Running title: Inhibition of bacterial growth and their biogenic amines production

The importance of lactic acid bacteria for the prevention of bacterial growth and their biogenic amines formation: A review

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Abstract

Foodborne pathogens (FBP) represent an important threat to the consumers' health as they are able to cause different foodborne diseases. In order to eliminate the potential risk of those pathogens, lactic acid bacteria (LAB) have received a great attention in the food biotechnology sector since they play an essential function to prevent bacterial growth and reduce the biogenic amines formation. The foodborne illnesses (diarrhea, vomiting, and abdominal pain etc.) caused by those microbial pathogens is due to various reasons, one of them is related to the decarboxylation of available amino acids that lead to biogenic amines (BAs) production. The formation of BAs by pathogens in foods can cause the deterioration of their nutritional and sensory qualities. Biogenic amines formation can also have toxicological impacts and lead to different types of intoxications. The growth of FBP and their BAs production should be monitored and prevented to avoid such problems. LAB is capable of improving food safety by preventing foods spoilage and extending their shelf-life. LAB are utilized by the food industries to produce fermented products with their antibacterial effects as bio-preservative agents to extent their storage period and preserve their nutritive and gustative characteristics. Besides their contribution to the flavor for fermented foods, LAB secretes various antimicrobial substances including organic acids, hydrogen peroxide, and bacteriocins. Consequently, in this paper, the impact of LAB on the growth of FBP and their BAs formation in food has been reviewed extensively.

Keywords

Foodborne pathogen, biogenic amine, lactic acid bacteria, foodborne disease, biopreservative, antimicrobial substances.

Introduction

Food safety is an important public health issue, since foodborne outbreaks due to the contamination by pathogenic microbes (bacteria, viruses, fungi and parasites) and their toxins are still emerging leading to many complications and sometimes even death (Velusamy et al., 2010; Law et al., 2015). Foods can be contaminated with microbial pathogens and toxins at all points of the food production cycle from pre-harvest through postharvest as well as within the home (Beier and Pillai, 2007). Foodborne pathogens (FBP) have a health risk to consumers causing different foodborne diseases including acute illnesses (diarrhea, vomiting, fever, weight loss, abdominal pain and other gastrointestinal manifestations), and in some cases chronic (secondary) complications (renal disease, cardiac and neurologic disorders) (Nyenje and Ndip, 2013). Beyond the health effects, foodborne diseases cost billions of dollars in terms of productivity lost and medical expenditures (IOM, 2012). Pathogenic bacteria are able to produce biogenic amines (BAs) through amino acid decarboxylation activity. Ingestion of food containing high amounts of BAs are implicated in various toxicological reactions (Moret et al., 2005) which lead to different types of foodborne poisoning (headaches, low blood pressure, heart palpitations, edema, vomiting, and diarrhea) (Maintz and Novak, 2007; Hungerford, 2010). Thus, the presence of BAs can affect both the quality and the safety of foods (Gram and Dalgaard 2002; Özogul et al., 2011).

Some lactic acid bacteria (LAB) are able to convert amino acid into BAs via decarboxylase activity during fermentation processes of different foodstuff (meat, dairy products, vegetables, and wine) (Coton and others 2010; Spano et al., 2010). In spite of their BAs production, LAB are widely employed in food industries to enhance the flavour, texture, nutritional value and biopreservation of fermented foods (Settanni and Moschetti 2010). LAB produces various microbicidal compounds including organic acids, diacetyl, reuterin, and bacteriocins.

LAB are generally regarded as safe (GRAS) and thus are used in foods due to their inhibitory substances against foodborne pathogens and spoilage bacteria (Gàlvez et al., 2010). LAB also possesses probiotic effects and competes against pathogenic bacteria colonizing the gastrointestinal tracts (Ljungh and Wadstrom 2006). LAB have been investigated in numerous researches for their antagonistic and stimulator effects on food-related pathogens and their BAs accumulation (Coton and others 2010; García-Ruiz and others 2011; Trias et al., 2008; Özogul, 2011; Küley and Özogul, 2011; Küley et al., 2011; Özogul, et al., 2015; Toy et al., 2015).

The current review is an update to the information related to the antimicrobial substances of LAB as bio-preservative agents focusing on the prevention of bacterial growth and inhibition of their biogenic amines formation. Biogenic amines production by FBP and LAB and the stimulation and inhibition effects of LAB on BAs formation are also discussed.

