*, 2021), and acting as an antihypertensive agent (Muthukumaran *et al.*, 2022).

There has been few research on the microbiological characterization of camel milk, which includes LAB. The majority of the population in raw milk is made up of LAB, which are important for food fermentation and preservation through synthesizing antimicrobials such as organic acids, hydrogen peroxide, antifungal peptides, and bacteriocins (Rahmeh *et al.*, 2019). A good supply of possible probiotic microorganisms may be found in raw camel milk and its fermented by-products. The most popular strains of probiotic bacteria include *Lactobacillus, Bifidobacterium, and Enterococcus* (Shori, 2017; Meena *et al.*, 2023a). The dairy sector is constantly looking for new ideas to raise the product's safety and quality (Bunkar

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et al., 2020). Due to its strong antibacterial action against several foodborne pathogens and spoilage organisms, bacteriocins generated by specific LAB, presents a possible option. Bacteriocin is a desirable alternative for usage in dairy products due to its safety profile and regulatory acceptance (Sumathi *et al.*, 2021).

2. Camel milk

In India, camels are regarded as essential components of the desert eco-system, and it is unclear whether they are present in other regions of the country where they are mostly supported by their milk. The south and south-eastern parts of Rajasthan make extensive use of camel milk. In these areas, the Mewari breed of camel is widespread. One of India's four main camel breeds, it is adapted to the mountainous environment of the Arawali hills in south Rajasthan. In comparison to cattle milk, camel milk is three times as rich in vitamin C, high in iron, zinc, copper, sodium, magnesium, manganese, and potassium, and low in lactose (Mehta *et al.*, 2009; Muthukumaran *et al.*, 2022). Camel milk typically contains strains of the lactobacilli species *Lactobacillus plantarum, Lactobacillus pentosus, Lactobacillus plantarum, Lactobacillus brevis and Lactococcus lactis, Entereococcus faceium,* and *Pediococcus pentosaceous* (Siboukeur and Siboukeur, 2013). Camel milk is a very good source for LAB that has a high probiotic potential. Camel milk contains a greater proportion of natural antibacterial compounds than bovine milk (Abushelaibi *et al.*, 2017).

3. Bacteriocin-producing lactic acid bacteria as probiotics

LAB one of the most frequent bacterial species, is used to enhance the sensory, taste, texture, nutritional, and functional qualities of fermented foods. Gram-positive, non-spore producing, cocci or rod-shaped lactobacilli are thought to be harmless bacteria since they do not make endospores (Queiroz *et al.*, 2022). They can also create ethanol, carbon dioxide, acetic acid or acetate in addition to the lactic acid that they are employed to make in normal fermentations. LAB predominates the probiotics used in the dairy and food industry due to their significant role in the production of healthy and nutritious foods for consumers (Pandey and Yadav, 2022). LAB are frequently used as starting cultures in foods that have undergone fermentation. "*Enterococcus, Lactococcus, Lactobacillus, Leuconostoc, Vagococcus, Pediococcus, Streptococcus, Tetragenococcus, Vagococcus,* and *Weissella*" are the main and most common genera of lactic acid bacteria (Meena *et al.*, 2023b, c). Probiotic bacteria affect the genetic make-up of the gut microbiota and are derived from dietary sources. These bacteria are utilized in the fermentation of foods that are healthy for both human and animal health and are in charge of the digestive, gastrointestinal, and overall well-being (Mishra *et al.*, 2020; Macœlak *et al.*, 2022).

