Science Forum (Journal of Pure and Applied Sciences)

journal homepage: https://atbu.edu.ng/science-forum/

Exopolysaccharide-producing lactic acid bacteria associated with indigenous fermented food products in resources-limited countries: A critical review

Binta Buba Adamu[1*], Jeremiah David Bala[1], Helen Shnada Auta[1], Ocheme Boniface Ocheme[2], Abdulameen Saheed Adedeji[1]

[1] *Department of Microbiology, School of Life Sciences, Federal University of Technology, Minna, Nigeria*

[2] *Department of Food Science and Technology, School of Agriculture and Agricultural Technology, Federal University of Technology, Minna, Nigeria*

ABSTRACT

Fermented foods alongside beverages of plant and animal origin are important nutrient sources globally. These food types provide essential nutrients such as important vitamins and cofactors, free radical oxygen, and other substances that promote human health and offer immunity to infectious diseases as well as physiological conditions. Lactic acid bacteria (LAB) are the main types of microbes connected with indigenous fermented foods. However, variations in the processing of these foods and geographical distribution of the LAB no doubts affect the types and nature of the traditionally fermented foods. LAB are exopolysaccharide (EPS) producing bacteria and are considered alternative sources of these important polymers. EPS is gaining application in local cultured milk, low-fat cheeses, fermented cereal foods, sourdough bread, and reduced-fat fermented meat production. This review provides an overview of EPS-producing LAB associated with indigenous fermented food products in resource-limited countries. EPS-producing LAB in traditionally fermented foods in Nigeria are also highlighted herein.

ARTICLE INFO

Article history:
Received 21 October 2022
Received in revised form 20 January 2023
Accepted 21 January 2023
Published 05 July 2023
Available online 05 July 2023

KEYWORDS

Beverages
Exopolysaccharide
Fermentation
Foods
Lactic acid bacteria

1. Introduction

Indigenous food processing employs microorganisms, particularly lactic acid bacteria (LAB), and yeast that colonized the raw material from the source (Pundir et al., 2013). Though this is an ancient technology for food preservation, it is still widely practiced in many homes mostly in developing countries (Mokoena et al., 2016). Characteristics of fermented foods such as aroma, taste, and texture appeal to consumers (Adesulu-Dahunsi et al., 2018). Traditionally, fermented foods and beverages are integral dietary components where, they are either used as meals or refreshments (Mokoena et al., 2016). In African countries and some regions of the world, fermentation plays an important role in the nutrition of infants and young children, it is used for the preparation of complementary foods (Adesulu and Awojobi, 2014).

Fermentation provides an economic approach to preserving food in developing countries; it also inhibits the growth of pathogens under conditions where refrigeration or other means of safe storage are not obtainable (Motarjemi, 2002). Fermented foods, which may be of animal or plant origin, are an

*** Corresponding author** Binta Buba Adamu bubabinta@gmail.com Department of Microbiology, School of Life Sciences, Federal University of Technology, Minna, Nigeria.

essential part of the food consumed in most parts of the world. Fermented food differs according to country (Table 1), signifying the staple diet and the raw ingredients available in that particular place. This dictates the protein demands of any given population. The preparation of many traditional fermented beverages and foods remains a household practice (Egwim et al., 2013). Fermentation enriches food, improves digestibility, and is easily accessible to all populace for consumption (Adesulu and Awojobi, 2014). The microorganisms liable for the fermentation may be the microflora originally present on the substrate, or they may be added as starter cultures.

LAB are common bacteria ubiquitous in areas rich in nutrients mainly carbohydrates, this includes plants, fermented foods, and the gastrointestinal tract of humans, and animals. This is why LAB have gained unprecedented attention in the food industries (Florou-Paneri et al., 2013). LAB are used in food preservation, to improve nutritional composition as well as to influence the organoleptic properties of foods, mainly the food aroma and texture (Barinov et al., 2011). LAB consist of different bacteria genera such as *Lactobacillus*, *Leuconostoc*, *Pediococcus*, *Lactococcus*, *Streptococcus*, and some peripheral microbes notably *Aerococcus*, *Carnobacterium*, *Enterococcus*, *Oenococcus*, *Tetragenococcus*, *Vagococcus*, and *Weissella* inclusive (Florou-Paneri et al., 2013). Fermented foods vary between regions (Table 1) and are a function of the climatic conditions which in turn determine the local indigenous microflora responsible for the fermentation. Thus, traditional fermented products especially milk products in a cold region often contain mesophilic bacteria such as *Lactococcus* and *Leuconostoc* spp. However, thermophiles, mostly *Lactobacillus* and *Streptococcus,* are common in subtropical or tropical climate regions (Kurmann, 1984; Savadogo et al., 2004). Of note, the selection and/or use of autochthonous bacterial strains for controlled fermentation may impact the attributes of fermented foods including stability, safety, and overall quality (Manini et al., 2016; Ogunremi et al., 2017). Industrial properties of interest usually include exopolysaccharide (EPS) or probiotic production potential of the LAB to be used as a starter culture.

EPSs are performed by single sugar or their derivatives secreted by plants and microbes (algae, fungi, and bacteria) (Sanalibaba and Çakmak, 2016). LAB have gained special attention among the various EPSs producers. LAB are "generally recognized as safe,"hence the acronym GRAS. More so, their ability to produce EPSs of diverse structures without known health risks however with health benefits to the consumers means can be a potential source of EPSs for industrial application. Genome analysis of LAB strains established their safety by failing to identify virulence

Table 1. Traditional fermented foods and beverages with microorganisms involved.