Lactic acid bacteria

Lactic acid bacteria (LAB) are gram positive, non-sporulating, catalase-negative, aerotolerant, rod or coccus shaped organisms. They are acid tolerant, devoid of cytochromes and are fastidious organisms which require a complex growth medium (amino acids, vitamins, nucleic acids and minerals components) (Mohankumar and Murugalatha, 2011; Konings, 2002). According to the taxonomic classification, they belong to the phylum *Firmicutes*, class *Bacilli* and order *Lactobacillales* (Von wright and Axelsson, 2011). LAB includes both homofermenters producing mainly lactic acid by glycolysis and heterofermenters which other than lactic acid yield significant amounts of fermentation products such as acetic acid, ethanol, and carbon dioxide. (Mayo et al., 2010).

LAB was among the first living organisms on the Earth. They appeared in the transition period from anaerobiosis to aerobiosis. They bear all the necessary proteins for respiration and several enzymes involved in fermentative pathways. Thus they are well adapted to both anaerobic and aerobic conditions (Pessione, 2012). LAB are a large group which contain an important number of bacterial genera among which the best known with industrial applications are lactobacilli (milk, meat, vetegtable, cereal), lactococci (milk), streptococci (milk), leuconostoc (vegetable, mik), and pediococci (vegetable, meat) (Klaenhammer et al., 2002). LAB is found in environments with a rich nutrient supply including dairy products, fermented meat and fish, sourdough, pickled vegetables (König and Fröhlich, 2009). They are also found in the gastrointestinal tract where they are part of the healthy gut‘s microbiota and genitourinary tract of humans and animals. Besides they are considered as probiotics since they participate in the host well-being by competing with the intestinal microflora’s pathogens and stimulating the mucosal immunity (Klaenhammer et al., 2002).

LAB are nonpathogenic organisms and are considered GRAS (generally regarded as safe) except for few species such as *Enterococcus* that are recognized as pathogens for humans and animals (Mayo et al., 2010; Pessione, 2012). LAB produce a large variety of antimicrobial substances such as lactic acid, acetic acid, ammonia, bacteriocins, ethanol, reuterin, hydrogen peroxide, and diacetyl which are able to stop the development of foodborne diseases by inhibiting the growth of food spoilage and pathogenic organisms (Zamfir et al., 2000; Mahrous et al., 2013; Abo-Amer, 2011). Besides acting as natural food preservatives that delay the spoilage, LAB contribute to the flavor and the aroma development in food and beverages (Malini and Janakiraman 2012).

LAB have been used as probiotics to reduce intestinal disorders such as lactose intolerance (Lomer et al., 2008), relief from symptoms of constipation (Higashikawa et al., 2010), treatment of diarrhea (Ljungh and Wadstrom, 2006), and activity against *Helicobacter pylori* responsible for chronic gastritis, peptic ulcers, and gastric cancer (Yang et al., 2012). LAB are traditionally used as starter cultures for the fermentation of foods and drinks to improve the

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storage quality and nutritive value of perishable food such as meat, fish, milk and vegetables (Halasz, 2009). In 1873, the first pure culture of a lactic acid bacterium (LAB) was obtained by J. Lister and starter cultures for cheese and sour milk production were introduced in 1890.

Biopreservatives properties of LAB

Some of the microorganisms are sources of bioactive compounds as they synthesize secondary metabolites as self-defense against other competitive microbes. Lactic acid bacteria produce various antimicrobial compounds such as organic acids (lactic acid and acetic acid), diacetyl, ethanol, hydrogen peroxide, reuterin, acetaldehyde, acetoine, carbon dioxide, and bacteriocins during fermentations processes (Figure 1). Those natural compounds could be used as biopreservative agents to inhibit pathogenic, non-pathogenic and spoilage microorganisms, extending thereby the shelf-life of food products, enhancing their safety and reducing the abusive use of antibiotics. Besides, these components can have an effect on food flavor and texture (Saranraj et al., 2013, Zbrun et al., 2013).

Bacteriocins are proteinaceous substances with bacteriocidal activity. Numerous bacteriocins are produced by different LAB and they can be classified according their properties, structure, molecular weight (MW), and antibacterial spectrum. Bacteriocins are classified in three different groups. Class I the lantibiotics are small (<5 kDa) and heat-stable peptides. A very well known example of this first group is nisin. Class II non-lantibiotics are small (<10 kDa), heat stable, and containing regular amino-acids such as glycine and pediocin. Class III are large (>30 kDa), peptides such as Enterolysin. Bacteriocins are considered safe additives (GRAS), used to limit pathogens and spoiling microorganisms instead of chemical preservatives which is more favorable for consumers (Parada et al., 2007).