Bacteriocins have become increasingly popular in food preservation, this is especially true for egg, vegetable, dairy and meat products. Among the LAB bacteriocins, nisin A and its natural variation, nisin Z, have been shown to be extremely powerful against microbial pathogens that cause food poisoning and spoiling. However, several preservation methods, such as heat treatment, pH and water activity reduction, and the addition of preservatives such as antibiotics and organic compounds, have been employed to prevent food illness and spoiling (Negash and Tsehai, 2020). Bacteriocins can be used in a variety of ways, including refined or crude form, fermentation with a bacteriocin-producing strain, or incorporation *via* a starting culture. A bacteriocin alone in a meal, on the other hand, is unlikely to provide total safety, particularly in the case of presence or contamination of gram-negative bacteria. These gram negative bacteria can be killed by combining the bacteriocins with other technologies that break cellular membranes. Non-thermal therapies, such as pulsed electric field (PEF), are useful since they have no effect on the functioning or nutritional characteristics of food (Sethi and Anurag, 2021). Bacteriocins can also be combined with other antimicrobial compounds to enhance inactivation of bacteria. They can also improve food quality and taste qualities by boosting proteolysis or avoiding gas blowing faults in cheese, for example. Bioactive packaging, which prevents food from external pathogens, can be made by directly immobilizing the bacteriocin to the food packaging or by introducing a bacteriocin sachet during storage. Gradual release of bacteriocins from a packing film on the food surface may be preferable than dipping and spraying meals (Woraprayote *et al.*, 2018). Probiotic bacteria that produce nisin can also be given to the body in place of nisin itself to shield it from digestive enzymes while still delivering the same benefits. The most prevalent probiotic bacteria discovered in the gastrointestinal tracts of both humans and animals are lactic acid bacteria (LAB), especially those belonging to the genera *Lactobacillus* and *Bifidobacterium*. *Lactotoccus lactis*, a nisin-producing organism, may synthesize and secrete proteins in the gut of mammals, although without any long-term colonization (Ma³aczewska and Kaczorek-£ukowska, 2021).

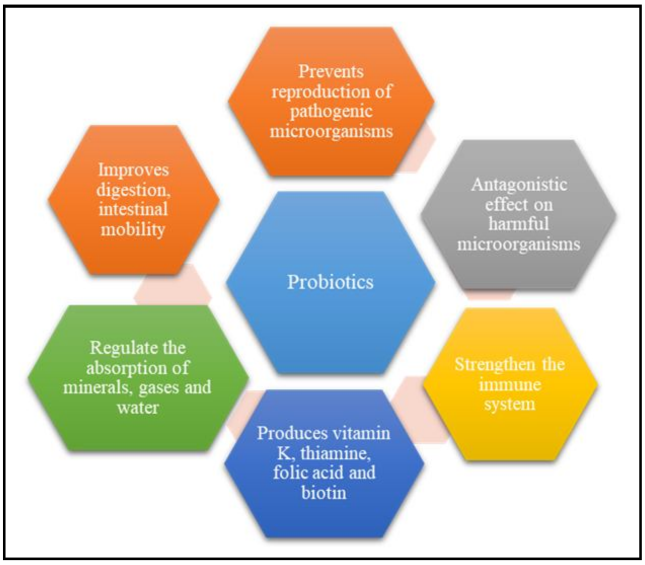

Figure 1: Characteristics of probiotics

4. Nisin-producing LAB

Nisin is a well-known and characterized bacteriocin with widespread commercial use. It has a pentacyclic structure with one lanthionine residue and four h-methyllanthionine residues and is made up of 34 amino acids. Nisin belongs to class I bacteriocins, also known as lantibiotics, one of four classes of bacteriocins produced by gram-positive bacteria. The bacterium *Lactococcus lactis* produces the polycyclic antimicrobial peptide known as nisin, which is used to preserve food. The unusual amino methyllanthionine (MeLan), acids lanthionine (Lan), didehydroaminobutyric acid (Dhb) and didehydroalanine (Dha) are among its 34 amino acid residues. The precursor peptide is modified post-translationally to introduce these novel amino acids. These processes transform a 57 monomer produced by ribosomal synthesis into the final peptide. The didehydro amino acids are the source of the unsaturated amino acids. The enzyme-catalyzed addition of cysteine residues to didehydro amino acids results in the formation of multiple thioether bridges (Malaczewska and Kaczorek-Lukowska, 2021). Nisin demonstrates a wide range of inhibitory efficacy against spore-forming Gram-positive bacteria. Due to its outer membrane permeability barrier, it is often inactive against gram-negative bacteria, yeasts, and fungi. A chelator or other physical therapies that change this barrier cause an induced sensitivity to nisin. *Lactococcus lactis* produces Nisin A, a class I bacteriocin., is widely used in food products as a safe and efficient preservative. FL-75, a bacitracin-resistant strain, showed accelerated growth rate, doubled the biomass production, and improved nisin A resistance. It exceeded the parental strain by 25% and showed improved resistance to oxidative stress, a first for bacitracin-resistant microorganisms. This strain is considered promising for industrial food and feed bio-preservative production (Todorov *et al.*, 2004). Some of important nisin producing strains reported by different researchers has been summarized in Table 1.

