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# DEVELOPMENTS OF LACTIC ACID BACTERIA AND THEIR METABOLITES FOR FOOD QUALITY, FOOD SAFETY AND HUMAN HEALTH

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## Abstract

Lactic acid bacteria (LAB) are a group of highly specialized bacteria specifically adapted to a diverse range of habitats. They are relevant not only for traditional food fermentations, but also as probiotics, potential therapeutics and cell factories for the production of naturally occurring antimicrobial compounds which could be applied as food preservatives to protect food quality and extend the shelf life of foods and beverages. The metabolic products of LAB improve shelf-life, organoleptic and nutritional properties of foods. The industrial potential of LAB, however, is much wider and many strains have well-established metabolites which represent promising avenues where nature's gifts may be repurposed for use in food quality and safety. The use of lactic acid bacteria and metabolites in food fermentations thereof to increase product shelf life has attracted much interest during recent years. Their potential use as biopreservatives and as probiotics in many food matrices appears to be huge. The bio-functional properties such as antimicrobial activity, anti-inflammatory, antioxidant, antidiarrheal, antiviral, immunomodulatory, anti-diabetic and anti-cancer activities are the very best applicable research areas of lactic acid bacteria in human health. This review shall give an overview highlighting some of the most striking technological/industrial applications of lactic acid bacteria as well as their metabolites in food safety and human health.

Keywords: Lactic acid bacteria, applications, fermented foods, biopreservation, antimicrobial activity, probiotics

**Introduction**

Fermentation of various foodstuffs by lactic acid bacteria (LAB) is one of the oldest forms of bio preservation practiced by mankind. In recent years, significant advances have been made in elucidating the genetic and physiological basis of key LAB traits involved in these industrially significant processes (Leroy and De Vuyst 2004). Important attributes of many LAB are their ability to start or modulate the fermentation by producing many acidic metabolites and other biomolecules such as antimicrobial compounds called bacteriocins including many molecules that contribute to the overall quality, shelf life and safety of foods and in addition, enhance their technological sensorial, nutritional and functional features ((Leroy and De Vuyst 2004; Binitiss 2020). Interest in these compounds has grown substantially due to their potential usefulness as natural substitutes for chemical food preservatives in the production of foods with enhanced shelf life and/or safety ((Hati et al., 2013; Ganzle, 2020).

There is growing consumer awareness of the link between diet and health. Recent scientific evidence supports the role of probiotic LAB in mediating many positive health effects. Most LAB are quite acid resistant which enables them to effectively survive passage through the stomach — a vital point in oral vaccine administration (Mercenier,2000). In that respect, some LAB is currently being assessed for their ability to act as live delivery vectors in the development of new oral vaccines. LAB as vaccine carriers is appealing as they are able to induce both mucosal and systemic immune responses, have adjuvant properties, and is free from risks associated with the use of conventional attenuated live pathogens such as *Salmonella* spp. and *Mycobacterium* spp. (Pouwels et al.,1998).

Due to their interesting beneficial properties, LAB is widely used as starter cultures, as probiotics, and as microbial cell factories in food and feed fermentation technology, (Mercenier et al. 2000). Given the economic value of food fermentations and a growing acceptance that at least some of these products may contribute to improved health, it is not surprising that LAB is attracting major attention at this time. This has led to the increased volume of fermented products available world-wide especially in the area of functional foods containing probiotic or health-promoting bacteria(**Figure 1).**

During fermentation, lactic acid bacteria produce organic acids and other metabolites that enhance flavor development in food, prevent spoilage, and control the growth of undesirable bacteria, including Enterobacteriaceae (Oguntoyinbo and Narbad, 2015; Anyogu et al., 2021).The use of lactic acid bacteria in food preservation is known as bio-preservation which is a natural approach to using controlled microbiota as an alternative for shelf-life extension and the preservation of food. Therefore, bio- preservation is considered as one of the many attributes derived from lactic acid bacteria under the scope of food safety/spoilage.

Because lactic acid bacteria naturally produce bacteriocins that aid in food bio-preservation, they function as the antagonistic, inhibitory, and antimicrobial defense system that acts against pathogens and spoilage microorganisms [Staton *et al.,* 2005]. As a

result, lactic acid bacteria can be used as tool to ensure the safety and quality of food products.