Fermented products	Region	Substrates	LAB involve
Ogi	West Africa	Maize, millet, sorghum	*Lactobacillus plantarum, L fermentum*
Garri	West Africa	Cassava	*Leuconostoc mesenteroide, Lactobacillus plantarum*
Mahewu	Southern Africa	Maize, sorghum	*Lactobacillus bulgaricus L. brevis*
BordeShamita	North East Africa	Barley	*Lactobacillus* spp.
Munkoyo (Chibwantu)	Southern Africa	Maize	*Weisella*, *Lactobacillus* spp.
Togwa	East Africa	Cassava, maize, sorghum, millet	*Lactobacillus* spp., *Pediococcus pentosaceus, Weisella confuse*
Mabisi/Amasi	Southern Africa	Milk	*Lactobacillus* spp. *Streptococcus* spp. *Leuconostoc* spp.
Amabereamaruranu	Southern Africa	Milk	*Streptococcus thermophilus*, *Lactobacillus plantarum*, *Leuconostoc mesenteriodes*
Bushera	East Africa	Sorghum, millet	*Lactobacillus* spp., *Streptococcus* spp., *Leuconostoc* spp., *Pediococcus* spp., *Weisella* spp.

Source: Ayo et al. (2011); Egwim et al. (2013); Akabanda et al. (2014); Mokoena et al. (2016).

and/or toxin-encoding genes in the LAB genome (Wu et al., 2017).

This review aimed at providing a critical review of EPS-producing LAB associated with indigenous fermented food products in resource-limited countries.

2. Characteristics of LAB

LAB are rod-shaped or spherical bacteria characterized by their ability to tolerate high acidity. This potential gives LAB an edge to dominate the bacteria community during fermentation. Most LAB species are incapable of aerobic respiration and are catalase-negative. LAB are no doubt the most essential groups of bacteria in the food industry (Sonomoto and Yokota, 2011). The metabolism of LAB has encouraged their use as microbial cell factories for the production of many important products for the food and non-food industries (Hatti-Kaul et al., 2018).

Since the early 21st century, LAB genomes are characterized by a small size 1.23 (*Lactobacillus sanfranciscensis)* to 4.91 Mb (*Lactobacillus parakefiri*) in range. To date, more than 200 LAB strains' genomic data are available from different databases (Sun et al., 2015). Analysis of LAB strains' genomic data revealed great phenotypic and genotypic diversity within this bacteria category and this is associated with their connections with varying environmental niches and their ability to exchange genetic information horizontally (Wu et al., 2017). Phenotypic variability is observed among the species as well as between strains. Reductive evolution of their genomes results in: (1) significant loss of several metabolic genes; (2) biosynthetic limitations; (3) presence of pseudogenes; (4) higher-level genetic control systems compared to other microorganisms. This is primarily due to their ability to adapt to any nutrient-rich environments (Hatti-Kaul et al., 2018; Wu et al., 2017). Some LAB have possessed transporter genes enabling these bacteria to obtain nutrients from any environment, environmental stresses genes, which prevent stress from environmental factors (pH, temperature, and salts) and have the ability to inhibit pathogens by secreting antimicrobial substances (Liu et al., 2014).

LAB possess collective genetic elements such as conjugative plasmids, transposons, and phages (Hatti-Kaul et al., 2018). The conjugative plasmids and transposons confer diverse metabolic functions for example lactose and citrate metabolism, bacteriocin production, phage, and resistance (Hatti-Kaul et al., 2018; Pfeiler and Klaenhammer, 2007). However, several LAB have clustered regularly interspaced short palindromic repeats and associated cas genes widely spread in their genomes (Barrangou et al., 2007; Sun et al., 2015), which profer adaptive immunity against invading distant DNA particularly phages and plasmids in the environments they inhabit (Pfeiler and Klaenhammer, 2007; Sun et al., 2015). The characteristics growth of LAB and their metabolism particularly their ability to secret antimicrobial compounds as well as their nutritional requirements results in the inhibition of the growth of pathogens, spoilage microbes, and production of fermented foods (Wu et al., 2017). To overcome environmental stresses either in the gastrointestinal tract or industrial setting, LAB do maintain cell membrane functionality, regulates cellular metabolism, produces EPS, and expresses stress response proteins (Abdel-Rahman and Sonomoto, 2016; Bosma et al., 2017; Papadimitriou et al., 2016; Wu et al., 2017).

2.1. Metabolism in LAB

There are basically two main carbohydrate fermentation pathways that have been successively used to classify LAB genera into homo-fermenters and hetero-fermenters. Fermentation of hexose by LAB generates adenosine triphosphate due to substrate level phosphorylation when they metabolize hexose sugar under limited oxygen via the Embden-Meyerhof pathway (glycolytic pathway) (Fig. 1), producing only lactic acid, a phenomenon termed homofermentation, or via phosphoketolase pathway in an oxygen-rich cell, where many end-products including acetic acid, propionic acid, carbon dioxide, and ethanol are produced alongside lactic acid. This is termed heterofermentative metabolism. Representative homolactic LAB genera include *Lactococcus*, *Enterococcus*, *Streptococcus*, *Pediococcus*, and group I *Lactobacilli* (Gänzle, 2015), while heterofermentative LAB are the *Leuconostoc*, *Oenococcus*, *Weissella*, and group III *Lactobacilli* (Gänzle, 2015). These end-products (lactic acid, ace- tic acid, propionic acid, carbon dioxide, and ethanol) are responsible for the production and development of organoleptic properties associated with fermented food products (Bintsis, 2018; Wedajo, 2015). Although the end-product of LAB fermentation depends on the starting materials, carbohydrates metabolism mainly generates pyruvate which is ultimately converted to lactate, some pyruvates are converted to diacetyl, acetoin, acetaldehyde, or acetic acid in yogurt fermentation and give the typical yogurt flavors and taste. Besides, carbohydrate metabolism, LAB are involved in lipolysis and proteolysis. The latter is responsible

