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An Overview of the Role of Lactic Acid Bacteria in Fermented Foods and Their Potential Probiotic Properties

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ABSTRACT

Fermentation is the process by which a complex food compound is broken down into a simpler compound by the action of microorganisms such as yeast, filamentous fungi, and bacteria. Although yeast and fungi play the most important roles in food fermentation, lactic acid bacteria (LAB), a generally recognized as safe (GRAS) probiotic, is frequently included in the starter culture. In the early stages of food fermentation, LAB created an acidic environment to minimize the prevalence of potentially harmful microorganisms. The presence of probiotic microorganisms in the finished food also qualifies it as a functional food item. When consumed, probiotics in food can help to maintain the microbial balance in the gut intestinal tract and hence enhance gut intestinal health. As a result, probiotics can provide extra health benefits in addition to the fundamental nutrient of the fermented product. *Lactobacillus*, *Lactococcus*, *Pediococcus*, *Streptococcus*, *Enterococcus*, *Oenococcus*, and *Leuconostoc* are some of the common genera of LAB. Good LAB usually has the following properties, including acid and bile tolerance, adherence to human epithelial cells, antibiotic susceptibility, no hemolytic and cytotoxicity activity, and antagonistic activity toward potential pathogenic bacteria, to serve as a good probiotic (antimicrobial). Scientists and the food industry are constantly isolating new candidates of LABs with better qualities from various food sources and introducing them as unique candidate probiotics in food.

Keywords: fermentation, functional food, probiotic, lactic acid bacteria

INTRODUCTION

Fermentation is one of the world's oldest techniques used for food preservation in the world. It can preserve the food from farm to fork. Fermentation alters the biochemical composition of the food by breaking down a large organic molecule into simpler ones (alcohol or organic acid) through microbial and enzymatic action (Sharma et al., 2020). These alcohol and organic acid are believed can preserve, enhance organoleptic properties, enhance food texture and reduce the toxicity of fermented foods.

Fermented foods are experiencing a resurgence, thanks to promises of multiple health benefits. Fermented food may have improved nutritional properties due to the presence of potentially beneficial bioactive compounds such as bioactive peptides, biogenic amines, and the reduction of anti-nutrient via microbial action (Dimidi et al., 2019). It also can help to assure food's microbiological safety by lowering the risk of pathogenic substances being transferred to the meal via antimicrobial metabolites formed during fermentation.

In Asia, fermented dairy products, fermented vegetable products, fermented fish products, and alcoholic beverages are widely available. Fermented foods contain a wide range of microorganisms, both naturally occurring and those that are added as functional microorganisms to alter the food's biochemical composition and organoleptic profile. Table 1 shows some fermented products available in Asia, as well as the microorganisms that contribute to the fermentation process.

Rice wine, a popular traditional Asian drink, is produced by the fermentation of starch substrate by microorganisms present in the starter culture. Yeast, filamentous fungi, and LAB usually make up the rice wine starter culture (Chen & Xu, 2010). While yeast and filamentous fungi play the most significant part in fermentation, LAB plays a crucial function in the early stages of alcoholic fermentation by facilitating the creation of a favourable environment for yeast fermentations later on. LAB produce some metabolite compounds such as organic acid during the early stage of fermentation, which contributes to the fermented beverage's distinctive taste and aroma (Bechman et al., 2012). These organic acids react with alcohol to produce ester, which is the main aroma contribution to fermented rice wine (Jiang et al., 2020). LAB, on the other hand, can sometimes impact the quality of a product during alcoholic fermentation.

Table 1 Fermented foods in Asia and the microorganisms involved

Product	Microorganism involve	References
Beverages		
Rice wine	**Bacteria** *Pediococcus**, *Leuconostoc**, *Lactobacillus**, *Streptococcus**, *Bacillus*, *Gluconobacter* **Fungi** *Rhizopus*, *Saccharomyces*, *Saccharomycopsis*	Jiang et al. (2020)
Wine	**Bacteria** *Lactobacillus plantarum** **Fungi** *Saccharomyces cerevisiae*, non-*Saccharomyces* yeasts	Tufariello et al. (2020)
Cereal products		
Tempeh	**Bacteria** *Lactobacillus plantarum**, *Lactobacillus fermentum**, *Lactobacillus reuteri**, *Lactococcus lactis** **Fungi** *Rhizopus oligosporus*	Nurdini et al. (2015)
Miso	**Bacteria** *Enterococcus faecium**, *Enterococcus durans**, *Enterococcus faecalis**, *Pediococcus acidilactici**, *Pediococcus pentosaceus**, *Lactobacillus plantarum**, *Tetragenococcus halophilus*, *Weissella confuse* **Fungi** *Aspergillus oryzae*	Onda et al. (2003)
Vegetable products		
Kimchi	**Bacteria** *Pediococcus pentosaceus**, *Leuconostoc citreum**, *Leuconostoc gelidum**, *Leuconostoc mesenteroides**, *Tetragenococcus*, *Pseudomonas*, *Weissella*	Hong et al. (2016)
Sauerkraut	**Bacteria** *Leuconostoc mesenteroides**, *Lactobacillus brevis**, *Lactobacillus plantarum**, *Enterococcus faecalis**, *Pediococcus cerevisiae**	Zabat et al. (2018)
Dairy products		
Yoghurt	**Bacteria** *Streptococcus thermophilus**, *Lactobacillus delbrueckii**, *Streptococcus thermophilus**, *Pediococcus acidilactici**, *Enterococcus faecium**, *Leuconostoc**	Velikova et al. (2018), Nagaoka (2019)
Cheese	**Bacteria** *Lactococcus lactis**, *Streptococcus* species*, *Lactococcus garvieae**, *Streptococcus parauberis**, *Streptococcus macedonicus** **Fungi** *Geotrichum* species, *Kluyveromyces lactis*, *Candida sake*, *Saccharomyces exigus*, *Penicillium* species, *Saccharomyces sylvae*, *Yarrowia lipolytica*, *Candida catenulate*	Quigley et al. (2011)
Fish products		
Ngari	**Bacteria** *Staphylococcus cohnii*, *Tetragenococcus halophilus*, *Lactobacillus pobuzihii**, *Enterococcus faecium**, *Bacillus indicus*, *Staphylococcus carnosus*	(Devi et al., 2015)

Note:* indicates the lactic acid bacteria present in the fermented food starter cultures

Tempeh, another regularly consumed food in Asia is made from fermented soybeans. *Rhizopus oligosporus* is the most common microorganism responsible for tempeh fermentation. The fermentation of soybean produces aroma compounds such as 2-acetyl-1-pyrroline, 2-ethyl-3,5-dimethylpyrazine, dimethyl trisulfide, methional, 2-methylpropanal and (E, E)-2,4-decadienal (Jeleń et al., 2013). Nurdini et al. (2015), on the other hand, reported that LAB plays an important role in tempeh fermentation. LAB lower the pH of the environment and thus inhibit the growth of Enterobacteriaceae and bacterial spores. The presence of these pathogenic bacteria may inhibit mould growth during the early stages of fermentation.