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Nisin is the most widely used bacteriocin. It is an antimicrobial peptide, produced by several strains of *Lactococcus lactis* isolated from milk and vegetable-based products. It is a small (3.5 kDa), cationic, hydrophobic, and 34-amino acid peptide. Nisin has a wide spectrum of activity especially against Gram-positive bacteria. Therefore it is used as food biopreservatives. However, it has a limited spectrum of activity against Gram negative bacteria or fungi (Cheigh and Pyun, 2005; Tiwari et al., 2009). Nisin was admitted into the European food additive list with the number of E234. It was also approved by the Food and Drug Administration as GRAS. Until now, it is the only bacteriocin that has been approved by the World Health Organization for use as a food preservative and it is commercialized as a dried concentrated powder. Nisin has various application including microbial control in dairy products and incorporation in active packaging (Sobrino-López and Martín-Belloso, 2008).

Organic acids such as lactic, acetic, and propionic acids provides an acidic environment that is unfavourable for the growth of many pathogenic microorganisms responsible for food poisoning and diseases. Acids exert their antimicrobial effect by lowering the pH and inhibiting various metabolic functions (Gemechu, 2015).

The bactericidal effect of hydrogen peroxide (H_2O_2) has been attributed to its strong oxidizing effect on the bacterial cells, to its peroxidation of membrane lipids thus increasing membrane permeability and to the destruction of basic molecular structures of cell proteins (Zalán et al., 2005). H_2O_2 was proven to be very effective in reducing food-borne pathogens (Ito et al., 2003). H_2O_2 may also be a precursor for the production of bactericidal free radicals such as superoxide (O^{-}_2) and hydroxyl ($OH^{\cdot}$) radicals which can damage DNA (Olaoye and Ntuen, 2011).

Reuterin has a broad spectrum antimicrobial activity against yeasts, molds, Gram-positive, and Gram-negative bacteria. Reuterin is able to inhibit various spoilage and pathogenic microorganism including *E. coli*, *Salmonella*, *Shigella*, *Clostridium* and *Candida* (Sharma et al., 2015).

Diacetyl is a volatile compound responsible for the typical flavor of butter and many fermented foods. It is used as a flavoring compound since it is generally recognized as safe (GRAS) food ingredient (Lanciotti et al., 2003; Langa et al., 2014).

Many other low molecular mass compounds with antimicrobial activity against Gram-positive and Gram-negative bacteria, moulds and yeasts have been determined, including antifungal cyclic dipeptides, phenyllactic acid, 4-hydroxyphenyllactic acid and 3-hydroxy fatty acids (Šušković et al., 2010).

Foodborne bacterial pathogens

Foodborne pathogens (FBP) are microorganisms that include bacteria, viruses, fungi and parasites. The common foodborne bacterial pathogens are *Listeria monocytogenes, Escherichia coli* O157:H7, *Staphylococcus aureus*, *Salmonella enterica*, *Bacillus cereus, Vibrio* spp., *Campylobacter jejuni, Clostridium perfringens,* and Shiga toxin-producing *Escherichia coli*. FBP lead to foodborne diseases (Table 1), also called food poisoning, by the ingestion of food and drinking of water contaminated by those pathogens or their toxins (Law et al., 2015; Zhao et al., 2014). Microbial pathogenic agents are able to contaminate different food supply such as *Campylobacter* and *Salmonella* that are found in poultry and cattle and *Vibrio* that infect molluscan shellfish (Behravesh et al., 2012). In 1982 after an outbreak of bloody diarrhea caused by *Escherichia coli* O157:H7 and associated with the consumption of undercooked ground beef, this bacteria was identified as a human pathogen. A wide range of food can harbor microbial pathogens including meat, dairy products, fruits, and vegetables (Meng and Schroeder, 2007; Smoot et al., 2009). According to the Centers for Disease Control and Prevention (CDC), more than 250 pathogens and toxins are known to cause foodborne illness (CDC, 2015). Nausea, vomiting, fever, abdominal cramps, diarrhea and other gastrointestinal manifestations such as dysentery are common symptoms in much foodborne intoxication (CDC, 2014).

Biogenic amines production by foodborne bacterial pathogens and LAB

A variety of microorganisms are able to produce biogenic amines (Table 2). Gram-negative bacteria belonging to the genera *Pseudomonas, Moraxella, Acinetobacter, Shewanella, Flavobacterium, Vibrionaceae* and *Aeromonadaceae* are common aquatic bacteria and typical of the fish flora. Although Gram-negative bacteria are the predominant microorganisms in fish, Gram-positive bacteria such as *Bacillus, Micrococcus, Clostridium, Lactobacillus,* and coryneforms have also been determined at various levels (Visciano et al., 2012). Gokdogan et al., 2012 studied the BAs production by eight common Gram negative and positive foodborne pathogens (FBP) in histidine decarboxylase broth. All the tested bacteria including *S. aureus*, *E. coli*, *K. pneumoniae*, *E. faecalis*, *P. aeruginosa*, *L. monocytogenes*, *A. hydrophila* and *Salmonella* Parathypi A were able to produce various BAs (Putrescine (PUT), cadaverine (CAD), spermidine (SPD), tryptophan (TRP), 2-phenylethylamine (PHEN), spermine (SPN), histamine (HIS), Serotonin (SER), tyramine (TYR), Trimethylamine (TMA), dopamine (DOP), and agmatine (AGM). Other investigations confirmed the production of biogenic amines by various bacteria (Özogul et al., 2015; Özogul et al., 2016). Putrescine, cadaverine, spermidine, and spermine were detected in sardines (Özogul and Özogul 2006). The strongest histamine

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producers were *Hafnia alvei*, *Morganella morganii*, *Klebsiella pneumonia* in histidine decarboxylase broth (Özogul and Özogul, 2007).