Lactic acid bacteria also possess therapeutic properties that are vital for human health enhancement. Distinct nutritional properties of lactic acid bacteria coupled with enhanced adhesional adaptive features enable the bacteria to easily thrive in different environments such as in dairy-based foods, fermented foods, vegetables as well as in the human gut (Marco et al., 2017; Benitis, 2020).

Probiotics are live microorganisms which when administered in adequate amounts confer a health benefit on the host (Fuller, 1989). Probiotics such as lactic acid bacteria work by promoting and maintaining a strong human immune system. For example, a number of human health diseases have been reported to be prevented by the administration of probiotics and lactic acid bacteria.

The regular consumption of probiotics and lactic acid fermented foods will thus benefit consumers nutritionally and serve as an immunity booster against diseases and infections. In this review, lactic acid bacteria, and their perspectives on industrial applications with a special focus on food safety and therapeutic benefits to human health was elucidated.

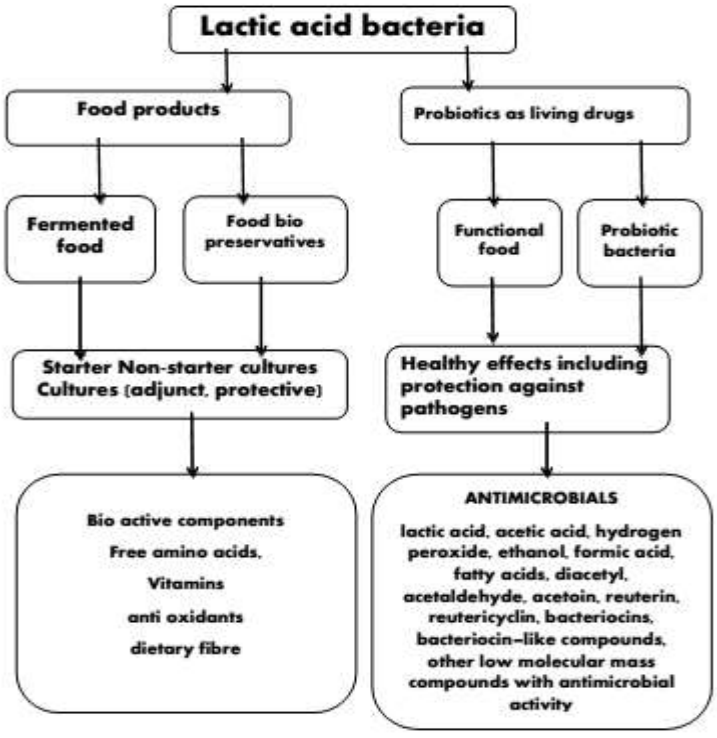



**Fig 1.** Functional properties of lactic acid bacteria

**LAB in food fermentation**

Fermentation is one of the oldest technologies for processing of food and beverages to improve qualities such as extended shelf-life and organoleptic properties. The natural fermentation process takes place in presence of a mixed colony of microorganisms such as bacteria, yeasts and molds (Chelule *et al.,* 2010. Franz *et al.,* 2014). LAB are the most common and dominant microorganisms present in fermented foods and therefore, lactic acid fermentation is considered as the major contributor to the beneficial characteristics observed in those foods

The earliest production of traditional fermented food products relied on spontaneous fermentation due to the development of the associated microflora present on raw materials and on materials that they are exposed to during production. They are still being produced in some developing countries due to the low technological input required, their shelf life, and their uniqueness in terms of taste, aroma, and texture.

Optimization of spontaneous fermentation processes has been made possible through inoculation of the raw material with a small quantity of a previously performed successful fermentation. After a few refreshments, repeated rebuilding or "back slopping" leads to a stable microbiota, giving rise to a selective enrichment of the best adapted strain. According to Todorov and Holzapfel (2015), the dominant strain can be seen as a starter that shorten the fermentation process and reduce the risk of fermentation failure as noted by Leroy and De Vuyst (2004).

Based on spontaneous methods, the back-slopping technique is used in the preparation of several traditional fermented products. Lactic acid bacteria (LAB) are the primary microorganisms used to ferment maize-, sorghum- or millet-based foods that are processed in West Africa. Reviews discussing indigenous fermented foods from Africa have focused on the microbial diversity of fermenting and technologically important bacteria (Achi and Asamudo, 2019; Parkouda et al., 2009; Tamang et al., 2015).