LAB are essential for the fermentation of vegetables. Rhee et al. (2011) reported that *Leuconostoc mesenteroides* commences the fermentation process by producing carbon dioxide, lactic acid, and acetic acids. The pH of the fermentation environment is swiftly lowered by these chemicals. This low pH prevents the growth of bacteria that could impair the crispness of the fermented vegetable. The carbon dioxide replaces the oxygen, allowing anaerobic fermentation to take place. Within one week, the dominant species in vegetable fermentation shifted from less acid-tolerant heterolactic to more acid-tolerant homolactic fermenting LAB species. The spontaneous sauerkraut fermentation is initiated by *Leuconostoc mesenteroides*, which is followed by the growth of other LAB primarily *Lactobacillus brevis*, *Pediococcus pentosaceus*, and *Lactobacillus plantarum*, of which *Lactobacillus plantarum* is responsible for the subsequent phase of fermentation and the high acidity of the resulting sauerkraut (Zabat et al., 2018).

Yoghurt is a fermented dairy product. The thermophilic LAB ferments the milk by converting the lactose into lactic acid. This lactic acid reduces the acidity of the milk and thus causes the coagulation of protein. The amount of lactic acid produced will impart the thickness and taste of the yoghurt (Ibrahim et al., 2019). Aside from lactic acid, other metabolites produced during fermentation including acetaldehyde, diacetyl, acetoin, acetone, and 2-butanone, also contribute to the distinctive scent and flavour of yoghurt (Cheng, 2010).

Fermentation incorporates a vast range of microorganisms to modify the desired biochemical composition of the food product. Besides yeast and filamentous fungi, LAB also plays important role in the fermentation process. LAB can act as a starter culture that initiates the fermentation and create favourable condition for the later stage of fermentation. Besides, the presence of LAB also will impart the organoleptic properties of the fermented product.

LACTIC ACID BACTERIA

LAB are a group of Gram-positive, non-spore-forming, catalase-negative (non-respiring) without cytochrome, cocci, or rods shape bacteria that are acid-tolerant, anaerobic, or aerotolerant. The LAB group is currently classified in the phylum *Firmicutes*, class *Bacilli*, and order *Lactobacillales* (Ringø et al., 2018).

The main group of LAB includes *Lactobacillus, Lactococcus, Pediococcus, Streptococcus*, *Enterococcus, Oenococcus, and Leuconostoc* (Mokoena, 2017). They are Generally Recognized As Safe (GRAS) by the US Food and Drug Administration (FDA) and meet the European Food Safety Authority's (EFSA) Qualified Presumption of Safety (QPS) criteria (EFSA) (Bermúdez-Humarán et al., 2013).

This GRAS designation refers to the food additive that is generally recognised as safe by experts under the conditions of its intended use. To obtain a GRAS status, a substance must either have a history of safe consumption for food before 1958 or have undergone a scientific procedure that meets the standards for the same amount and quality of substances required to obtain a food additive regulation (Sewalt et al., 2016). Therefore, LAB is safe under the condition of its intended use. With the probable exception of enterococci, the "Panel on Biological Hazards (BIOHAZ)" of the EFSA has found that there is no evidence for any clinical issue with respect to the fermenting bacteria linked with food, whether or not they are resistant to antibiotics.

Fermentation of Lactic Acid Bacteria

Lactic acid bacteria can be found in varying degrees in the majority of fermented products. The presence of LAB in fermented food makes it a functional food. It converts organic substrates into simple organic end products during the fermentation process (Mokoena, 2017).

LAB produce lactic acid as a major end-fermentation product of the metabolism of carbohydrates and a wide range of fermentation metabolite. LAB is involved in two main fermentation pathways: glycolysis (sugar fermentation) and proteolysis (breakdown of protein) (Bintsis, 2018).

Lactate is the main product of lactose metabolism, with some pyruvate being converted to diacetyl, acetoin, acetaldehyde, or acetic acid as a by-product. Proteinase and peptidases are the enzymes that degrade proteins into small peptides and free amino acids. These small peptides and free amino acids will then be transformed into a variety of alcohols, esters, aldehydes, acids, and sulphur compounds for specialized flavour development (Bintsis, 2018).

LAB can be divided into two groups during the fermentation of glucose which is homofermentative and heterofermentative. Homofermentative bacteria are *Lactobacillus* spp., *Lactococcus* spp., *Pediococcus* spp., *Enterococcus* spp., and *Streptococcus* spp. Lactic acid is the sole product produced in the fermentation of glucose (glycolytic pathway) with a homofermentative group of bacteria. The fermentation of one mole of glucose yields two moles of lactic acid ($C_6H_{12}O_6 \rightarrow 2CH_3CHOHCOOH$) (Rakhmanova et al., 2018).

On the other hand, heterofermentative bacteria produce an appreciable amount of ethanol, lactic acid, and carbon dioxide from glucose via the 6-phosphogluconate/phosphoketolase pathway ($C_6H_{12}O_6 \rightarrow 2CH_3CHOHCOOH + C_2H_5OH + CO_2$) (Rakhmanova et al., 2018). *Leuconostoc* spp. and *Oenococcus* spp. belong to this group of bacteria.

Functional Starter Culture

Functional starter cultures have at least one inherent functional property, such as improving food safety, imparting an organoleptic profile, or providing technological, nutritional, or health benefits. LAB are important food-grade bacteria that can act as functional starter cultures as they have a variety of inherent functional properties such as probiotic nature (Hoque et al., 2010), antimicrobial activity (Yerlikaya et al., 2021), multivitamin production (Capozzi et al., 2012), and exopolysaccharides (EPS) synthesis (Nguyen et al., 2020). The probiotic nature of the LAB can certify the lactic acid fermented food as a functional food.

Lactococcus are commonly used as a starter culture for the manufacturing of fermented dairy products because of their metabolic stability, bacteriophage resistance, and ability to create novel compounds from amino acid catabolism. Moreover, it can facilitate large-scale fermentation due to its high growth rate (King et al., 2015). *Lactococcus* is the most important constituent of starter culture for dairy fermentation because it converts lactose to lactic acid and milk fat and proteins into flavour compounds. Furthermore, they produce organic acid, which can inhibit the growth of spoilage bacteria in dairy products.

Streptococcus thermophilus is widely used in dairy product fermentation. *S. thermophilus* acts as a dairy starter culture, rapidly converting lactose to lactic acid, resulting in a rapid decrease in pH and milk protein coagulation (casein) (Linares et al., 2016). Furthermore, during fermentation, *S. thermophilus* forms a symbiotic relationship with *Lactobacillus delbrueckii*, which produces lactic acid and acetaldehyde, which contribute to the distinctive flavour of yoghurt.

Oenococcus oeni is a heterofermentative LAB widely used in the wine and cider industry because it can l-malic acid to l-lactic acid and CO_2. On top of that, it also can metabolize citric acid and produce volatile compounds such as diacetyl.

