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Original Scientific Paper

Biogenic amines in meat and meat products: markers of quality and factors affecting formation

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ABSTRACT

Biogenic amines (BAs) can be found in a wide range of meat and meat products, and, due to their toxicity, can cause adverse effects on the consumers. BAs are generally produced by microbial decarboxylation of amino acids in food products, and their formation is influenced by different factors associated with the raw material, microorganisms, processing, and conservation conditions. These factors do not act in isolation but rather have combined effects that dictate the final concentration of BAs in meat and products. Despite their strong influence on food quality, there is no specific regulation regarding BA content in meat and meat products, with the exception of histamine in fishery products. Therefore, the present paper reviews the main BAs in meat and products, effect of technological factors influencing biogenic amines content in meat and products and their use as markers of quality.

1. Introduction

The rapid increase in the production of meat (products) in the last decades and the desire to prolong its shelf-life cause the search for new methods of meat quality evaluation. As an alternative to sensory and microbiological analyses, it is increasingly often proposed to determine certain chemical indicators, such as biogenic amines (BAs), as an indicator for food safety and quality evaluation (*Chmiel et al.,* 2022). BAs are low molecular weight substances in food mainly produced by the decarboxylation of free amino acids under the influence of endogenous or bacterial enzymes or by amination or transamination of aldehydes and ketones (*Schirone et al.,* 2022). Spermine (SPM), spermidine (SPD), putrescine (PUT), cadaverine (CAD), tryptamine (TRP), phenylethylamine (PHE), histamine (HIS), and tyramine (TYR) commonly exist in meat and meat products and rapidly accumulate, especially during spoilage (*Jastrzębska et al.,* 2024). SPD and SPM are also naturally occurring BAs in fresh meat (*Schirone et al.,* 2022). Several factors associated with raw materials, such as chemical composition, pH, temperature, some handling and manufacturing operations (e.g., fermentation, ripening, curing), time of storage, and post contamination can influence BA presence in foods (*Dabadé et al.,* 2021). High concentrations of these compounds in food are associated with food poisoning, due to their toxicological effects, potentially causing adverse effects like nausea, headaches, gastric and intestinal problems, and

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pseudo-allergic responses (*Shashank et al.,* 2021). Despite their strong influence on both public health and food quality, specific legislation only covers histamine in fishery products, and no criteria have been established for other BAs or other food such as meat (*Schirone et al.,* 2022).

In the light of these considerations, the present study aimed to summarize the influence of the major environmental and process factors on the occurrence of BAs in raw meat and meat products produced by several manufacturing processes, taking into account both food quality and safety aspects of accumulation of BAs. This work intends to inspire establishment of more accurate permissible levels of BAs in meat and products.

2. Factors influencing biogenic amine formation

Meat and meat products are particularly subjected to BA production due to their high protein and amino acid content. Thus, the availability of BA precursors, free amino acids, and the presence of microorganisms able to biosynthesize enzymes catalyzing BA decarboxylation, are essential factors that affect the formation of BAs in meat and meat products (*Liu et al.,* 2024). Proteolytic activity can arise as a consequence of acidity increase, dehydration, temperature and the action of sodium chloride in some meat derived products, but also by microbial activity during fermentation and/or other food production processes, and during storage (*Dabadé et al.,* 2021). Many microorganisms which are present in meat and meat product, such as *Lactobacillus* spp., *Pseudomonas* spp., Enterobacteriaceae, and *Enterococcus* spp., exhibit decarboxylase activity (*Liu et al.,* 2024). A high content of some BAs in food can also be an indicator of poor microbiological quality (*Chmiel et al.,* 2022).

Since amino acid decarboxylase has higher activity under low pH conditions, to some extent, microbial amine production is a physiological reaction to resist an acidic environment (*Gardini et al.,* 2016). Also, low pH enhances the cathepsin activity in raw meat, resulting in the degradation of muscle proteins into peptides and free amino acids, substrates of amino acid decarboxylase (*Gökoğlu,* 2003).

