GSC Biological and Pharmaceutical Sciences

eISSN: 2581-3250 CODEN (USA): GBPSC2

Cross Ref DOI: 10.30574/gscbps

Journal homepage: https://gsconlinepress.com/journals/gscbps/

(REVIEW ARTICLE)

Check for updates

The role of lactic acid bacteria in food, agriculture and industry: A review

Binta Buba ADAMU *, Gloria Imoh Bassey OBIOH, Roseline Rumi IDEH and Gbadebo Barnabas OLUKOTUN

Department of Food and Industrial Biotechnology, National Biotechnology Research and Development Agency Musa yar adu'a Express way, Lugbe Abuja, Nigeria.

GSC Biological and Pharmaceutical Sciences, 2025, 30(01), 099-106

Publication history: Received on 27 November 2024; revised on 05 January 2025; accepted on 07 January 2025

Article DOI: https://doi.org/10.30574/gscbps.2025.30.1.0497

Abstract

Globally, COVID-19 pandemic imposed unparalleled challenges for food, agriculture and industries that led to disruptions in supply chains and demand dynamics. In Nigeria, this period showcased people's adaptability, resilience and innovativiness and underscored the importance of diversifying supply chains. This paper reviews the importance of Lactic Acid Bacteria (LAB) in food, agriculture and industry specifically highlighting their role as starter cultures for fermented foods. Lactic acid bacteria belong to a group of gram positive, beneficial bacteria, which produce lactic acid as their primary fermentation product. They have always been used for food and dairy products fermentation and focus has been on their applications. Fermented foods are produced through fermentation of certain sugars, especially lactose by LAB. The end products of the breakdown include bacteriocins which are bio-protective agents of industrial importance. Of particular agricultural and food importance is probiotic application of some LAB. Probiotics are living microbial feed supplement that beneficially affects the host by improving its intestinal microbial balance. The Bacteriostatic and bactericidal potentials of certain metabolites of LAB origins were elucidated. These polypeptides synthesized by the LAB ribosome have been reported to be antagonistic to several bacteria. The nutritional benefits and safety consideration of LAB were also emphasized. Limitations to the use of LAB and their future prospect were briefly highlighted. Given the potential applications of LAB to the Nigerian food, agriculture and industries, it is recommended that starter cultures with outstanding traits be further developed and adapted to local needs.

Keywords: LAB; Fermentation; Prospects; Applications

1. Introduction

Lactic Acid Bacteria (LAB) are heterogeneous group of bacteria which play a significant role in a variety of fermentation processes. They ferment food carbohydrates and produce lactic acid as the main product of fermentation. In addition, degradation of proteins, lipids and production of various alcohols, aldehydes, acids, esters and Sulphur compounds contribute to the specific flavour development in different fermented food products. Lactic acid was discovered in 1780 by C.W. Scheele in sour milk, and in 1881 Fermi obtained lactic acid by fermentation, resulting in its industrial production. The interest in lactic acid is related to many aspects, among which is its relatively high added-value. Lactic acid bacteria play a multifaceted role in the food, agricultural, and medicine sectors and has GRAS (Generally Recognized as Safe) status by the Food and Drug Administration Raman *et al*. [1]. They are safe for human and animal consumption and have become ideal for commercial development Sadiq *et al.* [2]. Lactic acid bacteria species are used in many food and feed industries, and those industries are constantly seeking potential strains to enhance sensor and product quality. They are isolated from decomposing plant material, vegetables, fruits, dairy products, fermented food, fermented beverages, silages, juices, sewage, and the gastrointestinal tracts and cavities of humans and animals Raman *et al*. [1]. They have been clustered into two different groups, homo- and hetero-fermentative strains, based on lactic acid yield. Homo-fermentation yields two molecules of lactic acid, while hetero-fermentation yields one molecule of lactic acid and one molecule of ethanol or acetic acid by utilizing glucose. Homo-fermentative strains are commercially important, and

* Corresponding author: Binta Buba ADAMU

they can produce optically pure lactic acid by downstream processes. Lactic acid is a by-product of metabolic activities produced by LAB. Therefore, silage can be considered a primary source to transmit and deliver the probiotic LAB species. Fermented cattle milk is a lactic acid source that enhances food quality and flavor.