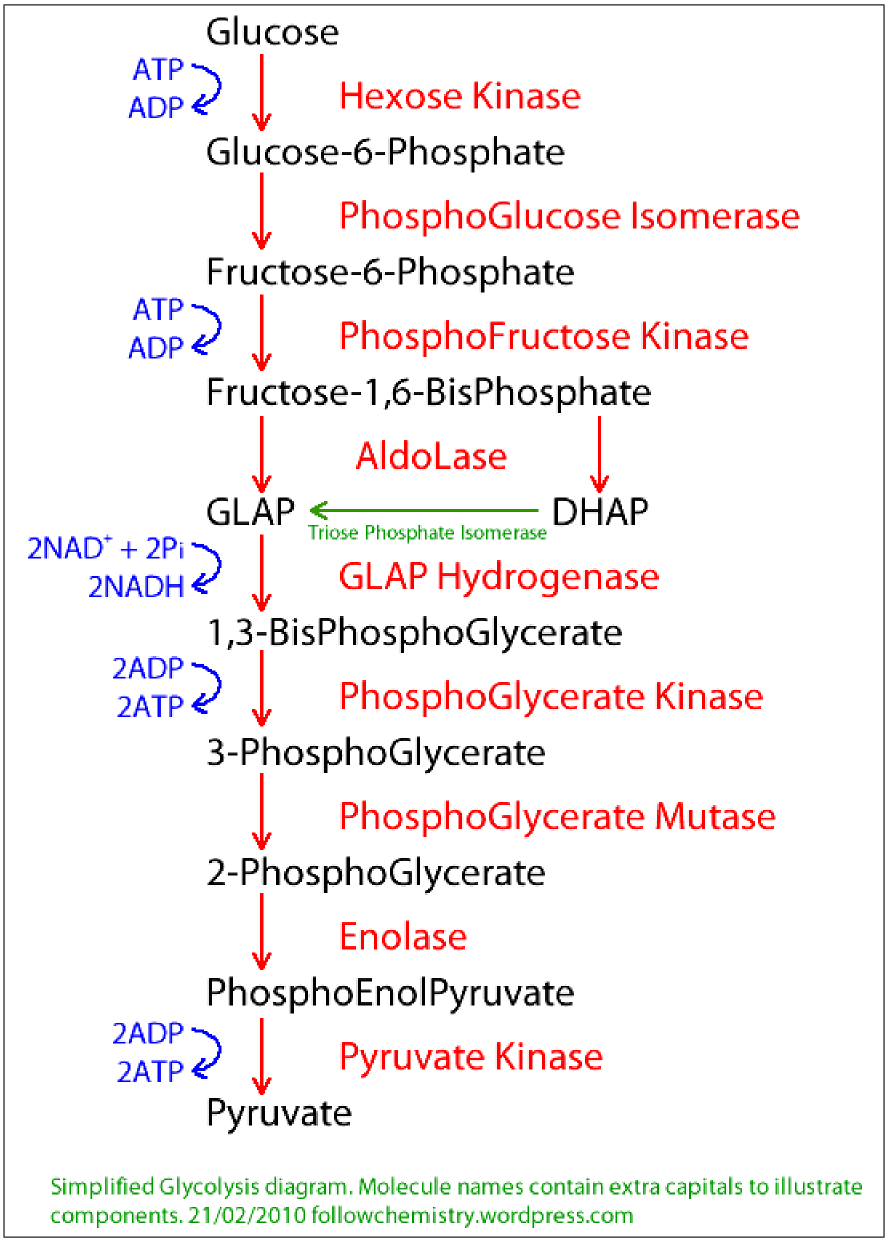

Figure 1. Glycolytic pathway. Source: Papagianni (2012)and Hassan (2019).

for the production of flavor-producing substances (alcohols, aldehydes, acids, esters, and sulfur compounds) in fermented foods (Ammor and Mayo 2007; Bintsis, 2018).

2.2. Glycolysis (Embden-Meyerhof pathway)

Glucose is enzymatically converted to pyruvic acid and finally to fermentation products (lactic acid, acetic acid, propionic acid, carbon dioxide, and ethanol). Blue letters depict the enzymes involved. Products molecules are in red color.

3. LAB as Source of EPSs

EPSs is a long-chain sugar polymer of different variety produced by a number of LAB. They are employed in the production of fermented dairy products, and are secreted extracellularly by glycansucrases or intracellularly by glycosyltransferases from sucrose and sugar nucleotide precursors respectively (Gänzle and Schwab, 2009). These EPS are classified based on their biosynthesis mechanism and chemical composition as homo-polysaccharide (HoPs) (single type monosaccharide) and heteropolysaccharides (alternating units of two or more monosaccharides types, substituted monosaccharides, and other units (acetyl, glycerol, and phosphate) (Florou-Paneri et al., 2013). HoPs are either fructans (including levan and inulin-type) or glucans which can be dextran, mutan, alteran, or b-1, 3glucan (Monsan et al., 2001). The HoPs have only one monosaccharide type (Fig. 1) and are synthesized by extracellular glycansucrases.

Two main types of HoPs are produced by LAB (Table 2), one of which is α-glucans namely dextrans and mutans. *Leuconostoc mesenteroides* subsp. *mesenteroides* and *Leuconostoc mesenteroides* subsp. *dextranicum* produced dextrans and *Streptococcus mutans* and *Streptococcus sobrinus* produced mutans. Glucans can be sub-classified into (i) α-glucans [dextran: α-DGlc (1,4); mutan: α-D-Glc(1,3); alternan: (α-D-Glc(1,6)/α-D-Glc(1,3); and reuteran: α-D-Glc(1,4)/α-D-Glc(1,6) with α-D-Glc(1,4)/αDGlc(1,6) branching points], and (ii) βglucans [β-D-Glc(1,3) with side chain linked (1,2)]. The second group is fructans, namely levan. *S. salivarius* produced levan (Freitas et al., 2011). Fructans can be classified into (i) levan type: βDFru(2,6), and (ii) inulin-type: β-D-Fru(2,1), being both β-fructans. Furthermore, polygalactans, an uncommon polymer are also HoPs.

