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A review on the Potential of Lactic Acid Bacteria in the Production and Degradation of Biogenic Amines in Food

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Abstract

Some species of lactic acid bacteria (LAB) produce biogenic amines (BA) in food. Biogenic amines are secondary metabolites and nitrogenous organic bases with a molecular weight of less than 200 Da, which can accumulate in food due to microbial activity and cause toxic and allergic effects in the human body. The most important biogenic amines found in foods are histamine, tyramine, putrescine, cadaverine, and phenylethylamine, which are often found in fermented foods such as dairy products, meat, and vegetables. These compounds can cause danger to human health, therefore it is very important to control the accumulation and reduction of these compounds in food. Some lactic acid bacteria isolated from fermented foods have been proven to degrade biogenic amines through the production of amine oxidase enzymes. The purpose of this article is to investigate the ability of lactic acid bacteria to produce and degrade biogenic amines in food, which is a safe and cost-effective method.

Keywords: Biogenic amines, Lactic acid bacteria, Amine oxidase, Biogenic amines degradation

1. Introduction

Biogenic amines (BA) are low molecular weight organic bases with aliphatic, aromatic, or heterocyclic structures that emerge by microbial decarboxylation of amino acids and can be found in a number of foodstuffs (Moracanin, Stefanovic, Radicevic, Borovic & Djukic, 2015; Niu, Li, Guo & Ma, 2019). BAs are often found in fermented foods such as dairy products (especially cheese), meat (especially fish and fermented sausages), and some vegetables and the amount and type of amines emerge depends on the type of food and especially the type of microorganism present (Latorre, Bover-Cid, Veciana-Nogues & Vidal-Carou, 2012). Several different bacterial species can produce BAs, and lactic acid bacteria (LAB) such as Enterococcus, Lactobacillus, Carnobacterium, Pediococcus, Lactococcus, and Leuconostoc have a high ability to produce BAs (Barbieri, Montanari, Gardini & Tabanelli, 2019; Ozogul & Ozogul, 2019). These amines are resistant to temperature and are not degraded by increasing the temperature during food processing and preparation. (Sahu, K. Panda, Paramithiotis, Zdolec & C. Ray, 2016).

Considering the potential toxicity of BAs for human health, it is very important to know them, because BAs are considered as potential health hazards and are involved in several pathogenic syndromes, which histamine and tyramine are the most dangerous and important. (Doeun, Davaatseren & Chung, 2017; Tabanelli, 2020). They are responsible for symptomatology known as “scombroid fish poisoning” and “cheese reaction,” respectively . The “scombroid fish poisoning”, often due to the consumption of fish such as tuna, sardines, mackerel and etc. Tyramine intoxication is known as “cheese reaction”because this BA is the most frequently found in cheese (Marcobal, Rivas, Landete, Tabera & Muñoz, 2012; Sellers, Staggs &Bogle, 2006). The intake of foods with high level of BAs could induce the release of adrenaline and noradrenaline, provoking gastric acid secretion, increased cardiac output, migraine, increased blood sugar levels, and higher blood pressure (Caston, Eaton, Gheorghiu & Ware, 2002). Biogenic amines are often food quality indicators because the presence of dangerous amounts of BAs is associated with the growth of spoilage carboxylating microorganisms, so intestinal amine oxidases can detoxify small amounts of these compounds. However, consuming high concentrations of them can inhibit or even disrupt the activity of amine oxidases. (Mahmoudzadeh, Abedi, Moslemi, Pilevar, Ghani, 2022).

Considering that controlling and reducing the accumulation of BAs in food is one of the current challenges in the food industry, this article describes the concepts, production and reduction of BAs by LAB in food.

2. Materials and methods

2.1. Data source

In this study, articles that were prepared between 2000 - 2023 and published in reputable journals have been examined. We used Mdpi ‹Researchgate ‹Science direct ‹Csic ‹Academia and Jmbfs database to access the relevant articles. To collect the required information, Keywords such as biogenic amines, amine oxidase, lactic acid bacteria, fermented foods and biogenic amines degradation were used for searching.

2.2. Selection of articles

From the total of 40 articles found, 33 articles were found suitable for this study. The criterion for selecting these articles was to have thematic relevance and availability. The articles were evaluated in terms of the relationship between the title and abstract . At the end the selected articles were studied completely.

2.3. Data extraction

The important points and results of the articles were noted and finally the contents were summarized, collected and organized.