2. Characteristics of Lactic Acid Bacteria

Lactic acid bacteria are gram-positive, non-sporing, non-respiring cocci or rods and they produce lactic acid as the major end product during the fermentation of carbohydrates. The common agreement is that there is a core group consisting of four genera; Lactobacillus, Leuconostoc, Pediococcus and Streptococcus. Their importance is associated mainly with their safe metabolic activity while growing in foods utilizing available sugar for the production of organic acids and other metabolites Khalid [3]. The LAB common occurrence in foods along with their long-lived uses contributes to their natural acceptance for human consumption. The European food safety association's (EFSA) 'Panel on Biological Hazards (BIOHAZ)' has concluded that for the fermenting bacteria associated with food, whether resistant to antibiotics or not - with the possible exception of enterococci - there is no evidence for any clinical problem. However, they can act as a reservoir for transferable resistance genes Bintsis [4].

3. Applications of Lactic Acid Bacteria

The uses of lactic acid bacteria cannot be overemphasized, as many studies have confirmed their potential use in various sectors, such as food, Agricultural, Pharmaceutical, cosmetic, textile and other industries as shown in figure 1.

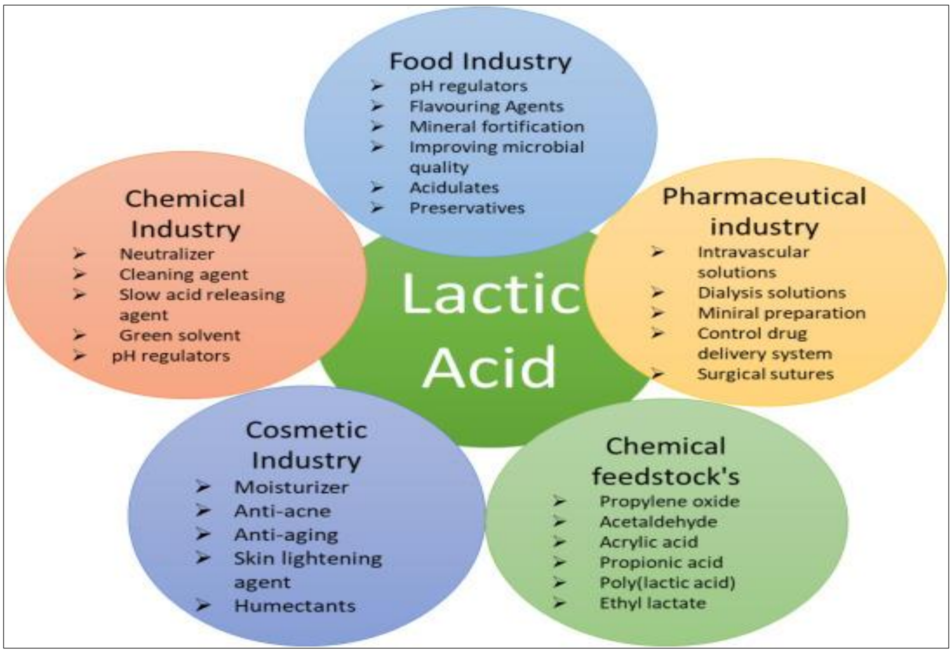

Figure 1 Industrial application of lactic acid bacteria Ahmad *et al.* [5]

4. Lactic Acid Bacteria in Food Industry

In foods, lactic acid bacteria are used in various ways depending on desired end product. These bacteria could be used as flavour enhancer to improve aroma, taste and texture; add nutritional value to the food; it serves as preservative that prevent the growth of pathogenic and spoilage bacteria and prolong the shelf life of the food. Furthermore, LAB is used to prevent food deterioration as biocontrol agents, some of these LAB strains mainly from Lactobacillus and Bifidobacterium genera can promote health, they are recognized as probiotics Mokoena *et al.* [6]. Probiotics produced different bacteriocins however, there is dearth of information focusing on the ability of LAB to inhibit foodborne pathogens, especially during the current era where consumers are becoming more health conscious when it comes to their food choices. The new omics technologies enable bioprospecting for LAB strains with robust antimicrobials and present an opportunity to maximize their contribution in food and nutrition backgrounds Soltani *et al*. [7].

Bacteriocin-producing cultures have been industrially applied to inhibit *Listeria monocytogenes* and *Clostridium* spp. in various fermented meats, vacuum-packaged products, and in vegetable-based foods Mokoena *et al.* [8]. The application of artificial chemicals to limit food spoilage organisms poses health risks which gives bacteriocins an edge as alternatives, in synergy with plant phenolic compounds and other antimicrobial agents Mokoena *et al.* [6]. The spread of antibiotic resistance and demand for food products with fewer chemical preservatives necessitates search for new alternatives to avoid the abuse of therapeutic antibiotics Darbandi *et al.* [9]. LAB isolated from homemade fermented vegetables produce antibacterial substances against both Gram-positive and Gram-negative common foodborne bacterial pathogens Mokoena *et al*. [6].

