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The Role of Lactic Acid Bacteria in Food Processing, Nutrition and Human Health

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ABSTRACT

Lactic acid bacteria have a long history of application in fermented foods due to their beneficial influence on nutritional, organoleptic, and shelf-life enhancements. Lactic acid bacteria, primarily from the Lactobacillus and Bifidobacterium genera, along with their bacteriocins, are widely used in industrial food preservation. They are known to prevent the growth of pathogens, degrade mycotoxins, and exhibit probiotic capabilities. Their common occurrence in foods along with long-lived uses contributes to their natural acceptance as GRAS (Generally Recognized as Safe). This paper reviews the role of lactic acid bacteria in food, agricultural, and clinical applications and numerous benefits of lactic acid bacteria in food industry and its key uses for fermentation and preservation.

Introduction

Lactic acid bacteria play an important role in food, agricultural, and clinical applications. The bacteria in this group are generally described as gram-positive, non-sporing, non-respiring cocci or rods that produce lactic acid as the major end product during carbohydrate fermentation (Hayek *et al.,* 2013). 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. Their common occurrence in foods, along with their long-standing use, contributes to their natural acceptance as GRAS (Generally Recognized as Safe) for human consumption (Bourdichon *et al.,* 2012).

The three main pathways which are involved in the manufacture and development of flavor in fermented food products are glycolysis (fermentation of sugars), lipolysis (degradation of fat) and proteolysis (degradation of protein) (Wedajo, 2015).

Currently, lactic acid bacteria isolates mainly from the *Lactobacillus* and *Bifidobacterium* genera and their bacteriocin are industrially used in food preservation. Lactic acid bacteria are known to prevent growth of pathogens, degrade mycotoxins and have probiotic capabilities. However, there is paucity of literature focusing on the ability of lactic acid bacteria to inhibit food borne pathogens, especially during the era where consumers are becoming more health conscious when it comes to their food choices. Lactic acid bacteria have very big importance industrially and are used for milk preservation, fermentation of cheese, yogurt and buttermilk. They can be recognized by their fermentative abilities and their roles in enriching nutrients, enhancing organoleptic attributes, improving food safety, and providing health benefits (Panesar, 2011). Milk is highly perishable in characteristics and lactic acid bacteria are used to prolong its shelf life with milk fermentation. It also helps to preserve the nutritional components of milk. The fermentation of milk with the usage of lactic acid bacteria produced high quality milk products and they have high organoleptic attributes. Recently, various products have been developed from fermented milk to benefit the health sector, such as in preventing toxins produced by pathogens and spoilage bacteria (Sharma *et al.,* 2012).

Lactic acid bacteria play a crucial role in milk fermentation, serving as immunizing starter cultures. Milk is also recognized as a natural habitat for these bacteria (Delavenne *et al.,* 2012). Milk fermentation technology is generally cost-effective and relatively simple. Lactic acid bacteria are important starter cultures used in large-scale production under controlled conditions. Compared to naturally fermented products, the use of lactic acid bacteria as starter cultures can reduce and dominate the diversity of microorganisms in fermented milk products, thereby enhancing preservation and improving the palatability of the milk.

The selection criteria for lactic acid bacteria for their use as starter culture has traditionally been related to the homo-fermentative metabolism that implies a rapid rate of sugar consumption and lactic acid production, good adaption to intrinsic conditions of temperature, pH, salt and inhibitory compound throughout the process and resistance to bacteriophages, bacteriocin production as an important factor in establishing strains which help to increase the quality and safety, improvement in organoleptic characteristics, minimum nutritional requirements and enzymatic activities.

Using lactic acid bacteria in food fermentation is one of the known ancient food preserving techniques. Properties such as nutritional, environmental, and adhesion adaptations enable lactic acid bacteria to survive and thrive in various environments, including food matrices like dairy products, meats, vegetables, sourdough bread, and wine (Morelli *et al.,* 2011). Lactic acid bacteria are known for their fastidious nutritional requirements which may vary among species and even among strains (Bringel, 1998). Strains of lactic acid bacteria are also known as fast growing microorganisms that can explore different metabolic activities. Metabolic activities are associated with production of many beneficial compounds such as organic acids and antimicrobial compounds, unique enzymes that can breakdown complex organic compounds into simple functional compounds among others (Delavenne *et al.,* 2012).

