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WORLD OF PRESERVED MEATS: AN INTRODUCTORY REVIEW

EDITED BY
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Preface

In this day and age, the global population are exposed to a variety of foods that originate from many different cultures and backgrounds. Globalization of food leads to a more heterogeneous diet for many people. With this current condition, it is important that the increasing popularity of foods from many different countries is also accompanied by an increase in the knowledge related to the food as well. This is the role that this book tries to fulfill, at least in relation to meat products around the world.

Each chapter in this book discusses a specified meat product which in general includes information such as; brief history of the product, global demands, raw material, processing steps, and regulatory information. The depth of this information varies, depending on the type of product that is being discussed. Chapters relating to a globally well known product offer a richer discussion and exposition, while other, more niche or region-specific items present rudimentary and introductory levels of knowledge. Both however, will provide valuable insights, popular commodities will be able to describe more information related to industrial level of processing. On the other hand, lesser known meat products could explain more on the cultural information or even highlight potential future developments.

The purpose of this book is not to offer detailed information on preserved meat products, nor is it intended to serve as a technical reference material. Rather, this book should be used to enrich the knowledge of readers interested in preservation of meat products from different parts of the world. Whether you are a student, professional, or simply someone who is interested in meat products across the globe, may this compilation serve as a window opener to the world of meat preservation.

Kenneth Francis Wibisono

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First and foremost, I am thankful to the contributors of this book who made it possible for me to complete this compilation. Moreover, my gratitude also goes to my valuable colleagues from the Food Technology Department (Miss Hanny, Miss Ariska, and Sir Ananditya) who were able to support the development of this book based on their expertise and knowledge. Without their support, this book would never have been as polished as it is now. It is by no means the perfect book, it is however a tremendous achievement for us to be able to work together and publish this work that could hopefully be of some use to anyone interested. I am grateful to Miss Hanny as the Head of Food Technology Department who provided constant support and guidance throughout the process. To Sir Ananditya as well, as the previous course coordinator of Meat Science and Technology imparted his experience to review this book. Special thanks to Desak Putu Ariska Pradnya Dewi for suggesting the development of this book as well as her feedback and critics.

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Editors Biography

Kenneth Francis Wibisono S.T.P., M.Sc.

In 2020, Kenneth graduated from Widya Mandala Catholic University in Surabaya with a bachelor's degree in food technology. He then continued his education in Italy by enrolling in Università di Parma's Food Safety and Food Risk Management program. It is an inter-university initiative connecting universities in Italy's food hub, Emilia-Romagna. In 2022, he earned his Master of Science degree.

In order to improve food traceability and food risk management for the safety of people and the environment, his master's thesis study focused on defining tomato terroir in a particular climate using geochemical and isotopic analysis.

Dr. oec troph. Hanny Angrainy B.Sc., M.A., M.Sc.

Dr. oec. troph. Hanny Angrainy earned the Magna Cum Laude (2012) achievement grade while completing her doctoral studies in nutritional science at Justus Liebig Universitaet Giessen (JLU), Germany. Her dissertation, which she delivered at the 2012 International Federation for Home Economics (IFHE) World Congress in Melbourne, Australia, earned her an award for one of the best presenters. Prior to receiving her doctorate, she earned two master's degrees from Germany: a Master of Arts in International Marketing from Fachhochschule Giessen-Friedberg with a Cum Laude (2005) achievement grade and a Master of Science in Nutritional Science from Justus Liebig Universitaet Giessen with a Magna Cum Laude (2008) achievement grade. Her primary research focused on Children’s Nutrition as well as their eating and buying behavior related to their surroundings and how these behaviors affect the society. After finishing her Doctor degree, she worked in the leading Healthcare and Wellness Nutrition Industry in Indonesia, where she was responsible for the projects such as; milk formula, beauty drinks, plant based beverages for pregnancy, etc.

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Ananditya Nugraha, S.T.P., M.Sc. graduated from IPB University with a Bachelor of Science and Technology in Food. After receiving the Endowment Fund for Education Scholarship (LPDP), he was able to enrol in

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Ananditya gained 5.5 years of substantial experience in the food business before taking on his current position at i3L. He developed his abilities and knowledge in key areas during this time, such as international sales market development, procurement, and quality control and assurance.

Desak Putu Ariska Pradnya Dewi S.T.P., M.Sc.

Ariska graduated from Brawijaya University with a bachelor's degree in bioprocess technology. She was awarded the Endowment Fund for Education (LPDP) scholarship to study for her master's degree at Wageningen University in the Netherlands in the same year that she graduated. Her speciality was Sustainable Food Process Engineering in Food Technology. She worked as a Product Developer Intern at one of the Belgian food firms before joining i3L. Ariska's current priorities are research on sustainable food processing and teaching at i3L.

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CHAPTER 1: LIVER PÂTÉ

Ellyn Patricia, Janice Clarisa Tissadharma, Kimberly Alecia Theo, Natasya Nobelta, Precia Aletha Widjaja

I3L University

1.1. Introduction

Description and History

Liver pâté is a traditional delicacy typically made from pig or calf liver, pork back fat, and other distinctive ingredients. Its origins can be traced back to medieval methods of preserving meat, especially game, which France eventually turned into a culinary art form, producing a variety of pâtés ranging from basic to luxury.

Figure 1.1. Chicken liver pate served with bread

It is widely consumed around the world, particularly in Europe, and is regarded as a luxurious product with notable nutritional and sensory benefits (Terrasa et al., 2015). The product is prepared by blending minced liver, fat, and meat with water and various additives, then packing the mixture into glass jars and subjecting it to thermal processing. However, due to its composition, rich in fat and non-heme iron but low in natural antioxidants, and the way it is produced, liver pâté is highly prone to lipid oxidation, which can lead to off-flavor and rancidity (Pateiro et al., 2013). To fully enjoy the luxurious taste of liver pâtés, it can be paired with crusty bread, crackers, or toast, but it can also be matched with hard cheeses, fresh vegetables, or fruit jams.

Importance of Pâté in the Market

Despite some concerns, liver pâté remains a staple in global markets due to its exceptional nutritional profile. Rich in vitamin A, it supports vision, immune function, and cellular health (McEldrew et al., 2025), while its high-quality protein aids tissue repair and enzyme production (LaPelusa & Kaushik, 2022). Additionally, it provides iron and B vitamins, particularly B12, which is vital for energy metabolism, nerve function, and preventing anemia (Obeid et al., 2019). Liver pâté provides nutrients in a food-based, bioavailable form, as opposed to artificial supplements.

Beyond nutrition, it has cultural significance, especially in French cuisine, which ensures steady demand. Liver pâté is also a typical holiday and special occasion dish in certain cultures. It is distinguished by its rich flavor and smooth, distinctive texture, which some consumers find particularly appealing. Its complex taste profile contributes to its popularity among those who appreciate bold and savory foods. Today, health-conscious consumers increasingly seek traditional, nutrient-dense foods, positioning liver pâté as both a functional and familiar choice (Oliveira et al., 2024). As markets shift toward natural and organic products, pâté's combination of heritage and health benefits reinforces its relevance.

Global/Local Demands

According to Ess Team (2025), market research expects that the worldwide pâté market will expand at a compound annual growth rate (CAGR) of 4.5% between 2021 and 2026. The growing customer demand for gourmet and elite food items, along with the growing appeal of grazing tables and charcuterie boards, are the main drivers of this rise. To support the research, a grand view research team stated that it was valued at USD 1.74 billion in 2023 and is expected to increase at a compound annual growth rate (CAGR) of 4.9% between 2024 and 2030. The demand for pates has mostly been driven by the growing appeal of Western cuisine on a global scale.

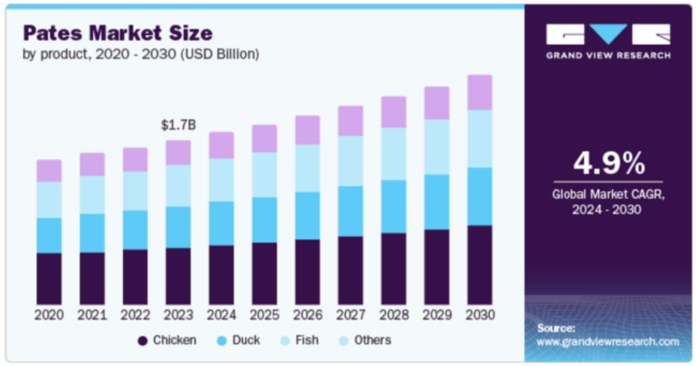

Figure 1.2. Pâté Market Size for 2024 - 2030

An analysis by Frunza et al. (2022) mentioned that the key factors influencing consumer preferences for chicken liver pâté were taste (15.63%), smell (15.63%), and appearance or color (15.63%). Other important attributes included a low content of saturated fats or the absence of added lard (12.5%), a smooth and spreadable texture (12.5%), the exclusion of synthetic colorants and preservatives (12.5%), affordability (9.37%), and the absence of flavor enhancers (6.24%).

1.2. General Information

Ingredient Selection Process

To create a high-quality liver pâté starts with a careful ingredient selection to achieve the ideal balance of flavor, texture, and nutrition (Almeida et al., 2024). The process involves choosing the right type of liver from fresh meat and incorporating complementary non-meat ingredients such as fats, aromatics, additives, and seasonings (Weiss et al., 2010). Additional components like binding agents, alcohol, or preservatives may also be included depending on whether the pâté is homemade or commercially produced. The main goal of the ingredient selection process is to create a smooth, flavorful, and nutrient-rich spread that is both palatable and safe for consumption (Totosaus-Sanchez, 2010).

Type of Meats

Liver pâté is made from the liver of various animals, most commonly poultry (chicken or duck), pork, or beef. Moreover, other types of liver, like veal or lamb can also be used. The choice of liver may influence the final flavor and the texture of the pâté (Terrasa et al., 2016). Chicken liver pâté is a popular and readily available option, known for its smooth texture and relatively mild flavor. Duck liver, or foie gras, is a more expensive and luxurious option, also known for its smooth texture and creamy taste (Porto-Fett et al., 2019). Pork liver pâté, especially when combined with pork fat, can have a richer, more robust flavor than chicken liver. Moreover, pork liver pâté is often seen as preferable due to its high nutritional value and palatability, making it a convenient and palatable option for various dietary needs (Lazárková et al., 2023). Beef liver pâté can be a good choice for those who prefer a stronger flavor, but it may require more seasoning to lessen its flavor due to its intensity (Yessimbekov et al., 2021). For other liver types like veal and lamb liver, it can offer a different flavor profile compared to the other common choices (Forouzesh et al., 2022).

Additives Needed

To enhance the richness and improve the texture of liver pâté, several additives are typically included (Terrasa et al., 2016). Fat is essential—commonly in the form of butter, cream, or pork fat—as it contributes to the pâté's signature smoothness and mouthfeel (Tiensa, 2017). Aromatics like onions, garlic, and shallots add depth, while herbs such as thyme and spices like nutmeg or allspice bring complexity (Farrimond, 2018). Alcohol, such as brandy, cognac, or sherry, is often added for a layer of sophistication (Hutchison et al., 2015). Eggs or gelatin may serve as binding agents in baked or molded versions. In commercial products, preservatives like nitrites or nitrates are sometimes added to improve shelf life and maintain color (Marcinkowska-Lesiak et al., 2023).

Meat Source and Type

The main source of liver pâté is liver. It's typically made with a mixture of finely ground or coarsely ground liver, often from pigs, poultry (like chicken), or veal (Cairncross, 2020). Additional ingredients like lard, onions, flour, egg, salt, pepper, and spices are commonly added, and the mixture is then baked. While liver is the primary ingredient, other meat or fish can also be used to create various types of pate (Yessimbekov et al., 2021).

The quality and source of the liver greatly affect the final product. Fresh, firm, and odorless liver is essential. Ethical sourcing is preferred, with free-range, organic, and hormone-free animal products being ideal for both taste and health considerations (Sexton, 2016). Sourcing from local farms or reputable butchers ensures better traceability and freshness, which is particularly important when using organ meats (Girish & Barbuddhe, 2020).

Non-Meat Ingredients

In addition to liver, non-meat ingredients play a crucial role in enhancing flavor and texture. Common inclusions are onions, garlic, and shallots, which provide aromatic richness (Kenenbay et al., 2022). Cream and butter contribute to a luxurious, smooth consistency, while herbs and spices tailor the flavor profile. Liquids such as broth, wine, or brandy are used to deglaze the pan and unify the mixture (Stobart, 2017). Some recipes incorporate acid, like lemon juice or vinegar, to brighten the taste. Binding agents like eggs or gelatin may be added for structure, especially in pâtés meant to be sliced or molded (Herz et al., 2023).

Nutritional Profile

Liver pâté is highly nutritious but should be eaten in moderation. It is rich in protein and an excellent source of iron, vitamin A, and B vitamins B12 and folate (Naumova et al., 2019). Due to its high vitamin A content, regular consumption should be monitored to avoid potential toxicity, particularly for pregnant individuals (Zając & Świątek, 2018). The fat and cholesterol content can be significant, especially when prepared with generous amounts of butter or cream, making portion control important for those with cardiovascular concerns (Mozaffarian, 2016).

Alternative Meat Sources

There are other variations or alternatives to traditional liver sources; several options are available. Turkey liver is milder and suitable for lighter pâtés. Game meats such as venison or rabbit liver provide deeper, more complex flavors (Al-Anbari, 2024). For pescatarians, fish-based pâtés made from smoked mackerel, salmon, or anchovies offer a distinct and flavorful alternative (Sen et al., 2022). Vegan and vegetarian versions use mushrooms, lentils, walnuts, and umami-rich ingredients like miso or nutritional yeast to mimic the depth and texture of meat-based pâté (Rombauer et al., 2019).

1.3. Processing Steps and Conditions

Liver Pâté Processing

The following Figure 2 explains the main processing of liver pâté. Based on research by Lazárková et al. (2023), the liver is first prepared and chopped, followed by a baking process and cooled to 30°C.