Whereas a food fermentation process with LAB is traditionally based on spontaneous fermentation or back slopping, industrial food fermentation is nowadays performed by the deliberate addition of LAB as starter cultures to the food matrix. Application of LAB has changed from traditionally fermented foods and beverages to rationally controlled food fermentation, *in situ* production of industrially relevant metabolites, and use as probiotics or as efficient microbial cell factories resulting in a high degree of control over the fermentation process and standardization of the end products (Taskila,2017 ; Brandt, 2014).

**Starter cultures for fermented foods**

A starter culture consists of a large number of live microorganisms of a single strain or a mixed culture that initiates and speeds up the food fermentation. LAB have a pivotal role in this and have long been used as starters in various food fermentation processes (Caplice and Fitzgerald 1999; Leroy and De Vusyt 2004). The use of starter cultures has been suggested as the appropriate approach to alleviate the problems of variations in the organoleptic quality and microbiological stability of many traditional fermented foods and beverages (Holzapfel, 2002; Sanni, 1993 Ruiz Rodríguez *et al*., 2019). Starter cultures of

lactic acid bacteria (LAB) do ensure the rapid initiation of broth acidification, reduce the risk of potential spoilage or pathogenic bacteria and produce positive flavors as well ((Franz et al., 2014; Altieri et al., 2017). They also make it easier to more effectively control the fermentation process. The use of starter cultures has been successfully applied to a wide range of products, and studies on the development of starter cultures for many African fermented foods and beverages have been reported: kivunde (Kimaryo et al., 2000), togwa (Mugula et al., 2003), bushera (Muyanja et al., 2004), ogi and kunu-zaki (Oguntoyinbo and Narbad, 2012) and gowé (Vieira-Dalodé et al., 2008; Ukwuru et al.,2019). Moreover, some strains of LAB have antibacterial and bioprotective activity. The study of LAB diversity in traditional food processing is important to develop starter cultures to produce safe fermented foods and beverages (Achi and Asamudo 2019).The most commonly LAB used as starter cultures in food fermentations are shown in **Table 1.**

Among the lactobacilli, *L. plantarum* and *L. fermentum* strains are particularly predominant in many traditional African fermentations. In some West African countries for example, the production of ‘‘fufu’’ (fermented cassava product), ‘‘ogi’’ (fermented maize, sorghum, or millet gruel), ‘‘fura da nunu’’ (fresh cow’s milk with fermented millet gruel), and ‘‘pito’’ and ‘‘burukutu’’ (cereal-based alcoholic beverages) are largely brought about by lactic acid bacteria and yeast, with *L. plantarum* predominating.(Franz et al., 2014).

Table 1: Some traditional fermented food and implicated lactic acid bacteria (adapted and modified from Olasupo et al., 2010; Franz et al., 2014; Bamgose et al., 2021).

| S/N | Fermented food | Region/country consumed | Isolated lactic acid bacteria |
|---|---|---|---|
| **1.** | Ogi | Nigeria/West Africa | *Lactobacillus fermentum, Lactobacilus plantarum* |
| **2.** | Abreh | Sudan | *Lactobacilus plantarum* |
| **3.** | Uji | Kenya/East Africa | *Leuconostoc mesenteroides* |
| **4.** | Kenkey | Ghana | *Lactobacillus spp.* |
| **5.** | Mahewu | South Africa | *Lactobacilus bulgaricus* |
| **6.** | Mawe | Benin/West Africa | *Pedicoccus pentosaceus* |
| **7.** | Zabadi | Egypt/North Africa | *Lactobacilus bulgaricus* |
| **8.** | Kawal | Egypt | *Lactobacilus plantarum* |
| **9.** | Kaffir | North Africa | *Lactobacilus delbrueckii* |
| **10.** | Burukutu | West Africa | *West Africa* |
| **11.** | Enjera | Ethiopia | *Leuconostoc mesenteroides* |
| **12.** | Palm wine | West Africa | *Lactobacilus plantarum, Leuconostoc mesenteroides* |
| **13.** | Gari | Africa | *Lactobacilus plantarum* |
| **14.** | Fufu | West Africa | *Lactobacilus brevis* |
| **15.** | Nono | West Africa | *Lactobacillus acidophilus, Lactococcus* |

Also, in a study, *L. plantarum* and *Lactobacillus brevis* were the dominant lactic acid bacteria isolated different batches of ‘‘pito’’ and ‘‘burukutu’’ collected from local producers in Nigeria. In the same vein, Nwachukwu *et al*., (2015) showed that *Lactobacillus plantarum* was the predominant bacteria in fermenting cereal-based foods which was always a prerequisite to the understanding needed to develop a multifunctional starter culture for these foods.