Temperature is another factor influencing the formation of BAs in meat and meat products (*Liu et al.,* 2024). High temperature during storage or fermentation accelerates protein decomposition and the growth of microorganisms, increases the activity of amino acid decarboxylase and proteolytic enzymes and, hence, accelerates the formation of BAs in meat and meat products. Formation of BAs is also influenced by atmospheric conditions, especially the atmospheric conditions in the packaging. The proportion of oxygen in packaging mainly affects the type, quantity, and metabolism of microorganisms in meat and meat products, thus leading to the differences in the formation of BAs (*Gardini et al.,* 2016).

The intrinsic properties of meat (products), influence BA generation. Due to the unique protein composition and softer texture of chicken meat, its BA content is generally higher than in beef and pork, under the same storage conditions (*Liu et al.,* 2024). For meat products, salts are often added during fermentation, curing or storage. High salt concentrations contribute to less accumulation of BAs in meat products, due to reduction of the metabolic activities of decarboxylating microorganisms (*Gardini et al.,* 2016). Gram-negative bacteria are more inhibited by increasing salt concentrations than Gram-positive microbiota (*Gardini et al.,* 2016). The content of BAs in fermented meat products was, due to the specific manufacturing process, significantly higher than those in cured or other kinds of meat products (*Schirone et al.,* 2022). Fermented meat products have conditions conducive to the growth of microorganisms, thus facilitating the production of BAs (*Schirone et al.,* 2022). Smoking treatment also influences BA formation in meat products, because smoking reduces water content and increases salt diffusion, thus inhibiting aminopeptidase, release of free amino acids, and ultimately, generation of BAs (*Gardini et al.,* 2016).

3. Biogenic amines in raw meat

In raw meat, the presence of BAs depends on different factors, such as meat origin, the specific microbiota, storage conditions, and meat shelf-life (*Schirone et al.,* 2022). Hence, inappropriate hygiene and storage conditions can increase the incidence of BAs. As mentioned above, environmental factors such as temperature and pH are of crucial importance for BA formation. However, packaging solutions can control the increase of BA in raw meat and meat preparations (*Chmiel et al.,* 2022). *Chmiel et al.* (2022) indicated that storage conditions are very important, since product stability was higher in cold rooms and dry conditions, than in display cases exposed to light. Raw meat mostly contains the polyamines, PUT, SPD, and SPM, in particular the last

two (*Schirone et al.,* 2022). Many researchers proposed using the ratio of SPM to SPD for raw meat quality evaluation, because it is independent from microbiological activity and relatively stable over time, as well as the sum of CAD + PUT to evaluate raw meat decay independently from the animal species. HIS and TYR start to increase after some days of storage, presuming the initial microbial count is not high (*Schirone et al.,* 2022). Quantification of TRP, CAD, PHE, and PUT is considered useful for early determination of meat spoilage in poultry, pork, and beef, based on the study by *Woinowski et al.* (2019).

4. Biogenic amines in processed meat

BAs can be found in a wide range of meat products. Fermented meat products are a primary source of BAs, mainly due to bacterial and fungal activities. These microorganisms take advantage of the available nutrients, the favourable water activity (at the beginning of the process), and the total and partial oxygen absence ensured by the environment, the former promoting the specific production of BAs like HIS, while reducing the amounts of PUT and CAD (*Schirone et al.,* 2022). In fermented meat products, main bacterial groups responsible for BA production are Enterobacteriaceae and *Pseudomonas*, some strains belonging to the genera *Staphylococcus* and *Bacillus*, and the lactic acid bacteria (*Li et al.,* 2020). Fermented products like sausages and salamis can impair food safety in regard to the accumulation of TYR, HIS, PUT, and CAD. TYR was the most frequent and abundant BA found in dry fermented sausages in Spain's retail sector, while fermented sausages and salamis from Portugal and Serbia had low amounts of TYR, CAD and PHE, and HIS was present only in two samples (*Latorre-Moratalla et al.,* 2017; *Alves et al.,* 2017). Different smoking processes can reduce the level of BAs due to the reduction of free amino acids in dry cured hams (*Martuscelli et al.,* 2009). Also, the diffusive phenomena of salt and water influence amino acid decarboxylase and/or amino oxidase activities (*Dabadé et al.,* 2021). TYR is the most common amine in cured meat products (*Schirone et al.,* 2022). Heat treatments do not affect the BA concentration in meat products. Chicken meat did not show any polyamine loss after different heat treatments, while beef and pork meat after cooking showed only slight reduction of BAs (*Schirone et al.,* 2022). Low levels of BAs usually indicate high quality of the raw materials, good hygiene and handling procedures, and suitable drying/fermenting conditions.