Furthermore, LAB can function as a protective microorganism, producing bacteriocin, an antimicrobial compound that inhibits the growth of spoilage and pathogenic bacteria in foods (Mokoena, 2017). As a result, the involvement of LAB may extend the product's shelf life. Furthermore, it also acts as a probiotic microorganism that can help to improve human health once ingested (Gaggia et al., 2011).

PROBIOTIC

Recently, there has been a steady increase in the demand for functional foods due to an increase in chronic risks such as cardiovascular disease, diabetes, and obesity, which has triggered an increase in health awareness. Pappalardo and Lusk's (2016) research highlighted that consumers who believed in the importance of functional foods and the benefits to their health are more likely to adopt functional foods.

The outbreak of COVID-19 in 2020 positively impacted this market. The Global Functional Food Market is valued at USD 176,518.97 million in 2020, and it is expected to grow at a CAGR of 2.71% between 2021 and 2022 (PR Newswire, 2022). This pandemic accelerated the growth and demand for functional food as people believe that functional food made up of functional bioactive compounds can provide functional benefits such as immune boosters in addition to regular nutrient intake.

Probiotic was first introduced by German scientist, Werner Kollath in 1953 to designate 'active substances that are essential for a healthy development of life' (Gasbaririni et al., 2016). Nowadays, probiotics are defined as 'living microbial food ingredients that confer significant health benefits on host when administered in adequate amounts' (Chingriyo & Uma, 2014). In addition, probiotics also known as microorganisms have low or no pathogenicity but exert health benefits to the host when administered in an adequate amount.

The probiotic strains that can be consumed by humans are *Lactobacillus*, *Bifidobacterium*, *Lactococcus*, *Streptococcus*, and *Enterococcus*. They are among the most common probiotic strains that reside in the human body. Besides, some yeast strains that belong to the genus *Saccharomyces* are commonly used in the fermentation of probiotic products (Simon, 2005). These strains are Generally Recognized As Safe (GRAS) organisms.

Characteristics of Probiotic

The microorganism that is categorized as a probiotic strain should have good technological properties such as can be manufactured under industrial conditions and retaining its functionality during storage before being delivered to the customer for them to benefit the host's health (Kechagia et al., 2013). Furthermore, it also must be viable and not produce off-flavour or impair the product texture.
Moreover, probiotics with beneficial effects must be able to survive in the human

gastrointestinal system while still maintaining their function within the host. The probiotic will degrade as it travels through the gastrointestinal system. The low pH and bile content reflect the stomach's acidic environment and the upper part of the intestines. Tolerance to these conditions is essential to allow the probiotics to survive and function in the small intestine and stomach (Corcoran et al., 2005).

Acid-tolerant LAB can be considered probiotic strains as they can tolerate pH 3.0 (pH in the stomach) with a survival percentage of more than 70% (Azat et al., 2016). In the human gastrointestinal tract, the bile concentration is about 0.3%. Therefore, the strain that can grow in this bile concentration can be considered a good bile tolerance strain (Azat et al., 2016).

To deliver health advantages to the host, the probiotic strain must be able to adhere to the intestinal epithelium. The microbe's capacity to adhere to the host's intestinal epithelium is determined by its cell hydrophobicity. Higher hydrophobicity probiotics are better at attaching to epithelial cells and promoting health benefits (Tarique et al., 2022).

Furthermore, hydrophobicity is highly related to auto-aggregation properties. Auto-aggregation examines the bacterial accumulation of the same species which can be used to improve the bacterial equilibrium in the human gastrointestinal system. Strains with higher adhesion to hydrocarbons demonstrated high auto-aggregation activity. These two properties are critical for conferring competitive advantage as well as bacterial maintenance in the human gastrointestinal (Campana et al., 2017).

Aside from its cell surface properties and functional characteristics, probiotic safety evaluations such as antibiotic susceptibility, blood hemolytic activity, cytotoxicity, and antimicrobial activity must be performed prior to contact with an animal or a human (Yasmin et al., 2020).

The selection of probiotic strains without hemolytic activity is crucial since these strains are non-virulent. In addition, the absence of hemolysin ensures that virulence will not develop among the bacterial strains (Yasmin et al., 2020). Besides, probiotics should not synthesize enzymes that can break down mucin and thus alters the intestinal mucosal lining. Alteration of the intestinal mucosal lining will increases the risk of infections and other hazardous substances invading the intestinal mucosa.

Probiotics shall have antagonistic activity against pathogenic bacteria (antimicrobial). This characteristic is important to suppress the growth of the pathogen in food that can cause the production of a potentially hazardous product and cause infection in the human body (Amenu, 2013). LAB can produce antimicrobial metabolites including lactic acid, acetic acid, diacetyl, fatty acid, aldehyde, hydrogen peroxide, bacteriocins, and bacteriocin-like substances to inhibit food-borne pathogenic and spoilage microorganisms (Amenu, 2013).

Health Benefits of Probiotics

Probiotics may help to improve gut function, strengthen the immune system, and reduce pathogens. Furthermore, studies show that LAB probiotics have an antihypertensive effect, a reduction in serum cholesterol levels, an antioxidant effect, protection against colon cancer, a reduction in allergy symptoms, and a reduction in the obesity index (Nazir et al., 2018).

The stomach, small intestine, and large intestine are the three major sections of the human gastrointestinal system. Every section of the body has its unique microbiota (Quinto et al., 2014). The aerobic Gram-positive microorganisms ($<10^3$ CFU/g) are the primary inhabitant of the stomach. *Lactobacillus*, *Bifidobacterium*, *Bacteroides*, and *Streptococcus* (10^3 – 10^4 CFU/g) predominate in the small intestine. The genera *Bacteroides*, *Fusobacterium*, *Lactobacillus*, *Bifidobacterium*, and *Eubacterium* (10^{11} – 10^{12} CFU/g) are abundant in the large intestine. The microbial equilibrium in the gastrointestinal is important to confer the host's health.

The greatest immunological organ in the human body is the gut. It also acts as a barrier against infections and antigens that are present in the intestinal lumen. Probiotics can influence human health via influencing gastrointestinal health. The predominantly commensal gut microbiota aids in infection resistance, immune system development, and nutrition production, including vitamins, short-chain fatty acids, and other low molecular mass molecules (Markowiak & Ślizewska, 2017).

Gut health can determine the health status of humans (Zhang et al., 2015). This is because the gut plays an important role in breaking down food into nutrients, facilitating nutrient absorption into the blood via the intestinal wall, and preventing foreign and toxic molecules from entering the bloodstream (Rowland et al., 2018).

Regular consumption of probiotics improves gut health. The study by Simon (2005) found that probiotics can help with gastrointestinal disorders like gastrointestinal illness and irritable bowel syndrome, as well as allergy diseases like dermatitis. Probiotics can also promote immunological function, decrease cholesterol, improve xenobiotic metabolism in the liver, and improve digestion.

Probiotic Lactic Acid Bacteria

LAB is widely utilized as a starter culture in fermentation and probiotics (Rodríguez et al., 2019). The presence of probiotic LAB in food can allow it to be classified as a probiotic product. The actions of LAB, however, differ depending on the species and strain. As a result, more research into the characteristics of the major LAB genera is required.