Similar to other fermented cereal foods that are available in Africa, these products suffer from inconsistent quality. The use of LAB starter cultures during cereal dough fermentation is a subject of increasing interest in efforts to standardize this step and guaranty product uniformity. However, their use by small-scale processing units or small agro-food industrial enterprises is still limited.

**Adjunct cultures**

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. Adjunct cultures are used in cheese manufacture to balance some of the biodiversity removed by pasteurization, improved hygiene and the addition of defined-strain starter culture (Cogan *et al.*,2007). These are mainly non-starter LAB which have a significant impact on flavour and accelerate the maturation process and are as important as the primary starter cultures (Rattanachaikunsopon and Phumkhachorn,2010).

The main function of starter cultures used in food from animal origin, consists in the rapid production of lactic acid, which causes a reduction in pH, inhibiting the growth of pathogenic and spoilage microorganisms, increasing the shelf-life of fermented foods. (Garcia-Diez and Saraiva 2021). Also, production of other metabolites (e.g., acetic acid, propionic acid, benzoic acid, hydrogen peroxide or bacteriocins) improves the safety of foods. Since starter cultures have become the predominant microbiota, it allows food processors to control the fermentation processes, excluding the undesirable flora and decreasing hygienic and manufacturing risks due to deficiencies of microbial origin.Starter cultures play an important role in the chemical safety of fermented foods by reduction of biogenic amine and polycyclic aromatic hydrocarbons contents (Garcia-Diez and Saraiva 2021).

**Bio preservatives properties of LAB**

Biopreservation refers to the use of antagonistic microorganisms or their metabolic products to inhibit or destroy undesired microorganisms in foods and to enhance food safety and extend shelf life (Swarnadyuti *et al*., 2014). As consumer demand for more natural appealing foods, the possibility of metabolites of lactic acid bacteria as antimicrobials may play an important and fundamental potential function in preventing foodborne illnesses and intoxications. Application of biopreservative strains as well as extracts and metabolites produced by them have demonstrated to control diverse undesirable microorganisms improving the enlargement of foods shelf-life and safety against bacteria that can affect the consumers health.

The use of biopreservation is considered as a technology barrier that combined with other conservation methods (hurdle technology) like refrigeration and

combined to good manufacturing practices can be an interesting option to diminish the addition of chemical preservatives, providing safe foods naturally preserved (Singh, 2018).

Lactic acid bacterial strains possess different prominent features that define the technological, organoleptic properties as well as nutritional and microbial safety aspects of the product (Altieri *et al.,* 2017; Ruiz-Rodriguez *et al.,* 2017). The bioprotective potential of the bacterial strains is a key feature related to antagonistic properties. The LAB exerts their protective activity mainly via three modes: namely displacement/exclusion, competition for nutrients, and production of antimicrobial metabolites (Ben Said *et al.*, 2019). The antimicrobial metabolites, however, may act through different mechanisms such as the inhibition of the spoilage microorganisms resulting in the membrane destabilization in spoilage microorganisms, proton gradient interference, enzyme inhibition, or creation of reactive oxygen species (Laslo *et al.,* 2020). Some of the microorganisms are sources of bioactive compounds as they synthesize secondary metabolites as self-defense against other competitive microbes.

Lactic acid bacteria produce various antimicrobial compounds such as organic acids (lactic acid and acetic acid), diacetyl, ethanol, hydrogen peroxide, reuterin, acetaldehyde, acetoine, carbon dioxide, and bacteriocins during fermentations processes **(Table2).**

Those natural compounds could be used as biopreservative agents to inhibit pathogenic, non-pathogenic and spoilage microorganisms, extending thereby the shelf-life of food products, enhancing their safety and reducing the abusive use of antibiotics. Besides, these components can have an effect on food flavor and texture (Saranraj *et al*., 2013, Zbrun *et al*., 2013).