5. Lactic Acid Bacteria in Agriculture

The role of LAB in agriculture are over emphasis, from soil preparation to product preservation. Lactic acid bacteria can be applied in compost teas to prepare soil for planting, it helps the soil to retain moisture and improve soil structure. Moreso, LAB improve soil fertility by increasing nutrient availability, organic decomposition and aeration. Heavy metals and fungal mycotoxins can be detoxified by LAB Lamont *et al*. [10]. Lactic acid bacteria stimulate plant ability to tolerate abiotic stress such as dehydration, flood, high temperature and also promote seed germination and plant growth. They are good biocontrol agents that help control plant diseases and inhibit bacterial and fungal population in the rhizosphere and phyllosphere. LAB can produce organic acid and bacteriocin metabolites that enrich silage and other feedstock Raman *et al.* [1].

In last century, the agricultural sector has experienced a tremendous increase in chemical use in response to the growing population. Consequently, the intensive and indiscriminate use of these substances caused serious damage on several levels, including threatening human health, disrupting soil microbiota, affecting wildlife ecosystems, and causing groundwater pollution. As a solution, the application of microbial-based products presents an interesting and ecological restoration tool. Lactic acid bacteria are considered an interesting candidate to be formulated and applied as effective microbes as Plant Growth-Promoting Microbes (PGPM) affected positive production, by increasing its efficiency, reducing production costs, environmental pollution, and chemical use Lahmamsi *et al*. [11].

6. Lactic Acid Bacteria in Cosmetics

Cosmetics are described by the US Food and Drug Administration (FDA) as "products (excluding pure soap) used to cleanse, beautify, enhance attractiveness, or alter the appearance of the human body" Dou *et al.* [12]. There is an interesting relationship between the skin and fermentation of lactic acid bacteria (LAB) or bifidobacterial. Supernatants of these bacteria contain lactate and amino acids, which contribute to the hydration of the skin. Many cosmetic ingredients have been developed using LAB and bifidobacteria Abd Alsaheb *et al*. [13]. In the ancient Egyptian era, the famous queen Cleopatra use to bath in diary milk with the believe to rejuvenate the skin. Till date lactic acid produced by LAB are highly recognized in cosmetics products. Lactic acid offers natural constituent for cosmetic implementations. At first, it has been used as pH good regulators. In addition, it had other features such as skin hydration, antimicrobial activity, and skin lightening Dou *et al.* [12]. The moisturizing efficiency was connected directly to lactate is moisture-detained capability, and the skin-lightening action of lactic acid was produced by the repression of the formation of tyrosine. Since they were normal constituent of the human body, following lactic acid and its salt fit completely into the renewed direction towards natural and safe formularization, and they produced such effects as renewal and skin illumination Singh *et al.* [14]. Probiotics have been demonstrated to possess a number of skin-beneficial features, including the ability to reduce skin inflammation, heal several skin conditions, and shield against allergic contact dermatitis. Additionally, they are essential for enhancing the skin barrier, promoting water absorption, and delaying the aging process of the skin Kober and Bowe [15].

7. Lactic Acid Bacteria in Pharmaceutical

Lactic acid has many applications in the drugs manufacture as an electrolyte in numerous, parenteral/I.V. (intravenous) solutions that are prepared to, supplement the bodily fluids or electrolytes. For Example, CAPD solution (continuous ambulatory peritoneal dialysis), and dialysis solution for classical synthetic renal machine Lin *et al. [*16]. The primary functions for the pharmaceutical applications are pH-regulation, chiral intermediate and metal sequestration, as a natural body constituent in pharmaceutical products. Furthermore, lactic acid is applied in a wide diversity of metal preparations that involve, surgical sutures, tablets, and controlled systems of drug deliver Abedi and Hashemi [17]. Lactic acid is a valuable component in biomaterials such as resorbs able screws, sutures and medical devices Sagir and Alipour [18].

8. Lactic Acid Bacteria as Starter Cultures for Food Fermentation

Fermented foods are produced through fermentation of certain sugars by LAB and the origins of them are lost in ancient times. It is well-known that the greatest proportion of LAB belong to the category of dairy products, namely cheese, yoghurt, fermented milks, while fermented meat products, fish products, pickled vegetables and olives and a great variety of cereal products are manufactured, nowadays, using starter cultures. These products, were produced in the past through back slopping and the resulting product characteristics depended on the best-adapted strains dominance, whereas, the earliest productions of them were based on the spontaneous fermentation, resulting from the development of the microflora naturally present in the raw material and its environment. Today, the majority of fermented foods are manufactured with the addition of selected, well defined, starter cultures with well characterized traits, specific for each individual product Bintsis [4].