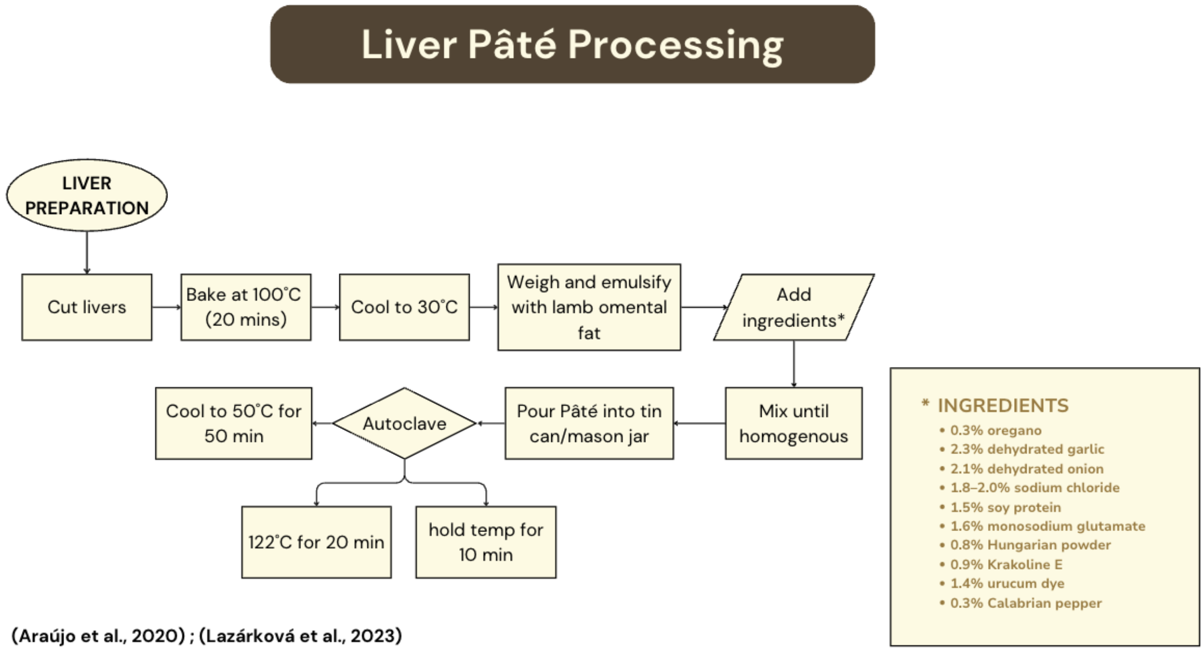

Figure 1.3. Main Processing of Liver Pâté

Then, the liver is weighed and emulsified with lamb omental fat, and other ingredients are added. The homogenous mixtures were poured into a tin or mason jar and autoclaved for sterility (Araújo et al., 2020).

Effect of Processing on Quality and Stability

Denaturation is an important process that occurs during heat treatment, leading to the aggregation of proteins and the formation of protein-protein bonds (Brodkorb et al., 2016). During sterilisation, a conformational change in the secondary and tertiary structure of proteins occurs as heat increases (Rahaman et al., 2016). A study conducted by Pětová et al. (2023) showed the stiffness of pork liver pâté when sterilized at a temperature of 122°C for 10 minutes, followed by cooling. The result showed that the final product exhibits better stiffness than the original meat. It not only ensures the sterility of the pâté but also allows longer storage time at room temperature.

However, while heat treatment through sterilization can increase the shelf life of pâté products, it may also reduce their nutritional value (Raseta et al., 2019). Moreover, an increase in temperature disrupts the native structure of polypeptides, which causes the breakdown of secondary and tertiary protein structure, resulting in a rupture of intermolecular interactions in the protein chains, such as electrostatic interactions, hydrophobic interactions, and disulfide bonds (Damodaran & Parkin, 2017). As proteins unfold during heat processing, they aggregate and undergo disulfide bond rearrangements, resulting in side chain modifications and the formation of cross-links with oxidized protein chains (Nawaz et al., 2021). This structural change can significantly impact the physical properties of meat products, such as the texture, water distribution, microstructure, and oxidative stability of the product (Zhang et al., 2023).

Likewise, at high temperatures, the pâté can accelerate the process of lipid oxidation, which results in off-flavor and reduced shelf life. This happens due to the degradation of polyunsaturated fatty acids and the generation of free radicals, causing lipid oxidation, which in turn causes protein deterioration, oxidation of heme pigments, and the development of rancid odor (Lazárková et al., 2023). These factors would affect the overall quality of the product and result in undesirable change in flavor, texture, color, and nutritional value (Wang et al., 2023).

Pate is a good source of vitamins, which include vitamin A, B12, and other B vitamins (B1, B2, B3, B5, and B6) (Andrii &Yevhen, 2022). A study states that in past years, the use of retinol and its esters in animal feed often resulted in high levels of vitamin A in animal-derived foods, especially in pig, bovine, and sheep liver and liver-based products (Schendel et al., 2022). This indicates that liver pâté is a highly nutritious product; however, high thermal processing steps such as sterilization (at 121.1˚C) can lead to significant degradation of these heat-sensitive vitamins, particularly vitamin A and most of the B-complex vitamins.

Sterilized products tested in various studies show a significant decrease in vitamin B1 (thiamine) content due to high-temperature processing. For example, a study on milk processing reported that sterilization at 122.6˚C, with holding time up to 6 hours resulted in thiamine losses of 10% (Dewi et al., 2019). Although this study focuses on milk, the findings are relevant for meat-based products like pork liver pâté, which undergo similar thermal sterilization processes.

Another study identified that a temperature of 70 °C is optimal to minimize the reduction of these sensitive vitamins during processing (Kadakal et al., 2017). This is particularly relevant for products like pork liver pâté, where processing occurs at temperatures exceeding 100 °C, which can lead to significant losses of these vitamins.

As for vitamin A, a study treated vitamin A palmitate with a temperature of 80 °C for 15 min and a degradation rate of 60% was observed. When the temperature was increased to 100 °C (30 min), vitamin A was completely degraded (Tian et al., 2023).

1.4. Regulatory and Labeling Requirements

Specific Rules and Related Regulatory Needs

Some specific rules and regulations have to be followed when producing and selling liver pâté. The rules and regulations may vary in different countries and regions. For example, the United States Department of Agriculture's Food Safety and Inspection Service (FSIS) has established guidelines stating that chicken liver must be thoroughly cooked to an internal temperature of 73.9°C to effectively destroy harmful microorganisms and prevent their growth. Moreover, high-pressure processing (HPP) is also known to effectively control pathogens in chicken liver.

Aside from processing, washing can also control the growth. Washing the chicken liver with organic acid for 2 minutes at 21°C, such as 5% lactic or 5% ethanoic (acetic) acid, can reduce the Campylobacter counts on the surface of contaminated chicken liver by 1.5 log. However, it is important to apply antimicrobial interventions that are considered safe by FSIS, and choose a list of approved antimicrobials in 9 CFR 424.21(c) and detailed in FSIS Directive 7120.1, titled Safe and Suitable Ingredients Used in the Production of Meat, Poultry, and Egg Products. Freezing the product can also result in significant reductions in Campylobacter counts. Placing the liver at -15°C freezer can reduce the Campylobacter counts by approximately 0.8 log after 24 hours or 1.5 log after 7 days (FSIS, 2018).

The Australian Government Department of Agriculture and Fisheries has also established rules and regulations regarding liver Pate production. This regulation focuses on risk management, particularly on Listeria monocytogenes. To control this risk, the products must be tested for the presence of Listeria monocytogenes. The regulatory standards require five samples to be taken from each lot of food, and all of the samples must test negative for the bacteria. The acceptable microbiological limit is that *Listeria monocytogenes* must not be detected in 25 grams of any sample (The Australian Government Department of Agriculture and Fisheries, 2020).

Labelling for Commercial Products

The labeling of liver pate should also comply with the regulations. FSIS requires a complete list of ingredients and nutritional information. The species used must be identified in the ingredients. For single-ingredient liver products, the species must be identified in the product name. Products that contain liver in the product name must contain a minimum of 30% liver (FSIS, 2018). Moreover, FSIS also recommends including validated cooking instructions that can efficiently destroy pathogens. For example, the packaging should mention cooking the liver pate to an internal temperature above 73.8 °C or frying the inoculated liver at 140°C for >8 minutes.

If the product is not fully cooked, the packaging must clearly mention that it has to be cooked. This is best conveyed through language like "cook and serve," "needs to be fully cooked," "see cooking instructions," or "cook before eating" (FSIS, 2018).

Authentications

Animal authentication in meat products is important to ensure food safety and promote fair trade, which allows consumers to make an informed decision. It is also important to ensure that the meat product is authentic and not adulterated. For liver pâté, it is important to ensure that the product contains at least 30% liver (FSIS, 2018). Methods such as protein or DNA analysis are usually employed to validate the meat's authenticity (Kalam et al., 2023). Multiple PCR methods have been used for the authentication of meat products. This method allows the analysis of new species-specific primers based on the mitochondrial DNA sequences (Cai et al., 2021). Other methods, such as liquid chromatography-mass spectrometry (LC-MS), are a proteomic method that identifies the peptide markers unique to pork liver tissues (Stachniuk et al., 2023).

1.5. Recent Studies and Future Improvements

Emerging Trends

Various high-fat ingredients, such as butter, animal fats, or cream, are added to liver pâté to enhance its texture and mouthfeel, which in turn raises its saturated fat content (Tiensa et al., 2017). Nowadays, the demand for low saturated fat products continues to increase are consumers have become more health conscious. This can be achieved by substituting high-fat food additives with alternatives that are lower in fat and contain more unsaturated fats. Substituting animal fats with healthy vegetable oil, along with gelled emulsion, can improve its nutritional value. Moreover, vegetable oil is known to improve the liver pâté spreadability as it reduces the firmness and hardness of the product (Botella-Martínez et al., 2024).

Several types of vegetable oil, such as canola oil, have been incorporated into liver pâté formulation. Full replacement of beef fat with liquid canola oil produces a firm and rubbery texture, which is undesirable in liver pâté. Therefore, liquid canola oil must be used in combination with an emulsifier such as xanthan gum and sodium caseinate, and only 50% of the meat fat can be replaced. This will result in liver pâté with a softer texture and better spreadability (Barbut et al., 2020). However, incorporating unsaturated vegetable oil can result in challenges as it is more susceptible to oxidation and rancidity (Wang et al., 2023).

Aside from vegetable oil, oleogels can be used in liver pâté formulation. Oleogel is a semi-solid gel with liquid oil entrapped in its network. It transforms unsaturated vegetable oil into a solid system that efficiently entraps liquid oils. Aside from lowering lipid saturation, oleogels can improve the textural properties, increase nutrient bioavailability, and form emulsions (Ferdaus et al., 2024). Additionally, the oleogel structure can protect oil from oxidation as it immobilizes the oil inside the food product structure (Hwang et al., 2018). According to Županjac et al. (2023), the utilization of sunflower oleogel improves the texture and spreadability of liver pâté, which increases the sensory acceptability. Furthermore, sunflower oleogel also decreases the backfat content and increases the proportion of unsaturated fat in the product.

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CHAPTER 2: PASTRAMI

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2.1. Introduction

Brief History of Pastrami

Pastrami is a dry-cured, seasoned, non-heated meat product that undergoes multiple preservation processes, including brining, smoking, and drying, to prolong its shelf life and develop complex sensory attributes. It is cured by table salt, nitrate, or nitrite for meat and seasoned with garlic and fenugreek (Sorour et al., 2024). The origin of pastrami can be traced back to the 19th century in Romania, where shepherds traditionally prepared a similar product known as *pastramă* as a method of preserving meat (Hanratty & Cawley, 2024). Historical records indicate that Romanian Jewish immigrants introduced *pastramă* to the United States around the 1870s, where it evolved into what is now known as pastrami, particularly popular in New York delicatessens. The traditional method employed involved dry-curing meat with salt and spices, followed by smoking and aging, primarily using beef brisket due to its structural and organoleptic suitability, finally cutting it into thin slices for consumption (Gürün et al., 2022).

Figure 2.1. New York delicatessens selling pastrami in the 1870s

Multiple types of pastrami have evolved globally, each reflecting regional dietary preferences and local availability of ingredients. In Argentina, pastrami is locally referred to as *pastrón,* and has undergone a process of Jewish gourmetization, particularly within the gastronomic landscape of Buenos Aires, where it is usually served in sandwich form (Jiménez, 2023). Another country that consumes pastrami is Egypt, which calls it *basturma*, and it is generally made not only from beef but also from lamb, water buffalo, goat, and camel (Abd-Elghany et al., 2020). *Bastruma* is typically served with crackers or potato chips. In Romania, *pastramă* is often produced from beef, pork, or lamb and is traditionally dry-cured and cold-smoked, served traditionally with mamaliga (cornmeal porridge). These adaptations reflect the influence of cultural and religious factors on processing and formulation techniques, resulting in diverse textural and flavor profiles.

Figure 2.2. Pastrami traditionally served with mamaliga in Romania

Romanian beef pastrami, when subjected to traditional dry-curing and cold smoking, exhibits distinct sensory properties. The product is characterized by a firm, chewy texture, with a dark exterior resulting from Maillard browning during smoking and a reddish-pink interior due to the curing process (Lequeux-Dincă et al., 2024). Flavor perception encompasses dominant umami and savory flavors, complemented by the aromatic complexity of garlic, pepper, and fenugreek paste, which are commonly used in traditional Romanian spice blends (Karabıyıklı et al., 2015). The smoky aroma, combined with the dense protein matrix, contributes to a prolonged flavor release and a satisfying mouthfeel.

2.2. General Information

Raw Materials for Pastrami Production

To produce a Romanian pastrami, cuts such as neck or shoulder are commonly used due to their flavor and the moderate amount of fat, which makes them suitable for curing and drying. Another type of meat that can be utilized is lamb and pork. A modern variation of pastrami, such as American pastrami, typically uses beef brisket, navel plate, or round cut. The brisket cut of beef is preferred due to its balanced ratio of fat and meat. This cut is particularly suitable for pastrami, as it retains moisture well during cooking, resulting in a tender and juicy final product (Cardoso et al., 2020). As an alternative, buffalo meat, turkey, and other poultry can serve as substitutes for beef in pastrami production (Gürün et al., 2022).

The curing process is crucial in pastrami preparation, and a specific curing combination is necessary to ensure preservation, flavor development, and microbial safety. This curing mixture typically consists of salt, nitrites, sugar, and various spices, such as black pepper, cloves, nutmeg, and coriander. Each component contributes specific functions. Salt enhances flavor, inhibits microbial growth, and facilitates protein extraction for improved binding. Sodium nitrite, on the other hand, preserves the color of the meat and prevents the growth of *Clostridium botulinum*. Spices are added not only to improve the overall flavors but also to utilize their natural antimicrobial and antioxidant properties (Abd-Elghany et al., 2020).