Lactic acid bacteria metabolites are a reliable alternative for reducing fungal infections pre-/post-harvest with additional advantages for cereal-base products which convene the food market's trend. Toxigenic and spoilage fungi are responsible for numerous diseases and economic losses. Cereal infections may occur in the field or post-processing, along the food chain. Consequently, the investigation of LAB metabolites with antifungal activity has gained prominence in the scientific research community.

Bacteriocins are proteinaceous substances with bacteriocidal activity. Numerous bacteriocins are produced by different LAB and they can be classified according their properties, structure, molecular weight (MW), and antibacterial spectrum (Twomey et al. 2002). Bacteriocins are classified in three different groups. Class I the lantibiotics are small (<5 kDa) and heat-stable peptides.

A very well-known example of this first group is nisin. Class II non-lantibiotics are small (<10 kDa), heat stable, and containing regular amino-acids such as glycine and pediocin. Class III are large (>30 kDa), peptides such as Enterolysin. Bacteriocins are considered safe additives (GRAS), used to limit pathogens and spoiling microorganisms instead of chemical preservatives which is more favorable for consumers (Parada et al., 2007).

Consumers are showing increasing interest in natural foods with general health

benefits. The functional foods market is highly expanding (Statista, 2018). Among them, probiotics and protein-enriched foods are very popular. Probiotics are defined as "live microorganisms that, when administered in adequate amounts, confer a health benefit on the host" (Hill et al., 2014). The most commonly used genera of bacteria showing beneficial properties are *Lactobacillus* spp. and *Bifidobacterium* spp. (Holzapfel et al., 2001). Most of the time, probiotic products are delivered through dairy products such as yogurt, but because of lactose intolerance, or by conviction, an increasing number of people turn towards plant alternatives. Another trend widely observed is consumption of protein-enriched foods, especially for nutritional purposes. Protein-enriched products are mainly popular within active individuals, people dieting, and can be an interesting source of protein for elderly people.

**Table 2: Antimicrobial substances derived from bacterial cell metabolism for food bio-preservation**

| Antimicrobials | Source | Food bio-preservation |
|---|---|---|
| **Organic acids** | Main end products of fermentation | Decrease the pH of surrounding environment creating a selective barrier against non-acidophiles. Lactic acid exerts antimicrobial effect by disruption of the cytoplasmic membrane and interference with membrane potential. |
| **$CO_2$** | Heterofermentative LAB produces CO2 as a byproduct of sugar fermentation | Creation of an anaerobic environment and antagonistic effects specifically against aerobic bacteria and produce carbonic acid |
| **Diacetyl (2,3-butanedione)** | LAB as a by-product of metabolic activity | Antibacterial activity against *Listeria, Salmonella, Escherichia coli Yersinia*, and *Aeromonas*. |
| **Hydrogen peroxide** | Produced by LAB in presence of oxygen and action of flavoprotein oxidases or NADH peroxidase | Antibacterial effect through oxidative damage of proteins and increase of membrane permeability. |
| **Reuterin** | Low molecular- weight antimicrobial compound produced by *Lactobacillus reuteri* and some other LAB | Activity against bacteria as well as yeasts and molds by inhibiting DNA |
| **Reutericyclin** | Reutericyclin-producing strains of LAB | Reutericyclin acts as a proton ionophore and dissipation of the proton motive force against gram-positive including *Lactobacillus* spp., *Bacillus subtilis, Bacillus cereus, Enterococcus faecalis, Staphylococcus aureus* and *Listeria* innocua |

**Protective cultures**

Protective culture is defined as live microorganisms that are added deliberately to foods to control its bacteriological status without changing its technological and sensory qualities. According to many recent studies,

lactic acid bacteria show promise as replacement for chemical additives in foods. Their use may increase product safety and shelf life while satisfying consumer demand for fresh, natural tastes and minimal processing of foods (Zhang *et al.,* 2018). This protective effect is related to their ability to produce natural antibacterial and antifungal compounds such as bacteriocins, organic acids, hydrogen peroxide and enzymes, often in combinations (Ben Said 2018). Protective lactic acid bacteria have been reported to exert their antibacterial activity primarily through three mechanisms: namely displacement/exclusion, competition for nutrients and production of antimicrobial metabolites. These bacterial strains possess different prominent features that define the technological, organoleptic properties as well as nutritional and microbial safety aspects of the product (Oladipo *et al.* 2017; Altieri *et al.,* 2017; Ruiz-Rodriguez *et al.,* 2017). The LAB exerts their protective activity mainly via three modes: displacement/exclusion, competition for nutrients, and production of antimicrobial metabolites (Ben Said *et al.,* 2019). The antimicrobial metabolites, however, may act through different mechanisms such as the inhibition of the spoilage microorganisms resulting in the membrane destabilization in spoilage microorganisms, proton gradient interference, enzyme inhibition, or creation of reactive oxygen species (Siedler *et al.,* 2019). The antimicrobial substances derived from bacterial cell metabolism for food bio-preservation.is shown in **Table 2**