Genus *Lactobacillus*

Lactobacillus is a Gram-positive, facultative anaerobic or microaerophilic genus of rod-shaped bacteria (Hoque et al., 2010). Lactobacillus belongs to the thermophilic LAB starter cultures. It is the most common strain in food fermentation. Sugars are converted into lactic acid during carbohydrate fermentation. As a result, a hostile environment for spoilage microorganisms is created, allowing for food preservation.

Lactobacilli are commonly used as probiotics due to their high tolerance to acid and bile (Hoque et al., 2010), ability to adhere to intestinal surfaces (Zhang et al., 2020), ability to inhibit potentially pathogenic species (antimicrobial activity), ability to resist antibiotics, ability to produce exopolysaccharides, and ability to remove cholesterol in humans.

Many studies are showing that *Lactobacillus* spp. has potential probiotic properties and health benefits for humans. *Lactobacillus plantarum* is the most prevalent lactobacilli microbiota in fermented vegetables, the human gastrointestinal tract (GIT), and dairy products (Devi et al., 2016). *L. plantarum* can be used as a probiotic because it is comparatively tolerant to bile juice and acid, exhibiting resistance to pathogenic bacteria (Kim et al., 2018). Besides, it is also resistant to antibiotics such as gentamycin, kanamycin, streptomycin, ampicillin, ciprofloxacin, tetracycline, vancomycin, and chloramphenicol. *L. plantarum* showed the highest vancomycin MIC because it has intrinsic resistance to glycopeptides.

Moreover, *Lactobacillus rhamnoses* and *Lactobacillus helveticus* in traditional fermented cheese are also tolerant to acidic and bile salt conditions, auto-aggregation, and hydrophobic activity (Azat et al., 2016). *L. rhamnosus* produce bacteriocin (antimicrobial agent) which effectively inhibits the growth of pathogenic bacteria such as *E. coli*, *S. aureus*, *S. typhimurium, L. monocytogenes*, and *E. faecalis*. These properties make them a potential probiotic.

In addition, *L. rhamnoses* also have potential health-promoting benefits such as cholesterol and triglyceride degradation. *L. rhamnoses* is also effective in the prevention of pediatric antibiotic-associated diarrhoea (Goldenberg et al., 2015). Probiotic plays a role in restoring the natural balance of the bacteria in the gastrointestinal tract.

Genus *Lactococcus*

The genus *Lactococcus* are mesophilic LAB that is Gram-positive, catalase-negative, facultatively anaerobic, nonmotile, and non-spore-forming (Jung et al., 2020). *Lactococcus* have cocci, spherical or ovoid-shaped cells and occur singly or in chains. *Lactococcus lactis* and *Lactococcus raffinolactis* are widely used as starter culture bacteria in fermented products (Kimoto-Nira et al., 2012). Besides acting as a starter culture, they also are potential probiotics in food.

L. lactis commonly present in the fermented vegetable, kimchi can become a potential probiotic because it can tolerate acid and bile, have high cell surface hydrophobicity and adhere to intestinal epithelial cells (Lee et al., 2015). In addition, it also has antimicrobial activity against *Listeria monocytogenes* and *Staphylococcus aureus*, as an anti-inflammatory, antioxidant, and anti-cancer effect.

Moreover, *Lactococcus raffinolactis* capable of producing vitamin B3 (niacin) which can act as an effective antioxidant, preventing oxidative damage in the human body (Jung et al., 2020). Furthermore, cell surface proteins of strain *L. raffinolactis* include glyceraldehyde-3-phosphate dehydrogenase, triosephosphate isomerase, trehalose, and maltose hydrolases (possible phosphorylases), beta-galactosidase, lipoprotein signal peptidase, and sortase (surface protein transpeptidase) allow it to adhere to the epithelial cell. These properties recognize *L. raffinolactis* as a potential probiotic.

Genus *Pediococcus*

The genus *Pediococcus* are facultative anaerobic LAB that is Gram-positive, nonmotile, acidophilus, coccus-shaped and has carbohydrate metabolize features. This group of LAB is a homofermentative LAB that produces lactic acid as a single major product by catabolizing glucose with limited oxygen present via Embden–Meyerhof–Parnas (EMP) pathway (Bhagat et al., 2020).

The *Pediococcus acidilactici* are widely used for the lactic acid fermentation of black raspberry extract (Song et al., 2021). *P. acidilactici* is considered a probiotic because it has a high tolerance to acid and bile, antimicrobial activity, and high adhesion capability. This group of LAB had been reported to have resistance to antibiotics cephalexin, neomycin, vancomycin, cefotaxime, and penicillin (Carolina et al., 2014). Moreover, *P. acidilactici* can cure peptic ulcer disease (PUD) by reducing the colonization of *Helicobacter pylori* within the stomach mucosa (Kaur et al., 2014).

The *Pediococcus pentosaceus* which is widely used in the fermentation of kimchi also pose potential probiotic properties because it has high tolerance toward gastric stress and bile condition (Zommiti et al., 2018). Besides, *P. pentosaceus* show adhesion ability to the human epithelial cell, cell hydrophobicity, and auto-aggregation. These properties help bacteria to colonize the gastrointestinal system.

Jiang et al. (2021) also reported that *P. pentosaceus* can inhibit the colonization of pathogenic bacteria besides enhancing the flavour of the kimchi. *P. pentosaceus* produce antimicrobial compounds such as 3-phenyllactic acid, bacteriocin, and exopolysaccharide against harmful pathogenic bacteria such as *Salmonella*, *E. coli*, *S. aureus*, and *L. monocytogenes*.

Genus *Streptococcus*

The genus *Streptococcus* is a facultative anaerobe that is Gram-positive, catalase-negative without cytochrome, and non-motile coccus occurs in pairs and chains. This genus is a thermophile because its optimal growth temperature is 37°C to 42°C (Yerlikaya et al., 2021).

Streptococcus salivarius are commonly present in soy fermentation (How et al., 2020). It is a potential probiotic in food because it has an antimicrobial effect against oral pathogens such as *Staphylococcus aureus*, *Streptococcus pyogenes*, and *Enterococcus faecalis*. This suggests that *Streptococcus* spp. can improve oral health by killing oral harmful bacteria.

Streptococcus thermophilus is widely used in the production of yoghurt. It also can be recognized as a probiotic because it has antimicrobial activity against *B. cereus*, *B. subtilis*, *Campylobacter jejuni*, *Candida albicans*, *Enterobacter aerogenes*, *E. coli*, *L. monocytogenes*, *Pseudomonas aeruginosa*, *Salmonella typhimurium*, and *Staphylococcus aureus (*Yerlikaya et al., 2021). Some strains of *Streptococcus thermophilus* have a weaker antimicrobial effect against these pathogenic bacteria.

However, Ravindran et al. (2016) have indicated that the mixed culture of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* can be used as a probiotic to enhance the immunity of the host because the combination of these two has an antimicrobial effect against *S.aureus* and *E. coli*.