They contain a pentameric repeating unit of galactose and are associated with the strain of *Lactococcus lactis* subsp. *lactis*H414 and two strains of *Lactobacillus delbrueckii* subsp. (CRL 406 and 142) (Torino et al., 2015). Sucrose is required for the production of HoPS as a specific substrate. HoPs are produced by LAB in low quantity when compared to other bacterial EPSs. EPSs produced by *Weissella* sp. and *L. sanfranciscensis* are as high as 16 and 5 g EPSs/kg dough (Sanalibaba and Çakmak, 2016). However, hetero-polysaccharides have a slight structural resemblance to one another. Bacterial growth, phase, medium composition (carbon and LAB as Source of Functional Ingredients 603 nitrogen source), pH, and temperature influenced the production of heteropolysaccharides (Florou-Paneri et al., 2013). HePs constitute the majority of EPSs produced by LAB and they contain 3–8 repeating units of monosaccharides (Fig. 2) (Ryan et al., 2015). A great variety of mesophilic and thermophilic LAB are the producers of HePSs. Mesophilic LAB include *L. lactis* subsp. *lactis*, *Lactobacillus rhamnosus*, and *Lactococcus lactis* subsp. *cremoris, Lactobacillus sakei*, and *Lactobacillus casei*. Similarly, thermophilic LAB include *L. delbrueckii* subspecies *bulgaricus, Lactobacillus acidophilus, Lactobacillus helveticus*, and *Streptococcus thermophiles* (Bajpai et al., 2016).

Hetero-EPSs are either linear or branched repeating units. These units contained a mixture of differ- ent monosaccharide types (D-glucose, D-galactose, and L-rhamnose) and rarely N-acetylglucosamine, N-acetylgalactosamine,orglucuronicacid.Occasionally, non-carbohydrate substituents like phosphate, acetyl, and glycerol are found in HePs. Common examples of HePS are Gellan, kefiranan, and xanthan (Sanalibaba and Çakmak, 2016). Hetero-polysaccharide-producing

Table 2. HoPs produced by LAB.

EPS		Strain
α-D-glucans	Dextran	*Leuconostoc mesenteroides* subsp. *Mesenteroides* *Leuconostoc mesenteroides* subsp. Dextranicum
	Mutan	*Streptococcus mutans* *Streptococcus sobrinus*
	Alterman	*Leuconostoc mesenteroides*
	Reuteran	*Lactobacillus reuteri*
β-glucans		*Pediococcus* spp. *Streptococcus* spp.
Fructans	Levans	*Streptococcus salivarius*
	Inulin-type	*Streptococcus mutans* *Leuconostoc citreum* *Lactobacillus reuteri*
Polygalactan		*Lactococcus lactis* subsp. lactis H414 *Lactobacillus delbrueckii* subsp. *bulgaricus* (CRL 406 and 142)

Source: Ruas-Madiedo et al. (2002); Torino et al. (2015); Sanalibaba and Çakmak (2016).

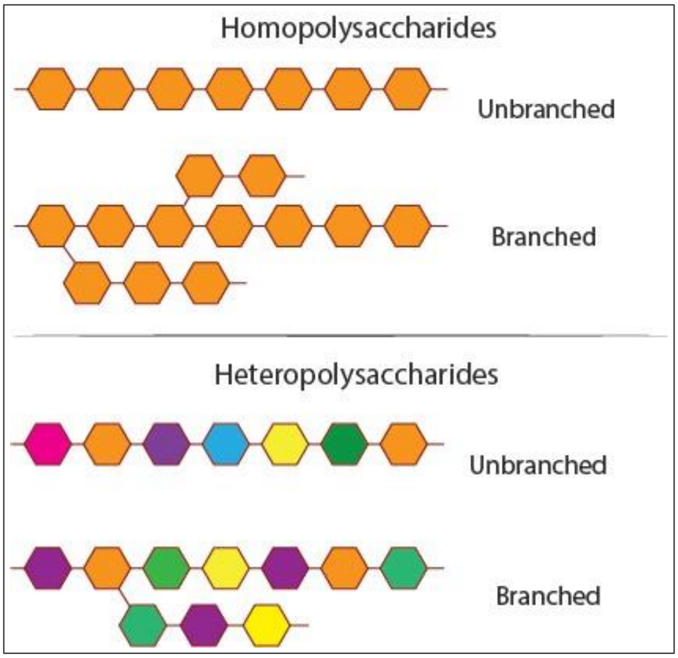

Figure 2. Homo- and hetero-EPS. Source: Sanalibaba and Çakmak (2016) and Muhammed et al. (2021).

LAB play an important role in food processing (Monsan et al., 2001). HoPs enhance the structural quality and nourish bakery products such as sourdough, while hetero-polysaccharides are important food additives in dairy food processing (Waldherr and Vogel, 2009). The organoleptic properties of fermented foods in terms of texture, taste perception, mouth-feel as well as stability are influenced by EPS addition (Florou-Paneri et al., 2013; Zhang et al., 2011).

4. LAB as Source of Starter Cultures

From time immemorial, LAB have been in use as starter cultures in food fermentation due to their nutritional, organoleptic, technological, and shelf-life characteristics (Florou-Paneri et al., 2013). These organisms initiate rapid acidic production in start-up materials, by the conversion of carbohydrates to organic acids. The most abundant organic acids are lactic acid and then acetic acid, whereas aroma compounds, bacteriocins, ethanol, EPSs, and some enzymes can also be produced by LAB (De Vuyst and Leroy, 2007). Earlier natural microflora present on the raw materials facilitates spontaneous fermentation in the production of fermented foods and beverages. Lately, the selected starter cultures are directly added to the food milieu based on the interest of the food industry. The advantage of using LAB as a starter culture lies in the high degree of control one has over the fermentation process and the influence it may have on the final product (Florou-Paneri et al., 2013). Starter culture can be defined as the microbial preparation of an enormous amount of a single or consortium of microorganisms inoculated into a raw material in order to produce a fermented food (Caplice and Fitzgerald, 1999). Traditionally fermented foods mostly utilize natural microflora of the food or previous batch (as mother culture) culture for the direct inoculation to the food matrix. However, the industries utilize commercially available starter cultures obtainable by freeze-drying the cell concentrates or lyophilization (Florou-Paneri et al., 2013). These LAB cultures have at least one or more functional properties, contributing to the development of the fermentation process, augmenting the quality of the end safety product, and also the health benefits (Leroy and De Vuyst, 2004). However, to eliminate undesirable side effects like the formation of D-lactic acid or a racemate of lactic acid or the formation of biogenic amines starter cultures must be selected (Florou-Paneri et al., 2013).