Food fermentation process with lactic acid bacteria is traditionally based on spontaneous fermentation or back slopping, industrial food fermentation which is performed by the deliberate addition of lactic acid bacteria as starter culture to the food matrix. This has been a breakthrough in the processing of fermented foods, resulting in a high degree of control over the fermentation process and standardization of the end products. The use of functional starter culture, a novel generation of starter cultures that offers functionalities beyond acidification is being explored (Leroy & De Vuyst, 2004). For instance, lactic acid bacteria are capable of inhibiting various microorganisms in a food environment and display crucial antimicrobial properties with respect to food preservation and safety.

In addition, it has been shown that some strains of lactic acid bacteria possess interesting health promoting properties known as probiotics; one of the characteristics of these probiotics is the potential to combat gastrointestinal pathogenic bacteria such as *Helicobacter pylori*, *Escherichia coli* and *Salmonella.* The aim of this review is to discuss the role of lactic acid bacteria in foods as well as the current insight into their effect on human health. Further research will focus into the exploration of new strains of lactic acid bacteria which will help to increase the quality and safety in foods and capable of inhibiting various microorganisms in food environment and also display crucial antimicrobial properties with respect to food preservation and safety.

Characteristics of the Genera *Lactobacillus*

Lactobacilli are described as gram-positive, catalase-negative, nonsporing rods whose length varies between 15 um and 5 um. They may also have a slender, curved or bend appearance and frequently are able to form chains (Gorner & Valik, 2004). Most of the *Lactobacilli* are mesophilic but the genus also contains species that are psychotropic, thermoduric or thermophilic. Temperature optimum varies from 30°C to 45°C. Some species show high tolerance to salt, osmotic pressure and low water activity. Acid tolerance is a common feature of

Lactobacilli and most of the strains are able to grow at pH below 4.4. The optimum pH value for their growth is 5.5-6.5. Some strains are ethanol tolerant and bile tolerant as well. Most of the species are aerotolerant but some of them require strict anaerobic conditions (Hutkins, 2006).

Applications of Lactic Acid Bacteria

Starter Cultures for Fermented Foods

Fermented foods are produced by the fermentation of certain sugars by lactic acid bacteria, with their origins dating back to antiquity. It is well-known that the greatest proportion of them belong to the category of dairy products namely cheese, yoghurt, fermented milk while fermented meat products, fish products, pickled vegetables and olives and a great variety of cereal products are manufactured, nowadays, using starter cultures. In the past, these products were made through back-slopping, where the characteristics depended on the dominance of the best-adapted strains (Bintsis & Athanasoulas, 2015).

Adjunct Culture

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 (Rattanachaikunsopon and Phumkhachorn, 2010). These are mainly non-starter lactic acid bacteria which have a significant impact on flavor and accelerate the maturation process (Cogan *et al.,* 2007).

Bio-Protective Cultures

Certain lactic acid bacteria have been found to produce bacteriocin namely polypeptides synthesized ribosomally by bacteria that can have a bactericidal or bacteriostatic effect on other bacteria (McAuliffe *et al.,* 2001). In general, bacteriocins lead to cell death by inhibiting cell wall biosynthesis or by disrupting the membrane through pore formation (Twomey *et al.,* 2002). Bacteriocins are therefore important in food fermentation where they can prevent food spoilage or the inhibition of food pathogens. The best known bacteriocin is nisin, which has gained widespread applications in the food industry and is used as a food addictive in at least 50 countries particularly in processed cheese, dairy products and canned foods (Delves-Broughton *et al.,* 1996). In addition, lactic acid bacteria strains also have the ability to reduce fungal mycotoxins either by producing anti-mycotoxinogenic metabolites or by absorbing it (Dalie *et al.,* 2010).

Probiotic Culture

Lactic acid bacteria are considered a major group of probiotic bacteria (Collins *et al.,* 1998). Probiotics has been defined by Fuller as "a live microbial feed supplement which beneficially affects the host animal by improving its intestinal microbial balance". Salminen *et al.,* (1999) propose that probiotics are microbial cell preparations or components of microbial cells that have a beneficial effect on the health and well-being of the host. Commercial cultures used in food applications include mainly strains of *Lactobacillus spp*., *Bifidobacterium spp*. and *Propionibacterium spp. Lactobacillus acidophilus, Lactobacillus casei, Lactobacillus reuteri, Lactobacillus rhamnosus* and *Lactibacillusplantarum* are the most used lactic acid bacteria in functional foods containing probiotics (Champagne *et al.,* 2005).

Metabolic Activity of Lactic Acid Bacteria

Metabolic activity of lactic acid bacteria has gained much focus in research and food industry. The main metabolic activity of lactic acid bacteria is breaking down different carbohydrates and related compounds to obtain energy and carbon molecules (Hoefnagel *et al.,* 2002). Other metabolic activities such as breaking down proteins, lipids and other compounds are also important for normal growth. Thus, the metabolic activities of lactic acid bacteria can include: carbohydrates metabolism, protein metabolism, lipids metabolism and other metabolic activity.