Genus *Enterococcus*

The genus *Enterococcus* are a member of the LAB family. They are Gram-positive, catalase-negative, cocci-shaped, facultative anaerobes, and non-spore-forming bacteria (Haghshenas et al., 2016). Even though most species in the genus will grow at temperatures ranging from 10°C to 45°C, *Enterococcus* grows best at 35°C.

Enterococcus is widely used in the fermentation of cheese owing to its ability to tolerate low pH, high salt, and extreme temperature (Foulquié Moreno et al., 2006). Moreover, *Enterococcus* is a common commensal microbiota in the gastrointestinal of humans and animals (Li et al., 2018). Therefore, it plays a vital role in maintaining the balance of microbiota in the human gastrointestinal.

Nami et al. (2019) reported on the probiotic properties of *Enterococcus*. Results showed that *Enterococcus* isolated from artisanal dairy products tolerant to low pH and high bile salts have cell surface hydrophobicity and adhesion ability to the human intestinal Caco-2 cell line, antibiotic susceptibility, and EPS production (Nami et al., 2019). These properties enable *Enterococcus* to be considered probiotics.

Moreover, Nami et al. (2019) also found that *Enterococcus* has cholesterol-lowering properties. It can produce bile salt hydrolase by deconjugation of bile salt. The deconjugated bile salt is less soluble and excreted out of the body. The excreted bile salts are replaced by new bile salts formed from cholesterol in the bloodstream (Liong & Shah, 2005). Thus, the more bile salt is excreted, the more cholesterol is removed from the bloodstream. Therefore, probiotics can lower cholesterol in the human body.

Genus *Oenococcus*

The genus *Oenococcus* are LAB, from the *Leuconostocaceae* family, and are part of the order *Lactobacillales.* This genus is Gram-positive, nonmotile, nonsporulating, catalase-negative, ovoid-shaped, and can grow in both aerobic and anaerobic conditions (Kot et al., 2014). They are mesophiles with optimum growth at 30°C.

Oenococcus oeni is one of the potential probiotic bacteria present in the fermentation of wine. *O. oeni* can tolerate low pH and bile salt conditions (Su et al., 2015). These two properties are important to indicate that this strain can survive in the human gastrointestinal system. Moreover, *O. oeni* exhibits antioxidant properties because it can scavenge the 2,2-diphenyl-1-picrylhydrazyl radical, and thus reduce the risk of accumulation of reactive oxygen species (ROS) *in vitro*.

Genus *Leuconostoc*

The genus *Leuconostoc* is Gram-positive, non-motile, catalase-negative, cocci-shaped, facultatively anaerobic, and non-spore-forming LAB (Lee et al., 2012). They are mesophilic and psychotropic bacteria with optimum growth at 25°C to 30°C. *Leuconostoc* are heterofermentative LAB. They can metabolize glucose into lactate, ethanol, and CO_2 via the phosphoketolase pathway. In addition, *Leuconostoc* can metabolise pentose into lactate and acetate.

Leuconostoc mesenteroides are widely used as starter bacteria in fermented vegetable and dairy products (Hong et al., 2016). It had potential probiotic properties such as tolerance to the acid condition of the stomach, tolerance to bile salt in the small intestine, and being ability to adhere to the intestinal mucosa (Benmechernene et al., 2013). *L. mesenteroides* have antagonistic activity against pathogenic bacteria because they can produce antimicrobial substances such as bacteriocins or bacteriocin-like substances (Diana et al., 2015).

Furthermore, *L. mesenteroides* are sensitive to amoxicillin, ampicillin, cephalothin, chloramphenicol, erythromycin, lincomycin, and penicillin, but are resistant to kanamycin, streptomycin, tetracycline, and vancomycin. This vancomycin resistance may be linked to the presence of a pentadepsipeptide with a C terminal-lactate instead of a D-alanine in the peptidoglycan of the bacteria (Benmechernene et al., 2013).

CONCLUSION

Fermentation is an important method of food preservation. In fermentation, LAB together with yeasts and fungi are used as the starter cultures. Although the role of LAB is important during fermentation, it is not always highlighted when compared to yeasts and fungi. Fermented foods containing LAB provide more value and higher quality than those that do not. However, not all LAB are good probiotics; only those with acid and bile tolerance, antimicrobial and antibiotic resistance, cell surface hydrophobicity, no hemolytic and cytotoxicity activity, and auto-aggregation in the majority of LAB are. Good quality LAB has been widely used as probiotics in the food industry, and new LAB with improved qualities are isolated, researched, and incorporated into food products regularly to meet the growing demand for them from a health-conscious society.

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REFERENCES

Amenu, D. (2013). Antimicrobial activity of lactic acid bacteria isolated from "Ergo", Ethiopian traditional fermented milk. *Current Research in Microbiology and Biotechnology*, *1* (6), 278 – 284.

Azat, R., Liu, Y., Li, W., & Kayir, A. (2016). Probiotic properties of lactic acid bacteria isolated from traditionally fermented Xinjiang cheese. *Journal of Zhejiang University-SCIENCE B (Biomedicine & Biotechnology)*, *17* (8), 597 – 609. https://doi.org/10.1631/jzus.B1500250

Bechman, A., Phillips, R. D., & Chen, J. (2012). Changes in selected physical property and enzyme activity of rice and barley koji during fermentation and storage. *Journal of Food Science*, *77* (6), M318 – M322. https://doi.org/10.1111/j.1750-3841.2012.02691.x

Benmechernene, Z., Chentouf, H. F., Yahia, B., Fatima, G., Quintela-Baluja, M., Calo-Mata, P., & Barros-Velázquez, J. (2013). Technological aptitude and applications of *Leuconostoc mesenteroides* bioactive strains isolated from Algerian raw camel milk. *BioMed Research International*, *2013* (418132), 1 – 14. https://doi.org/10.1155/2013/418132

Bermúdez-Humarán, L. G., Aubry, C., Motta, J.-P., Deraison, C., Steidler, L., Vergnolle, N., Chatel, J. M., & Langella, P. (2013). Engineering lactococci and lactobacilli for human health. *Current Opinion in Microbiology*, *16*, 1 – 6. https://doi.org/10.1016/j.mib.2013.06.002

Bhagat, D., Raina, N., Kumar, A., Katoch, M., Khajuria, Y., Slathia, P. S., & Sharma, P. (2020). Probiotic properties of a phytase producing *Pediococcus acidilactici* strain SMVDUDB2 isolated from traditional fermented cheese product, Kalarei. *Scientific Reports Nature Research*, *10* (1926), 1 – 11. https://doi.org/10.1038/s41598-020-58676-2

Bintsis, T. (2018). Lactic acid bacteria as starter cultures : An update in their metabolism and genetics. *AIMS Microbiology*, *4* (4), 665 – 684. https://doi.org/10.3934/microbiol.2018.4.665

Campana, R., van Hemert, S., & Baffone, W. (2017). Strain-specific probiotic properties of lactic acid bacteria and their interference with human intestinal pathogens invasion. *Gut Pathogens*, *9*, 1 – 12. https://doi.org/10.1186/s13099-017-0162-4