9. Bio-Preservation Applications

Certain LAB has been found to produce bacteriocins, namely, polypeptides synthesized ribosomally by bacteria that can have a bacteriocidal or bacteriostatic effect on other bacteria Ross *et al.* [19]. In general, bacteriocins lead to cell death by inhibiting cell wall biosynthesis or by disrupting the membrane through pore formation Twomey *et al.* [20]. Bacteriocins are therefore important in food fermentations where they can prevent food spoilage or the inhibition of food pathogens. The best known bacteriocin is nisin, which has gained widespread application in the food industry and is used as a food additive in at least 50 countries, particularly in processed cheese, dairy products and canned foods Bintsis [4]. Examples of useful bacteriocins produced by LAB are lacticin 3147 from *lactococci, macedovicin* from *Streptococcus macedonicus* ACA-DC 198, reuterin from *Lactobacillus reuteri*, sakacin M from *Lactobacillus sake* 148 curvacin A, curvaticin L442 and lactocin AL705 from *Lactobacillus curvatus* LTH1174, pediocin PA-1/AcH from *Pediococcus acidilactici*, plantaricins (A, EF and JK) from *Lactobacillus plantarum* Castellano *et al.* [21]. The above bacteriocins have proved effective in many food systems for the control of food spoilage or pathogenic bacteria. In addition; LAB strains also have the ability to reduce fungal mycotoxins, either by producing anti-mycotoxinogenic metabolites, or by absorbing them Bintsis [4]. For LAB to be used as bio-protective starter cultures, they must possess a range of physical and biochemical characteristics, and most importantly, the ability to achieve growth and sufficient production of antimicrobial metabolites, which must be demonstrated in the specific food environment Cheong *et al.* [22].

10. Lactic Acid Bacteria as Probiotic Cultures

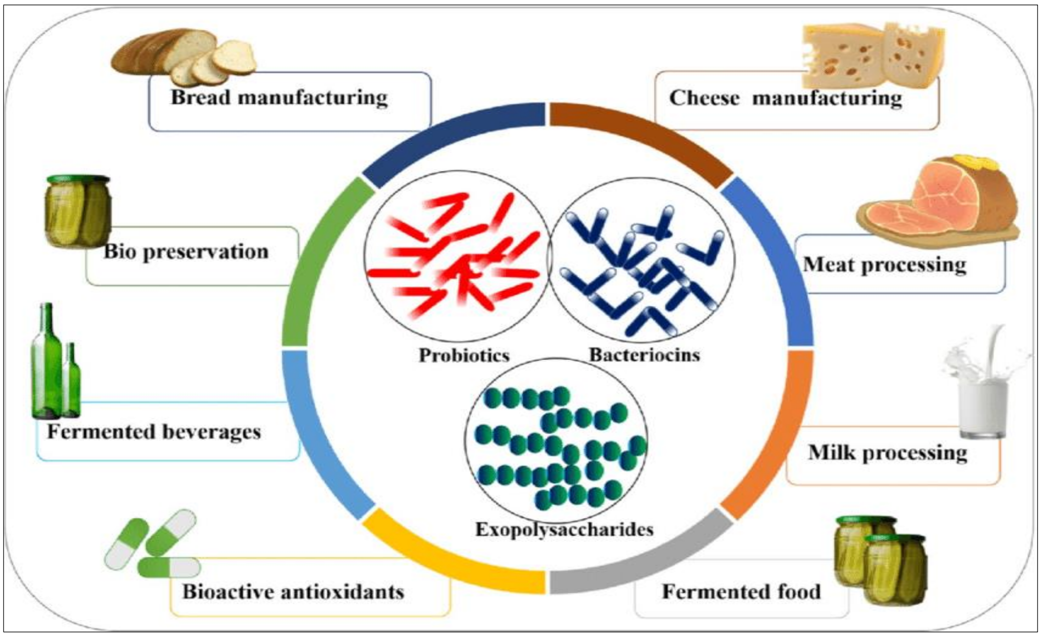

Figure 2 Lactic acid application in food Raj [23]

Probiotic are defined as living microbial feed supplement which beneficially affects the host animal by improving its intestinal microbial balance. Commercial cultures used in food applications include mainly strains of *Lactobacillus* *spp*., *Bifidobacterium spp.* and *Propionibacterium spp. Lactobacillus acidophilus, Lactobacillus casei, Lb. reuteri, Lactobacillus rhamnosus* and *Lb. plantarum* are the most used LAB in functional foods containing probiotics Champagne and Møllgaard [24]. Argentinean Fresco cheese, Cheddar and Gouda are some examples of applications of probiotic LAB, in combination with bifidobacteria, in cheeses Bintsis [4]. In addition, LAB, as part of gut microbiota ferment various substrates such as biogenic amines and allergenic compounds into short-chain fatty acids and other organic acids and gases Almalki [25].