Lactic acid bacteria (LAB) are the main BA producers in fermented food products. *Oenococcus oeni, Lactobacillus hilgardii* and *Pediococcus parvulus* are responsible for histamine accumulation in wine. Tyramine is the most abundant and commonly detected BA in cheese and fermented meat products, in which LAB strains of *Enterococcus* and *Lactobacillus* are the main producers. *Enterococcus faecalis, Enterococcus faecium* and *Enterococcus durans* strains are considered very strong tyramine-producers. Histamine was detected at the end of cheese ripening process and cadaverine has been described as the most abundant BA in Brazilian cheeses (Russo et al., 2010). Certain LAB strains such as *Lb. brevis and Lb. hilgardii* isolated from wine and *Lb. curvatus, E. faecalis, Lb. fermentum, and Lb. paracasei* isolated from cheese, meat and sausage are able to produce putrescine (Ladero et al., others 2010; Wunderlichovà et al., 2014).

Biogenic amines formation and health risk

Biogenic amines (BAs) are low molecular weight, organic, basic, nitrogenous compounds. BAs are heat-stable which means that after their formation it is difficult to remove them by high temperature and other treatments. Therefore, BAs formation should be avoided by strict use of good hygiene in raw and processed food (Valsamaki et al., 2000). BAs can be classified as heterocyclic (histamine and tryptamine), aliphatic (putrescine, cadaverine, spermine and spermidine) or aromatic (tyramine and phenylethylamine) on the basis of their chemical structure and they can be divided into monoamines (tyramine and phenylethylamine) and diamines (putrescine and cadaverine) by their number of amine groups (EFSA Panel on

Biological Hazards, 2011). They exist in a wide range of food and beverages including dairy products, meat, fish, fermented vegetables and wine (Spano et al., 2010).

The common way of BAs synthesis is the decarboxylation of free amino acids by decarboxylases. The removal of the alpha carboxyl group from an amino acid produces its corresponding BA. The names of many biogenic amines are given according to the names of their originating amino acids. For instance, the decarboxylation of histidine produces histamine, tryptophane produces tryptamine, tyrosine yields tyramine, lysine is decarboxylated to produce cadaverine and putrescine can be formed from the decarboxylation of ornithine (Stadnik and Dolatowski, 2010). Putrescine can be converted into spermidine that can form spermine (Pegg 1986). Decarboxylases are enzymes (substrate-specific) produced by microorganisms that are strain-specific rather than bacterial species-specific (Buňková et al., 2010; Landete et al., 2007). Many bacteria such as *Enterobacteriaceae, Clostridium*, *Lactobacillus*, *Streptococcus, Micrococcus*, and *Pseudomonas* are able to produce BAs through amino acid decarboxylation activity (Shalaby 1996).

The detection of amines in foodstuff has been used as food quality indicator since their presence is a sign of spoilage (Gram and Dalgaard 2002; Gram et al., 2002; Özogul et al., 2011). Histamine, tyramine, putrescine, cadaverine, tryptamine, agmatine, spermine and spermidine are the principle BAs found in foods and beverages (Silla Santos, 1996; Visciano et al., 2012). Different factors have been identified to influence the BAs formation such as free amino acids (substrate) availability, pH, and temperature etc.

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Consumption of food containing high amounts of BAs especially tyramine and histamine are implicated in various pharmacological reactions (Moret et al., 2005) which lead to different types of foodborne diseases including histamine poisoning (scombroid poisoning) and tyramine toxicity (cheese crisis) (Shalaby, 1996). Histamine is known to cause headaches, low blood pressure, heart palpitations, edema, vomiting, and diarrhea (Maintz and Novak, 2007; Hungerford, 2010). Tyramine can engender hypertension, dilate the pupils and the palpebral tissue, cause lacrimation and salivation, increase respiration and escalate the blood sugar (Abreu Gloria, 2005). The diamines like putrescine and cadaverine, although not toxic themselves aggravate the adverse effects of histamine and tyramine (Landete et al., 2007). Diamines compete for some of the mechanisms involved in the detoxification of BAs by inhibiting their metabolizing enzymes (Košmerl et al., 2013).