5. EPS-Producing LAB in Traditional Fermentation

LAB in traditional fermented products usually originates from the environment where the different plant and animal starting material originated from. Often during the harvest of plant materials as well as in their processing for fermentation (Adebayo-Tayo and Onilude, 2008). Each particular plant material serves as a substrate and supports the development of epiphytic flora, from which arises a population and sequence of fermentation microorganisms (Adebayo-Tayo and Onilude, 2008).

5.1. Fufu and Garri

Cassava slurry effluents (from Fufu and Garri processing) have been found to contain *Lactobacillus fermentum.* However, a specific compound that permits the favor of the survival of the strains and the mechanism(s) by which these compounds may favor *L. fermentum* is not fully understood. Ayodeji et al. (2017) opined that these compounds may act as an additional energy source for the bacteria. In addition, the influence of low pH on bacteria survival has also been reported (Obadina et al., 2006). Of the EPSs produc- ing LAB isolated in Fufu, *L. casei* sp. *tolerans* (LCN6) 1 produced more EPS and improved the Fufu texture the most (Adebayo-Tayo and Onilude, 2008).

5.2. Sour starch

"Almid´onagrio," fermented sour cassava starch is native to Colombia and it is obtained by cassava starch fermentation followed by drying. Fermentation is characterized by microbial succession with a huge diversity of LAB species (Lacerda et al., 2005). The most frequent species isolated are *Lactobacillus manihotivorans* and *Lactobacillus plantarum*, however, *L. casei, Lactobacillus hilgardii, Lactobacillus buchneri, L. fermentum, Leuconostoc mesenteroides,* and *Pediococcus* sp. have been also reported (Lacerda et al., 2005; Omar et al., 2006). These strains possess high amylolytic activity which offers them an ecolog- ical advantage as such readily hydrolyze raw starch (Rodriguez-Sanoja et al., 2000) to glucose or maltose that serves as an energy source for succeeding LAB. Although *L. manihotivorans* have only been isolated in the first period of fermentation (Lacerda et al., 2005), *L. plantarum* are known to participate in all the fermentative processes acidifying the substrate.

5.3. Flour (sough making)

EPS formed during sourdough fermentation do influence the viscoelastic properties of the dough and positively affects the rheological characteristics and shelf-life (in particular starch retrogradation) (Lynch et al., 2014). Types of monosaccharides, types of linkages, degree of branching, and molecular weight of EPS impact the feature of dough. For example, (1) sucrose-containing EPS influences the viscoelastic properties of the dough and prevent starch retrogradation (Lynch et al., 2014), (2) Fructan from *L. sanfranciscensis* positively influences dough rheology and bread texture (Correia et al., 2010). Similarly, *L. reuteri* (Zheng et al., 2020) is responsible for fructans and glucans containing EPS dough during fermentation. EPS on bread forms a network with other dough components and binds water (Xu et al., 2020). EPS in situ production is more suitable for bread formulation than the addition of the same polysaccharide into the formulation or processing (Galle et al., 2012). Therefore, the use of LAB species singly or in a consortium is required for the production of better-quality gluten-free bread with softer crumbs and improved shelf life (Daba et al., 2021).

5.4. Milk and cheese

EPS-producing LAB are used traditionally to ferment milk for the production of dairy foods such as kefir, yogurt cultured cream, milk-based desserts, and cheese (Zhang et al., 2016). In this context, EPS secreting LAB improve the textural and sensory properties of dairy foods, particularly those that reduced fat content impacting their quality negatively (Widyastuti et al., 2021). Adebayo-Tayo and Onilude (2008) obtained highly viscous yogurt following the fermentation of milk with *L. plantarum* LBIO28 isolated from traditional Algerian fermented milk (Korcz and Varga, 2021) coddled skim milk with two isogenic strains of *S. thermophiles* to produce Karish cheese in Egypt: moderate EPS-producing and a non-EPS-producing genetic variant of the same strain. Cheeses produced by the moderate EPS-producing variant differ significantly in terms of their moisture contents and viscoelastic properties. Similarly, in another independent research by Adebayo-Tayo and Onilude (2008), strains of *L. brevis* obtained from “nono” and yogurt that produce EPS moderately were used to improve the consistency and organoleptic properties of cheese.

5.5. Meat fermentation

LAB have been applied in meat production since time immemorial and this application has given rise to an enormous variety of indigenous foods globally. *Lactobacillus* and *Pediococcus* sp. are frequently used to attain food safety. Both bacteria are capable of secreting substances (such as lactic acid and acetic acid) that reduce indigenous bacteria in raw meat or via competition for space and nutrients as well as via bacteriocin secretion (Ryan et al., 2015). The growth of these bacteria also impacts the moisture content, fat content, texture, and color of meat products positively. Of note, is the reduction of fat that accomplish meat fermentation resulting in an increased interest in meat fermentation as consumer demand for fat-reduced meat products is growing (Kumar, 2021). Hilbig et al. (2019) reported that LAB were able to form EPS in meat matrices in a traditional spreadable fermented raw sausage called “Teewurst” and reduced its fat concentration.

5.6. Ogi

Numerous LAB strains associated with Ogi fermentation (sorghum-based) are EPSs producers (Ripari et al., 2019). Sawadogo-Lingani et al. (2008) reported that approximately 89% of 264 strains of the isolated *L. fermentum* from spontaneous fermentation of 2 West African sorghum beers, Dolo and Pitowere EPS producers. These isolates conferred the thicker texture property of these products, important for product quality and for its sensorial features. Heperkan et al. (2014), identified and evaluated some technological properties of 13 LAB isolated from Boza production and found that a strain, besides *Streptococcus macedonicus* (A15), produced EPSs. Ripari et al. (2019) reported high EPS-producing strains of *Leuconostoc citreum* (E55) and *L. lactis* (A47) (2.39 and 1.98 g/l of EPSs, respectively) as such LAB strains with low-EPS production capability were selected. Boza is a highly viscous beverage with no desire for gel formation. Since EPS-producing LAB are able to colonize cereal beverages, identification of the LAB population in traditional cereal beverages will aid their application in the food industry (Ripari et al., 2019).