11. Nutritional Benefits of Lactic Acid Bacteria

Several metabolites produced during fermentation are strain specific. LAB produce vitamins (e.g. folate) in variety of fermented dairy products such as curd, yoghurt, cultured butter milk, cheeses etc. Amount of folate in yoghurt depends on starter cultures Ghosh *et al.* [26]. Folate is a water-soluble vitamin B and very important for human health. Deficiency of folate may lead to a variety of health complications like osteoporosis, Alzheimer's disease, coronary heart disease, and high risk of breast and colorectal cancer Rossi *et al.* [27]. Folate biosynthesis is strain-dependent property, as many *Lactobacillus spp*. and *Lactococci spp*. Like *L. plantarum, L. bulgaricus, L. lactis, S. thermophilus,* and *Enterococcus spp*. are able to produce folate while some lactobacilli (*L. gasseri, L. salivarius, L. acidophilus,* and *L. johnsonii*) cannot due to absence of genes responsible for folate biosynthesis Ghosh *et al.* [26]. In a study, cow's milk-isolated folate-producing lactic acid bacteria were screened for probiotic properties. It was found that *L. lactis* subsp. *cremoris* and *L. lactis* subsp. *lactis* showed efficient probiotic properties with significant folate production Gangadharan *et al.* [28]. These folate-producing strains can be used for developing fermented dairy food with good nutrition profile. Riboflavin, a precursor of the coenzymes flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD) have been shown to be produced by *L. acidophilus* isolated from yoghurt samples in Vellore, India Jayashree *et al.* [29]. Whey was recommended as a better fermentation medium compared with skim milk for riboflavin production Guru and Viswanathan [30]. The gut bacteria can also transform anti-nutritive factors present in cereals or plant products into nutritional metabolites improving nutritional value of the food product. Phytase-producing strains have long been used in degradation of phytate in wheat dough to increase calcium, phosphorus, and magnesium in food Palacios *et al.* [31]; Ghosh *et al.* [26]. Sharma *et al.* [32] have recently reported a novel tyrosine phosphate like phytase from a probiotic bacterium *L. fermentum* NKN51 isolated from Himalayan yak cheese Chhurpi. The enzyme showed high specificity to its substrate phytate, a compound which chelates micronutrients and cationic proteins and limits their availability in food. Phytase from *L. fermentum* NKN51 also showed significant dephytanation of finger millet and Durum wheat under in vitro gastrointestinal conditions and displayed potential as food and feed additive Sharma *et al.* [32]. Novel phytase have also been reported in other probiotic strains like *Bifidobacterium pseudocatenulatum* Tamayo-Ramos [33], and *Lactobacillus sanfranciscensis* Ghosh *et al.* [26].

12. Food Safety Application of Lactic Acid Bacteria Strains

Food spoilage can occur at various stages of food production, supply, and consumption. That is why food safety receives a lot of attention in wealthier societies, but it is a much more pressing concern in developing countries. One reason for food contamination is the polluted water used for washing and processing; others include primitive ways of production and improper use of agricultural chemicals, poor storage and lack of regulations. Many agents that causes diseases are transmitted from domestic animals to humans through food products; in addition, the warm climate further contributes to the spread of natural toxigenic producers in tropical countries Petrova *et al.* [34].

The raw material of sausage, especially fresh meat, contains diverse bacteria. The growth of undesired bacteria has to be reduced or eliminated to an acceptable level and it can be achieved through fermentation. Since the fermented sausage may still be inhabited by pathogenic bacteria, which sometimes cause food borne diseases, therefore its safety depends on successful fermentation and the usage of starter culture is one of the premier options. *P. acidilactici* has also been demonstrated to be able to reduce pathogenic bacteria in salami fermentation Kang and Fung [35] as well as in fish sausage fermentation Antara *et al.* [36].

The natural and safe preservatives of traditional dairy products are ensured by LAB-produced antimicrobial peptides called bacteriocins de Souza *et al.* [37]. Bacteriocins have proved effective in many food systems for the control of food spoilage or pathogenic bacteria. In addition; LAB strains also have the ability to reduce fungal mycotoxins, either by producing anti-mycotoxinogenic metabolites, or by absorbing them Bintsis [4].