In addition to the curing process, pastrami is traditionally coated with a spiced paste known as *seasoning çement*, which further enhances its sensory qualities and extends shelf life. Fenugreek paste is a spreadable mixture made from fenugreek flour, various spices, garlic, salt, and water. This paste contributes to a distinctive flavor and aroma to pastrami while also improving its physicochemical and microbiological properties (Erginkaya & Konuray, 2016). Moreover, the incorporation of fenugreek paste has been shown to increase moisture retention and reduce cooking weight loss, resulting in a juicier and more appealing final product (Patriani et al., 2024).

2.3. Processing Steps and Conditions

Processing Steps

According to Gürün et al. (2022), pastrami is made from uncooked bovine meat and prepared through a process that includes curing, washing, pressing, drying, coating with fenugreek, and a final drying step, as seen in Figure 3.

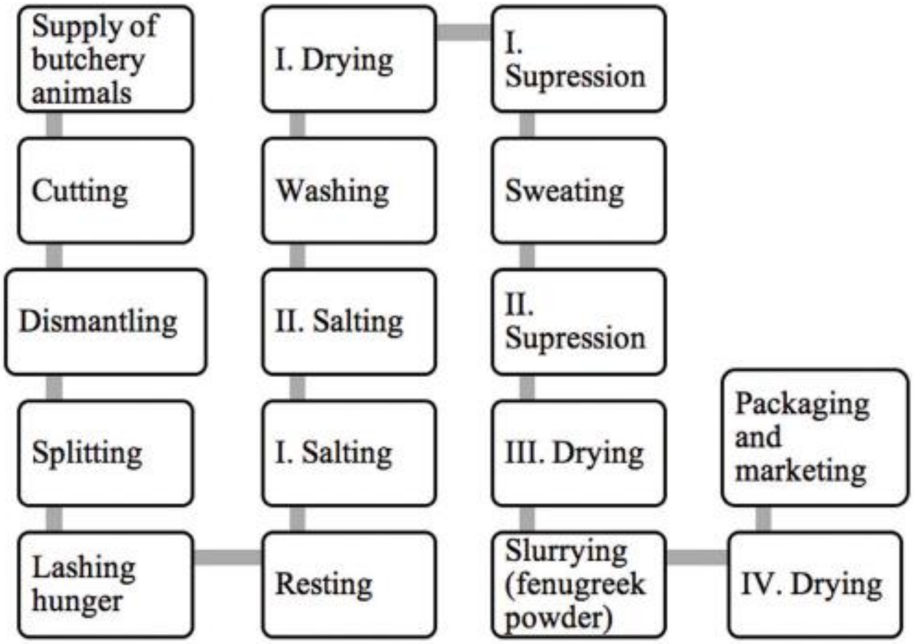

Figure 2.3. General flow chart of pastrami production
(Gürün et al., 2022)

Since it is consumed raw, pastrami requires high-quality meat, which is closely tied to the animal's health (Abd-Elghany et al., 2020). Suitable meat typically comes from cows, young bulls (tosun), or non-sterilized buffalo (toska) within an age range of 3 to 6 years (Gürün et al., 2022). In contrast, meat from oxen, female buffalo, heifers, or animals that are very young or old is generally not preferred (Akköse et al., 2018). To make pastrami, the process involves two main parts, including preparation and main processing, as follows.

Preparation Steps

The preparation steps are primarily based on a study conducted by Gürün et al. (2022). For pastrami production, it is crucial to start with healthy, well-fed, and stress-free animals to ensure the production of high-quality meat. Proper handling and resting before slaughter help prevent defects such as PSE (pale, soft, exudative) and DFD (dark, firm, dry), which can impact meat quality (Faucitano, 2018). Slaughtering should occur at least 8 hours after feeding to reduce microbiological risks. After slaughter, the meat undergoes rigor mortis during resting, which firms the muscles, making them easier to handle and improving tenderness and flavor (Joo et al., 2023). The meat is then tightly tied or lashed to maintain its shape during curing and drying, allowing seasonings and smoke to penetrate evenly. Once rigor mortis begins, muscles are separated from the carcass and classified into cuts such as arm, thigh, back, and brisket. Each cut has different muscle structures, fat content, and tenderness, which affect how the meat cures, dries, and develops flavor (Listrat et al., 2016). During dismantling, unwanted parts, such as bones, excess fat, and connective tissues, are trimmed to create uniform pieces ready for the next processing steps, ensuring consistent texture and quality in the final pastrami.

Main Process

The main processing steps are also primarily based on a study conducted by Gürün et al. (2022). Salt plays a crucial role in curing pastrami due to its antimicrobial properties. Table salt (NaCl) not only enhances flavor and aroma but also helps preserve the meat by drawing out moisture and preventing harmful microbial growth (Vidal et al., 2020). This loss of moisture initiates the curing process, which protects the pastrami and develops its unique flavor. Proper salting is crucial for extending the shelf life and ensuring the meat is safe to consume. During curing, salt is applied in two stages—first and second salting—on both the front and back sides of the meat. However, using salt alone can make the meat hard and dark, so other ingredients, such as nitrate, nitrite, ascorbic acid, and sugar, are added to tenderize meat, prevent unwanted color changes, and give pastrami its characteristic pink-red hue (Cantwell & Elliott, 2017).

After curing, the meat undergoes washing to remove excess surface salt. This step prevents oversalting, which can cause off-flavors and dryness in the final product. Washing also cleans the meat to remove residues that might block moisture evaporation during the drying process (Mediani et al., 2022). The meat is soaked in cold water to remove remaining salt, then hung on shelves to prepare for drying.

Drying reduces the meat's water content to lower water activity and balance moisture between the product and the environment (Mediani et al., 2022). This stage is crucial for preservation, as it limits the growth of microorganisms. The first drying phase removes moisture from the surface, thereby improving shelf life and facilitating the development of flavor and texture. It also firms the pastrami, making it safe to eat. Depending on weather conditions, drying can last 2-3 days or up to 10-15 days in colder climates (Gürün et al., 2022). During drying, changes occur in the meat's texture, color, and aroma.

Pressing begins after drying. Cold meats are stacked and pressed at 0.9-1.0 kg/cm^2 for one day (Gürün et al., 2022). This cold pressing shapes the pastrami, making it firm and compact by removing air pockets and moisture. It enhances texture, appearance, and mouthfeel, creating a dense and uniform structure.

Sweating follows as the second drying stage, where the meat is hung in the sun for 1-3 days, or 8-10 days in cold weather (Gürün et al., 2022). During sweating, fat softens and slightly melts, redistributing evenly inside the meat. This improves juiciness, texture, and flavor by blending the fats throughout (Schumacher et al., 2022). After sweating, a second pressing is done, but for a shorter time, because pressing hot meat too long can damage its structure.

The third drying stage further reduces moisture, increasing firmness and stability while extending shelf life by lowering water activity. After this drying, the meat is carefully taken off the racks and inspected. Any shape defects are corrected to ensure uniformity. Then the pastrami is dipped into a fenugreek-based paste called *cemen*, starting the fenugreek coating process. This coating gives pastrami its distinctive taste, aroma, and color, while also protecting it from over-drying and microbial contamination by acting as a protective barrier.

Figure 2.4. Fenugreek flour

The fenugreek paste is made from fenugreek flour (*Trigonella foenum-graecum*), garlic, red pepper, water, and spices (Figure 2.4.). Typically, the mix contains 25-50% fenugreek flour, 20-35% garlic, and 7-15% red pepper, with water added to achieve the desired consistency (Gürün et al., 2022). Studies show that an optimal formula consists of approximately 50% water, 20% fenugreek flour, and 10% garlic for optimal quality and microbial control (Çakıcı et al., 2015). The pastrami is soaked in this paste at around 10°C for 1 to 4 days to absorb flavors and mature fully. After soaking, the product is hand-wrapped tightly to remove air pockets, which helps the coating adhere and form the product's final shape. The fenugreek paste typically accounts for 5-15% of the meat's total weight before the final drying stage.

The fourth and final drying stage involves hanging the fenugreek-coated pastrami in open air for 1 to 7 days. This drying solidifies the spice coating, giving the pastrami its firm texture. It also ensures the meat reaches the optimal moisture level for safe packaging, which extends shelf life and completes the product preparation process. Properly stored pastrami can last 3 to 5 months at temperatures below 15°C (Gürün et al., 2022). Maintaining good ventilation and stable, cool conditions prevents spoilage and preserves quality.

Finally, the pastrami is packaged and prepared for marketing. Hygienic sealing protects the product from contamination during storage and transport. Proper packaging preserves flavor, texture, and safety until the product reaches consumers, making it an essential final step (Nayak & Dutta, 2023). Pastrami that has completed all processing and taken its final shape is usually vacuum-packed for long-term preservation (Ayas et al., 2020). Modified Atmosphere Packaging (MAP) is also commonly used, particularly for sliced pastrami, as it helps maintain freshness and quality (Zhang et al., 2015).

2.4. Effects of Processing on Quality and Stability

Pastrami Quality Limits

Table 1 shows the key quality limits for pastrami, specifying the acceptable range of the pastrami's contents based on the mass.

Table 2.1. Pastrami product features (Gürün et al., 2022)

Pastrami	Limit (by mass)
Moisture content (except fenugreek)	Max. 50%
pH	Max 6.0%
Amount of salt (except fenugreek, in dry matter)	Max 10%
Amount of fenugreek	Max 10%

Firstly, the moisture content of pastrami, excluding fenugreek, should be maintained below 50% to ensure proper texture, flavor, and stability. Regarding the acidity level of pastrami, it must be maintained at or below pH 6.0, which is crucial for preserving its quality. Moreover, the salt content in pastrami without fenugreek should be limited to 10% of the dry matter to balance the flavor, in accordance with safety standards. Lastly, the amount of fenugreek added must be capped at 10% by mass to maintain the consistency of the pastrami's flavor and prevent the flavors from being too overpowering for consumers to taste (Gürün et al., 2022).

Flavor Development

Salt plays a crucial role in enhancing the taste and aroma of pastrami. This is necessary to make the product more palatable. Moreover, the fenugreek paste contributes to the unique sensory qualities such as color, taste, and antimicrobial properties, further improving the pastrami's quality. Additionally, processes such as drying and curing can lead to the development of distinct flavors, which result from protein denaturation and lipid oxidation, resulting in a unique taste that distinguishes pastrami from fresh meat (Kim et al., 2021).

Physical and Physicochemical Properties

The texture of pastrami is influenced by the pressing and drying process, which affects its firmness, chewiness, and cohesiveness. As for the pastrami's color, it is maintained by the nitrite and ascorbic acid, which can preserve the cured meat's red appearance. Moreover, during production, the pH of pastrami decreases after curing, but it increases after post-drying. In addition, throughout the process, the moisture content of pastrami decreases, while its salt content increases over time (Kırkyol & Akköse, 2022).

Stability

Lipid oxidation is the primary cause of quality deterioration in pastrami, leading to off-flavors and undesirable color changes. To prevent this, adequate packaging methods and storage temperatures are necessary to maintain its quality. Packaging methods, such as vacuum or modified atmosphere packaging (MAP), can extend shelf life to 3 to 5 months (Rodriguez–Amaya & Shahidi, 2021). In addition, vacuum or MAP packaging is heavily dependent on temperature conditions, where, in this case, lower temperatures below 15°C are necessary to delay lipid oxidation and microbial growth, thereby improving its shelf life (Austrich-Comas et al., 2023).

2.5. Regulatory and Labelling Requirements for Pastrami

In the United States, pastrami is classified by the USDA Food Safety and Inspection Service (FSIS) as a ready-to-eat meat product. Specifically, it can fall under the category of not heat-treated shelf-stable, meaning it achieves food safety through curing, drying, or fermenting without requiring further cooking. A low-level heat treatment may be applied, but it must not be the primary method of ensuring safety. To qualify for this classification, the product must undergo FSIS inspection, where establishments are required to validate that the processing steps effectively control pathogens and ensure shelf stability (Food Safety and Inspection Service, 2020). FSIS also regulates labeling requirements. The product name must accurately reflect its processing method and composition. For example, pastrami should be labeled as "cooked pastrami" and must include a statement, such as "up to X percent of a solution," if it has been injected or marinated. The use of curing agents, such as sodium nitrite, is allowed but must not exceed 200 parts per million for immersion-cured products. All ingredients, including curing salts, spices, and any additives, must be clearly declared on the label (Figure 2.5.).

Figure 2.5. Pastrami sold in USA with label regarding percentage of seasoning solution

In the European Union, pastrami is classified as a cured and processed meat product and is subject to Regulation (EU) No 1333/2008 (Roland et al., 2024). This regulation requires that all food additives used in the curing process, such as sodium nitrite, be listed with their functional class and corresponding E-number, for example, preservative E250 (Figure 2.6.). The product name must also accurately reflect the true nature of the product, such as 'cured beef pastrami', to ensure transparency and avoid misleading consumers.

Figure 2.6. Pastrami sold in UK with additives written as E250 for sodium nitrite

In Indonesia, the authentication of pastrami may involve advanced analytical techniques, such as isotopic analysis, DNA barcoding, and Fourier-transform infrared spectroscopy (FTIR), to verify the origin, species, and processing integrity of the meat (Abd-Elghany et al., 2020). These methods are particularly important for detecting adulteration and ensuring compliance with halal standards. According to the Regulation of the Minister of Religious Affairs of the Republic of Indonesia No. 748 of 2021, halal certification is mandatory for processed meat products such as pastrami. The regulation outlines detailed requirements for halal slaughtering, ingredient verification, production facilities, and packaging. All products claiming halal status must be certified by the Halal Product Assurance Organizing Body (BPJPH) and display the official halal logo issued by the Indonesian government (Figure 2.7.). For export-oriented products, producers must also comply with the destination country's import requirements, including microbiological testing, shelf-life validation, and traceability under HACCP or ISO 22000-certified systems (Department of Foreign Affairs and Trade, 2021). Failure to meet regulatory or labeling standards may lead to product recalls, trade barriers, or legal consequences.

Figure 2.7. Pastrami sold in Indonesia with the official halal logo

2.6. Recent Studies or Future Improvements for Pastrami

Despite its popularity and nutritional value, pastrami is particularly susceptible to contamination during the manufacturing process. The process can introduce spoilage microorganisms and dangerous foodborne pathogens, most notably *Escherichia coli*. Another major concern is the presence of mycotoxins, particularly aflatoxins, that are often introduced through low-quality non-meat additives such as spices, curing agents, and seasoning pastes. A critical issue identified in recent research is that these non-meat ingredients can become major contamination sources if they are not properly sterilized or sourced from reputable suppliers. Contaminated spices and additives compromise both the safety and consumer acceptability of the final pastrami product. Ensuring the hygienic quality of these components is therefore essential to public health. HACCP-compliant spices are used to ensure safety, meaning the components were produced and handled under strict hygiene controls and monitored for hazards like pathogens and mycotoxins. These spices are traceable and certified for food safety.