3. Results and discussion

3.1. Lactic acid bacteria(LAB)

Lactic acid bacteria (LAB) are a group of bacteria that have morphological, metabolic and physiological similarities. These bacteria are Gram-positive and non-sporulating cocci that produce lactic acid through the fermentation of carbohydrates (Khalid, 2011). LAB can produce various products such as short chain fatty acids, bacteriocins and vitamins during metabolism. Therefore, these bacteria are widely used in the food industry, especially in fermented foods (Wang et al., 2021). However, LAB produce useful metabolites, they can produce biogenic amines in food under a series of conditions. In general, different genera of LAB such as Enterococci, Streptococci, Leuconostoc and Lactobacillus, which are usually found in fermented food and have decarboxylase activity, cause the production of these compounds. Among the above cases, Lactobacillus strains such as *L. buchneri*, *L. alimentarius*, *L. plantarum*, *L. curvatus*, *L. farciminis*,*L. bavaricus*, *L. homohiochii*, *L. reuteri* and *L. sakei* produce the highest amount of BAs (Moracanin et al., 2015; Tabanelli, 2020).

۳.2. Biogenic amines

Biogenic amines (BAs) are organic compounds formed from amino acids by decarboxylation or amination and transamination of aldehydes and ketones (Tırıs et al., 2023). These compounds are commonly found in plants, animals and foods. BAs are vital for maintaining cell survival and improving metabolic activities of microorganisms such as hormone synthesis, protein synthesis and DNA replication (Wójcik, Łukasiewicz & Puppel, 2020). But in addition to their positive effects on the functioning of microorganisms, they may have negative effects and their excessive accumulation has a toxic effect on the human body. Histamine, tyramine, phenylethylamine, tryptamine, serotonine, putrescine, cadaverine, spermidine and spermine are the most important biogenic amines. The molecular structure of some main BAs which can occur in food and which are involved in food poisoning is shown in Fig.1 (Danchuk et al., 2020).

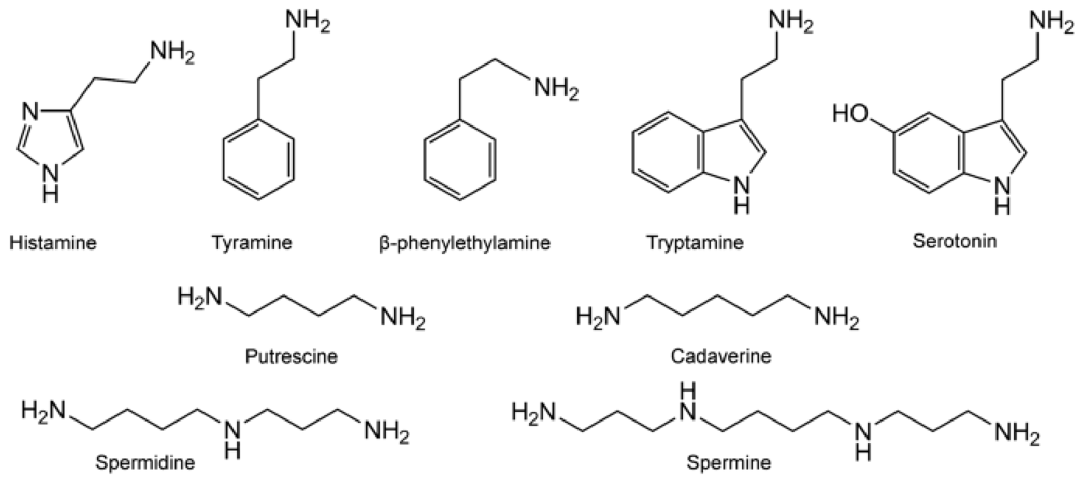

Fig. 1. molecular structure of main BAs

3.3. Classification of biogenic amines

BAs are secondary metabolites with a molecular weight below 200 Da (Wójcik, Mierzejewska, Damaziak & Bien, 2022). BAs are formed from amino acids by decarboxylation or amination and transamination of aldehydes and ketones. Due to the structure of their precursor amino acids, they can have aliphatic, aromatic or heterocyclic chemical structures (Mooraki & Sedaghati, 2018; Nuñez & Medina, 2011). Also, based on the number of amine groups, they can be divided into three groups: monoamine, diamine and polyamine (Ozogul & Hamed, 2018).