Carbohydrate Metabolism

Carbohydrates are the main source of energy for bacterial growth. Lactic acid bacteria metabolize carbohydrates into different useful compounds (mainly lactic acid) through a common process known as fermentation. Fermentation is the metabolism of sugar in which energy is derived from partial oxidation of an organic compound using organic intermediates as electron donors or electron acceptor (Yuan & Furuta, 2003).

Based on fermentation pathways, lactic acid bacteria can be divided into two physiological groups:

homofermentative (e.g. *Pediococcus, Streptococcus,* Lactococcuslactis, *Lactobacillus delbrueckii* and *Lactobacillus casei)* and heterofermentative (e.g. *Lactobacillus amylovorus, Lactobacillus reuteri* and *Lactobacillus manihotivorans, Weisella, Leuconostoc*) (John *et al.,* 2007). Homofermentative lactic acid bacteria metabolize one molecule of hexose sugars such as glucose to two molecules of lactic acid and two molecules of ATP resulting in more than 85% lactic acid from one molecule of glucose (Axelsson, 2004).

Heterofermentative lactic acid bacteria produce only 50% lactic acid fermenting one molecule of glucose to one molecule of lactic acid, one molecule of ethanol/acetate, one molecule of CO_2 and only one molecule of ATP (Axelsson, 2004).

Protein Metabolism

Lactic acid bacteria have gained much attention due to their proteolytic activities which are of special importance in the accelerated maturation and enzyme modification of different food products such as cheese. Proteolysis is the process in which proteins are broken down by proteinases and peptidases into polypeptides, amino acids and peptides (Bintsis *et al.,* 2003).

Proteinases and peptidases can be found as extracellular and secreted as free enzymes outside the cell or intracellular inside the cell. The proteolytic systems of lactic acid bacteria are important as a means of making proteins, peptide and amino acid available for bacterial growth but these systems can also form the rheological and organoleptic properties of fermented foods (Liu *et al.,* 2010).

Lactic acid bacteria proteolytic systems are comprised of three components: cell wall bound proteinase that initiates the degradation of extracellular protein into oligopeptides, peptide transporters that take up the peptides into cell wall and intracellular peptidases that degrade peptides into shorter peptides and amino acids. Amino acids can be further converted into various flavor compounds such as aldehydes, alcohol and esters (Liu *et al.,* 2008).

Lipid Metabolism

Lipid metabolism is the breakdown of lipid by lipases into fatty acids and glycerol. Lactic acid bacteria strains have either intracellular or extracellular lipases (Meyers *et al.,* 1996). In addition, lactic acid bacteria strains perform unique fatty acids transformation reaction including hydration, dehydration and saturation (Ogawa *et al.,* 2005). These functions can be used in food industry and probiotics. Lipase activity of lactic acid bacteria has shown to provide different health benefits to the host. Lipases are useful in the preparations of dietetic formulations for infants, geriatrics and convalescents (Taranto *et al.,* 1998).

Other Metabolic Activities

Lactic acid bacteria strains express several other metabolic activities that are major contributor to sensory changes in fermented foods such as flavor, astringency and color by breaking down different organic compounds in the food matrix (Rodrigues *et al.,* 2011). These enzymes also play important roles in the probiotic characteristics or lactic acid bacteria contributing to a variety of health benefits in humans, animals and plants (Song *et al.,* 2012).

Lactic acid bacteria metabolize various simple and complex functional compounds, such as terpenoids, carotenoids, sterols, polyphenols, and isoflavones (Chen *et al.,* 2012). In general, these complex functional compounds are known for their health benefits but they are unavailable for gut absorption. The metabolic processes in food fermentation or the gut degrade these compounds into smaller metabolites that can be absorbed, benefiting the host organism (Chen *et al.,* 2012).

Lactic Acid Bacteria as Functional Starter Cultures

A starter culture can be defined as a microbial preparation of large numbers of cells of at least one microorganism to be added to a raw material to produce a fermented food by accelerating and steering its fermentation process. The group of lactic acid bacteria occupies a central role in these processes and has a long and safe history of application and consumption in the production of fermented foods and beverages (Caplice & Fitzgerald, 1999). They cause rapid acidification of raw material through the production of organic acids mainly lactic acid. They also produce acetic acid, ethanol, aroma compounds, bacteriocin, exopolysaccharide and several enzymes. In this way, they enhance shelf-life and microbial safety, improve texture and contribute to the pleasant sensory profile of the end products.