Three types of beef cuts; fresh, frozen, and chilled were used to prepare different pastrami batches. The control sample is made with non-autoclaved spices and additives. Sample 2 is treated with autoclaved spices and additives, and sample 3 is a group of meat that is inoculated with *Escherichia coli* to track microbial reduction throughout the production stage. The microbial quality was assessed using aerobic plate counts and enumeration of *Escherichia coli* at various stages.

Pastrami produced using autoclaved non-meat additives showed a significant decrease in microbial counts. The result from the aerobic plate count in the treated group was reduced by over 3-4 log cycles compared to the control group. Notably, *Escherichia coli* was undetectable in the treated samples by the final drying stage, even in those that were artificially inoculated. The *Escherichia coli,* when artificially introduced into meat, was only partially reduced during early processing (curing and pressing). However, it was eliminated after the second pressing and seasoning steps in pastrami made with autoclaved ingredients. For the aflatoxin contamination test, the highest level of aflatoxin was detected in pastrami made using sterilized but low-quality spices. In contrast, pastrami made with HACCP-compliant spices showed significantly lower aflatoxin content.

The findings confirm that autoclaving spices and additives effectively reduces microbial contamination and enhances food safety without compromising flavor or functionality. The treatment allows spices to exert their natural antimicrobial properties without adding harmful bacteria or toxins. The study also underlines the importance of supply chain quality. Spices from HACCP-certified sources were safer, containing fewer aflatoxins and posing lower microbial risks. This supports a broader recommendation for producers to invest in high-quality, traceable ingredients and maintain strict hygiene protocols throughout processing. Additionally, temperature management during pressing and drying stages emerged as a key factor in microbial control. These steps should be carefully controlled to limit bacterial growth and ensure final product safety (Abd-Elghany et al., 2020).

Another recent study aimed at improving pastrami has explored the use of fermented milk permeate as a natural marination agent to enhance the safety, quality, and sensory attributes of the product. Pastrami is prone to deterioration during storage due to microbial spoilage, lipid oxidation, and physicochemical degradation. To address these challenges, researchers investigated the effect of marinating pastrami meat in milk permeate fermented with lactic acid bacteria (LAB), specifically *Lactobacillus paracasei* and *Lactobacillus pentosus*. To conduct the study, beef meat was divided into four treatment groups. The control group (C) received no marination. Treatment one (T1) was marinated in unfermented milk permeate, while treatment two (T2) and treatment three (T3) were marinated in milk permeate fermented with *L. paracasei* and *L. pentosus*, respectively. All samples were processed into pastrami and stored at 5 ± 1°C for 60 days. Periodic analyses were performed to measure chemical indicators, such as peroxide value (POV), free fatty acids (FFA), TBARS, and pH, as well as microbial quality (total viable count, fungi, coliforms, *Staphylococcus* *aureus*, and LAB presence). Sensory properties, including color, flavor, tenderness, and overall acceptability, were also evaluated.

The results demonstrated that pastrami samples in the T2 and T3 groups showed the greatest physicochemical improvements. These treatments had the lowest values of POV, TBARS, and FFA, indicating reduced lipid oxidation and rancidity. Their lower pH levels reflected greater acidification from LAB fermentation, and a higher degree of protein breakdown (proteolysis) contributed to improved meat tenderness. From a microbiological perspective, no samples tested positive for *Staphylococcus aureus* or coliforms. However, T2 and T3 had the highest LAB counts and showed no fungal growth, while some fungi were detected in the control (C) and T1 samples. This antimicrobial effect is likely due to bacteriocins produced by LAB strains during fermentation. In terms of sensory evaluation, T2 and, especially, T3 were rated higher in terms of tenderness and appearance. All treatments were deemed acceptable in terms of flavor, but the fermented samples had a lighter red color, influenced by the acidity developed during marination.

In conclusion, marinating pastrami in fermented milk permeate significantly improved its overall quality, microbial safety, and sensory appeal. The treatments using *L. paracasei* (T2) and *L. pentosus* (T3) were particularly effective, outperforming both the control and unfermented permeate treatments. These findings support the application of naturally fermented milk permeate as a sustainable and functional solution in pastrami production (Abd-Eltawab & Elgarhi, 2019).

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CHAPTER 3: *KATSUOBUSHI*

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3.1. Introduction

Brief History

Katsuobushi in Japan refers to dried, fermented, and smoked skipjack tuna *(Katsuwonus pelamis)*, an important food additive in Japanese cuisines as it creates a flavorful and traditional Japanese flavor in dashi (Japanese fish broth) (Park et al., 2024) (Figure 3.1). According to history, *katsuobushi* production has existed since the Edo Period (17th century), involving boiling, smoking, and fermenting as its processing methods. In the past, this *katsuobushi* was sun-dried to prevent spoilage in fish, thus increasing its shelf life. Then, the preservation method was refined by smoking and fermenting it with xerophilic *Aspergillus* molds, especially *Aspergillus chevalieri* and *Aspergillus pseudoglaucus* (Takenaka et al., 2025). All these methods combined changes the tuna's overall flavor, aroma, texture, and nutritional value due to (Gómez et al., 2020).

Figure 3.1. Katsuobushi and its shredded form

A dried bonito dashi has a complex flavor profile that includes a mix of sourness, bitterness, and umami (Kondoh, 2023). The compounds that contribute to the umami flavor are L-glutamate, inosine monophosphate (IMP), and amino acids (Satake et al., 2024). Aside from its umami-contributing flavor, katsuobushi is high in bioactive peptides, proteins, and amino acids with anti-inflammatory and anti-hypertensive properties (Chiesa et al., 2016; Shahidi & Saeid, 2025). Since it is derived from skipjack tuna, its marine bioactive peptides are also able to reduce the risk and control the progression of cardiovascular diseases (CVDs).

The current trends in the market involves incorporating *katsuobushi* in various foods, often referred to as dried bonito flakes. They are often used as flavor enhancers to provide a unique and distinct savory taste in other countries as well, also improvised by consumers around the world (Park et al., 2024). Especially in the high demands for more umami-substances, *katsuobushi* may soon be sought after by cuisines around the world (Yamamoto & Inui-Yamamoto, 2023).

3.2. General Information

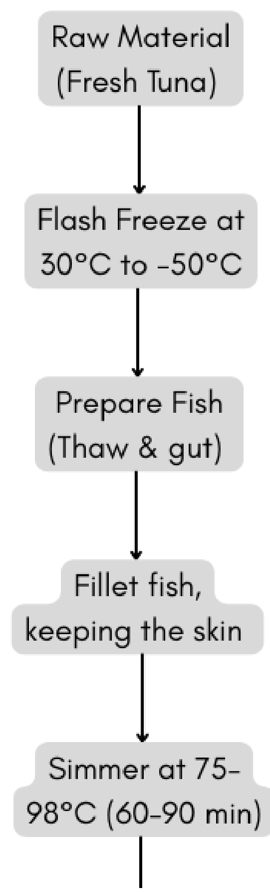
Katsuobushi is a traditional Japanese ingredient made from bonito, or skipjack tuna, a saltwater fish valued for its quality, size, and rich fat content (Yu et al., 2023). Naturally gluten-free and abundant in amino acids, katsuobushi serves as both a flavorful seasoning and a highly nutritious addition to meals. Through a meticulous process involving boiling, smoking, sun-drying, and fermentation with *Aspergillus glaucus* or *A. sydowii*, the fish is transformed into a dense, umami-rich product (Takenaka et al., 2023). In bonito extract, hypoxanthine and histidine are identified as the main putrefaction compounds, while inosine-5′-monophosphate (IMP) and glutamic acid contribute to its distinctive savory flavor (Chen et al., 2019).

Due to water removal and fermentation, *katsuobushi* is remarkably high in protein (77g per 100g) and rich in essential nutrients such as iron, potassium, and vitamin B (Yu et al., 2024). It also contains selenium, which protects cells from oxidative damage and supports immune and thyroid function. Vitamin B12 aids in cell division and mental clarity, while niacin (B3) plays a role in energy production and nervous system health. Additionally, phosphorus supports bone strength and cellular function, and trace amounts of iron and thiamin (B1) contribute to red blood cell formation and energy metabolism. *Katsuobushi* also offers health benefits, including antioxidative properties, antihypertensive effects, and mood-enhancing qualities through GABA receptor modulation (Zhao et al., 2024)

For those seeking plant-based alternatives, dried shiitake mushrooms and kombu seaweed provide similar umami flavor (Ramesh et al., 2025). Shiitake mushrooms offer a meaty texture and robust flavor ideal for dashi broth, soups, and stir-fries (Kong et al., 2019). On the other hand, kombu, rich in glutamic acid, or a blend of miso paste, soy sauce, and agar-agar, can also replicate *katsuobushi*'s savory profile in vegan and vegetarian dishes (Kurihara, 2015). These substitutes ensure that the distinctive taste and nutritional benefits of umami-rich ingredients remain accessible to all dietary preferences.

3.3. Processing Steps and Condition

Figure 3.2. below outlines the traditional katsuobushi production process. The production process starts from fresh tuna to the final product, including flash-freezing, simmering, smoking, mold fermentation, and packaging. Further explanations regarding each step will be covered in the next section.



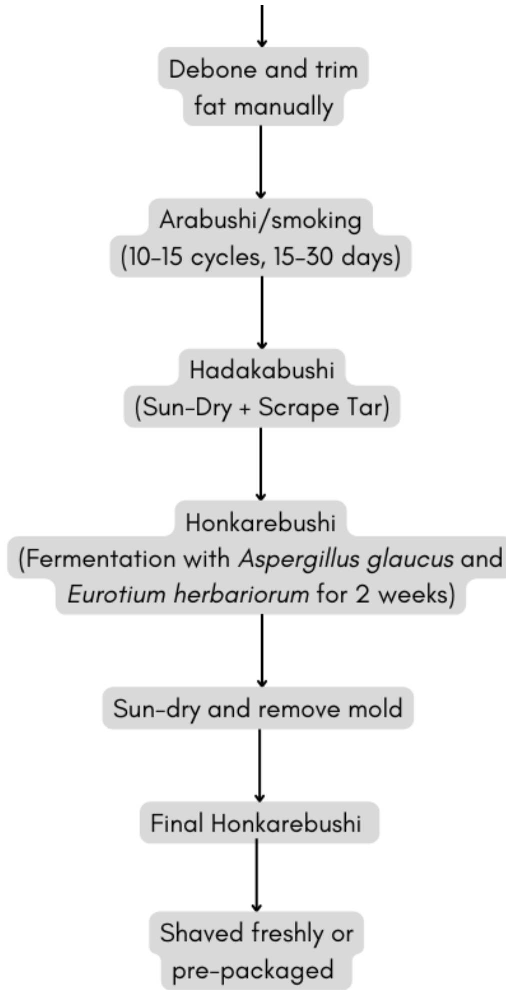


Figure 3.2. Katsuobushi Traditional Production Process

Effect of Processing on Quality and Stability

Initial Freezing and Filleting

The *katsuobushi* processing begins with the immediate flash-freezing of the freshly caught skipjack tuna at extremely low temperatures ranging from -30 to -50 °C. This critical first step preserves freshness by rapidly halting autolytic enzymatic activity, particularly cathepsins and other proteases, as well as microbial growth that could otherwise degrade muscle proteins and generate off-flavors (Fitri et al., 2022; Iwata et al., 2015). Flash-freezing also preserves ATP and inosine monophosphate (IMP), which later degrade into inosinic acid during simmering, contributing to the characteristic umami profile that enhances its taste and leads to sensory acceptance (Indriani et al., 2024). In addition, rapid freezing minimizes the formation of large ice crystals, thereby maintaining the integrity of muscle fibers and preventing structural collapse (Poudyal et al., 2024; PennState Extension, 2018). This helps ensure even drying in later stages and enhances protein stability. Furthermore, lipid oxidation is minimized at these low temperatures, preserving omega-3 fatty acids from rancid degradation and the formation of undesirable volatiles like hexanal (Suárez-Medina et al., 2024)

Simmering

After thawing, the tuna is gutted, filleted, and cleaned before undergoing a simmering process at 75–98 °C for 60 to 90 minutes. This thermal step denatures both sarcoplasmic and myofibrillar proteins (such as myosin and actin), firming the flesh and creating a porous structure that facilitates smoke penetration and moisture loss in subsequent steps (Glorieux et al., 2017). Additionally, this process is a more gentle thermal process compared to boiling, which does not damage the filleted tuna as well as preserves the nutritional quality of the fish (Chew et al., 2024; Pasaribu et al., 2020). Simmering also significantly reduces the microbial load by eliminating spoilage bacteria such as *Vibrio* and *Pseudomonas* species (New York State Department of Health, 2023). Heat-induced enzymatic activation, particularly of 5'-nucleotidases, converts preserved IMP into inosinic acid, enhancing the product's umami potential (often reaching 700–800 mg/100 g) (Haskó et al., 2014). Concurrently, glutaminase activity releases glutamic acid from glutamine, laying the groundwork for synergistic umami perception when paired with glutamate-rich ingredients like kombu (Ito et al., 2013).

Deboning and Cleaning by Hand

Once cooled, the fillets are carefully deboned and cleaned by hand. This manual precision helps retain the structural integrity of the fillet, ensuring it remains undistorted and uniform in shape, critical for producing thin, even shavings. The removal of bones and connective tissue eliminates internal cavities where spoilage organisms could colonize, further contributing to microbiological stability (Tahiluddin et al., 2022). Additionally, this step ensures consistent drying and smoke absorption across the fillet.

Smoking (Arabushi Phase)

The next phase, known as the *Arabushi* stage, involves repeated cycles of smoking and resting over a period of up to 30 days. During this time, the fillets are exposed to hardwood smoke, commonly from oak or cherry, through 10 to 15 rounds of treatment. The smoke deposits phenolic compounds such as guaiacol and syringol, which impart characteristic smoky, sweet, and medicinal notes while acting as natural antioxidants (Suryani et al., 2022; Wang et al., 2018). These compounds significantly reduce lipid oxidation, as shown by decreases of up to 60% in TBARS values and 50% in peroxide levels compared to unsmoked fish (Priya et al., 2022). The intermittent heating and resting prevent case hardening, allowing moisture to diffuse evenly from the interior and reducing water content to approximately 23–28% (Parvej et al., 2024). The resulting fillets become firm and dense, with a tar-like outer coating that serves as a protective microbial and oxidative barrier (Mouritsen & Styrbæk, 2017). The water activity drops below 0.85, effectively inhibiting the growth of spoilage organisms such as *Staphylococcus* and *Aspergillus* (Fitri et al., 2022).