5. Biogenic amine index and recommended limits

To control the processing and development of various food (meat, fish, etc.), and to signal degree of food freshness and/or deterioration, BAs have been frequently employed as quality indexes. However, establishing a biogenic amine index (BAI) that reliably predicts product quality is no simple matter. The BAI calculated from the sum of HIS, TYR, PUT, and CAD (mg/kg) was proposed for meat (*Wójcik et al.,* 2022). Good quality fresh meat should not have a BAI exceeding 5 mg/kg. Acceptable meat, but with signs of initial spoilage, has a BAI of between 5 and 20 mg/kg. Meat of low hygienic quality is classified in the range 20–50 mg/kg, and spoiled meat has a BAI above 50 mg/kg (*Ruiz-Capillas and Herrero,* 2019; *Hernández-Jover et al.,* 1996). The usefulness of BAI as a quality index depends on many factors, which include the nature of the product (fresh, canned, modified atmosphere, fermented, etc.). BAI levels have proven to be more satisfactory in fresh meat and meat products and heat-treated products than in fermented products, due to the latter having varying amounts of BAs over time, owing to the number of different factors involved in the processing (ripening, maturation, starter, additives, etc.) (*Ruiz-Capillas and Herrero,* 2019).

Since the consumption of foods containing high amounts of BAs have been associated with health hazards, restricted consumption of BA-rich products is recommended (*Wójcik et al.,* 2022). However, international permissible levels of biogenic amine consumption are lacking. Numerous consumer organizations and food safety agencies, which include the European Food Safety Authority (EFSA), the Food and Drug Administration (FDA), Food Safety Commission of Japan (FSCJ), and the World Health Organization (WHO), are dealing with this problem (*Ruiz-Capillas and Herrero*, 2019). One of the toxins targeted by the *FDA* (2025) and *EFSA* (2011) is HIS in fish and fish products. The maximum level of tolerated HIS in meat was determined as 100 mg/kg (*Feddern et al.,* 2019), whereas daily HIS consumption should not exceed 50 mg (*Rabie et al.,* 2014). Also, *Danchuk et al.* (2020) suggested a HIS level between 50 and 200 mg/kg could have a harmful effect on consumer health,

and levels above 200 mg/kg exhibit toxic properties. *Feddern et al.* (2019) reported the toxic effects of TYR content above 100 mg/kg. For healthy people who do not take drugs from the group of monoamine oxidase inhibitors (MAOI), *EFSA* (2011) recommended a daily limit of 600 mg of TYR, 50 mg for people taking third-generation MAOI drugs and 6 mg for people taking classic MAOI drugs. PHE levels above 30 mg/kg show toxic effects on consumer health status (*Feddern et al.,* 2019). *EFSA* (2011) also suggested that information on PUT and CAD have proven insufficient to draw any conclusions on limits.

6. Conclusion

One of the major challenges in modern times is to produce adequate amounts of safe food. Due to the impact of BAs on human health, it is of great importance to prevent the excessive accumulation of these compounds in food. Controlling these compounds implies a deep understanding of the formation and monitoring mechanisms, and an ability to reduce biogenic amines during the processing and storage of meat and products. Such control of BAs would benefit consumers, public authorities, and industry. Apart from being a food safety concern, BAs also serve as an indicator of quality. Obtaining deeper knowledge about levels that could be used as guidelines in the different meat and products that are available on the market is needed. Such an endeavour requires a commitment, not only from public institutions, but also from production sectors and commercial processors, and ultimately from consumers.

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