The impact of LAB on FBP growth

There are many techniques for detecting antimicrobial activity. For instance, well diffusion assay, disc diffusion assay, and spot on lawn method (Çadirci and Çitak 2005). Different studies have proved the antimicrobial effects of LAB on FBP growth (Table 3). Abedi et al., (2013) tested the antibacterial effect of *Lactobacillus delbrueckii* subsp *bulgaricus* on *Escherichia coli* using disc diffusion and spot on lawn methods. A good antibacterial activity against *E. coli* in both methods was determined by measurement of inhibition zones. In spot on lawn method, the inhibition zone of *E. coli* by *L. delbrueckii* was 21.1 mm while it was 9.1 mm for the disc diffusion method.

LAB was isolated and identified from curd (*Lactobacillus leichmannii Lactobacillus casei, Lactobacillus delbrueckii, Lactobacillus brevis, Lactobacillus fermentum, Lactobacillus coagulans, Lactobacillus acidophilus, Lactobacillus lactis and Lactobacillus rhamnosus*) and tested against five pathogens (*Staphylococcus* sp., *Bacillus* sp., *Klebsiella* sp., *Pseudomonas* sp., and *E. coli* sp.) using the disc diffusion methods. Among all tested bacteria *Lactobacillus delbrueckii* and *Lactobacillus casei* had the most significant diameters of inhibition against all pathogenic bacteria (Hawaz, 2014). In another research with the antimicrobial activity of LAB isolated from minced beef meat were tested on *Escherichia coli*, *Pseudomonas aeruginosa*, *Bacillus cereus*, *Klebsiella pneumoniae*, *Proteus* spp., *Salmonella* spp., *Corynebacterium* spp., *Streptococcus pneumoniae* and *Staphylococcus aureus* (AL-Allaf et al., 2011). The maximum inhibition zone was detected against *Bacillus cereus* (4mm) using agar well diffusion assay. LAB isolated from fermented fish was tested against *E. coli, S. aureus, and Salmonella* sp. using an agar spot test. Antagonistic activity was detected for all pathogenic bacteria that showed excellent inhibition zones diameters that are larger than 40 mm especially due to *Streptococcus salivarius* and *Enterococcus faecalis* (Hwanhlem et al., 2011). Tomé et al., (2006) tested LAB isolated from cold-smoked fish against *Listeria monocytogenes* and *Listeria innocua*. The anti-listerial activity was proven for both bacteria.

The influences of LAB on BAs formation by FBP

Numerous researches have been conducted on the effect of LAB on FBP and their BAs production (Gàlvez, 2010; Özogul, 2011; Küley and Özogul 2011; Küley et al., 2011; García-Ruiz et al., 2011; Küley et al., 2012; Gezginc et al., 2013; Küley et al., 2013; Özogul et al., 2015; Toy et al., 2015). Küley et al., (2013) tested eight LAB (*Lactococcus lactis* subsp. *cremoris,* *Lactococcus lactis* subsp. *lactis, Lactobacillus plantarum, Streptococcus thermophilus, Leuconostoc mesenteroides* subsp. *cremoris, Lactobacillus acidophilus, Pediococcus acidophilus, Lactobacillus delbrueckii* subsp. *lactis)* on five fish infusion broths (anchovy, mackerel, white shark, sardine, and gilthead seabream). The used LAB, in this study were able to decarboxylate the amino acids present in the fish broths and to produce all the BAs with significance differences ($p<0.05$). Serotonin was the most produced BA in anchovy infusion decarboxylase broth with the highest amount being noticed for *Lb.delb.* subsp *.lactis* (589.27 mg/L). *Ped. acidophilus* produced the most significant BA in sardine infusion broth (1157.25 mg/L of tyramine). They concluded that the BAs production was depending on 2 criteria the LAB strains and the fish species. These results could be applied in food industry especially in case of fermented foods that use LAB as starter culture. The LAB strains used and the fish species selected should give the lowest BAs formation to avert any risk for consumers. Another study carried on by Toy et al., (2015) investigated the effect of 4 LAB (*Lactococcus lactis* subsp. *lactis*, *Leuconostoc mesenteroides* subsp. *cremoris, Pediococcus acidophilus* and *S. thermophilus*) on BAs produced by 4 FBP (*S. aureus, E. coli, L. monocytogenes* and *S.* Paratyphi A). The LAB action was tested *in vitro* in a tyrosine decarboxylase broth. Tyramine (TYR) and other BAs were produced in different amounts. Although LAB had an inhibition effect on BAs production by some FBP, *P. acidophilus* inhibited up to 98% the tyramine produced by *S.* Paratyphi A. However LAB showed also a stimulation effect on the BAs formation, *Leu. mes.* subsp. *cremoris* and *Lc. lactis* subsp. *lactis* increased the TYR formation by *L. monocytogenes* (160%). The TYR generation by *S. aureus* was more than 70% due to *S. thermophilus* and *Lc. lactis* subsp. *lactis* addition in the broth. Those results led to the conclusion that in order to avoid