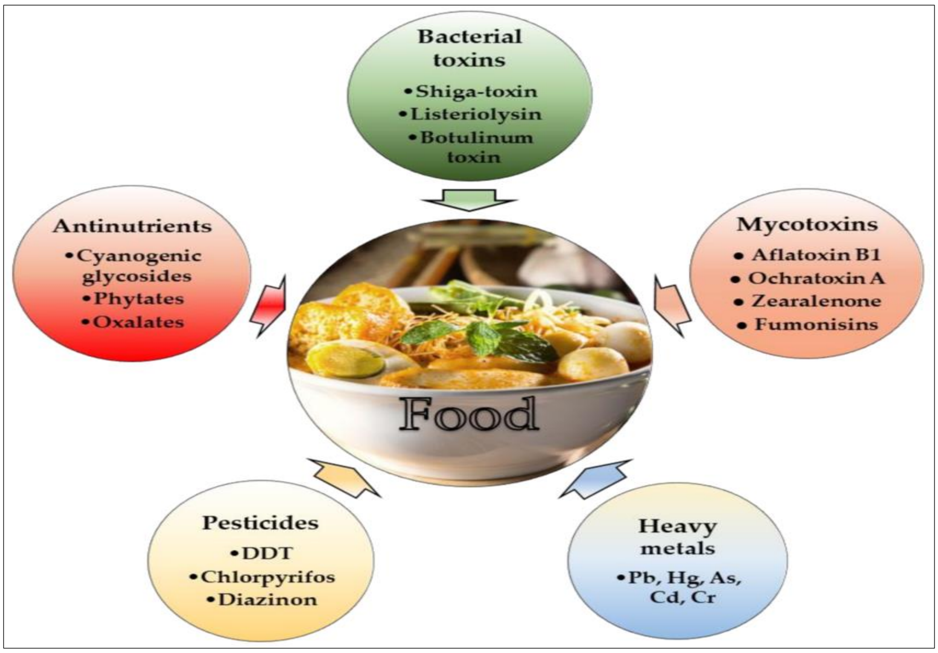

Figure 3 Toxic compounds that could be found in food products Petrova *et al*. [34]

13. Limitations and Future Prospects of Lactic Acid Bacteria

Since ancient times, lactic acid bacteria have been used as food and medicine, and are the most commonly used probiotics in food. They synthesize various organic acids and other metabolites in the fermentation process. At the same time, the primary acidification process in the fermentation of food and feed substrates prevents the spoilage of microbe populations. Hence, LAB are the most promising candidates for preventing food spoilage and are used as food/feed preservatives Dopazo *et al*. [38]. Lactic acid bacteria-derived metabolites are highly beneficial to human and animal health, and are used as food supplements, medicine, and cosmetic products. In addition, the high production cost and acidic conditions are drawbacks, limiting the commercial application. However, several studies have pointed out that LAB probiotics are complementary to treating urinary tract infections and respiratory tract infections in humans. However, very limited studies elucidated the role of LAB in the rhizosphere and their plant-growth-promoting properties Raman *et al.* [1]. Lactic acid bacteria promote growth in different crops, even though the underlying mechanisms behind this bio-stimulation remain unclear. In addition, LAB showed weak inhibitory activity against plant pathogenic fungi and bacteria. However, LAB exhibited a wide range of antagonistic effects against Gram-positive bacteria. They have minimal effects on Gram-negative bacteria Govindaraj, *et al.* [39]. The positive explanation regarding genetically modified LAB was found to have limited evidence, and legal issues limit advanced technology. However, specialization in the LAB gene structure and function and amino acid biosynthesis pathways are warranted Raman *et al.* [1]. In the future, those emerging technologies will increase the yield and build sustainability across food, agriculture and industries.

14. Conclusion

The 21st century is associated with food shortage, global warming, and increasing pollution of water and soils. The use of lactic acid bacteria to preserve, improve and provide food in various forms is important. Due to their wide substrate spectrum and diverse enzyme pool, LAB can ferment almost any food of any quality and potentially detoxify it to safety level. Today's consumers' desires products with pre-defined qualities. Therefore, foods like yoghurt could be better developed through the functional and technological properties of the producing bacteria strains. Flavour development, for instance, being a complex and dynamic biochemical process, advance classical genetic improvement protocol should be provided in order to influenced positively the LAB used as starter cultures since the flavour-related compounds in yoghurt are primarily derived from microorganism-mediated glycolysis, proteolysis, and lipolysis.

Compliance with ethical standards

Disclosure of conflict of interest

The authors hereby jointly affirm that there is no conflict of interest to be disclosed.