Sun-Drying and Scraping (Hadakabushi Stage)

Following smoking, the fillets undergo the *hadakabushi* stage, during which they are sun-dried and scraped to remove surface tar and residual fats (Tokyo Foundation, 2019). This cleaning process eliminates oxidized compounds and bitter residues, further improving flavor and enhancing shelf stability (Chan et al., 2023). The sun exposure also aids in mild dehydration, and the removal of surface lipids prevents reoxidation. This pre-fermentation conditioning results in a lighter, more brittle texture, ideal for mold inoculation and enzymatic penetration in the next phase.

Mold Fermentation (Karebushi Stage)

The fermentation stage marks the transition to *karebushi*. Fillets are inoculated with specific mold strains such as *Aspergillus glaucus* and *Eurotium herbariorum*, which secrete proteases and lipases that degrade remaining proteins and fats into flavorful compounds (Takenaka et al., 2021). Proteolytic activity releases glutamic acid and generates peptides with kokumi properties, enhancing mouthfeel and depth of flavor, while lipases produce free fatty acids that contribute to broth clarity (Heres et al., 2023). Mold metabolism also leads to the generation of ethyl esters and methyl ketones (e.g., 2-heptanone), adding fruity and cheesy aromatic notes detectable via GC-MS (Zhang et al., 2023). Simultaneously, mold hyphae extract residual internal moisture, reducing water activity to 0.70 - 0.75 and creating an inhospitable environment for bacterial growth (Ruijten et al., 2021). The molds also produce antimicrobial compounds and create a competitive exclusion zone that inhibits pathogens such as *Bacillus cereus*, all while showing no detectable mycotoxins when analyzed by HPLC (Du et al., 2018).

Final Honkarebushi Stage

At the end of multiple fermentation and drying cycles, the product transforms into *honkarebushi*, *katsuobushi* in its most refined and shelf-stable form. Moisture content is reduced to under 18%, resulting in a dense, woody texture with a hardness of approximately 50 N/mm² (Kikkoman Corporation, 2015). The final product is so dry and light that fillets produce a clicking sound when tapped together. Mold-derived melanins and Maillard reaction products such as furans serve as natural antioxidants, helping preserve flavor and preventing oxidative degradation during long-term storage (Liu et al., 2020). Bioactive peptides, including ACE inhibitors like Val-Pro-Pro, are also formed during fermentation, providing potential health benefits such as blood pressure reduction and antioxidative activity (Bolivar-Jacobo et al., 2025). The exceptional dryness, enzymatic conditioning, and antioxidant content render *honkarebushi* remarkably shelf-stable, allowing it to be stored at room temperature for years without spoilage, while retaining a concentrated, synergistic umami flavor that intensifies upon shaving and dissolution in broth (Spice Exotica, 2024).

3.4. Regulatory and Labeling Requirements

Regulations

Katsuobushi is exposed to considerable regulatory oversight due to the risk of contamination with polycyclic aromatic hydrocarbons (PAHs), especially benzo(a)pyrene (BaP) and the PAH4 group. These carcinogenic chemicals develop during the prolonged wood-smoking process essential to the *katsuobushi* production process (Seko et al., 2022). Studies by the Japanese Ministry of Agriculture, Forestry and Fisheries (2015) have recorded average BaP concentrations of 24-29 µg/kg in commercial products, significantly surpassing the strict limits set by key international markets. The European Union (2020) enforces strict regulations, allowing a maximum of 5 µg/kg of BaP and 30 µg/kg of PAH4 in smoked fish products. Likewise, South Korea's Ministry of Food and Drug Safety (2019) specifies a maximum limit of 10 µg/kg for BaP in dried and smoked seafood products. The rigorous international standards have established considerable trade barriers for *katsuobushi* exporters, even though risk assessment models indicate that conventional Japanese consumption patterns, where the product is utilized minimally as a flavoring agent rather than in large amounts, are unlikely to present significant health risks to domestic consumers (Seko et al., 2022). The existing rules and regulations pose an array of problems for Japanese manufacturers, who have to balance traditional manufacturing techniques with increasing global food safety standards.

The primary contradiction between conventional *katsuobushi* production methods and contemporary food safety regulations arises from the crucial smoking process that imparts the product's distinctive flavor profile. The conventional *kyuzokko* smoking technique, characterized by prolonged exposure to wood smoke for durations ranging from 14 to 30 days, is especially susceptible to the generation of PAHs. This method is essential for cultivating the product's distinctive sensory attributes (Nizio et al., 2023). The process, however, creates the ideal conditions for PAH accumulation as smoke ascends through various layers of drying fish (Sei et al., 2021). Modern smoking technologies utilizing temperature regulation, smoke filtering, and indirect heating methods could reduce PAH levels; however, numerous manufacturers argue that these alterations would significantly alter the product's original essence and flavor (Nizio et al., 2023). The Japanese food industry presently functions without set PAH restrictions for domestic products; however, rising international trade pressures and advancing scientific insights into PAH hazards might require regulatory modifications. Several manufacturers started experiments with altered smoking protocols, various wood varieties, and pretreatment techniques to decrease contamination while maintaining traditional characteristics (Seko et al., 2022). The *katsuobushi* industry has to make significant choices regarding modernization, with potential solutions that include the creation of standardized smoking protocols, the introduction of quality control measures, and the possible establishment of domestic PAH guidelines to enhance international trade while preserving product integrity.

Labeling Requirements

Japan *Katsuobushi* Labeling Requirements

In Japan, food labels are controlled by the Food Labeling Act, which is managed by the Consumer Affairs Agency (CAA). According to the Consumer Affairs Agency (2015), all labels must be in Japanese, and the product name must be written clearly, such as "*Katsuobushi*," "*Arabushi*" (which means smoked and dried), or "*Karebushi*" (which is fermented using mold). The ingredient list must specify what the product is made of, typically 100% skipjack tuna (Katsuo), and if any mold, such as *Aspergillus glaucus*, is used during fermentation, it must be included in the list. If any food additives are used, they must also be written down, although most traditional *katsuobushi* has no additives. The label must also show the net weight in grams, the best-before date (in the format of year-month-day), and how to store the product (usually in a cool, dry place, away from sunlight). The name and address of the manufacturer or seller must be included too. If the fish or raw material comes from outside Japan, the country of origin must be written. Although *katsuobushi* is typically made from a single ingredient, Japan still requires fish to be listed as an allergen, especially for individuals who may have allergies. If the product is made using non-traditional processing methods, that must also be explained. While nutrition facts are not always required, they must be added if the product makes any health or nutrition claims. Some packages may also include serving suggestions, such as using *katsuobushi* to make *dashi* (Japanese soup stock) or as a topping for dishes like *okonomiyaki*.

Indonesia *Katsuobushi* Labeling Requirements

In Indonesia, food labeling is controlled by BPOM (Badan Pengawas Obat dan Makanan), especially under Regulation No. 31 of 2018. The label must be in Bahasa Indonesia, and the product name should be clear and easy to understand, such as "*Katsuobushi* (Ikan Cakalang Serut Kering)." The ingredients must be listed, showing that it is made from skipjack tuna (ikan cakalang), and if mold is used for fermentation, it should also be mentioned. The net weight must be written in grams, and the expiration date must be in the format of day-month-year. A production code or batch number is also needed for tracking. The label must include the name and address of the producer, and if the product is imported, it must also list the importer or distributor in Indonesia. The country of origin must be stated clearly. Every product must be registered with BPOM and display an official number, such as ML (for imported foods) or MD (for local foods). A clear allergen warning must be written with the phrase "Mengandung alergen: ikan" (contains allergen: fish), and this must be written in bold letters. Storage instructions should also be included, typically advising to store the product in a cool, dry place. If the product makes nutrition or health claims or is fortified, then a nutrition facts table is required. If a product is claimed to be halal, it must display a halal certificate and show the BPJPH or MUI halal logo on its packaging. Other helpful information, such as usage instructions (for broth or topping), serving sizes, or preparation tips, can also be added to assist consumers.

3.5. Recent Studies and Future Improvements

Ensuring the sustainability of skipjack tuna is very important to maintain the production stability of *katsuobushi* as it is its main ingredient. Skipjack is known to be one of the most sustainable tuna fishery species because of its rapid growth and short lifespan (Peter et al., 2023). Especially when skipjack tuna is one of the most fished tuna species globally, reaching 60% of all tuna species, overfishing needs to be prevented (Druon et al., 2017).

Future improvements in the utilization of *katsuobushi* focus on increasing the value of its byproducts, especially after broth extraction. Although the residues are currently considered to be low in value, they still contain significant amounts of water-insoluble proteins with potential to be sources of bioactive compounds. These nutrients are then extracted using sustainable and gentle hydrolysis techniques to improve the recovery and support the production of functional food ingredients. In addition, the bioactivity of these hydrolysates could increase their appeal and promote the upcycling of *katsuobushi* waste into high-value, health-promoting products (Takenaka et al., 2023).

A research by Cheung et al. (2015) isolated *katsuobushi* oligopeptide, a linear pentapeptide known to produce angiotensin-I converting enzyme inhibitory activity. This peptide is often incorporated into anti-hypertensive drugs to treat patients with high blood pressure in their systemic arteries (Oparil et al., 2019). Currently, peptide drugs have undergone a series of clinical trials to ensure its safety and efficacy as therapeutic drugs (Jülke & Beck-Sickinger, 2025).

Katsuo extracts have been observed to contain anti-inflammatory and blood brain barrier consolidation effects and non-neuronal cardiac cholinergic system activation (Hokari et al., 2022). The BoE (bonito extract) was able to reduce systemic inflammation in a high-fat diet that uses obese mouse models. Through ELISA analysis, the results showed that BoE can reduce IL-5, IL-6, IL-13, and G-CSF (Ikebe et al., 2017). For the blood brain barrier, it helps reinforce the structure and protects the central nervous system from inflammation.

The findings showed that mold fermentation could be an effective method for improving the color characteristics of *Katsuobushi* (Yu et al., 2023). This occurs because the molds secrete enzymes that degrade proteins and lipids, resulting in alterations in the dried fish's color, texture, and taste.

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CHAPTER 4: THAI *NHAM*

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4.1. Introduction

History

Nham, also spelled "Naem", is a traditional Thai fermented sausage deeply rooted in the country's rural culinary heritage, especially among communities in northeastern Thailand (Isaan) and parts of Laos, where similar versions are known as "Lam" or "Som moo" (Vo et al., 2022) (Figure 4.1.). The origins of *Nham* can be traced back to the resourceful practices of rural Thai communities who sought ways to preserve meat without refrigeration. Pork was chopped, mixed with salt, rice (or cooked sticky rice), garlic, and spices, then wrapped in banana leaves to ferment. The rice starch and salt create the conditions for lactic acid fermentation, which preserves the meat and gives it a characteristic tangy flavor (Swetwiwathana & Visessanguan, 2015). *Nham* is believed to have developed over centuries as part of broader Southeast Asian fermentation techniques used for meats, fish, and vegetables.

Figure 4.1. Thai *Nham* as sold in Thai markets

Historically, a common event for *Nham* is during *Tết*, the Vietnamese Lunar New Year, when families prepare or buy it as a festive snack and symbolic gift. Offering homemade *Nham* during this time reflects hospitality, family unity, and the spirit of sharing (Avieli, 2005). In wedding and engagement ceremonies, *Nham* is included in the food offerings exchanged between families, symbolizing respect, tradition, and the care involved in long-term commitment—its fermentation process metaphorically representing patience and readiness for marriage (Santiyanont, 2019).

Global demands

The global demand for *Nham* is experiencing a notable rise, driven by evolving consumer preferences and heightened awareness of the health benefits associated with fermented foods. As part of the broader fermented food category, *Nham* is gaining international attention for its unique flavor profile and probiotic content (Swetwiwathana & Visessanguan, 2015). In Southeast Asia, *Nham* remains a staple, deeply rooted in cultural practices and daily diets. However, its appeal is expanding beyond regional boundaries. In North America and Europe, there is a growing interest in fermented foods due to their perceived health benefits, including improved digestion and immune system support (Tamang et al., 2020). This trend is contributing to the increased visibility and consumption of traditional products, such as *Nham*, in these markets.

The fermented processed food market is projected to witness significant growth, with North America generating a revenue of USD 36.2 billion in 2023 and expected to surpass USD 265.7 billion by 2032 (Global Market Insights, 2024).

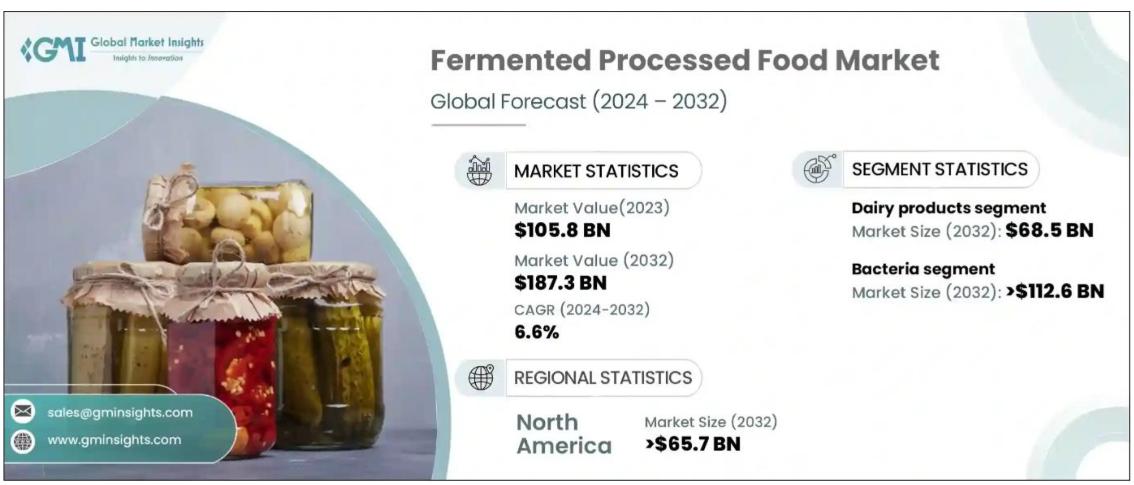

Figure 4.2. Global forecast for fermented food from 2024 to 2032

This growth is attributed to consumers' preference for natural, minimally processed foods with clean labels, aligning well with products like *Nham* (Anjali et al., 2024). Despite its growing popularity, *Nham*'s safety and quality remain paramount. Studies have highlighted the importance of controlled fermentation processes to inhibit the growth of harmful bacteria and ensure the product's safety for consumption (Santiyanont et al., 2019).