Pure cultures isolated from complex ecosystem of traditionally fermented foods exhibit a diversity of metabolic activities that diverge strongly from the ones of comparable strains used as industrial bulk starters. These include differences in growth rate and competitive growth behavior in mixed cultures, adaptation to a particular substrate or raw material, antimicrobial properties and flavor, aroma and quality attributes.

The use of functional starter cultures in the food fermentation industry is being explored (De Vuyst, 2000). Functional starter cultures are starter that possess at least one inherent functional property. They can contribute to food safety and/or offer one or more organoleptic, technological, nutritional or health advantages. The implementation of carefully selected strains as starter cultures or co-cultures in fermentation processes can help to achieve in situ expression of desired property, maintaining a perfectly natural and healthy product. Examples of lactic acid bacteria that are able to produce antimicrobial substances, sugar polymers, sweeteners, aromatic compound, useful enzymes or nutraceuticals or lactic acid bacteria with health promoting properties are called probiotics strains.

Antimicrobial Compounds Produced By Lactic Acid Bacteria

The preservatives action of starter culture in food and beverage system is attributed to the combined action of a range of antimicrobial metabolites produced during the fermentation process (Caplice & Fitzgerald, 1999). These include many organic acids such as lactic, acetic and propionic acid produced as end products which provide an acidic environment unfavorable for the growth of many pathogenic and spoilage microorganisms.

Obviously, each antimicrobial compound produced during fermentation provides an additional hurdle for pathogens and spoilage bacteria to overcome before they can survive and/or proliferate in foods or beverages, from time of manufacture to time of consumption. Since any microorganism may produce a number of inhibitory substances, its antimicrobial potential is defined by the collective action of its metabolic products on undesirable bacteria. Secondary metabolites produced by lactic acid bacteria which have antagonistic activity include the compound reuterin and the antibiotic reuterocyclin (Ganzle *et al.,* 2000), both of which are produced by strains of *Lactobacillus reuteri*. Reuterin is an equilibrium mixture of monomeric, hydrated monomeric and cyclic dimeric forms b-hydroxypropionaldehyde. It has broad spectrum of activity and inhibits fungi, protozoa and a wide range of bacteria including both gram-positive and gram-negative bacteria.

Bacteriocin producing strains can be used as part of or adjuncts to starter cultures for fermented foods in order to improve safety and quality.

Niche or Habitat of Lactic Acid Bacteria

Lactic acid bacteria constitute a ubiquitous bacterial group that is widespread in nature, in niches of diary (fermented), meat and vegetables origin, the gastrointestinal and urogenital tracts of humans and animals and soil and water (Liu *et al.,* 2014). The ecology of lactic acid bacteria has transitioned over time from their soil and plants habitats to the mammalian gut. The mammalian intestine is a repository of 100 trillion microorganisms generally called microbiota (Hooper & Macpherson, 2010). The microbiota colonizes the gastrointestinal tract and is essential for health by enhancing metabolism, digestion and boost the immune system (Hooper & Macpherson, 2010). The microbiota is well adapted to the mammalian gut based mainly on three factors which include adhesion to intestinal cells, resistance to host barriers and substrate fermentation in the gut (Lebeer *et al.,* 2008). Bile salts and low pH also affect the lipid membrane composition of the microbiota.

Antimicrobial substances that are produced by *Lactobacillus* and *Bifidobacterium* spp. have been confirmed to possess antimicrobial properties that are exerted against enteropathogenic bacteria linked to causing diarrhea (Servin, 2004), and both genera can exert an inhibitory effect on the action of pathogenic enteric bacteria (Moal & Servin, 2006).

Lactic Acid Bacteria in Bio-Preservation

Fermentation is a process by which a carbon source is dissimilated by microorganisms yielding energy without net oxidation. The primary end products of microbial fermentation are generally alcohol and organic acids such as lactic acid, acetic acid and propionic acid. Food fermentation has been widely practiced using lactic acid bacteria which are able to preserve food and prevent spoilage.

Consumer food preferences are now driven by nutrition and health benefits resulting in choices that are trending more and more towards the sustainable use of natural ingredients as preservatives instead of chemicals (Asioli *et al.,* 2017). As a result of this shift in preferences, the use of lactic acid bacteria in food applications has become more important.

Lactic acid bacteria have been used extensively in food processing and many fermented foods as a result of their preservative capacity coupled with the health benefits that they provide to humans when lactic acid bacteria fermented foods are consumed. Lactic acid bacteria synthesize small proteins called bacteriocins from ribosome and it is these bacteriocins that are inhibitory against foodborne pathogens, thus ensuring safe food. Moreover, bacteriocinogenic lactic acid bacteria are good candidates as diary starter cultures that play an important role in food application processes.