Table 1: Nisin producing strains

Species	Class	Antimicrobial spectrum	References
Enterococcus faecium	IIb	Moderate, two-peptide, lantibiotic	Hu *et al.*, 2010
Enterococcus faecium	IIa	Moderate (anti-Listeria)	Ennahar *et al.*, 2001
Lactococcus sp.	IIc	Broad, circular	Iwatani *et al.*, 2007
Enterococcus faecalis	I	Broad, two-peptide, lantibiotic	Sawa *et al.*, 2012
Lactococcus garvieae	IId	Narrow	Tosukhowong *et al.*, 2012
Lactococcus lactis	I	Broad, lantibiotic	Ennahar *et al.*, 1999
Enterococcus durans	IId	Narrow	Du *et al.*, 2017
Pediococcus pentosaceus	IIa	Moderate (anti-Listeria)	Kingcha *et al.*, 2012
Enterococcus faecium	IId	Narrow, two-peptide, lantibiotic	Himeno *et al.*, 2012
Enterococcus mundtii	IIa	Moderate (anti-Listeria)	Belletti *et al.*, 2009

5. Application of nisin

Nisin, a naturally occurring antimicrobial peptide, finds wide application in the food industry due to its potent inhibitory effects against various pathogenic and spoilage microorganisms. Its ability to target and disrupt bacterial cell membranes, leading to leakage of cellular content and ultimately cell death, makes it an effective tool for controlling microbial growth. Some of the uses of nisin is depicted in Figure 2. Nisin, an antimicrobial peptide produced by certain *Lactococcus* species, is a safe and natural food preservative in over 50 countries. It inhibits the growth of gram-positive bacteria particularly *Staphylococcus aureus*, *Listeria monocytogenes,* and psychrotrophic enterotoxigenic *Bacillus cereus*. LAB that produce nisin can be used as fermentation starting cultures and applied directly to a variety of dishes. Nisin Z, a lantibiotic bacteriocin, is still not approved as a food additives (Lahiri *et al.*, 2022). The primary issue in nisin synthesis is growth inhibition caused by increasing lactate content and pH reduction. However, to avoid certain growth inhibition, pH control methods like alkali or extraction with organic solvents have been reported. Continuous-culture techniques for lactic biofermentation processes, using free or immobilized cells, and separation systems like membranes or electrodialyzers have also been reported. However, these processes are mechanically complex and costly (Heidari *et al.*, 2022).

Nisin is largely used in cheese manufacture to limit spoilage and harmful bacteria. It is generated by a lactococcal culture. Because of its capacity to develop at low temperatures and tolerate acidic environments*, Listeria monocytogenes* is an important concern in many cheeses. *Listeria* may also survive the cottage cheese, cheddar and camembert production processes. Nisin has been found in studies to be effective in preventing *L. monocytogenes* in cheese, as demonstrated in cottage cheese. Nisin has also been found to be effective in processed cheese, canned foods, brewing, milk products, fish and meat products, wine production, confectionary and liquid egg. Numerous comprehensive evaluations document the numerous widespread applications of nisin as a bio-preservative, with examples provided in the text (Malaczewska and Kaczorek-£ukowska, 2021; Meena *et al.*, 2023d).