Table1 Classification of BAs on the basis of their chemical structure

Classification	Amines	Molecular formula	Molar mass
Heterocyclic	Histamine Tryptamine	$C_5H_9N_3$ $C_{10}H_{12}N_2$	111.15 160.22
Aliphatic	Putrescine Cadaverine Spermine Spermidine	$C_4H_{12}N_2$ $C_5H_{14}N_2$ $C_5H_{14}N_2$ $C_7H_{19}N_3$	88.15 102.18 202.34 145.25
Aromatic	Tyramine Phenylethylamine	$C_8H_{11}NO$ $C_8H_{11}N$	137.18 121.18

Table2 Classification of BAs by their number of amine groups

Classification	Amines
Monoamines	Tyramine Phenylethylamine
Diamines	Putrescine Cadaverine
Polyamines	Spermidine Spermine

3.4. Mechanism of biogenic amines formation in food by lactic acid bacteria

In general, LAB are gram-positive, non-spore-forming and incapable of producing catalase bacilli and cocci and they tolerate the acidic pH of the environment (Zapa´snik, Barbara Sokołowska & Bryła, 2022).They are considered GRAS (Generally Recognized as Safe) or non-toxic and non-pathogenic. However, some species of LAB, which are the natural microbiota of fermented foods or may be added to foods as a starter, can cause the production of BAs in foods (Sahu et al., 2016; Yazgan, Kuley, Gökmen, Regenstein & Özogul, 2020). The production mechanism of these BAs-producing species is that these bacteria convert amino acids into biogenic amine compounds during fermentation by decarboxylase activity (Yazgan et al., 2020). Amino acid decarboxylation takes place by the removal of the α-carboxyl group give the corresponding amine (Sahu et al., 2016). Therefore, it can be said that the production of BA in food depends on the presence of precursors such as amino acids and microorganisms that have decarboxylation activity. For the success of this process, favorable conditions are needed for microbial growth and their enzyme activity (Moracanin et al., 2015). High temperature increases the production of BAs, and low temperatures decrease bacterial growth and decarboxylase activity, so the formation of BAs decreases significantly below 5°C (Sahu et al., 2016).

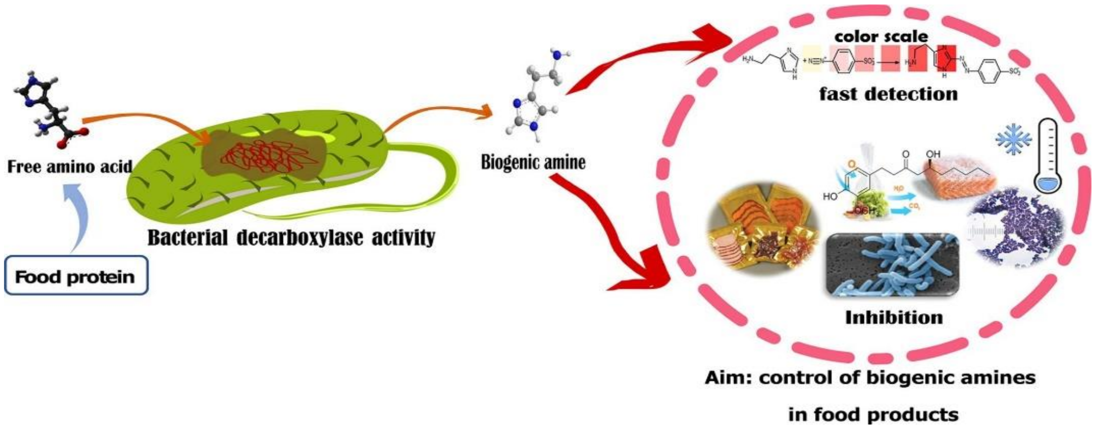

Fig. 2. biogenic amines formation

3.5. Presence of biogenic amines in food and their health risks

The amount and type of BAs formed in food depends on the type of food and the type of microorganism present in it (Latorre et al., 2012). The availability of free amino acids, the existence of decarboxylase-positive microorganisms and suitable conditions for bacterial growth and their decarboxylase activity are three important prerequisites for the production of BAs in food. Accordingly, all fermented foods have the risk of contamination with BAs (Flasarová, Pachlová, Buňková, Menšíková, Georgová, Dráb, Buňka & 2016). In general, processes such as ripening, fermentation and salting can increase the possibility of BAs formation (Mahmoudzadeh et al., 2022).