Nisin has significant commercial value and is commonly used as an ingredient in milk and dairy products, mayonnaise, canned foods, and many infant and baby foods (Quinto *et al.,* 2019). Bacteriocinogenic cultures are also vital as ingredient in fermented and non-fermented foods as they are usually employed as starter cultures. In addition, harmless bacteriocins are at risk of being digested by some proteases due to their susceptible and sensitive nature (Bernbom *et al.,* 2006). Consequently, bacteriocins are considered as safe food addictives and beneficial to the gastrointestinal system (Quinto *et al.,* 2019).

Lactic Acid Bacteria in Fermented Foods

Lactic acid bacteria are essential and their usefulness cannot be overemphasized in many food fermentation applications and preservation activities. Many traditional foods have been developed using lactic acid bacteria which improve product characteristics and impart certain properties that enhance consumer acceptance and appeal. Most of the products that are developed by the use of lactic acid bacteria also provide superior health benefits to the consumer which is the key to maintaining a healthy gastrointestinal system. Some of the fermented food products from lactic acid bacteria include: cheese, butter, yoghurt, sauerkraut, buttermilk, brined vegetables, sourdough, soya curd, fermented meat and beverages (Gupta & Jeevaratnam, 2018).

Lactic acid bacteria are lactose fermenters that also preserve the taste and nutritional properties of milk. Bacterial species associated with fermented dairy products belong to the genera of *Lactobacillus, Lactococcus, Leuconostoc, Pediococcus, Bacillus, Propionibacterium* and *Bifidobacterium*. These bacteria inhabit the same ecological niches and interact mutualistically. There are approximately 400 traditional fermented milk products that contain a diverse group of microorganisms, including lactic acid bacteria, which contribute to various health benefits.

Antiviral Activity of Lactic Acid Bacteria

The benefits of lactic acid bacteria are significant, as numerous studies confirm their potential use in treating viral diseases and infections. It is also worth noting that there are diverse probiotic lactic acid bacteria with health-promoting antiviral properties. Some of these probiotic lactic acid bacteria are endowed with anti-influenza properties and have been confirmed to modulate and exert antagonistic effects on influenza virus in mice (Harata *et al.,* 2010). Lactic acid bacteria are therefore regarded as potent antidotes for many viral infections.

Moreover, the emergence of viral infections, such as the recent COVID-19, has posed a significant challenge to scientists as they scramble to find a potent drug to combat this global menace. A natural alternative viral infection treatment approach such as the use of probiotics and lactic acid bacteria is thus highly warranted as the conventional prophylactic antiviral drugs and medications are often accompanied by many adverse side effects.

One of the leading causes of mortality globally is the influenza virus which primarily results in an acute respiratory viral infection (Nagai *et al.,* 2011). In addressing immune function challenges in humans, it is important to consider boosting the natural immune defences by adopting probiotic lactic acid bacteria as a tool against viral diseases. The need to embrace probiotic microorganisms and their derived metabolic products is thus a promising approach in the fight against many viral diseases and essentially vital in protecting public health. The mechanisms by which probiotics and lactic acid bacteria exert their antiviral properties are diverse. Some of the well-known probiotic antiviral mechanisms include direct viral interaction, synthesis of antiviral inhibitory compounds, immune system modulation and stimulation. Many research studies have confirmed the antiviral property of probiotic lactic acid bacteria to be strain-specific and dependent (Al-Kassaa *et al.,* 2014).

Lactic acid bacteria are the most commonly used microorganisms in the food industry for fermentation and preservation. Their importance lies primarily in their safe metabolic activity during growth in foods, where they utilize available sugars to produce organic acids and other beneficial metabolites. However, a major challenge for the food industry is to develop multifunctional products tailored to specific regions of the world. It is also challenging to produce foods that match the sensory characteristics and nutritional value of traditional products while incorporating health-promoting properties, all within standardized, safe, and controlled processes.

Lactic acid bacteria play a critical role in food and agricultural applications. Their rapid growth and metabolic activity are essential for various uses, including food production, agriculture, and probiotics. In fermented foods, lactic acid bacteria exhibit antimicrobial properties, primarily due to the production of organic acids, as well as other compounds such as bacteriocins and antifungal peptides. Additionally, lactic acid bacteria strains are used in the food industry as starter cultures, co-cultures, or bio-protective cultures to enhance food quality and safety.

Author Contributions

I. C. Oladipo: Investigation, formal analysis, writing—original draft. M. M. Oyewumi: Validation, methodology, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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