Bacteriocins also have applications beyond preservation. They can improve food quality by affecting processes like proteolysis or preventing defects like gas blowing in cheese. Bacteriocins are also explored for bioactive packaging, which shields food from external contaminants, enhancing food safety and extending shelf life (Rakhmanova *et al*., 2018). Additionally, bacteriocins have shown potential in treating peptic ulcers. These ulcers result from an imbalance between mucosal defense mechanisms and gastric acid/pepsin damage, often combined with environmental or immunological factors (Negash and Tsehai, 2020). They exhibit inhibitory effects against anaerobic *Helicobacter pylori*, which is excessively present in patients with gastric and duodenal ulcers (Kaur *et al*., 2014). Bacteriocins also exhibit potential as spermicidal agents by affecting sperm motility (Lopez-Cuellar *et al.*, 2016) and also shows protection against vaginal infections (Kaur *et al*., 2013). They also shown promising results in cancer therapy by inhibiting DNA and membrane protein synthesis, leading to apoptosis or cytotoxicity in tumor cells (López-Cuellar *et al.*, 2016). Notably, nisin, a bacteriocin, shows potential for treating head and neck squamous cell carcinoma (HNSCC) (Kamarajan *et al.*, 2015). Certain bacterial strains like "*Lactobacillus plantarum* ACA-DC 269, *Lactobacillus fermentum* ACA-DC 179, and *Streptococcus macedonicus* ACA-DC 198" inhibit oral pathogens responsible for oral health issues (Badaoui-Najjar *et al.*, 2009; Birk *et al.*, 2021).

Figure 2: Application of nisin producing lactic acid bacteria

6. Probiotic potential of LAB isolated from camel milk and its fermented products

Camel milk contains lactoferrin, mono and polyunsaturated fatty acids, bioactive peptides, and other useful components in sufficient amount for human consumption. These ingredients of camel milk may be used to treat serious human conditions such as tuberculosis, asthma, gastrointestinal problems, and jaundice (Hines, 2021; Muthukumaran *et al.*, 2022). The composition of camel's milk varies substantially depending on place and season. Camel's whey protein contains natural proteases such as chymotrypsin A and cathepsin D, in addition to a significant number of soluble proteins. According to Swelum *et al.* (2021) camel's milk protein hydrolysis by LAB produces bioactive peptides which provides many health benefits to consumer. Camel milk has antiinflammatory, anticancer, antidiabetic, anti-angiotensin-converting enzyme (ACE)-inhibitory, and anticholesterol effects (Solanki and Hati, 2018; Undhad Trupti *et al.*, 2021).

Sharma *et al.* (2021) isolated a total of 80 LAB isolates from camel milk and evaluated for various probiotic (bile salt tolerance, antibacterial, cell-surface hydrophobicity and auto-aggregation) and technological attributes (fermentation ability, curd formation, and syneresis). The selected candidate probiotic isolates showed inhibitory potential against pathogenic microbes such as *Staphylococcus aureus, Pseudomonas aeruginosa, Bacillus cereus* and *E. coli*. Zhao *et al.* (2020) collected 15 camel milk samples from Inner Mongolia and studied for microbial diversity. The samples also have LAB which includes, including "*Lactobacillus paracasei, Enterococcus italicus, Enterococcus durans, Lactococcus lactis ssp. lactis, Weissella confusa,* and *Enterococcus faecium*". Premasiri *et al.* (2021) collected 20 fresh camel's milk samples in Sri Lanka and obtained a total of 100 isolates. The isolates were identified and evaluated for potential beneficial properties such as acid and bile tolerance, growth at different temperatures, salt concentration, and pH levels. The study reported that the isolates were of "*Lactobacillus pentosus, Lactobacillus plantarum, Streptococcus thermophilus, Streptococcus bovis, Lactococcus lactis* and *Enterococcus faecium*" species.

Rahmeh *et al.* (2019) isolated the LAB from raw camel milk obtained from the Arabian Peninsula of western Asia and assessed the antimicrobial activity of 58 isolates. *Pediococcus pentosaceus* CM16 and *Lactobacillus brevis* CM22 showed the highest 1600 and 800 AU/ml bacteriocinogenic activity against *Listeria monocytogenes*. Mahmoudi *et al.* (2019) studied the probiotic potential of LAB isolated from raw camel milk and traditional fermented camel milk and evaluated for hemolytic activity, antibiotic susceptibility, antimicrobial attributes, tolerance to low pH and bile salts, survival under simulated gastric and pancreatic digestion conditions, ability to adhere with hydrocarbons, and their auto-aggregation and co-aggregation properties. They identified two putative isolates *viz.*, *Lactococcus lactis* KMCM3 and *Lactobacillus helveticus* KMCH1 and also evaluated antibacterial activity against pathogenic strains. The antibacterial activity might be due to production of nisin and other antimicrobial substances. Souid *et al.* (2015) isolated a nisin producing strain (*Lactococcus lactis* ssp. *lactis*) from fresh camel cheese and its antibacterial activity was assessed against *Pseudomonas fluorescens*.