Protective cultures essentially consist of bacteria that have been specifically selected for their ability to inhibit the growth of pathogenic organisms or microbiological spoilage agents, and have GRAS (generally regarded as safe) status. Thus, these bacterial species are fully natural and therefore provide a useful 'green' benefit to the labelling of food products, a demand that is on the increase. The protective cultures have in themselves antimicrobial effects through production of specific metabolites such as organic acids (lactic, acetic and propionic), and engage in competitive exclusion where they outcompete the spoilage agent for nutrients and oxygen, and furthermore can take part in the phenomenon known as quorum sensing – where they 'feel' their environment and adjust their performance to deal with these new challenges. A number of factors will influence the activity of the protective culture, and vary according to: the initial level of the contamination; the nature of the contaminant species; the fermentation time; storage conditions, i.e. temperature, of the final product. It should be pointed out that if the initial contamination level is high, then the use of a protective culture cannot make a bad food good again. Rather, the protective culture has the ability to delay the onset of further contamination, thus extending the shelf life of the product through protection as opposed to open attack on already high concentrations of microbial contaminants. LAB bioprotection retards the development of fungal diseases in the field and inhibit pathogens and spoilage fungi in food products.

The growing consumer demand for foods that do not contain artificial additives and are "clean labeled" can be addressed in fermented products by using lactic acid bacteria (LAB) capable of synthesizing exopolysaccharides (EPS). Lactic acid bacteria (LAB)-derived exopolysaccharides are an alternative class of bio-thickeners widely used in the food industry.

There is great variability in LAB-based EPS in terms of quantity, monomer composition, molecular weight, charge, and structure, which results in an array of physicochemical and rheological properties that have been exploited for varied applications in the food industry especially in the manufacture of dairy foods.

Their use in the production process of low-fat cheeses, different plant-based yogurt alternatives, diverse types of sourdough breads, and reduced-fat fermented meat products are some of the novel applications of these polymers (Badel*et al*., 2011)

EPS has been shown to interact with other food components to improve the rheological and sensory properties and, thus, can act both as texturizers and stabilizers, thereby increasing the viscosity and mouthfeel enhancement properties of products (Nwodo*et al.,* 2012). EPS-producing LAB are industrially important microorganisms in the development of functional food products and are used as starter cultures or coadjutants to develop fermented foods such as yoghurt, cheese, and cereal-based products (Jolly *et al.* 2002; Tieking*et al.,* 2003).

**Lactic acid bacteria as probiotic starter cultures**

Probiotics are defined as "live microorganisms that, when administered in adequate amounts, confer a health benefit on the host. such as balancing microflora, increasing resistance to infection, and improving the host immune system" (Fuller, 1989; Shi *et al.*,2016). It has been identified that the foods and beverages in which a fermentation process has been carried out contain various nutritional and therapeutic properties. Probiotic-containing foods can be categorized as functional foods and, along with prebiotics, represent the largest segment of the functional food market around the world. Fermented foods are the main vehicle of administration of probiotic organisms and, among them, dairy products are by far the most widely used. Strains of the genera *Lactobacillus, Bifidobacterium,* and *Propionibacterium* are the most widely used and commonly studied probiotic bacteria. LAB fulfill the criteria that have to be met by the organisms to be selected as probiotics like resistance to the enzymes in the oral cavity, survival through the GI tract, arrival at the site of action in a viable physiological state and adherence to the host cell surface(Otero *et al* 2004; Mokoena *et al*., 2016).

Some examples of the health benefits of probiotics are shown in **Table 3**. Health claims provided by LAB range from the regulation of intestinal microbial homeostasis to the modulation of immune responses. The probable and theoretical benefits obtained with the consumption of probiotics have been outlined in several recent reviews and include reduced lactose intolerance, a reduction in the risk of diarrhea caused by bacteria and virus as well as lowering serum cholesterol, increased immune responses and prevention of cancer (Roberfroid 2000; Vantsawa et al.,2017).