FBP development and formation of high BAs concentrations, LAB could be used as biopreservative to prevent these undesirable effects on the food. The inhibitory and stimulation effects depended on the strains that should be chosen carefully to ensure the food safety. Same conclusions were reported by Küley and Özogul who looked into the effects of LAB on the BAs production by eight FBP in tyrosine decarboxylase broth. LAB and FBP were tested separately and their mix cultures were studied. The results showed that it was better not to combine LAB and FBP since higher amounts of BAs were noticed. However a reduction of the BAs formation was also recorded, which means that the stimulator or inhibitory effects were strains depended. Özogul, 2011 proved that there was also a stimulation effect when LAB was associated with FBP in histidine decarboxylase broth. Nevertheless, most of the mix cultures (LAB with FBP) inhibited significantly ($P < 0.05$) the ammonia accumulation. Özogul et al., (2015) concluded, after testing cell-free supernatants (CFSs) of Lactic Acid Bacteria on BAs production by foodborne pathogens in ornithine decarboxylase broth, that LAB strains with non-decarboxylase activity are capable of inhibiting biogenic amine formation by FBP. The tested LAB were *Leuconostoc mesenterodies subsp. cremoris, Pediococcus acidilactici*, *Lactococcus lactis subsp. lactis, Streptococcus thermophilus* and the amines producers were *Salmonella* Paratyphi A, *Listeria monocytogenes*, *Staphylococcus aureus*, and *Escherichia coli*. The most significant amine production was PUT and SPD. All of the CFSs reduced the formation of PUT by ≥65%. SPD was produced in lower amount comparing to control groups. Awaisheh and Ibrahim, (2009) tested the antibacterial effects of different isolated LAB (human, meat and fermented vegetables) against foodborne pathogens *Escherichia coli O157:H7, Salmonella spp.*, *Listeria monocytogenes,* and *Staphylococcus aureus* using spot on lawn method. The determined

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inhibition zones of the tested had an effective effect against all pathogenic strains. Besides the activities of cell-free supernatant of these isolates were studied against the different pathogenic strains to confirm bacteriocins production which were present and were also efficient against the pathogenic strains. The isolated LAB were determined to be *L. acidophilus, L. casei,* and *L. reuteri* (Human), *L. sake* (meat) and *L. plantarum* (fermented vegetables).

All the aforementioned researches agree on some points including that LAB in certain cases is able to inhibit food spoilage compounds such as biogenic amines and ammonia. However the inhibitory action depends on the selected strains since according to many studies LAB could have a synergistic effect by increasing the BAs formation. In the food sector the prevention of such spoilage compounds is sought-after to enhance the foods' shelf life. Therefore the LAB strains selection is very important to have the desired effect. Table 4 summarizes the effects of LAB on biogenic amines production by foodborne pathogens.

Conclusion

Foodborne diseases constitute a major public health problem worldwide since they harm people and cost billions of dollars in health care every year. Thus, if these diseases are prevented not only tremendous amount of lives can be saved but also billions of dollars. In order to assure food safety, it is essential to monitor foodborne pathogens to reduce the risk of foodborne disease. Prevention or elimination of pathogens from contaminated foodstuff is one of the main objectives of food biotechnology and a proper surveillance should be provided before food reaches the consumers. The use of lactic acid bacteria as bio-preservative agent could help to inhibit the growth of FBP resulting in a decreasing of their biogenic amines formation. Moreover, LAB strains should be selected with care in order to prevent the growth of FBP and their BAs formation since some of the LAB is able to increase the formation of BAs especially when combined with other FBPs. Consequently, further research have to be conducted for selection of the right strains with a more desirable effect that might be used in food products to ameliorate their quality, shelf-life and consumers' well-being.

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Table 1: Some of the diseases caused by foodborne pathogens and their associated food