Capozzi, V., Russo, P., Dueñas, M. T., López, P., & Spano, G. (2012). Lactic acid bacteria producing B-group vitamins: A great potential for functional cereals products. *Applied Microbiology and Biotechnology*, *96*, 1383 – 1394. https://doi.org/10.1007/s00253-012-4440-2

Carolina, M., Ribeiro, D. O., Porto, L., & Vandenberghe, D. S. (2014). Evaluation of probiotic properties of *Pediococcus acidilactici* B14 in association with *Lactobacillus acidophilus* ATCC 4356 for application in a soy based aerated symbiotic dessert. *Brazilian Archives of Biology and Technology: An International Journal*, *57* (5), 755 – 765. https://doi.org/10.1590/S1516-8913201402258

Chen, S., & Xu, Y. (2010). The influence of yeast strains on the volatile flavour compounds of Chinese rice wine. *Journal of the Institute of Brewing*, *116* (2), 190 – 196. https://doi.org/10.1002/j.2050-0416.2010.tb00417.x

Cheng, H. (2010). Volatile flavor compounds in yogurt: A review. *Critical Reviews in Food Science and Nutrition*, *50* (10), 938 – 950. https://doi.org/10.1080/10408390903044081

Corcoran, B. M., Stanton, C., Fitzgerald, G. F., & Ross, R. P. (2005). Survival of probiotic lactobacilli in acidic environments is enhanced in the presence of metabolizable sugars. *Applied and Environmental Microbiology*, *71* (6), 3060 – 3067. https://doi.org/10.1128/AEM.71.6.3060-3067.2005

Devi, K. R., Deka, M., & Jeyaram, K. (2015). Bacterial dynamics during yearlong spontaneous fermentation for production of ngari, a dry fermented fish product of Northeast India. *International Journal of Food Microbiology*, *199*, 62 – 71. https://doi.org/10.1016/j.ijfoodmicro.2015.01.004

Devi, S. M., Subramanian, A., & Halami, P. M. (2016). Discrimination and divergence among Lactobacillus plantarum-group (LPG) isolates with reference to their probiotic functionalities from vegetable origin. *Systematic and Applied Microbiology*, *39*, 562 – 570. https://doi.org/10.1016/j.syapm.2016.09.005

Diana, C. R., Humberto, H. S., & Jorge, Y. F. (2015). Probiotic properties of Leuconostoc mesenteroides isolated from Aguamiel of Agave salmiana. *Probiotics and Antimicrobial Proteins*, *7* (2), 107 – 117. https://doi.org/10.1007/s12602-015-9187-5

Dimidi, E., Cox, S. R., Rossi, M., & Whelan, K. (2019). Fermented foods: Definitions and characteristics, gastrointestinal health and disease. *Nutrients*, *11* (1806), 1 – 26. https://doi.org/10.3390/nu11081806

Foulquié Moreno, M. R., Sarantinopoulos, P., Tsakalidou, E., & De Vuyst, L. (2006). The role and application of enterococci in food and health. *International Journal of Food Microbiology*, *106*, 1 – 24. https://doi.org/10.1016/j.ijfoodmicro.2005.06.026

Gaggia, F., Di Gioia, D., Baffoni, L., & Biavati, B. (2011). The role of protective and probiotic cultures in food and feed and their impact in food safety. *Trends in Food Science and Technology*, *22*, S58 – S66. https://doi.org/10.1016/j.tifs.2011.03.003

Gasbarrini, G., Bonvicini, F., & Gramenzi, A. (2016). Probiotics History. *Journal of Clinical Gastroenterology*, *50 (Suppl 2),* S116 – S119. https://doi.org/10.1097/MCG.0000000000000697

Goldenberg, J. Z., Lytvyn, L., Steurich, J., Parkin, P., Mahant, S., & Johnston, B. C. (2015). Probiotics for the prevention of pediatric antibiotic-associated diarrhea. *Cochrane Database of Systematic Reviews*, 1 – 12. https://doi.org/10.1002/14651858.CD004827.PUB4/ABSTRACT

Haghshenas, B., Haghshenas, M., Nami, Y., Khosroushahi, A. Y., Abdullah, N., Barzegari, A., Rosli, R., & Hejazi, M. S. (2016). Probiotic assessment of *Lactobacillus plantarum* 15HN and *Enterococcus mundtii* 50H isolated from traditional dairies microbiota. *Advanced Pharmaceutical Bulletin*, *6* (1), 37 – 47. https://doi.org/10.15171/apb.2016.007

Hong, S. W., Choi, Y. J., Lee, H. W., Yang, J. H., & Lee, M. A. (2016). Microbial community structure of Korean cabbage kimchi and ingredients with denaturing gradient gel electrophoresis. *Journal of Microbiology and Biotechnology*, *26* (6), 1057 – 1062. https://doi.org/10.4014/jmb.1512.12035

Hoque, M. Z., Akter, F., Hossain, K. M., Billah, M. M., Rahman, M. S. M., & Islam, K. M. D. (2010). Isolation, identification and analysis of probiotic properties of Lactobacillus spp from selective regional yoghurts. *World Journal of Dairy and Food Science*, *5* (1), 39 – 46. https://idosi.org/wjdfs/wjdfs5(1)/7.pdf

How, Y. H., Ewe, J. A., Song, K. P., Kuan, C. H., Kuan, C. S., & Yeo, S. K. (2020). Soy fermentation by indigenous oral probiotic Streptococcus spp . and its antimicrobial activity against oral pathogens. *International Food Research Journal*, *27* (2), 357 – 365. http://www.ifrj.upm.edu.my/27%20(02)%202020/17%20-%20IFRJ19824.R1.pdf

Ibrahim, I. A., Naufalin, R., Erminawati, & Dwiyanti, H. (2019). Effect of fermentation temperature and culture concentration on microbial and physicochemical properties of cow and goat milk yogurt. *IOP Conference Series: Earth and Environmental Science*, *406* (1), 1 – 8. https://doi.org/10.1088/1755-1315/406/1/012009

Jeleń, H., Majcher, M., Ginja, A., & Kuligowski, M. (2013). Determination of compounds responsible for tempeh aroma. *Food Chemistry*, *141* (1), 459 – 465. https://doi.org/10.1016/j.foodchem.2013.03.047

Jiang, L., Su, W., Mu, Y., & Mu, Y. (2020). Major metabolites and microbial community of fermented black glutinous rice wine with different starters. *Frontiers in Microbiology*, *11* (April), 1 – 13. https://doi.org/10.3389/fmicb.2020.00593

Jiang, S., Cai, L., Lv, L., & Li, L. (2021). Pediococcus pentosaceus , a future additive or probiotic candidate. *Microbial Cell Factories*, *20* (45), 1 – 14. https://doi.org/10.1186/s12934-021-01537-y

Jung, M. Y., Lee, C., Seo, M. J., Roh, S. W., & Lee, S. H. (2020). Characterization of a potential probiotic bacterium *Lactococcus raffinolactis* WiKim0068 isolated from fermented vegetable using genomic and *in vitro* analyses. *BMC Microbiology*, *20* (136), 1 – 10. https://doi.org/10.1186/s12866-020-01820-9

Kaur, B., Garg, N., Sachdev, A., & Kumar, B. (2014). Effect of the oral intake of probiotic *Pediococcus acidilactici* BA28 on *Helicobacter pylori* causing peptic ulcer in C57BL/ 6 mice models. *Applied Biochemistry and Biotechnology*, *172*, 973 – 983. https://doi.org/10.1007/s12010-013-0585-4

Kechagia, M., Basoulis, D., Konstantopoulou, S., Dimitriadi, D., Gyftopoulou, K., Skarmoutsou, N., & Fakiri, E. M. (2013). Health benefits of probiotics: A Review. *ISRN Nutrition*, *2013* (481651), 1 – 7. https://doi.org/10.5402%2F2013%2F481651

Kim, S., Huang, E., Park, S., Holzapfel, W., & Lim, S. D. (2018). Physiological characteristics and anti-obesity effect of *Lactobacillus plantarum* K10. *Korean Journal of Food Science of Animal Resources*, *38* (3), 554 – 569.