**Production of antimicrobial compounds**

The antimicrobial properties of lactic acid bacteria are also of special interest in developing strongly competitive starter cultures for food fermentation. Lactobacilli has been shown to exert strong antagonistic activity against many microorganisms, including food spoilage organisms and pathogens

(Ogunbanwo et al., 2003; Afolayan et al.,2017). Production of the primary metabolite, lactic acid, and the resulting pH decrease is the main preserving factor in food fermentation. In addition, some strains may contribute to the preservation of fermented foods by producing other inhibitory substances, such as bacteriocins (Okereke *et al*., 2012).

When using the term bacteriocins, we refer to a bioactive nontoxic ribosomally synthesized heterogeneous antimicrobial peptides produced and released extracellularly from certain lactic acid bacteria with a narrow killing range for prokaryotes. Two Lactobacillus plantarum strains isolated from fermented cereal foods by Oguntoyinbo and Anard (2015) were studied for usage as starter cultures and probiotic functions with the overall aim of selecting multifunctional cultures that could bring about fermentation of cereals as well as rendering health benefits. In vivo and in vitro analyses identified their probiotic properties that included bile and acid tolerance, adhesion, gut colonization, and pathogen competitive exclusion (Obi et al.,2018).

Bacteriocins produced by LAB, including lactacin B from L. acidophilus, plantaricin from L. plantarum and nisin from Lactococcus lactis) have a narrow activity spectrum and act only against closely related bacteria, but some bacteriocins are also active against food-borne pathogens (Franz and Arneborg, 2010).

Results from various studies also show that LAB not only help to reduce the pH more rapidly, but also compete with pathogenic bacteria for the available nutrients and produce antagonistic primary and secondary metabolites, ensuring the safety of the product, effect that is more rapidly achieved at higher temperatures, which agree with the conclusions drawn by García-Díez and Patarata (2017) and Olaoye and Onilude (2010).

The potential applications of bacteriocins as ‘consumer friendly biopreservatives either in the form of protective or additive cultures are significant. However, with the exception of nisin and to a lesser extent, pediocin, very little of this potential has been realized when upscaled in an industrial context.

Table 3 Examples of beneficial effects provided by LAB used as probiotics (Mozzi 2016)

- Health beneficial effect Related LAB
- Antidiarrheal *Lactobacillus acidophilus*
- Anti-cancer effects *Lactobacillus paracasei*
- Anti-tumor activity *Lactobacillus reuteri*
- Antimutagenic activity *Lactobacillus casei*
- Prevention of gastrointestinal infections *Lactobacillus plantarum*
- Decrease in serum cholesterol *Lactobacillus rhamnosus*
- Modulation of the immune response *Lactobacillus delbrueckii* subspecies *lactis*

One of the main challenges according to the report by Barcenilla *et al.,* (2022) could be related to the regulatory framework, as the approval of novel bacteriocins as food additives could be tangled, and to their formulation in the food product, as the dose of the biopreservative agent needs to be fine-tuned so that the required antimicrobial activity is achieved without the development of undesirable effects on the end product

On the other hand, some of the limitation to their use may be related to the fact that not all-natural antimicrobials demonstrate the same activity in different food matrices or against different target microorganisms.

Probiotic LAB has also been reported to have diverse inhibitory mechanisms that can disrupt the formation of pathogenic microbial biofilms. They can inhibit the growth of pathogens by releasing antimicrobial metabolites (organic acids, hydrogen peroxide, and bacteriocins) and inhibitory exopolysaccharides (EPS) surrounding the pathogenic microorganisms (Chlebowska-Smigiel et al., 2017). Bacteriocin produced by lactic acid bacteria initiate the formation of pores in the bacterial cell membrane, which result in cell content leakage loss of essential molecules and ions causes ultimate cell death; can also interference with targeted bacterial DNA replication to causes cell death (Cotter et al., 2013). Antimicrobial compounds, produced by probiotic bacteria, can exert direct antimicrobial action toward competing enteropathogens that may lead to the prevention of pathogenic colonization of the GIT.

**Probiotics and Human Health**

Probiotic microorganisms colonize the mammalian gut and the intestinal system as confirmedby many research studies. The gastrointestinal tract has been ascribed to provide conduciveenvironmental conditions for the proliferation and existence of probiotic bacteria. These essentialmicroflorae directly confer immense health benefits to their host and in general are very vital forhuman health and nutrition.