6. Benefits of Food Fermentation

The main advantage of the fermentation of food is the conversion of sugars and complex carbohydrates to digestible products. Fermentation converts food energy and inhibits the growth of spoilage and disease-causing microbes. Fermentation makes foods more palatable by predigesting the foods for us. There are serious examples of poisonous plants such as cassava that are transformed into edible products by fermentation. Antinutritional or toxic components such as cyanogenic glycosides, phytates, tannins, oxalates, saponins, lectins, and enzymes inhibitors available in fermentable grains, legumes, and tubers (Egwim et al., 2013) that are capable of interfering with the bioavailability of mineral, proteins, and carbohydrates digestibility. Fermentation of plant foods by yeasts and bacteria can reduce antinutritional components by 50% and also reduces toxic components, for example, lectins in tempe and other fermented bean foods by 95% (Egwim et al., 2013). Nutritional values of foods can be increased by fermentation activities such as grains, seeds, and nuts sprouting that can multiply the amino acid, vitamin, and mineral content and antioxidant qualities of the food product.

Beans fermentation increases its digestibility, for example, unfermented soybeans proteins are nearly indigestible (Katz, 2003). Fermented dairy products (cheese, yogurt, and kefir) are digested easily compared to raw milk and are friendly to those with lactose intolerance and autism. Soy milk is suitable for LAB growth mainly Bifidobacteria (Wedajo, 2015). Numerous studies have revealed the production and use of fermented soymilk drinks as probiotics, mainly soybean yogurt, which can be further supplemented with oligofructose and inulin. Similarly, fermented grains porridge increases its nutritional value greatly and reduces the risk of childhood disease (Egwim et al., 2013).

Research has shown that *L. rhamnosus* and *L. reuteri* from Nigerian fermented foods (kunun-zaki and ogi) when inoculated into the vagina inhibit viruses, and reduces the risk of colonization by disease agents particularly bacterial vaginosis (Cadieux et al., 2002; Reid et al., 2001a). The immuno-stimulatory effect of LAB from Nigerian fermented foods most likely is associated with prime changes they cause in the gastrointestinal microflora that subdue the growth of pathogens microbes. Its immuno-stimulatory effect also decreases the incidence of sexually transmitted diseases such as gonorrhea and chlamydia (Adebolu et al., 2007; Reid et al., 2001b).

7. Conclusion

In developing countries, LAB are an integral dietary component and is largely consumed in fermented cereals and grains. The worth of fermented foods cannot be overstressed why because fermented foods especially cow milk products are major sources of proteins in resources limited countries. Thence, the utilization of LAB strains as starter cultures or co-cultures to impact the quality and consistency of food will no doubt improve the quality of life. EPS-producing starter culture is preferred to non-EPS producer due to their ability to enhance the texture and rheology and improves the technological properties of the food produced. More so, they easily resist and adapt to gastrointestinal tract conditions, and secrete antibacterial substances. Undoubtedly, LAB are favorable sources of innovative products and applications, particularly strains that can achieve increasing consumer demands for natural products and functional foods. A diet containing LAB plays a specific role in the health status of both humans and animals. However, the study of LAB and its potential properties are ongoing.

References

Abdel-Rahman MA, Sonomoto K. Opportunities to overcome the current limitations and challenges for efficient microbial production of optically pure lactic acid. J Biotechnol 2016; 236:176–92.

Adebayo-Tayo BC, Onilude AA. Screening of lactic acid bacteria strains isolated from some Nigerian fermented foods for EPS production. World Appl Sci J 2008; 4(5):741–7.

Adebolu TT, Olodun AO, Ihunweze BC. Evaluation of ogi liquor from different grains for antibacterial activities against some common pathogens. Afr J Biotechnol 2007; 6(9):1140–3.

Adesulu AT, Awojobi KO. Enhancing sustainable development through indigenous fermented food products in Nigeria. Afr J Microbiol Res 2014; 8:1338–43; doi:10.5897/AJMR2013.5439.

Adesulu-Dahunsi AT, Jeyaram K, Sanni AI, Banwo K. Production of exopolysaccharide by strains of Lactobacillus plantarum YO175 and OF101 isolated from traditional fermented cereal beverage. Peer J 2018; 6:e5326.

Akabanda F, Owusu-Kwarteng J, Tano-Debrah K, Parkouda C, Jespersen L. The use of lactic acid bacteria starter culture in the production of Nunu, a spontaneously fermented milk product in Ghana. Int J Food Sci 2014; 11:721067; doi:10.1155/2014/721067.

Ammor MS, Mayo B. Selection criteria for lactic acid bacteria to be used as functional starter cultures in dry sausage production: an update. Meat Sci 2007; 76(1):138–46.

Ayo A, Onuoha G, Ikuomola DS, Esan YO, Ayo VA, Obetta F. Production and evaluation of starter culture for Kununzaki: a millet based beverage drink. ISABB J Food Agric Sci 2011; 1(2):30. Available via http://www.isabb.academicjournals.org

Ayodeji BD, Piccirillo C, Ferraro V, Moreira PR, Obadina AO, Sanni LO, et al. Screening and molecular identification of lactic acid bacteria from gari and fufu and gari effluents. Ann Microbiol 2017; 67(1):123–33.

Bajpai VK, Rather IA, Majumder R, Shukla S, Aeron A, Kim K, et al. Exopolysaccharide and lactic acid bacteria: perception, functionality and prospects. Bangladesh J Pharmacol 2016; 11(1):1–23.

Barinov A, Bolotine A, Langella P, Maguin E, Van De Guchte M. Genomics of the genus Lactobacillus. In: Sonomoto K, Yokota A (Eds.). Lactic acid bacteria and bifidobacteria: current progress in advanced research, Caister Academic Press, Portland, OR, 2011.

Barrangou R, Fremaux C, Deveau H, Richards M, Boyaval P, Moineau S, et al. CRISPR provides acquired resistance against viruses in prokaryotes. Science 2007; 315(5819):1709–12.