Foodborne pathogens	Foodborne diseases caused by pathogens	Symptoms	Sources of infections	References
E. coli	Hemorrhagic colitis Hemolytic-uremic syndrome (HUS)	stomach pain, diarrhea, vomiting, nausea, fever	undercooked ground beef/meat, salami unpasteurized dairy products and fruit juice, vegetables (lettuce, radish and sprouts) and water	Sharapov et al., 2016; Slayton et al., 2013; IOM 2002
Salmonella spp.	Salmonellosis	abdominal cramps enteric fever (typhoid), vomiting, nausea, enterocolitis/diarrhea, bacteremia	poultry and meat, raw milk, raw milk	Coburn et al., 2007; Mayrhofer et al., 2004; Oliver et al., 2005
L. monocytogenes	Listeriosis	fever, headache, abdominal pain and diarrhea	cheese, dairy and meat products, vegetables, poultry	Ooi and Lorber, 2005; Gahan and Hill, 2005
Campylobacter jejuni	Campylobacteriosis	fever, headache, diarrheal illness, nausea and abdominal pain	raw milk, undercooked/uncooked meat, poultry or shellfish.	Allos, 2001; Silva et al., 2011.
Bacillus cereus	Bacillus cereus food poisoning	diarrhea, abdominal cramps, nausea, and vomiting	meat, chicken, dairy products, dried milk, vegetables, fruits, seafood, rice, and pasta	Velusamy et al., 2010; Kotiranta et al., 2000
Clostridium perfringens	Perfringens food poisoning	Abdominal cramps, nausea and diarrhea	Meat products, poultry, salmon, stew and spices	Brynestad and Granum, 2002; Lindström et al., 2011

Table 2: The main biogenic amines and their BAs producer microorganisms isolated from food.

Biogenic amines	**BAs-producing microorganisms**	**Source**	**References**
Histamine	*Morganella morganii*, *Klebsiella pneumonia*, *Hafnia alvei*, *Lactobacillus buchneri*, *Oenococcus oeni*, *Lactobacillus hilgardii* and *Pediococcus parvulus*	Fish, cheese, wine	Russo et al., 2010 Özogul and Özogul, 2007 Smit et al., 2008
Tryamine	*Enterococcus faecalis*, *Enterococcus faecium* and *Enterococcus durans*	Cheese, fermented meat product	Ladero et al., 2010 Russo et al., 2010
Putrescine	*Lb. brevis*, *Lb. hilgardii*, *Lb. curvatus*, *E. faecalis*, *Lb. fermentum*, *Lb. paracasei*, *Proteus vulgaris*, *Aeromonas hydrophila*	Wine, cheese, sausage, meat, poultry skin, salad, fish	Wunderlichovà et al., 2014 Ladero et al., 2010
Cadaverine	*Lactococcus lactis* subsp. *cremoris*, *Lactococcus lactis* subsp.*lactis*, *Lactobacillus plantarum*, and *Streptococcus thermophilus*, *Staphylococcus aureus*, *E. coli*,	Cheese, fish	Özogul and Özogul, 2006. Kuley et al., 2012 Russo et al., 2010

Table 3: Inhibitory effects of some lactic acid bacterial against foodborne pathogens

Foodborne pathogens	Lactic acid bacteria	Methods	LAB sources	Incubation time (hour)	Inhibition zone (mm)	References
Staphylococcus aureus	*Lactoccocus lactis subsp lactis*	Agar well diffusion	Raw goat and ewes' milk	48	10	Guessas et al., 2005
Listeria monocytogenes	*Lactobacillus plantarum*	Agar disc diffusion	Industrial microorganisms collection of the Institute of Fermentation Technology and Microbiology of Engineering College of Łódź	48	6	Ligocka and Paluszak 2005
Yersinia enterocolitica	*Lactobacillus fermentum*	Agar Well diffusion	Home-made fermented vegetables	48	14	Kazemipoor et al., 2012
Escherichia coli	*Leuconostoc lactis*	Agar Well diffusion	Naturall	72	22.33	Princewill-Ogbonna and

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			y fermenting food products (cow milk and soybean)			Ojimelukwe, 2014
Salmonella typhimurium	*Lactobacillus casei*	Spot on lawn	Human fecal samples	24	21	Awaisheh and Ibrahim, 2009
Shigella	*Lactobacillus acidophilus*	Agar disc diffusion	Milk, dahi, sausage, yoghurt and meat	24	6-9	Sumathi and Reetha, 2012
Bacillus cereus	*Lactobacillus rhamnosus*	Spot on lawn	Rhodia Austrialia Pty. Ltd. Nottinghill, Australia.	72	20	Tharmaraj and Shah, 2009
Klebsiella pneumoniae	*Lactobacillus brevis*	Agar well diffusion	Fermented dairy food	24	7	Datta et al., 2013
Salmonella Paratyphi A	*Streptococcus thermophilus*	Agar well diffusion	Traditional home-made yogurt	24	9.33	Toy et al., 2015

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Salmonella Heidelberg	*Lactobacillus paracasei*	Agar well diffusion	Kimchi	48	≥13	Kim et al., 2015
Vibrio	*Pediococcus pentosaceus*	Agar well diffusion	Fermented products including curd and idly	18-20	14.2	Puttalingamma et al., 2006
Enterococcus faecium	*Leuconostoc mesenteroides*	Agar well diffusion	Rhizosphere samples of olive trees and desert truffles	18	13	Fhoula et al., 2013
Enterococcus faecalis	*Lactococcus lactis* subsp. *lactis*	Agar well diffusion	Dairy (milk) and non-dairy (cattle hair and dung) sources	24	6-10	Khemariya et al., 2013