Probiotics confer an array of human health benefits including the following: 1) Maintains thehealthy microbiota balance of the intestine by competing and excluding harmful pathogens, as well as adheres to the gastrointestinal gut (Nagpal, et al 2007). Stimulate and enhance the immune response by increasing the release of serum antibodies (Immunoglobulin M (IgM), Immunoglobulin G (IgG), and Immunoglobulin A (IgA) and balancing pro-inflammatory and anti-inflammatory cytokines (Nagpal et al., 2012; Kumar et al., 2009).

Probiotics also help to prevent or decrease the duration of intestinal diseases such as Inflammatory bowel disease, diarrhea, and constipation by colonizing and modulating the gut microflora, synthesizing antimicrobial compounds, and enhancing the immune response and secretion of mucus (Ezendam and Van Loveren 2008). Additionally, probiotics are important in the prevention of metabolic disorders such as obesity, diabetes, and cardiovascular diseases by enhancing gut microbiota, restoring the antioxidant systems and decreasing insulin resistance and inflammation (Parvez et al., 2006). Probiotics inhibit the growth of Candida and Helicobacter

pylori, thus preventing intestinal infection by competing and adhering to the mucosal surface and enhancing immune responses (Nagpal et al., 2012). They also help to prevent the growth of cancer by acting as a therapeutic agent for cancer treatment by detoxification of chemical carcinogens, decreasing the release of toxic metabolites, enhancing the antioxidant system, modulating the immune response to inhibit self-proliferation of cancer and generating metabolites like butyrate which increases cancer cell death (apoptosis) and produces anti-mutagenic effects. Probiotics assist in the maintenance and alleviation of lactose intolerance by providing β-galactosidase (lactase) enzyme which breaks down lactose into simple sugars (Nagpal *et al.,* 2012). Another key benefit from probiotics includes the lowering of cholesterol levels by precipitating cholesterol with free bile salts into bile acids and thereby reducing cholesterol absorption (Park *et al.,* 2018).

Additionally, probiotics enhance the absorption of minerals such as calcium to help to prevent mineral deficiency diseases such as osteoporosis. They also enhance nutritional value by synthesizing cofactors and vitamins (K and B) and by producing various enzymes that are useful in the digestion of food (Masood *et al*., 2011).

**Conclusion**

Lactic acid bacteria are a group of ubiquitous, heterogeneous, and ecologically diverse bacteria with significance in food fermentation processes. 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. As a natural biological control agent, lactic acid bacteria are a good choice in food preservation due to its antifungal properties.

Knowledge of the actual contribution and potential of LAB in food fermentation has evolved over time, from popular but uninformed use of fermentation to well-thought-out selection and application of LAB as starter cultures for the food industry. In fact, transforming carbohydrates provided by the raw materials to mainly lactic acid, LAB have contributed to food quality and safety for decades. Overall, the numerous enzymatic activities that can be carried out during food fermentation by LAB can change the biochemical composition of foods, releasing bioactive compounds that can provide health-promoting properties that the same matrix would not display without fermentation. Fermented Foods will continue to serve as inexhaustible sources of potential probiotic LAB strains and as natural dietary sources of live LAB cells with a promising role in human gut health.

Lactic acid bacteria (LAB) are effective, safe, biodegradable and have additional health benefits. LAB is effective in controlling microbial growth and mycotoxin and can positively impact the health of human due to their ability to extend shelf life of many food products suggesting its suitability as bio-preservative in agricultural and food products.

Lactic acid bacteria are an important class of microorganisms known for their benefits to produce, under appropriate conditions, natural antimicrobial compounds, that produce several metabolites showing bio-preservative abilities and contribute to the increase of shelf life of many foods. Several

strains of LAB are well-known to fulfil the requirements for their application as bio-preservatives due to the GRAS status. Bacteriocins are proteins or peptides produced that have the capacity to act against certain pathogens, preventing their multiplication in products during the periods of storage and distribution. Biopreservation using bacteriocins has been studied and established as a new and important method on controlling food spoilage and render pathogen inactive. Thus, LAB has exhibited excellent antimicrobial activity and positive interactions in human health and the concept of bio-preservation through lactic acid fermentation is a highly recommended alternative for product shelf-life extension.

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