Kimoto-Nira, H., Aoki, R., Mizumachi, K., Sasaki, K., Naito, H., Sawada, T., & Suzuki, C. (2012). Interaction between Lactococcus lactis and Lactococcus raffinolactis during growth in milk: Development of a new starter culture. *Journal of Dairy Science*, *95*, 2176 – 2185. https://doi.org/10.3168/jds.2011-4824

King, M. S., Boes, C., & Kunji, E. R. S. (2015). Membrane protein expression in *Lactococcus lactis*. *Methods in Enzymology*, *556*, 77 – 97. https://doi.org/10.1016/bs.mie.2014.12.009

Kot, W., Neve, H., Heller, K. J., & Vogensen, F. K. (2014). Bacteriophages of *Leuconostoc*, *Oenococcus*, and *Weissella*. *Frontiers in Microbiology*, *5* (186), 1 – 9. https://doi.org/10.3389/fmicb.2014.00186

Lee, N. K., Han, K. J., Son, S. H., Eom, S. J., Lee, S. K., & Paik, H. D. (2015). Multifunctional effect of probiotic Lactococcus lactis KC24 isolated from kimchi. *LWT - Food Science and Technology*, *64*, 1036 – 1041. https://doi.org/10.1016/j.lwt.2015.07.019

Lee, S. H., Park, M. S., Jung, J. Y., & Jeon, C. O. (2012). *Leuconostoc miyukkimchii* sp. nov., isolated from brown algae (*Undaria pinnatifida*) kimchi. *International Journal of Systematic and Evolutionary Microbiology*, *62*, 1098 – 1103. https://doi.org/10.1099/ijs.0.032367-0

Li, B., Zhan, M., Evivie, S. E., Jin, D., Zhao, L., & Chowdhury, S. (2018). Evaluating the safety of potential probiotic *Enterococcus durans* KLDS6 . 0930 using whole genome sequencing and oral toxicity study bacterial strains and culture conditions. *Frontiers in Microbiology*, *9* (1943), 1 – 15. https://doi.org/10.3389/fmicb.2018.01943

Linares, D. M., Callaghan, T. F. O., Connor, P. M. O., Ross, R. P., & Stanton, C. (2016). Streptococcus thermophilus APC151 strain is suitable for the manufacture of naturally GABA-enriched bioactive yogurt. *Frontiers in Microbiology*, *7* (1876), 1 – 9. https://doi.org/10.3389/fmicb.2016.01876

Liong, M. T., & Shah, N. P. (2005). Bile salt deconjugation ability, bile salt hydrolase activity and cholesterol co-precipitation ability of lactobacilli strains. *International Dairy Journal*, *15* (4), 391 – 398. https://doi.org/10.1016/j.idairyj.2004.08.007

Markowiak, P., & Ślizewska, K. (2017). Effects of probiotics, prebiotics, and synbiotics on human health. *Nutrients*, *9* (9), 1021. https://doi.org/10.3390/nu9091021

Mokoena, M. P. (2017). Lactic acid bacteria and their bacteriocins: Classification, biosynthesis and applications against uropathogens: A mini-review. *Molecules*, *22* (1255), 1 – 13. https://doi.org/10.3390/molecules22081255

Nagaoka, S. (2019). Yogurt production. *Methods in Molecular Biology*, *1887*, 45 – 54. https://doi.org/10.1007/978-1-4939-8907-2_5

Nami, Y., Bakhshayesh, R. V., Jalaly, H. M., Lotfi, H., Eslami, S., & Hejazi, M. A. (2019). Probiotic properties of Enterococcus isolated from artisanal dairy products. *Frontiers in Microbiology*, *10* (300), 1 – 13. https://doi.org/10.3389/fmicb.2019.00300

Nazir, Y., Hussain, S. A., Hamid, A. A., & Song, Y. (2018). Probiotics and their potential preventive and therapeutic role for cancer, high serum cholesterol, and allergic and HIV diseases. *BioMed Research International*, *2018* (3428437), 1 – 17. https://doi.org/10.1155/2018/3428437

Nguyen, P. T., Nguyen, T. T., Bui, D. C., Hong, P. T., Hoang, Q. K., & Nguyen, H. T. (2020). Exopolysaccharide production by lactic acid bacteria: The manipulation of environmental stresses for industrial applications. *AIMS Microbiology*, *6* (4), 451 – 469. https://doi.org/10.3934/MICROBIOL.2020027

Nurdini, A. L., Nuraida, L., Suwanto, A., & Suliantari. (2015). Microbial growth dynamics during tempe fermentation in two different home industries. *International Food Research Journal*, *22* (4), 1668 – 1674. http://www.ifrj.upm.edu.my/22%20(04)%202015/(50).pdf

Onda, T., Yanagida, F., Uchimura, T., Tsuji, M., Ogino, S., Shinohara, T., & Yokotsuka, K. (2003). Analysis of lactic acid bacterial flora during Miso fermentation. *Food Science and Technology Research*, *9* (1), 17 – 24. https://doi.org/10.3136/fstr.9.17

Pappalardo, G., & Lusk, J. L. (2016). The role of beliefs in purchasing process of functional foods. *Food Quality and Preference*, *53*, 151 – 158. https://doi.org/10.1016/j.foodqual.2016.06.009

PR Newswire. (2022). *Functional food ingredients Global Market Report 2022*. Cision. https://www.prnewswire.com/news-releases/functional-food-ingredients-global-market-report-2022-301709635.html

Quigley, L., O'Sullivan, O., Beresford, T. P., Ross, R. P., Fitzgerald, G. F., & Cotter, P. D. (2011). Molecular approaches to analysing the microbial composition of raw milk and raw milk cheese. *International Journal of Food Microbiology*, *150*, 81 – 94. https://doi.org/10.1016/j.ijfoodmicro.2011.08.001

Quinto, E., Jiménez, P., Caro, I., Tejero, J., Mateo, J., & Girbés, T. (2014) Probiotic lactic acid bacteria: A Review. *Food and Nutrition Sciences*, *5* (18), 1765 – 1775. http://dx.doi.org/10.4236/fns.2014.518190