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Table 4: Effect of lactic acid bacteria on the production of biogenic amines by foodborne pathogens

LAB	HIS	TYR	PUT	CAD	Unit	Pathogens	Broth/Food	References
Control	20.32	2167.25	638.68	48.37	mg/L	*E. coli*	Tyrosine decarboxylase broth	Toy et al., 2015
Pediococcus acidophilus	11.16^{I}	351.13^{S}	192.07^{I}	27.12^{I}				
Control	177.4	502.8	563.3	644.1	mg/kg	pathogen	Fermented sausages	Xie et al., 2015
Lactobacillus plantarum	28.93^{I}	268.1^{I}	70.03^{I}	252.6^{I}				
Control	0.00	0.82	35.33	185.87	mg/L	*S.* Paratyphi A	Lysine decarboxylase broth	Kuley et al., 2012
Lactobacillus plantarum	1.10^{S}	8.02^{S}	31.10^{I}	433.98^{S}				
Control	673.9	7.5	-	-	mg/L	*L. monocytogenes*	Ornithine decarboxylase broth	Özogul et al., 2015
Streptococcus thermophilus	37.8^{I}	93.9^{S}	-	-				
Control	0.90	-	-	-	mg/100g	pathogen	Tuna (*Euthinus affinis*)	Thiruneelakandan et al., 2013
Lactobacillus plantarum	0.60^{I}	-	-	-				
Control	0.57	2.52	10.05	0.78	mg/L	*S. aureus*	Histidine decarboxylase broth	Özogul, 2011
Lactococcus lactis	5.79^{S}	41.13^{S}	61.95^{S}	7.60^{S}				
Control	-	-	207.3	228.2	mg/ml	*E. faecium*	Traditional Chinese sausage	Xie et al., 2016
Lactobacillus plantarum	-	-	147.9^{I}	197.9^{I}				
Control	-	-	138.59	235.95	mg/kg	pathogen	Fermented pork sausage	Limsuwan et al., 2007
Lactobacillus sakei	-	-	82.23^{I}	224.74^{I}				
Control	1.00	18.6	11.6	7.59	mg/kg	pathogen	Spanish Type Culture Collection (CECT, Valencia, Spain)	Peñas et al., 2010
Leuconostoc mesenteroides	2.14^{S}	26.4^{S}	32.1^{S}	19.1^{S}				

^{S}: stimulation effect of LAB on pathogenic bacteria

^{I}: Inhibition effect of LAB on pathogenic bacteria

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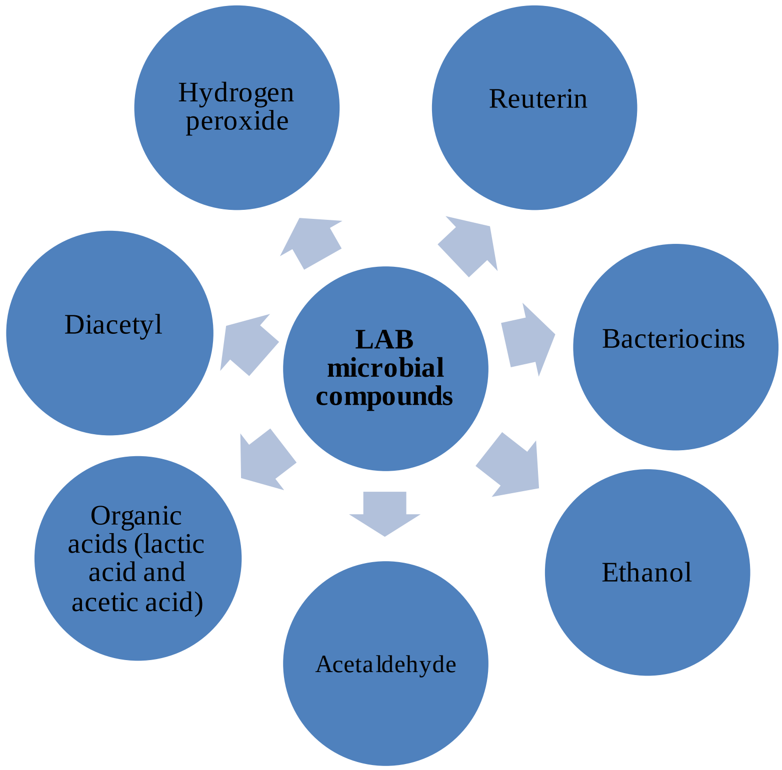

Figure 1: Some of the antimicrobial substances excreted from LAB