4.2. General Information

Raw Materials

Traditional *Nham* is made from minced pork and shredded cooked pork rind (Owens, 2025). In this study, pork is substituted with chicken meat to explore a more acceptable and potentially halal-friendly alternative for the Indonesian market. Chicken meat, particularly lean breast or thigh, is chosen for its mild flavor, lower fat content, and widespread availability (Kralik, 2018). The substitution aims to maintain similar fermentation behavior while offering a product that is more culturally and religiously suitable.

Non Meat Ingredients

The standard non-meat ingredients include cooked rice (as a carbohydrate source for microbial fermentation), garlic, salt, sugar, and fresh chili, which contribute to both flavor and fermentation dynamics. Cooked chicken skin may be considered as a textural substitute for pork rind, although its lower collagen content may influence the final texture (Shang et al., 2022).

Additives Needed

Sodium nitrate is traditionally used to inhibit pathogenic bacteria and contribute to the formation of the pink color (Szymański et al., 2020). However, for a more natural formulation, alternatives such as celery powder (a natural nitrate source) or omission altogether might be explored, depending on regulatory and consumer preferences (Flores Llovera, Mónica & Toldrá Vilardell, Fidel, 2020).

Nutritional Profile

Compared to pork, chicken is generally lower in fat and calories while still providing a good source of high-quality protein (*Animal Husbandry and Nutrition*, 2018). This modification may result in a healthier product with lower lipid content, but it might require textural adjustments due to the reduced fat and connective tissue. Additionally, chicken contains less saturated fat, which can contribute to a more heart-friendly nutritional profile (Fagerhøi, 2017). The lean nature of chicken also aligns well with current consumer trends favoring lower-fat and high-protein foods, making it a suitable substitute in efforts to produce more health-conscious meat-based products (Shahida Anusha Siddiqui et al., 2023). Furthermore, chicken is rich in essential nutrients, including B vitamins (especially niacin and B6), phosphorus, and selenium, which are crucial for energy metabolism and immune function (Shastak & Pelletier, 2023). These benefits support the development of functional food products targeting wellness and balanced nutrition.

Alternative Meat Source

The use of chicken instead of pork not only meets potential dietary restrictions but also opens up a broader market opportunity in predominantly Muslim regions like Indonesia (Ahamat, 2021). It also aligns with global trends toward leaner, lower-fat meat options in fermented products (Boukid et al., 2023).

4.3. Processing Steps and Conditions

Preparation

To prepare *Nham*, pork meat, preferably with a good amount of fat for enhanced flavor and texture, is first thoroughly washed with clean drinking water. The meat is then blanched by boiling it for approximately 10 minutes to eliminate surface bacteria and improve the final product's hygiene. After blanching, the pork is patted dry with a kitchen towel to remove excess moisture and then ground using a food processor until it reaches a fine consistency suitable for fermentation (Santiyanont et al., 2019; Ismail, 2024).

Meanwhile, the sticky rice component, which plays a critical role as the carbohydrate source for fermentation, is prepared by boiling it for about 40 minutes. During this process, finely minced garlic, salt, sodium nitrite, a small amount of sugar, and white pepper are added to the rice to infuse flavor and promote the growth of lactic acid bacteria. Additionally, thinly sliced, cooked pork skin may be incorporated into the mixture to provide a unique, chewy texture that enhances the sensory profile of the final product (Tangkham et al., 2022; Ismail, 2024).

Main Processing

Once both the pork and rice components are prepared, they are combined and further blended using a food processor to ensure a homogeneous mixture. This blend is then seasoned with additional salt, sugar, and flavor enhancers to balance the taste. The seasoned mixture is carefully packed into square-shaped polyethylene (PE) plastic sheets, which help shape the product and maintain hygiene during the fermentation period (Ly et al., 2018).

Fermentation is conducted at a controlled temperature of 37°C for 72 hours, allowing beneficial bacteria to proliferate and develop the characteristic tangy flavor of *Naem*. After fermentation, the product is transferred to refrigeration at 4°C to halt the fermentation process and preserve freshness until consumption. This preparation method reflects the traditional knowledge and modern adaptation of *Naem* production, ensuring both food safety and sensory quality (Ismail, 2024).

Effect of Processing on Quality and Stability

The processing techniques employed in the preparation of *Naem play* a crucial role in determining both its quality and shelf stability. Each step, from meat selection and preparation to fermentation and storage, significantly influences the microbiological safety, texture, flavor profile, and preservation of the final product. For instance, the initial blanching of pork not only reduces the microbial load but also helps in developing a firm texture post-fermentation. The inclusion of cooked sticky rice, enriched with garlic and seasoning, provides essential carbohydrates that fuel the growth of lactic acid bacteria, key agents in the fermentation process that contribute to the product’s characteristic sour taste and natural preservation. Moreover, the optional addition of pork skin introduces a desirable textural complexity. Temperature-controlled fermentation (typically at 37°C for 72 hours) ensures the rapid development of the desired microflora while minimizing the risk of spoilage organisms. Subsequent refrigeration at 4°C halts microbial activity, thereby extending the product's shelf life. Overall, these processing steps must be carefully controlled and standardized to ensure the consistent quality, sensory appeal, and safety of *Naem*, particularly as it gains popularity beyond its traditional markets.

Sodium nitrate inside the Naem ingredients can be replaced by *Hibiscus sabdariffa* (HS). Tangkham et al. (2022) investigate the potential of using *Hibiscus sabdariffa* (HS) as a natural alternative to sodium nitrite in Naem. Recognizing growing consumer concerns over synthetic additives, the researchers aimed to assess how varying concentrations of HS (0%, 1%, 3%, and 5%) influence the product's sensory attributes.

Table 4.1. Consumer acceptance for sensory attributes and overall liking of the four Naem treatments (Tangkham et al., 2022)

Parameter	Control	1% HS	3% HS	5% HS
Flavor	5.24	5.16	5.81	5.05
Texture	5.39	5.13	5.63	5.03
Taste	5.45	5.13	5.66	4.76
Sourness	5.42	5.47	5.34	4.74
Firmness	6.24	5.42	5.63	4.97
Overall Liking	5.53	5.11	5.76	4.82

Naem samples with 3% HS received the highest overall acceptance scores, particularly in flavor and taste, indicating enhanced consumer appeal at this concentration (Table 4.1.). The study concludes that *Hibiscus sabdariffa* can serve as a viable natural additive in *Naem*, potentially improving sensory qualities, thereby offering the meat industry an innovative product that aligns with health-conscious consumer trends.

Fermentation

Lactic acid bacteria (LAB) are the major microorganisms responsible for *Nham* fermentation. These bacteria are Gram-positive, acid-tolerant, non-sporulating rods or cocci that ferment carbohydrates to create lactic acid. The major LAB species in *Nham* are *Lactobacillus plantarum*, *Lactobacillus sakei*, *Pediococcus pentosaceus*, and *Weissella* species (Ngasotter et al., 2020). These microorganisms are either naturally occurring in the raw materials (meat, rice, garlic) or are introduced from the environment during handling. These LABs are important because they start and prolong the fermentation process by acidifying the environment, inhibiting spoilage and harmful organisms while generating *Nham*'s distinctive sour flavor (Swetwiwathana & Visessanguan, 2015).

The primary metabolic reaction in *Nham* is lactic acid fermentation, which is catalyzed by LAB via either a homofermentative or heterofermentative pathway (Santiyanont et al., 2019). *Lactobacillus plantarum* and other homofermentative LAB largely use the Embden-Meyerhof-Parnas (EMP) route to convert glucose to lactic acid (Figure 2). This reaction lowers pH and produces a sour flavor (Phupaboon et al., 2022).

$$C_6H_{12}O_6 \rightarrow 2\ CH_3CHOHCOOH\ \text{(Lactic acid)}$$

Figure 4.3. Homofermentative pathway of lactic acid bacteria

In contrast, heterofermentative LAB, such as *Weissella spp*., ferment sugars by the phosphoketolase pathway, resulting in lactic acid, carbon dioxide, and ethanol or acetic acid (Santiyanont et al., 2019) (Figure 4.4.). These byproducts add to the distinct scent and somewhat fizzy texture of tightly wrapped *Nham*. Fermentable sugars are generally derived from cooked sticky rice, which contains starch and is broken down into simpler sugars by endogenous enzymes or microbial amylases (Lee et al., 2019).

$$C_6H_{12}O_6 \rightarrow CH_3CHOHCOOH + CO_2 + C_2H_5OH\ /\ CH_3COOH$$

Figure 4.4. Heterofermentative pathway of lactic acid bacteria

Nham fermentation is normally carried out at ambient tropical temperatures ranging from 25 to 35° Celsius. This temperature range promotes rapid growth of LAB while inhibiting the growth of undesirable microorganisms (Santiyanont et al., 2019). Fermentation occurs under anaerobic or semi-anaerobic conditions, which are created by firmly wrapping the substance in banana leaves or plastic bags. The absence of oxygen promotes the growth of LAB over aerobic rotting microbes (Wittanalai et al., 2019). Salt is added at a dosage of about 2-3%, which serves two purposes: it inhibits the growth of spoilage and pathogenic bacteria while also improving the flavor of the finished product. The fermentation process typically takes 2 to 5 days, during which time the pH declines from roughly 6.0 to around 4.0-4.5 due to lactic acid generation (Santiyanont et al., 2019).

Several significant biochemical changes occur during fermentation. The most significant is the buildup of lactic acid, which lowers the pH and protects the product by suppressing spoilage and pathogenic microbes (Kumar et al., 2015). Additionally, proteolysis occurs, in which proteins in pork are broken down by both microbial and endogenous enzymes into peptides and free amino acids, thereby improving flavor and texture. Lipolysis also occurs, converting fats into free fatty acids, which can then be broken down into volatile chemicals that contribute to the scent (Wang et al., 2022). Microbial activity produces gases such as CO_2, which might cause mild swelling of the package when sealed. Together, these adjustments produce a soft, tasty product with a longer shelf life (Leroy et al., 2022).

Following fermentation, *Nham* has particular sensory properties that make it a valued traditional dish. The flavor is mildly to moderately sour due to the lactic acid, with a delicate note of garlic. The aroma is slightly fermented yet nice, and there may be a subtle fizz from CO_2 when firmly packed (Leroy et al., 2022). *Nham* has a solid yet somewhat chewy texture, and the collagen-rich pork skin adds to the mouthfeel (Vo et al., 2022). The hue remains pinkish to pale due to the lack of cooking (if ingested raw), although boiling can turn it somewhat brown. A high-quality *Nham* product is defined by its balance of acidity, saltiness, and umami resulting from protein breakdown (Santiyanont et al., 2019).

4.4. Safety Concerns

Nham Standards

Nham is a traditional food product that is rarely seen as a commercial product in modern stores such as supermarkets, and so there are no international regulations on what is commercially considered as *Nham*. Traditionally, *Nham* is composed of minced pork, pork rind, cooked rice, garlic, seasonings, salt, sugar, and sodium nitrite, the mixture is then shaped and fermented at room temperature for 3-4 days, letting the microorganisms naturally present within the meat ferment the product (Kingcha et al., 2024). Fermentation for 3-4 days can achieve the targeted pH by Thai standards of *Nham* at 4.6 or less (Visessanguan et al., 2015).

Nham uses sodium nitrite or curing salts to give a desirable cured meat color, cured flavor, antioxidant activity, as well as antimicrobial activity (Chazelas et al., 2022). However, sodium nitrite can cause certain health issues when used in excessive concentrations. The maximum concentration of nitrite and nitrate allowed to be used in *Nham* according to Thai standards is 125 and 500 mg/kg, respectively

(Visessanguan et al., 2015). If an excessive quantity of nitrate and nitrite is added to the *Nham* mixture, the remaining substances in *Nham* will break down into free radicals and react with an amine to form nitrosamine, a harmful carcinogen (Singkhum & Kangkun, 2021).

Microorganism Contamination

As a fermented food product, there are certain safety concerns that must be considered during the production of *Nham*. Fermented food products typically are left to ferment over a few days, however this carries the risk of dangerous microorganism contaminating the food product or causing spoilage, which can cause food poisoning (Anal et al., 2020). The production of fermented food must be done properly to prevent the spoilage of the product and the accumulation of unwanted microorganisms.

Fermentation of *Nham* requires the growth of different microorganisms, primarily of lactic acid bacteria naturally present in the ingredients. According to Visessanguan et al. (2015), the predominant microorganisms in *Nham* fermentations are known to be *Lactobacilli* (*Lb. plantarum*, *Lb. pentosus*, and *Lb. sakei*) and *Pediococci* (*P. acidilactici* and *P. pentosaceus*). However, fermented meat products, which are produced by naturally occurring LAB in the ingredient, can result in inconsistent qualities or unsafe products, proven by reports on *Salmonella spp.*, *Staphylococcus aureus*, and *Listeria monocytogenes* contaminations in *Nham* products (Swetwiwathana & Visessanguan, 2015).

Biogenic Amine Accumulation

Aside from concerns regarding the prevalence of unwanted microorganisms, fermented food products can generate biogenic amines, which can be a safety issue at high concentrations. When microbial species decarboxylate amino acids to produce the equivalent amine and CO2 or during amination and transamination of ketones and aldehydes, they produce biogenic amines (BAs), which are low-molecular-weight organic bases that can cause adverse health effects (Erdag et al., 2018). Fermented foods with high microbial activity are at high risk of developing excessive amounts of biogenic amines, and so the development of these compounds must be monitored. According to Turna et al. (2024), the biogenic amine that accumulates in high amounts on fermented meat products are tyramine, cadaverine, putrescine, and histamine. The chemical reaction producing biogenic amines can be seen in Figure 4.5.