Rakhmanova, A., Khan, Z. A., & Shah, K. (2018). A mini review fermentation and preservation: Role of lactic acid bacteria. *MOJ Food Processing & Technology*, *6* (5), 414 – 416. https://doi.org/10.15406/mojfpt.2018.06.00197

Ravindran, L., Manjunath, N., Darshan, R. P., & Manuel, S. G. A. (2016). *In vitro* study analysis of antimicrobial properties of lactic acid bacteria against pathogens. *Journal of Bio Innovation*, *5* (2), 262 – 269. https://www.jbino.com/docs/Issue02_10_2016.pdf

Rhee, S. J., Lee, J. E., & Lee, C. H. (2011). Importance of lactic acid bacteria in Asian fermented foods. *Microbial Cell Factories*, *10* (S5), 1 – 13. https://doi.org/10.1186/1475-2859-10-S1-S5

Ringø, E., Hoseinifar, S. H., Ghosh, K., Doan, H. Van, Beck, B. R., & Song, S. K. (2018). Lactic acid bacteria in finfish – An update. *Frontiers in Microbiology*, *9*, 1 – 37. https://doi.org/10.3389/fmicb.2018.01818

Rodríguez, L. G. R., Mohamed, F., Bleckwedel, J., Medina, R., Vuyst, L. De, Hebert, E. M., & Mozzi, F. (2019). Diversity and functional properties of lactic acid bacteria isolated from wild fruits and flowers present in Northern Argentina. *Frontiers in Microbiology*, *10* (1091), 1 – 26. https://doi.org/10.3389/fmicb.2019.01091

Rowland, I., Gibson, G., Heinken, A., Scott, K., Swann, J., Thiele, I., & Tuohy, K. (2018). Gut microbiota functions: metabolism of nutrients and other food components. *European Journal of Nutrition*, *57* (1), 1–24. https://doi.org/10.1007/s00394-017-1445-8

Sewalt, V., Shanahan, D., Gregg, L., La Marta, J., & Carillo, R. (2016). The Generally Recognized as Safe (GRAS) process for industrial microbial enzymes. *Industrial Biotechnology*, *12* (5), 295 – 302. https://doi.org/10.1089/ind.2016.0011

Sharma, R., Garg, P., Kumar, P., Bhatia, S. K., & Kulshrestha, S. (2020). Microbial fermentation and its role in quality improvement of fermented foods. *Fermentation*, *6* (106), 1 – 20. https://doi.org/10.3390/fermentation6040106

Simon, O. (2005). Micro-organisms as feed additives – Probiotics. *Advances in Pork Production*, *16*, 161 – 167. https://www.banffpork.ca/documents/BO07-SimonO.pdf

Song, Y. R., Lee, C. M., Lee, S. H., & Baik, S. H. (2021). Evaluation of probiotic properties of *Pediococcus acidilactici* m76 producing functional exopolysaccharides and its lactic acid fermentation of black raspberry extract. *Microorganisms*, *9* (1364), 1 – 17. https://doi.org/10.3390/microorganisms9071364

Su, J., Wang, T., Li, Y., Li, J., Zhang, Y., Wang, Y., Wang, H., & Li, H. (2015). Antioxidant properties of wine lactic acid bacteria: *Oenococcus oeni*. *Applied Microbial and Cell Physiology*, *99*, 5189 – 5202. https://doi.org/10.1007/s00253-015-6425-4

Tarique, M., Abdalla, A., Masad, R., Al-Sbiei, A., Kizhakkayil, J., Osaili, T., Olaimat, A., Liu, S. Q., Fernandez-Cabezudo, M., Al-Ramadi, B., & Ayyash, M. (2022). Potential probiotics and postbiotic characteristics including immunomodulatory effects of lactic acid bacteria isolated from traditional yogurt-like products. *LWT – Food Science and Technology*, *159* (113207), 1 – 10. https://doi.org/10.1016/j.lwt.2022.113207

Tufariello, M., Capozzi, V., Spano, G., Cantele, G., Venerito, P., Mita, G., & Grieco, F. (2020). Effect of co-inoculation of *Candida zemplinina*, *Saccharomyces cerevisiae* and *Lactobacillus plantarum* for the industrial production of Negroamaro wine in Apulia (Southern Italy). *Microorganisms*, *8* (5), 726. https://doi.org/10.3390/microorganisms8050726

Velikova, P., Petrov, K., Lozanov, V., Tsvetanova, F., Stoyanov, A., Wu, Z., Liu, Z., & Petrova, P. (2018). Microbial diversity and health-promoting properties of the traditional Bulgarian yogurt. *Biotechnology and Biotechnological Equipment*, *32* (5), 1205 – 1217. https://doi.org/10.1080/13102818.2018.1475255

Yasmin, I., Saeed, M., Khan, W. A., Khaliq, A., Farhan, M., Chughtai, J., Iqbal, R., Tehseen, S., & Naz, S. (2020). In vitro probiotic potential and safety evaluation (hemolytic, cytotoxic activity) of *Bifidobacterium* strains isolated from raw camel milk. *Microorganisms*, *8* (3), 354. https://doi.org/10.3390/microorganisms8030354

Yerlikaya, O., Saygili, D., & Akpinar, A. (2021). Evaluation of antimicrobial activity and antibiotic susceptibility profiles of *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* strains isolated from commercial yoghurt starter cultures. *Food Science and Technology*, *41* (2), 418 – 425. https://www.scielo.br/j/cta/a/hCqCcpHjZwCdYFDsgrnBFsr/?format=pdf

Zabat, M. A., Sano, W. H., Wurster, J. I., Cabral, D. J., & Belenky, P. (2018). Microbial community analysis of sauerkraut fermentation reveals a stable and rapidly established community. *Foods*, *7* (77), 1 – 8. https://doi.org/10.3390/foods7050077

Zhang, X., Ali Esmail, G., Fahad Alzeer, A., Valan Arasu, M., Vijayaraghavan, P., Choon Choi, K., & Abdullah Al-Dhabi, N. (2020). Probiotic characteristics of Lactobacillus strains isolated from cheese and their antibacterial properties against gastrointestinal tract pathogens. *Saudi Journal of Biological Sciences*, *27* (12), 3505 – 3513. https://doi.org/10.1016/j.sjbs.2020.10.022

Zhang, Y. J., Li, S., Gan, R. Y., Zhou, T., Xu, D. P., & Li, H. Bin. (2015). Impacts of gut bacteria on human health and diseases. *International Journal of Molecular Sciences*, *16* (4), 7493 – 7519. https://doi.org/10.3390/ijms16047493

Zommiti, M., Bouffartigues, E., Maillot, O., Barreau, M., Szunerits, S., Sebei, K., Feuilloley, M., Connil, N., & Ferchichi, M. (2018). *In vitro* assessment of the probiotic properties and bacteriocinogenic potential of *Pediococcus pentosaceus* MZF16 isolated from artisanal Tunisian meat "Dried Ossban". *Frontiers in Microbiology*, *9* (2607), 1 – 15. https://doi.org/10.3389/fmicb.2018.02607