References

[1] Raman J, Kim JS, Choi KR, Eun H, Yang D, Ko YJ, Kim SJ. Application of lactic acid bacteria (LAB) in sustainable agriculture: advantages and limitations. International Journal of Molecular Sciences. 2022 Jul 14;23(14):7784.

[2] Sadiq FA, Yan B, Tian F, Zhao J, Zhang H, Chen W. Lactic acid bacteria as antifungal and anti-mycotoxigenic agents: a comprehensive review. Comprehensive Reviews in Food Science and Food Safety. 2019 Sep;18(5):1403-36.

[3] Khalid K. An overview of lactic acid bacteria. (2011), 1 (3), 1- 13.

[4] Bintsis TJ. Lactic acid bacteria: their applications in foods. J. Bacteriol. Mycol. 2018;6(2):89-94.

[5] Ahmad A, Banat F, Taher H. A review on the lactic acid fermentation from low-cost renewable materials: Recent developments and challenges. Environmental Technology & Innovation. 2020 Nov 1;20:101138.

[6] Mokoena MP, Omatola CA, Olaniran AO. Applications of lactic acid bacteria and their bacteriocins against food spoilage microorganisms and foodborne pathogens. Molecules. 2021 Nov 22;26(22):7055.

[7] Soltani S, Hammami R, Cotter PD, Rebuffat S, Said LB, Gaudreau H, Bédard F, Biron E, Drider D, Fliss I. Bacteriocins as a new generation of antimicrobials: toxicity aspects and regulations. FEMS microbiology reviews. 2021 Jan;45(1):fuaa039.

[8] Mokoena MP, Mutanda T, Olaniran AO. Perspectives on the probiotic potential of lactic acid bacteria from African traditional fermented foods and beverages. Food & Nutrition Research. 2016 Jan 1;60(1):29630.

[9] Darbandi A, Asadi A, Mahdizade Ari M, Ohadi E, Talebi M, Halaj Zadeh M, Darb Emamie A, Ghanavati R, Kakanj M. Bacteriocins: properties and potential use as antimicrobials. Journal of Clinical Laboratory Analysis. 2022 Jan;36(1):e24093.

[10] Lamont JR, Wilkins O, Bywater-Ekegärd M, Smith DL. From yogurt to yield: Potential applications of lactic acid bacteria in plant production. Soil Biology and Biochemistry. 2017 Aug 1;111:1-9.

[11] Lahmamsi H, Ananou S, Lahlali R, Tahiri A. Lactic acid bacteria as an eco-friendly approach in plant production: Current state and prospects. Folia Microbiologica. 2024 Feb 23:1-25.

[12] Dou J, Feng N, Guo F, Chen Z, Liang J, Wang T, Guo X, Xu Z. Applications of probiotic constituents in cosmetics. Molecules. 2023 Sep 22;28(19):6765.

[13] Abd Alsaheb RA, Aladdin A, Othman NZ, Abd Malek R, Leng OM, Aziz R, El Enshasy HA. Lactic acid applications in pharmaceutical and cosmeceutical industries. Journal of Chemical and Pharmaceutical Research. 2015;7(10):729-35.

[14] Singh SK, Ahmed SU, Pandey A. Metabolic engineering approaches for lactic acid production. Process Biochemistry. 2006 May 1;41(5):991-1000.

[15] Kober MM, Bowe WP. The effect of probiotics on immune regulation, acne, and photoaging. International journal of women's dermatology. 2015 Jun 1;1(2):85-9.

[16] Lin L, Lee Y, Park HE. Recycling and rheology of poly (lactic acid)(PLA) to make foams using supercritical fluid. Physics of Fluids. 2021 Jun 1;33(6).

[17] Abedi E, Hashemi SM. Lactic acid production–producing microorganisms and substrates sources-state of art. Heliyon. 2020 Oct 1;6(10).

[18] Sagir E, Alipour S. Photofermentative hydrogen production by immobilized photosynthetic bacteria: Current perspectives and challenges. Renewable and Sustainable Energy Reviews. 2021 May 1;141:110796.

[19] Ross RP, Morgan S, Hill C. Preservation and fermentation: past, present and future. International journal of food microbiology. 2002 Nov 15;79(1-2):3-16.

[20] Twomey D, Ross RP, Ryan M, Meaney B, Hill C. Lantibiotics produced by lactic acid bacteria: structure, function and applications. Antonie Van Leeuwenhoek. 2002 Aug;82:165-85.