Bintsis T. Lactic acid bacteria: their applications in foods. J Bacteriol Mycol 2018; 6(2):89–94

Bosma EF, Forster J, Nielsen AT. Lactobacilli and Pediococci as versatile cell factories—evaluation of strain properties and genetic tools. Biotech Adv 2017; 35(4):419–42.

Cadieux P, Burton J, Kang CY. Lactobacillus strains and vaginal ecology. J Am Med Assoc 2002; 287:1940–1.

Caplice E, Fitzgerald GF. Food fermentations: role of microorganisms in food production and preservation. Int J Food Microbiol 1999; 50(1–2):131–49.

Correia I, Nunes A, Guedes S, Barros AS, Delgadillo I. Screening of lactic acid bacteria potentially useful for sorghum fermentation. J Cereal Sci 2010; 52(1):9–15.

Daba GM, Elnahas MO, Elkhateeb WA. Contributions of exopolysaccharides from lactic acid bacteria as biotechnological tools in food, pharmaceutical, and medical applications. Int J Biol Macromol 2021; 173:79–89.

De Vuyst L, Leroy F. Bacteriocins from lactic acid bacteria: production, purification, and food applications. Microb Physiol 2007; 13(4):194–99.

Egwim Evans AM, Abubakar Y, Mainuna B. Nigerian indigenous fermented foods: processes and prospects. In Mycotoxin and food safety in developing countries. Intech Open, p 153, 2013; doi:10.5772/52877.

Florou-Paneri P, Christaki E, Bonos E. Lactic acid bacteria as source of functional ingredients. In Lactic acid bacteria—R & D for food, health and livestock purposes. Intech Open, vol. 25, pp 589–613, 2013; doi:10.5772/47766.

Freitas F, Alves VD, Reis MA. Advances in bacterial exopolysaccharides: from production to biotechnological applications. Trends Biotechnol 2011; 29(8):388–98.

Galle S, Schwab C, Dal Bello F, Coffey A, Gänzle M, Arendt E. Comparison of the impact of dextran and reuteran on the quality of wheat sourdough bread. J Cereal Sci 2012; 56(3):531–7.

Gänzle MG. Lactic metabolism revisited: metabolism of lactic acid bacteria in food fermentations and food spoilage. Curr Opin Food Sci 2015; 2:106–17.

Gänzle M, Schwab C. Ecology of exopolysaccharide formation by lactic acid bacteria: sucrose utilization, stress tolerance, and biofilm formation. In Ullrich M (Ed.). Bacterial polysaccharides: current innovations and future trends, Caister Academic Press, Poole, UK, pp 263–78, 2009.

Hassan BA. Carbohydrate fermentation test & starch hydrolysis test; glycolysis Embden–Meyerhof–Parnas (EMP) pathway. Project Log, 2019; doi: 10.13140/RG.2.2.36127.82089.

Hatti-Kaul R, Chen L, Dishisha T, Enshasy HE. Lactic acid bacteria: from starter cultures to producers of chemicals. FEMS Microbiol Lett 2018; 365(20):fny213; doi:10.1093/femsle/fny213.

Heperkan D, Daskaya-Dikmen C, Bayram B. Evaluation of lactic acid bacterial strains of boza for their exopolysaccharide and enzyme production as a potential adjunct culture. Process Biochem 2014; 49(10):1587–94.

Hilbig J, Gisder J, Prechtl RM, Herrmann K, Weiss J, Loeffler M. Influence of exopolysaccharide-producing lactic acid bacteria on the spreadability of fat-reduced raw fermented sausages (Teewurst). Food Hydrocoll 2019; 93:422–31.

Katz SE. Wild fermentation: the flavor, nutrition, and craft of live-culture foods. Chelsea Green Publishing Company, White River Junction, VT, 2003.

Korcz E, Varga L. Exopolysaccharides from lactic acid bacteria: techno-functional application in the food industry. Trends Food Sci Tech 2021; 110:375–84.

Kumar Y. Development of low-fat/reduced-fat processed meat products using fat replacers and analogues. Food Rev Int 2021; 37:296–312.

Kurmann JA. The production of fermented milk in the world. Int Dairy Federation Bull 1984; 179:8–26. Lacerda IC, Miranda RL, Borelli BM, Nunes ÁC, Nardi RM, Lachance MA, et al. Lactic acid bacteria and yeasts associated with spontaneous fermentations during the production of sour cassava starch in Brazil. Int J Food Microbiol 2005; 105(2):213–19.

Leroy F, De Vuyst L. Lactic acid bacteria as functional starter cultures for the food fermentation industry. Trends Food Sci Tech 2004; 15(2):67–78.

Liu W, Pang H, Zhang H, Cai Y. Lactic acid bacteria: fundamentals and practice. Springer, Amsterdam, The Netherlands, vol. 10, pp 978–94, 2014.

Lynch KM, McSweeney PL, Arendt EK, Uniacke-Lowe T, Galle S, Coffey A. Isolation and characterisation of exopolysaccharide-producing Weissella and Lactobacillus and their application as adjunct cultures in ceddar cheese. Int Dairy J 2014; 34(1):125–34.

Manini F, Casiraghi MC, Poutanen K, Brasca M, Erba D, Plumed-Ferrer C. Characterization of lactic acid bacteria isolated from wheat bran sourdough. LWT Food Sci Technol 2016; 66:275–83.

Mohammed ASA, Naveed M, Jost N. Polysaccharides; classification, chemical properties, and future perspective applications in fields of pharmacology and biological medicine (a review of current applications and upcoming potentialities. J Polym Environ 2021; 29:2359–71; doi:10.1007/s10924-021-02052-2.

Mokoena MP, Mutand T, Olaniran AO. Perspectives on the probiotic potential of lactic acid bacteria from African traditional fermented foods and beverages. Food Nutr Res 2016; 60(1):29630.

Monsan P, Bozonne S, Albenne C, Joucla G, Willemot RM, Remaud, et al. Homopolysaccharides from lactic acid bacteria. Int Dairy J 2001; 11:675–85; doi:10.1016/S0958-6946(01)00113-3.

Motarjemi Y. Impact of small scale fermentation technol- ogy on food safety in developing countries. Int J Food Microbiol 2002; 75(3):213–29.