Abushelaibi *et al.* (2017) study found that all identified *Lactococcus lactis* (LAB) showed strong antimicrobial activity, EPS production, high cholesterol removal, and auto-aggregation. The most impressive cholesterol removal isolates were *Lactococcus lactis* KX881768, KX881772, KX881782, and KX881779. Fguiri *et al.,* (2015) identified ten *Enterococcus faecium* strains from camel milk, with *Enterococcus faecium* HM1624 showing a higher survival percentage after lypholization. Two bacteriocin-producing isolates from camel milk, *Enterococcus faecium* S6 and R9, were biochemically characterized after partial purification using ammonium sulphate precipitation. The bacteriocins showed antimicrobial activity of 6,400 and 400 AU/ml, respectively. They were proteinaceous, neutralized by lipolytic and glycolytic enzymes, and had a broad pH stability range of 2.0 to 10.0. Gel filtration confirmed the presence of carbohydrate and lipid moieties, while PCR identified enterocin-coding genes. These findings show that partly purified *E. faecium* S6 and R9 bacteriocins may be effective in the dairy business for avoiding Listeria (Rahmeh *et al.*, 2018). Fguiri *et al.* (2015b) isolated 25 LAB species from camel milk samples collected in Ethiopia and evaluated for functional properties such as acid production, proteolytic and antimicrobial activities, and ability to produce exopolysaccharide (EPS). The authors reported that among all LAB, *Lactobacillus plantarum* HUM19, *Lactobacillus acidophilus* HUM20, and *Streptococcus cremoris* HUM8 showed high antimicrobial activity, fermentation ability, and EPS production. The diversity of LAB in camel milk and its fermented products are summarized in Table 2.

Table 2: Major LAB associated with camel milk and its fermented products

Microflora	Camel milk/ fermented camel milk	Studied region	References
Lactobacillus salivarius, Lactococcus raffinolactis, L. plantarum, Lactobacillus curvatus and Leuconostoc mesenteroides sub sp. *mesenteroides*	Suusac	Kenya	Lore *et al.*, 2005
Enterococcus and Lactococcus genus	Shubat		Akhmetsadykova *et al.*, 2013
Leuconostoc lactis, Lactobacillus plantarum, L. paracasei, L. kefiri, L. gasseri, Enterococcus faecium and *Weissella cibaria*	Chal	Turkman Sahra, Golestan Province, Iran	Soleymanzadeh *et al.*, 2016
Lactococcus lactis ssp. *lactis, Lact. raffinolactis, Lact. lactis* ssp. *cremoris, Leuconostoc mesenteroides* ssp. *cremoris, Lactobacillus casei, L. homohiochii, L . plantarum, L. acetotolerans* and *L. kefiranofaciens*	Hurunge	China	Shuangquan *et al.*, 2006
Lactobacillus plantarum- SH1 to SH38	Shmen		Maurad and Meriem, 2008
Lactobacillus fermentum, L. casei, L. curizae, L. oryzae, L. brevis, L. plantarum, L. rhamnosus, L. paracasei	Raw and fermented camel milk	Kazakhstan	Nagyzbekkyzy *et al.*, 2020
Pediococcus pentosaceus, Enterococcus faecium strain Y-2, E. faecium strain JZ1-1, E. faecium strain E6, E. durans, E. lactis, Leuconostoc mesenteroides, Lactobacillus casei and *Weissella cibaria*	Camel milk	Iran	Davati *et al.*, 2015