The most important BAs in food are histamine, tyramine, putrescine, cadaverine, and phenylethylamine, which are produced from the carboxylation of histidine, tyrosine, ornithine, lysine, and phenylalanine, respectively (Alvarez & Arribas, 2014). Some BAs such as histamine, tyramine, putrescine and cadaverine are important because of their toxic effects on the human body. But among the above cases, histamine causes the most common food poisoning related to biogenic amines and causes dilation of peripheral blood vessels, capillaries and arteries, thus resulting in hypotension, flushing, headache, allergies and inflammation in sensitive people (Hungerford, 2010; Ruiz, Rompinelli, Bartolomé & Arribas, 2011). Also, some polyamine BAs such as putrescine, cadaverine, agmatine, spermine and spermidine may react with nitrites and produce carcinogenic nitrosamines. In addition to toxicological effects, these compounds may cause food spoilage, unpleasant smell and taste, and cause undesirable changes in the organoleptic properties of the product (Mahmoudzadeh et al., 2022).

One of the important challenges and concerns that exist today is the presence of more than one BA in food and their synergistic effects. For example, cadaverine and putrescine act as diamine-oxidase inhibitors and they enhace histamine toxicity (Lehane & Olley, 2000). Accordingly, the qualitative and quantitative measurement of biogenic amines in food is very important. Techniques such as gas chromatography-mass spectrometry (GC-MS), high performance liquid chromatography (HPLC), reverse-phase high performance liquid chromatography (RP-HPLC),High Performance Liquid Chromatography-Mass Spectrometry (HPLC-MS) and thin layer chromatography (TLC) are used to detect biogenic amines in food. These methods are relatively complicated and difficult. Nowadays, new methods such as enzymatic biosensors and nanomaterials with enzyme mimicking activities are used for the quantitative and qualitative detection of biogenic amines. These methods are easy to use and have a low price (Ahangari, Kurbanoglu, Ehsani & Uslu, 2021).

3.6. The ability of lactic acid bacteria to degrade biogenic amines

Depending on the type of food, there are different ways to limit the formation of BA. Considering the negative effects of BA consumption on the human body and the organoleptic properties of the product, it is very important to limit the formation of these BAs. The use of methods such as freezing, cooking and pasteurization have no effect on eliminating BAs. Because some BAs like histamine are resistant to heat (Naila, Flint, Fletcher, Bremer & Meerdink, 2010). Methods such as freezing, use of food additives and preservatives, application of hydrostatic pressure, irradiation and smoking delay the formation of biogenic amines in food. However, these techniques may negatively affect the nutritional quality and organoleptic properties of the product, including color, texture, and flavor (Alvarez & Arribas, 2014; Tabanelli, 2020). Another way to reduce the content of BAs is to remove them from the food matrix. But this method is ineffective in the case of fermented products because LAB are part of the natural microbiota of these products. Also, it is difficult to prevent the accumulation of BAs in some fermented foods since the microbiological, chemical and physical conditions of fermentation cannot be easily modified (Alvarez & Arribas, 2014). Therefore, the use of bacteria with BAs-decomposing enzymes is a suitable method to reduce the concentration of BAs in food (Mooraki, Sedaghati, 2018). One of the most useful microorganisms are LAB that decompose BAs by amine oxidase enzymes and turn them into products that can be used as a source of carbon, nitrogen or energy(Lee et al., 2021 ; Ruiz et al., 2011). In other words, these amine oxidases are flavoproteins that catalyze the oxidative deamination of a number of biogenic monoamines and form the corresponding aldehydes, hydrogen peroxide, and ammonia (Wang, Billett, Borchert, Hartmut & Christoph, 2013). Research also shows that the multicopper oxidase genes present in LAB strains can be the main responsible for the degradation of BAs (Lee, Jin, Pawluk & Hyung Mah, 2021). In fact, multicopper oxidase is a group of enzymes that oxidize phenolic and non-phenolic compounds. For example, there is a gene encoding multicopper oxidase in the *Lactobacillus curvatus* genome, and this enzyme can degrade histamine, tyramine and putrescine (Ni, Chen, Du & Fang, 2022).

4. Conclusions

In general, some bacterial species cause the formation of biogenic amines in food, especially fermented products. Due to the increase in the consumption of fermented products such as dairy products, meat and fermented sausages, it is necessary to use new and safe techniques to reduce biogenic amines and prevent poisoning caused by the consumption of biogenic amines. Several studies have shown that the use of some methods causes negative effects on the organoleptic properties of the product such as taste, aroma and texture. For this reason, one of the safe and economical methods is the use of lactic acid bacteria strains that destroy biogenic amines through their amino oxidase activity.

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