[21] Castellano P, Belfiore C, Fadda S, Vignolo G. A review of bacteriocinogenic lactic acid bacteria used as bioprotective cultures in fresh meat produced in Argentina. Meat science. 2008 Jul 1;79(3):483-99.

[22] Cheong EY, Sandhu A, Jayabalan J, Le TT, Nhiep NT, Ho HT, Zwielehner J, Bansal N, Turner MS. Isolation of lactic acid bacteria with antifungal activity against the common cheese spoilage mould Penicillium commune and their potential as biopreservatives in cheese. Food Control. 2014 Dec 1;46:91-7.

[23] Raj T, Chandrasekhar K, Kumar AN, Kim SH. Recent biotechnological trends in lactic acid bacterial fermentation for food processing industries. Systems Microbiology and Biomanufacturing. 2022 Jan;2(1):14-40.

[24] Champagne CP, Møllgaard H. Production of probiotic cultures and their addition in fermented foods. Handbook of fermented functional foods. 2008:513-32.

[25] Almalki MA. Exopolysaccharide production by a new Lactobacillus lactis isolated from the fermented milk and its antioxidant properties. Journal of King Saud University-Science. 2020 Mar 1;32(2):1272-7.

[26] Ghosh T, Beniwal A, Semwal A, Navani NK. Mechanistic insights into probiotic properties of lactic acid bacteria associated with ethnic fermented dairy products. Frontiers in microbiology. 2019 Mar 26;10:502.

[27] Rossi M, Amaretti A, Raimondi S. Folate production by probiotic bacteria. Nutrients. 2011 Jan 18;3(1):118-34.

[28] Gangadharan D, Sivaramakrishnan S, Pandey A, Madhavan Nampoothiri KE. Folate-producing lactic acid bacteria from cow's milk with probiotic characteristics. International Journal of Dairy Technology. 2010 Aug;63(3):339-48.

[29] Jayashree S, Jayaraman K, Kalaichelvan G. Isolation, screening and characterization of riboflavin producing lactic acid bacteria from Katpadi, Vellore district. Recent Res Sci Technol. 2010 Feb 13;2(1):83-8.

[30] Guru V, Viswanathan K. Riboflavin production in milk whey using probiotic bacteria-Lactobacillus acidophilus and Lactococcus lactis.

[31] Palacios MC, Haros M, Sanz Y, Rosell CM. Selection of lactic acid bacteria with high phytate degrading activity for application in whole wheat breadmaking. LWT-Food Science and Technology. 2008 Jan 1;41(1):82-92.

[32] Sharma R, Kumar P, Kaushal V, Das R, Navani NK. A novel protein tyrosine phosphatase like phytase from Lactobacillus fermentum NKN51: cloning, characterization and application in mineral release for food technology applications. Bioresource technology. 2018 Feb 1;249:1000-8.

[33] Tamayo-Ramos JA, Sanz-Penella JM, Yebra MJ, Monedero V, Haros M. Novel phytases from Bifidobacterium pseudocatenulatum ATCC 27919 and Bifidobacterium longum subsp. infantis ATCC 15697. Applied and environmental microbiology. 2012 Jul 15;78(14):5013-5.

[34] Petrova P, Arsov A, Tsvetanova F, Parvanova-Mancheva T, Vasileva E, Tsigoriyna L, Petrov K. The complex role of lactic acid bacteria in food detoxification. Nutrients. 2022 May 12;14(10):2038.

[35] Kang DH, Fung DY. Stimulation of starter culture for further reduction of foodborne pathogens during salami fermentation. Journal of food protection. 2000 Nov 1;63(11):1492-5.

[36] Antara NS, Gunam IB, Kencana PK, Utama I. The role of lactic acid bacteria on safety and quality of fermented foods. InAIP Conference Proceedings 2019 Sep 6 (Vol. 2155, No. 1). AIP Publishing.

[37] de Souza EL, de Oliveira KÁ, de Oliveira ME. Influence of lactic acid bacteria metabolites on physical and chemical food properties. Current Opinion in Food Science. 2023 Feb 1;49:100981.

[38] Dopazo V, Luz C, Quiles JM, Calpe J, Romano R, Mañes J, Meca G. Potential application of lactic acid bacteria in the biopreservation of red grape from mycotoxigenic fungi. Journal of the Science of Food and Agriculture. 2022 Feb;102(3):898-907.

[39] Govindaraj K, Samayanpaulraj V, Narayanadoss V, Uthandakalaipandian R. Isolation of lactic acid bacteria from intestine of freshwater fishes and elucidation of probiotic potential for aquaculture application. Probiotics and Antimicrobial Proteins. 2021 Dec;13(6):1598-610