7. Antimicrobial potential of LAB from camel milk

The LAB isolated from camel milk and its products have the antimicrobial activity against different pathogenic microbes. However, very few studies are available about bacteriocin/nisin producing LAB from camel milk and its derivatives. Recently, Algboory and Muhialdin (2021), reported that fermented camel milk produces bioactive peptides which showed antimicrobial activity against *Escherichia coli* and *Staphylococcus aureus* subsp. *aureus*. The bioactive peptides were extracted and identified using RP-HPLC fractionation and LC-MS/MS. Laiche *et al.* (2019) reported to isolate bacteriocin producing LAB from camel milk of southern Algeria (El Oued region) and evaluated their antimicrobial spectra. The predominant isolates belong to genus *Lactococcus* (*Lactococcus lactis* subsp. *lactis, Lactococcus lactis* subsp. *cremoris*) and *Pediococcus* (*P. acidilactici*), *Lactobacilli* (*L. amylophilus*), and *Streptococcus*. The bacteriocin produced by *Lactococcus lactis* subsp. *cremoris* showed highest zone of inhibition against *Staphylococcus aureus.* The study deducted that the production of bacteriocin is dependent on the dose of LAB apart from exhibiting bactericidal activity.

Another study by Mahmoudi *et al.* (2016) exanimated the antimicrobial effect of LAB isolated from raw camel milk collected in Tunisia. The authors concluded that these LAB showed good inhibitory activity against *Staphylococcus aureus, Listeria monocytogenes, Escherichia coli, and Salmonella typhimurium.* Yateem *et al.* (2008) studied the antimicrobial potential of LAB from spontaneously fermented camel milk (fermented for 7 days) and identified through molecular methods (16S rRNA gene sequencing). The isolates *Lactobacillus plantarum, Lactobacillus pentosus* and *Lactococcus lactis* subsp. *lactis* exhibited goods zone of inhibition against pathogenic bacteria such as *Salmonella typhimurium* ATCC 14028, *Salmonella enteritidis* ATCC 13076, *E.coli* 8739, *Staphylococcus epidermis and Staphylococcus capitis.*

8. Challenges and opportunities

Despite the fact that bacteriocin produced by LAB from camel milk have many benefits, but using them in the food industry has significant drawbacks. One of the major challenges is production cost of bacteriocin production. Nisin or any other bacteriocin can be expensive and difficult to produce and extract. The challenges that need to be overcome also include strain-specific concerns, stability during food processing, and regulatory approval. It is still difficult to choose and improve LAB strains with high amounts of nisin production and good fermentation characteristics. Technical and financial challenges must be overcome in order to scale up nisin production and include nisin-producing LAB into large-scale dairy operations. Market approval for the use of nisin in dairy products depends on regulatory criteria being met. The commercial penetration of dairy products with nisin enhancement will depend on consumer awareness and approval.

Microbiology is entering the postgenomic era, with numerous bacteria sequenced for food production. This presents new knowledge-based approaches for exploitation of bacteria, including metabolic engineering, molecular mining, and designing novel antimicrobials. The genomes of bacteria that cause food deterioration and pathogens may provide new design opportunities for antibiotics that specifically target vital processes. The challenge lies in harnessing this information for improved culture performance, safety, quality, and composition of our food supply. The food sector has a very good chance to capitalize on the potential of nisin-producing LAB derived from camel milk in the preservation of canned goods and processed cheese. Incorporating these bacteria into dairy-based goods like yoghurt and cheese can boost their nutritional content while also extending their shelf life. Furthermore, the sector might study the creation of innovative probiotic supplements and formulations

9. Conclusion

The investigation of bacteriocin produced by LAB is an emerging field of study and has important implications for both industry and public health. Probiotics derived from camel milk that generate bacteriocin have a lot of promise for application in the food industry and offer significant health benefits. Finally, the probiotic potential of nisin-producing LAB from camel milk offers up exciting options for the food industry to generate healthier and more useful food products that can increase human wellness. In the future, future research and technological advancements will undoubtedly reveal the full potential of these beneficial bacteria.

Conflict of interest

The authors declare no conflict of interest relevant to this article.

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