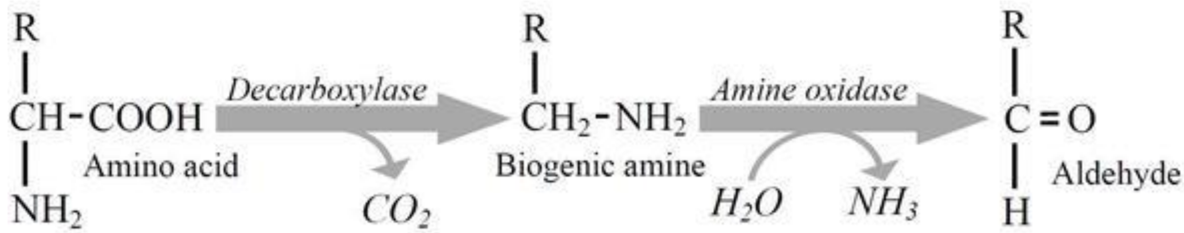

Figure 4.5. Chemical Reaction of Biogenic Amine Production

Biogenic amines in low concentrations do not have adverse health effects and are instead useful for metabolic processes in the human body. Amines participate in the synthesis of proteins, hormones, nucleic acids, support normal cell growth and proliferation, act as neurotransmitters, and more (Doeun et al., 2017). However, at high concentrations, biogenic amines can cause effects such as headache, dizziness, nausea, vomiting, diarrhea, intestinal distension, and hypertension (Ozcelik et al., 2020). The effect of biogenic amines on the human body is not only affected by the concentration of amine being consumed, but also by certain other factors. One such main factor is the capability of natural detoxification mechanisms, primarily being enzymes belonging to monoamine oxidase (MAO), diamine oxidase (DAO), and polyamine oxidase (PAO) that can detoxify excess biogenic amines (Wójcik et al., 2020).

4.5. Recent Studies

Recent studies have focused on improving the quality and safety of naem, a traditional Thai fermented pork sausage. One of the studies by Phupaboon et al. (2022), explored the use of microencapsulated probiotics to enhance the bioactivity of *Nham* protein hydrolysates. Three *Lactobacillus* strains were encapsulated using glutinous rice flour and inulin. The encapsulated Lactobacillus strains enhance antimicrobial activity by promoting the production of functional peptides that effectively inhibit pathogenic bacteria.

Among the formulations, *Nham*-1 exhibited the strongest inhibition against all tested pathogens, with the largest zones of inhibition observed for *E. coli* (22.0 mm) and *Ent. aerogenes* (18.0 mm). *Nham*-2 and *Nham*-3 also demonstrated improved antimicrobial effects, though their inhibition zones were slightly smaller than those of *Nham*-1. In contrast, the control sample showed minimal to no inhibition, highlighting the role of the specific probiotic combination in enhancing antimicrobial properties (Phupaboon et al., 2022). Another improvement uses the optimization of nitrite levels. While nitrites help prevent bacterial contamination, excessive use may pose health risks. By adjusting nitrite levels, researchers have found a balance that maintains safety while preserving product quality (Ritthiruangdej, 2023). Additionally, understanding the different microbial in *Nham* helps in selecting beneficial bacteria like *Lactococcus* and *Pediococcus*, making it more consistent fermentation (Burintramart et al., 2017). Supporting this research, Srisanga et al. (2023) also showed that adding 1% of a controlled mix of *Pediococcus acidilactici* and *Pediococcus pentosaceus* and fermenting for 2 days at 30°C significantly improved the sensory quality, safety, and shelf life of *Nham* compared to traditional methods.

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CHAPTER 5: *BRATWURST*

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5.1. Introduction

Brief History

Bratwurst sausage is one of Germany's most well-known traditional foods, produced and consumed for centuries (Figure 5.1.). The word "bratwurst" comes from the old German "brat", which means chopped meat, and "wurst" means sausage (Lonergan et al., 2019). *Bratwurst* is often associated with Oktoberfest and beer culture (Raak et al., 2020). Bratwurst has been developed for hundreds of years. Originating in Franconia around the 14th century, the documented recipe was in 1313 in the city of Nuremberg, a city in Germany, which until now still produces one of the most famous types of *bratwurst* out of more than 40 types across the country, called Nuremberger Rostbratwurst (Volkswurst, 2024). Traditionally, this sausage is made from pork meat, spices, and natural casings and utilises simple tools.

Figure 5.1. Typical appearance of a German Bratwurst

What differentiates German *bratwurst* from other sausages is that it originates from Germany, with variations of types according to region, such as Nurnberger, Thuringer, and Frankische. The texture of the *bratwurst* itself is chunkier as the meat is coarsely ground rather than finely ground like the commercial sausage (Ruther et al., 2020). The unique point of *bratwurst* is that it uses marjoram for seasoning and pork intestine for casing, adding extra aroma and “snap” sensation when bitten.

Global Demands

In Germany, *Bratwurst* is a staple food and widely recognised across Europe and beyond. Not only serves as a main dish, but also commonly found in street food, festivals, and traditional meals. Due to its versatility on various occasions, German *Bratwurst* plays a significant role in supporting local butchers, meat producers, and small regions such as Thuringia, Nuremberg, and Franconia, which are known for their authentic traditional *Bratwurst* making. Germany is the largest producer and exporter of sausages in the world, with one of the dominating products being *Bratwurst*. There is a reported number of consumption of bratwurst in Germany by Hoek et al. (2019), which stated that in a year, approximately 2.6kg of bratwurst is consumed per person, which is equivalent to 80 bratwurst annually. According to (Maia Research co., 2022), in 2021, the global bratwurst market, including Germany and worldwide, was worth up to US $906.6 million and was predicted to be US $1.14 billion by 2027.

5.2. General Information and Processing Methods

Raw materials & nutritional content

Traditionally, *Bratwurst* is made from pork, particularly from the shoulder (boston butt) and belly which are high in fat and connective tissue, contributing to the good emulsification, flavour, and juiciness. It is then seasoned with salt, white pepper, nutmeg, lemon peel, marjoram, caraway, and garlic (Heinen's, 2019). Traditionally, German bratwurst does not incorporate any additives. However, as bratwurst is a type of sausage, it is commonly added with preservatives, stabilisers, flavour enhancers, colourants, antioxidants, and acidity regulators to prolong the shelf life and enhance the taste when processed commercially (Zulkarnain et al., 2021). Other than pork, cow meat can also be used as a replacement. According to (Lindberg et al., 2024) 24-month-old Holstein steers can be used. A mix of beef and veal is also highly in demand in some regions, importing bratwurst.

Bratwurst provides a high source of protein. Usually have 15-20 grams of protein, which includes essential amino acids. Bratwurst is also relatively high in fat, usually has 20 to 25 grams of fat, including saturated fat. Meanwhile, the carbohydrate content is generally lower compared to protein and fat, and some additives may contribute to a higher carbohydrate count. Lastly, *Bratwurst* can have a high sodium content since it usually contains about 600 milligrams of sodium in each piece of bratwurst (RenalDosage, 2025; C Gréa et al., 2023).

Processing methods

A general overview of *Bratwurst* processing steps can be seen in Figure 5.2. Traditionally, bratwurst is made by firstly cutting the pork and beef into two-inch cubes, then grinding via a 1/4-inch grinding plate. In a small mixing bowl, combine the eggs and beer until completely combined and add the dry ingredients. In a large mixing bowl, blend the ground beef and wet ingredients until thoroughly combined. After that, stuff the mixture into the pork intestine (the pork intestine works as casing for the sausage). Lastly, the sausage will be boiled or frozen to set it as a sausage.

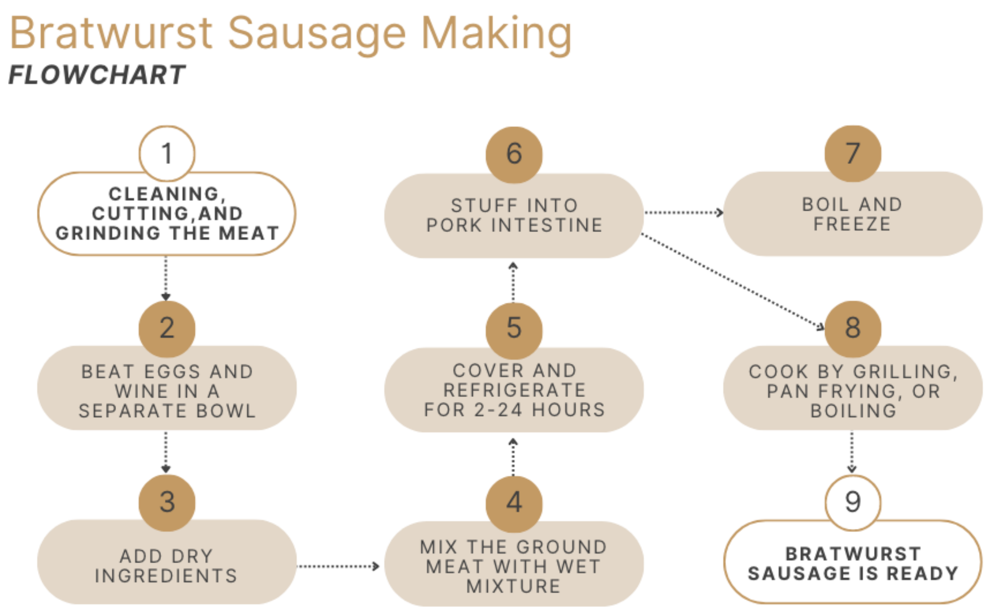

Figure 5.2. Bratwurst processing methods

The steps involved in processing German *Bratwurst* give a significant impact on its quality and stability. Effective emulsification during the mixing process results in a uniform texture, juiciness, and the characteristic "snap," particularly when utilizing natural casings (Ruther et al., 2020). Keeping temperatures low (≤12–14 °C) throughout the mixing and chopping stages helps maintain protein functionality, thereby preventing fat separation and the breakdown of the emulsion (Zulkarnain et al., 2021). Additionally, flavor primarily develops through the Maillard reaction during grilling, while an even distribution of spices during mixing ensures a well-balanced taste profile.

5.3. Regulatory and Labelling

Regulatory

Strict food regulations govern bratwurst production in Germany to ensure product authenticity, safety, and quality. Under EU Regulation (EC) No. 853/2004, *Bratwurst* is classified as a meat preparation and must follow standards regarding meat content, additive use, and hygiene. Specific types, such as Nürnberger Rostbratwurst, are protected under the EU's Protected Geographical Indication (PGI) scheme, meaning they must be produced using traditional recipes and methods in Nuremberg. The recipe for 'Nürnberger Bratwürste/'Nürnberger Rostbratwürste' provides for a fat content of more than 30% and a connective tissue content of 25%, using roughly defatted pig meat: Fatty meat, notably pork belly, belly fat, jowl, jowl fat, back, and back fat.

Labelling

Labelling regulations under EU Regulation No 1169/2011 require that all ingredients, allergens, additives (like nitrites and phosphates), meat types, and nutritional information be declared on the packaging. The term "*Bratwurst*" is also protected, and the product must meet traditional definitions in terms of composition and appearance. Additionally, for export, proper documentation and certification are required to comply with international standards and specific market needs, such as halal labelling or traceability requirements.

5.4. Recent Studies

Effects of high-pressure processing

In a study done by Katsaros & Taoukis (2021), *Bratwurst* sausages were used as one of the test products to evaluate the effectiveness of high pressure (HP) processing at 600 MPa for 5 minutes at 25 °C. The results showed that HP treatment significantly reduced the initial microbial load, particularly lactic acid bacteria and spoilage organisms. This led to a substantial extension of the *Bratwurst*'s shelf life, up to 3 to 5 times longer than untreated samples, depending on the storage temperature. Importantly, the HP-treated *Bratwurst* maintained its sensory qualities, including colour, texture, and taste, with no major changes observed after processing. During storage, the treated sausages retained their freshness better than untreated ones, and consumer panel evaluations indicated a preference for HP-treated Bratwurst after extended storage. Overall, the study concluded that high-pressure processing is a safe and effective method for extending the shelf life of Bratwurst sausages while preserving their quality and reducing food waste in the cold chain.

Effects of carrot paste incorporation

Sam et al. (2021) investigated the effects of incorporating carrot paste (CP) at 3%, 5%, and 10% into frankfurter-type sausages. The goal was to evaluate its impact on physicochemical properties, oxidative stability, and sensory characteristics during 14 days of refrigerated storage. Results showed that CP-enriched sausages had lower cooking loss, higher moisture and ash content, and reduced fat content. They also exhibited higher antioxidant activity and lower peroxide values, indicating better resistance to lipid oxidation. Sensory analysis revealed that CP, especially at 10%, improved colour, texture, and overall acceptability without negatively affecting flavour or juiciness. Therefore, CP can be used as a natural antioxidant to enhance the nutritional and storage qualities of sausages without compromising their sensory appeal.

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CHAPTER 6: *VENTRICINA*

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6.1. Introduction

History

Ventricina is a traditional fermented sausage that originated in Italy from areas between the Abruzzo and Molise regions. Generally Ventricina is made with roughly 80% lean pork meat cut into large cubes, combined with fat from bacon and pork thigh, although the recipes can vary depending on the area.

Figure 6.1. A typical *Ventricina del Vastese* salami

Historically, the mixture was stuffed into a pig's stomach for aging, which is shown in the name "*Ventricina*" from the word *ventre*, meaning stomach in Italian, but as of today, it is usually encased in natural materials such as pig bladder or veal caecum or synthetic casing, which are left to mature at low temperatures for at least 100 days (Montanari et al., 2021). Ventricina undergoes a natural fermentation process facilitated by lactic acid bacterias such as *Lactobacillus sakei* and coagulase-negative staphylococci. Lactic acid bacteria such as *Latilactobacillus sakei*, *L. plantarum*, *Leuconostoc mesenteroides*, and *Weissella* species start the fermentation. The lactic acid bacteria consume sugars which produce lactic acid that lowers pH, this inhibits spoilage organisms and contributes to the flavor and preservation of the meat. Then *Staphylococcus xylosus* and *S. equorum* grow and help develop flavor and aroma through the breakdown of proteins and fats into volatile and aromatic compounds (Amadoro et al., 2015). In traditional artisanal production, fermentation occurs spontaneously using the sausage's own environment (Barbieri et al., 2024).

Regional Variations

Ventricina is a meat product that can be made differently depending on the area. There are two regional variants of ventricina, which are the *Ventricina del Vastese* and *Ventricina Teramana*.

Figure 6.2. Typical appearance of *Ventricina Terama*

Ventricina del Vastese is a coarsely chopped, firm salami from Vasto and the surrounding areas in Abruzzo and Molise (Amadoro et al., 2015) while *Ventricina Teramana* (Figure 6.2.) is from the Teramo province is characterized by finely ground meat with a higher fat percentage, and uses orange peel and garlic. It is usually used as a spread after it is aged (Iseppi & Patrizia Messi, 2023).