Obadina AO, Oyewole OB, Sanni LO, Tomlins KI. Biopreservative activities of Lactobacillus plantarum strains in fermenting Casssava 'fufu'. Afr J Biotechnol 2006; 5(8):620–3.

Ogunremi OR, Banwo K, Sann AI. Starter-culture to improve the quality of cereal-based fermented foods: trends in selection and application. Curr Opin Food Sci 2017; 13:38–43.

Omar NB, Abriouel H, Lucas R, Martínez-Cañamero M, Guyot JP, Gálvez A. Isolation of bacteriocinogenic Lactobacillus plantarum strains from ben Saalga, a traditional fermented gruel from Burkina Faso. Int J Food Microbiol 2006; 112(1):44–50.

Papadimitriou K, Alegría Á, Bron PA, De Angelis M, Gobbetti M, Kleerebezem M, et al. Stress physiology of lactic acid bacteria. Microbiol Mol Biol Rev 2016; 80(3):837–90.

Papagianni M. Metabolic engineering of lactic acid bacteria for the production of industrially important compounds. Comput Struct Biotech J 2012; 3(4):e201210003; doi:10.5936/csbj.201210003.

Pfeiler EA, Klaenhammer TR. The genomics of lactic acid bacteria. Trends Microbiol 2007; 15(12):546–53.

Pundir RK, Kashyap SRN, Kaur A. Probiotic potential of lactic acid bacteria isolated from food samples: an in vitro study. J Appl Pharm Sci 2013; 3(3):085–93.

Reid G, Bruce AW, Fraser N, Heinemann C, Owen J, Henning B. Oral probiotics can resolve urogenital infections. FEMS Immunol Med Microbiol 2001a; 30(1):49–52.

Reid G, Beuerman D, Heinemann C, Bruce AW. Probiotic Lactobacillus dose required to restore and maintain a normal vaginal flora. FEMS Immunol Med Microbiol 2001b; 32(1):37–41.

Ripari V, Ba Y, Gänzle MG. Metabolism of phenolic acids in whole wheat and rye malt sourdoughs. Food Microbiol 2019; 77:43–51.

Rodriguez Sanoja R, Morlon-Guyo, J, Jore J, Pintado J, Juge N, Guyot JP. Comparative characterization of complete and truncated forms of Lactobacillus amylovorus α-amylase and role of the C-terminal direct repeats in raw-starch binding. Appl Environ Microbiol 2000; 66(8):3350–6.

Ruas-Madiedo P, Hugenholtz J, Zoon P. An overview of the functionality of exopolysaccharides produced by lactic acid bacteria. Int Dairy J 2002; 12(2–3):163–71.

Ryan PM, Ross RP, Fitzgerald GF, Caplice NM, Stanton C. Sugar-coated: exopolysaccharide producing lactic acid bacteria for food and human health applications. Food Func 2015; 6(3):679–93.

Sanalibaba P, Çakmak GA. Exopolysaccharides production by lactic acid bacteria. Appl Microbiol Open Access 2016; 2(115):1000115.

Savadogo A, Ouattara CA, Savadogo PW, Barro N, Ouattara AS, Traoré AS. Identification of exopolysaccharides-producing lactic acid bacteria from Burkina Faso fermented milk samples. Afr J Biotech 2004; 3(3):189–94.

Sawadogo-Lingani H, Diawara B, Traore AS, Jakobsen M. Technological properties of Lactobacillus fermentum involved in the processing of Dolo and Pito, West African sorghum beers, for the selection of starter cultures. J Appl Microbiol 2008; 104(3):873–82.

Sonomoto K, Yokota A. (Eds.). Lactic acid bacteria and bifidobacteria: current progress in advanced research. Caister Academic Press, Poole, UK, pp 10–286, 2011.

Sun Z, Harris H, McCann A, Guo C, Argimón S, Zhang W, et al. Expanding the biotechnology potential of lactobacilli through comparative genomics of 213 strains and associated genera. Nat Commun 2015; 6(1):1–3.

Torino MI, Font de Valdez G, Mozzi F. Biopolymers from lactic acid bacteria. Novel applications in foods and beverages. Front Microbiol 2015; 6:834.

Waldherr F, Vogel RF. Commercial exploitation of homo-exopolysaccharides in non-dairy food systems. In Bacterial polysaccharides. Current innovations and future trends. Caister Academic Press, Poole, UK, pp 313–29, 2009.

Wedajo B. Lactic acid bacteria: benefits, selection criteria and probiotic potential in fermented food. J Emerg Technol Innov Res 2015; 3(2):411–24.

Widyastut Y, Febrisiantosa A, Tidona F. Health-promoting properties of Lactobacilli in fermented dairy products. Front Microbiol 2021; 12:673890.

Wu C, Huang J, Zhou R. Genomics of lactic acid bacteria: current status and potential applications. Critic Rev Microbiol 2017; 43(4):393–404.

Xu D, Ding Z, Wang M, Bai J, Ke W, Zhang Y, et al. Characterization of the microbial community, metabolome and biotransformation of phenolic compounds of sainfoin (Onobrychis viciifolia) silage ensiled with or without inoculation of Lactobacillus plantarum. Biores Technol 2020; 316:123910.

Zhang L, Folkenberg DM, Amigo JM, Ipsen R. Effect of exopolysaccharide-producing starter cultures and post-fermentation mechanical treatment on textural properties and microstructure of low fat yoghurt. Int Dairy J 2016; 53:10–9.

Zhang YU, Li S, Zhang C, Luo Y, Zhang H, Yang Z. Growth and exopolysaccharide production by Lactobacillus fermentum F6 in skim milk. Afr J Biotechn 2011; 10(11):2080–91.

Zheng J, Wittouck S, Salvetti E, Franz CM, Harris H, Mattarelli P, et al. A taxonomic note on the genus Lactobacillus: Description of 23 novel genera, emended description of the genus Lactobacillus Beijerinck 1901, and union of Lactobacillaceae and Leuconostocaceae. Int J Syst Evol Microbiol 2020; 70:2782–858.