6.2. Raw Materials

Ventricina is a traditional long-cured fermented sausage from central Italy, primarily made using pork meat and fat. While the recipe does not strictly mandate a specific cut nor type of meat, pork shoulder and muscles such as longissimus dorsi and psoas are commonly used, often cubed or minced into pieces of 2–4 cm (Tremonte et al., 2020; Montanari et al., 2021). Pork fat, typically comprising 20–30% of the mixture, is essential for texture and flavor (Amadoro et al., 2022). During preparation, the meat is mixed with sodium chloride (2.5–3%), curing agents like potassium nitrate or nitrites, and sugars such as glucose or dextrose (0.1–0.3%) to support fermentation. Starter cultures containing *Latilactobacillus sakei*, *Pediococcus pentosaceus*, *Staphylococcus xylosus*, and *Staphylococcus carnosus* are added to ensure controlled microbial activity.

The mixture is seasoned with a robust blend of spices including sweet and hot chili pepper powder (15–30 g/kg), black pepper, fennel, and sometimes bell pepper powder, contributing to the sausage's distinctive Southern Italian flavor (Amadoro et al., 2022). The seasoned meat rests for 12–24 hours before being stuffed into natural casings such as pig bladder (Tremonte et al., 2016). Although detailed nutritional information is not specified, Ventricina is typically high in protein, saturated fat, and sodium due to its composition and curing process. No alternative meats are cited in traditional or industrial practices, underscoring pork as essential to *Ventricina*'s authentic identity (Montanari et al., 2021; Tremonte et al., 2020).

6.3. Processing Steps and Conditions

Preparation

The production of *Ventricina* salami first begins with the preparation of coarsely minced pork, lean meat and fat. The meat chosen would typically be the shoulder or thigh meat while the fat used would oftentimes be sourced from the pig's back. Moreover, the lean meat to fat ratio used for the salami would be about 70-80% lean meat and 20-30% fat (Amadoro et al., 2022). Next, spices as per mentioned above would be incorporated into the meat and fat mixture. Not only that, curing salts such as sodium nitrate or sodium chloride are added to give the characteristic cured flavor to the meat, reduce water activity, inhibit potential microbial growth and maintain a stable cured color. Additionally, curing salts contribute to the uniform reddish-pink color by facilitating the reduction of nitrates to nitrites, which will then form nitrosomyoglobin, giving the cured meat its characteristic color (Shakil et al., 2022).

Other than curing salts, the other important component added is the starter culture. According to (Tremonte et al., 2016), lactic acid bacteria and coagulase-negative cocci are both used to ferment Ventricina salami. The lactic acid bacteria, *Lactobacillus*, *Lactococcus*, and *Pediococcus*, acidifies the environment to inhibit microbial spoilage. While the coagulase-negative cocci, *Staphylococcus*, *Kocuria*, and *Micrococcus*, is to stabilize the specific red color of the salami by reducing nitrates (V) to nitrates (III), thus the formation of nitrosomyoglobin (Montanari et al., 2021).

Main processing

Once the pork mixture is thoroughly mixed, it can then be stuffed into casings such as pig's bladder or synthetic alternatives like collagen or cellulose. These stuffed sausages will next be tightly tied and pricked to remove any air bubbles, which could otherwise lead to uneven fermentation, causing the potential growth of spoilage bacteria (Franciosa et al., 2018). The stuffed sausages will then be transferred to a fermentation chamber where the fermentation process will begin with a "warm" phase lasting for 3 days. There, the temperature will be set to 24-26 ºC with a relative humidity of 85-90% to let the lactic acid bacteria ferment the carbohydrates, acidifying the environment (Dasiewicz et al., 2024).

Following the warm fermentation, a "cold" fermentation will take place for an additional 2-3 days at 12-15 ºC with the same relative humidity. This step is done to allow the fermentation to continue at a slower rate while maintaining an optimal moisture level to further develop flavor and acidity (Brugnini et al., 2024). Once fermentation is complete, the sausage will be left to ripen for 14 days in a controlled environment of 70-80% humidity. Additionally, the temperature will gradually be adjusted to 16 ºC. This ripening stage promotes gradual drying, texture development as well as the accumulation of characteristic aroma compounds (Miroslav Dučić et al., 2023). Lastly, a final drying step is carried out at 15 ºC with about 75% humidity to achieve the desired consistency of the final product.

Conditions

The processing step is important to achieve the best quality *Ventricina* salami. *Ventricina* is famous for its rich and complex flavor that can be achieved by using high quality ingredients and from the fermentation and curing process (Tremonte et al., 2020). According to Allen (2015), a good *Ventricina* must have a vibrant red color with spicy, smoky, and slightly sweet that can be achieved by adding paprika powder and chilli pepper. Fermentation contributes to the microbial activity from lactic acid bacteria to produce lactic acid that lowers pH and gives tanginess to the *Ventricina* salami (Aquilanti et al., 2016). Enzymatic reactions of lipolysis and proteolysis also occur to break down fats and protein free fatty acids and amino acids that give umami, nutty, and aged flavors to ventricina salami (Fu et al., 2022).

The physical properties of *Ventricina* salami are different from other types of salami. *Ventricina* uses chopped meat instead of ground meat and chunks of fat to get the marbling effect, rustic appearance, and different mouth feel during consumption (Tremonte et al., 2016). The slow drying contributes to creating the firm texture and deep flavor of *Ventricina* effect from moisture loss. However, an uncontrolled drying process could lead to hardening to the casing where the outer layer dries rapidly resulting in uneven dehydration (Cascone et al., 2015). The use of natural casing such as pig bladder contributes to a flattened shape and regulates moisture during curing. Additionally, the red color of *Ventricina* is stabilized during the process by the presence of paprika pigments and the cured meat pigment nitrosomyoglobin, both of which are preserved by the mildly acidic and low-oxygen environment (Demarco et al., 2022).

Microbial stability and longer shelf life could be achieved through several steps of preservations (Montanari et al., 2021). The reduction in pH to 5.3 or below during the fermentation process creates an environment that could kill most pathogenic bacteria (Gonzalez-Fandos et al., 2021). The water activity is lowered through slow drying to around 0.88 until 0.92 creates a hurdle to further inhibit microbial growth (Tapia et al., 2020). The presence of lactic acid bacteria not only helps in acid production but also provides antimicrobial benefits by producing bacteriocins and other inhibitory substances (Ibrahim et al., 2021). These combined preservation steps ensure the safety and long-term stability of *Ventricina* even without refrigeration. In some traditional versions, the development of surface mold is allowed and managed carefully, as it can contribute to the aging process by helping in regulating moisture and enhancing the flavor (Tremonte et al., 2016).

6.4. Regulatory and Labelling Requirements

Although most salamis are similar in terms of ingredients, the amount allowed to be used for *Ventricina* salami has different regulations compared to other types of salami. According to a processed meat company, Villani Salumi (Villani, 2022), their standards of *Ventricina* salami must have a total mesophilic bacterial load of higher than 10^7 CFU/g, *E.coli*, faecal *Coliforms* and *Staphylococcus aureus* lower than 10^2 CFU/g. The packaging for the product was also said to only include 2 pieces, with a dimension of 0.14 m x 0.24 m x 0.525 m. Their meat itself was said to have a hot and strong spicy flavor and a total energy being 335 kcal. This is the standard precaution used for one of the many companies that produced ventricina salami, and not every company has the same standard.

The European Food and Safety Authority (EFSA) has yet to have a standard for *Ventricina* Salami, however, a food research company named Erudus has conducted research regarding the safety precautions and standards that should be followed and used to commercialize *Ventricina* Salami. According to Erudus (2024), the standard packaging should be 0.36 m x 0.26 m x 0.12 mm, which is slightly smaller when compared to Villani's packaging size. Erudus also mentioned that the salami may contain additives such as antioxidants as well as preservatives. The microbial load of *Clostridium perfringens*, *Listeria monocytogenes* and

Staphylococcus aureus are needed to be lower than 10^3 CFU/g, *E.coli* and *Enterobacteriaceae* lower than 10 CFU/g and no salmonella is allowed to be detected. The total energy that the standard mentioned needs to be 414 kcal, which is higher than the energy content found in Villani Salumi's Ventricina Salami.

As mentioned before, the energy content found in Villani's *Ventricina* salami was lower compared to the Erudus standard. Another aspect that was found to be lower than Erudus was the amount of fats available, with Villani having a lower fat content than the Erudus' standard. However, some components were found higher in the villani standard compared to the Erudus standard, such as sugar and carbohydrates but both standards showed the same amount of protein to be used as standard, with it being 22 grams. Villani salami is considered to be an artisanal producer of processed meat products, which has been established before, which can be a reason for their lower content compared to Erudus' standard. Artisanal meat products often avoid using preservatives and use natural ingredients (Gambi et al., 2023), which means their antimicrobial and antioxidant activities will be lower than those with preservatives. This causes the lower amount of bacterial load allowed than those commercialized and have antioxidants or antimicrobial preservatives.

6.5. Recent Studies

In recent years, *Ventricina* Salami production is still increasing, however there are demands by the consumers and nutritionists in terms of lowering down the salt content as well as changing the starters for fermentation (Monatari et al., 2021). However, according to Magnani (2020), the change in salt formation could lead to microbial changes that could impact the safety and flavor of the salami. Therefore, even though the reduction of salt may have a better nutritional value, the decrease of it can cause problems in the safety and overall quality of the salami.

Ventricina salami were first made using Coagulase-Negative *Staphylococci* (CNS) as well as other dry meat sausages, because they are naturally found colonizing the human and animal skins, which can be dangerous if unmonitored properly (Amadoro et al., 2022). This leads to most industries trying other starters such as lactic acid bacteria, as done by Dasiewicz et al., (2024). Additionally, their research also examined another factor affecting the production, the usage of low temperatures for fermentation. The product was stored in different temperatures from day to day, such as 24-26ºC for the first 3 days, and then lowered down after every 2-3 days, with the last temperature being 15ºC. The meat was then smoked to cook it. The experiment resulted in an increased nutritional as well as sensorial aspect as the decrease in fermentation rate causes it to increase the pH, therefore making it more palatable.

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CHAPTER 7: PARMA HAM

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7.1. Introduction

Description

Parma ham or locally known as *Prosciutto di Parma*, is a traditional Italian dry-cured ham known for its high quality and unique sensory characteristics (Figure 7.1.). It was made from the hind legs of specially-bred pigs, processed with sea salt only, without any additives or preservatives (Paredi et al., 2017). Only sea salt is used in the salting stage to keep minimal intervention in preserving the natural flavor and integrity of the product. Parma ham must be produced in Parma, Italy, to carry the official Protected Designation of Origin (PDO) status (Sirtori et al., 2020). This ham is different from other dry-cured ham due to its strict adherence to traditional methods and protected designation of origin (PDO) standards, which prohibit the use of chemical additives, such as nitrates and nitrites, as well as smoking techniques.

Figure 7.1. A whole *Prosciutto di Parma*

Parma ham contains important sources of proteins, iron, B-complex vitamins, and phosphorus (Ivanovic et al., 2016). The curing process takes at least 12 months, resulting in a product that is sweet, delicate, and tender. During curing, the temperature and humidity are carefully controlled to help good microbes grow and to allow natural changes in the meat, which create Parma ham's unique taste, smell, and texture. Molds, including *Aspergillus*, grow on the surface, while helpful bacteria inside the meat make it safe and flavorful. After about 7-8 months, a mix of lard, pepper, and salt is spread on the exposed part to keep it from drying out too much. The hams must undergo an organoleptic inspection called "la cala," in which a bone needle is inserted into specific points to check for any off-odors before approval for sale (Chizzo et al., 1993).

Importance of Product in the Market

Parma ham PDO holds a strong position in both the Italian and international markets. It is highly regarded in the gourmet sector and is recognized as a symbol of authentic Italian culinary tradition. In 2020, the industry reached a production value of €687 million, with exports contributing €253 million, making it a significant source of revenue for Italy (Mazzocchi et al., 2022). The product also supports local agriculture and the economy of the Parma region. Its quality and authenticity are guaranteed through the Protected Designation of Origin (PDO) certification, which is trusted by many consumers (Sirtori et al., 2020). In addition, recent research indicates that consumers are increasingly interested in more sustainable and ethical options, such as Parma ham produced without antibiotics, utilizing pollutant-reducing technologies, or with enhanced animal welfare practices. Many are willing to pay a higher price for these features (Gaviglio & Pirani, 2016).

Global and Local Demand

Parma ham is in high demand both in Italy and around the world. In Italy, it is an important part of local food culture, especially in the Parma region, where it is seen as a symbol of tradition. Most people know about Parma ham, but there is still a chance to make it even more well-known across the country (Casangiu, 2022). Around the world, more people are starting to enjoy Parma ham, similar to the growing popularity of Iberian ham (Lorenzo-Romero et al., 2023). Its special taste, long aging process, and PDO (Protected Designation of Origin) label make it a popular choice in the premium food market (Iotti et al., 2023). Consumer demand for Parma ham is influenced by factors such as sustainability, health, and animal welfare (Mazzocchi et al., 2022). Promoting food tourism in Italy, especially related to Parma ham, could also help increase international interest, as has been done in Spain (Jiménez et al., 2019).

History

Parma Ham has a long history going back over 2,000 years to ancient Roman times. The Romans were already using methods to salt and dry pork legs. The Parma region in Italy was known for raising pigs and making ham (Wagner, 2024). In the Middle Ages, making ham became an important craft, with special guilds such as the Lardaroli setting rules for production (Bargelli, 2002). Over time, Parma Ham became popular with European royalty. The region's special climate, with dry and fragrant air from the hills, helps create the ham's unique taste and texture. Nowadays, Parma Ham is protected by the European Union's PDO (Protected Designation of Origin), meaning only ham made in Parma using traditional methods can use the name (Kavuşan & Serdaroğlu, 2021).

Moreover, since 1963, the *Consorzio del Prosciutto di Parma* has overseen quality control and global promotion of this iconic Italian product. It protects and promotes Parma Ham as a high-quality traditional Italian product. It was formed to ensure that only ham produced within the Parma region and according to strict traditional methods could carry the Parma Ham name (O'Reilly et al., 2003). The Consortium played a key role in gaining legal protection for Parma Ham under Italian law, especially with the 1970 law on origin labeling and the 1978 ministerial decree that gave it the power to oversee production. Starting with just 23 companies, the Consortium has grown to about 150 producers, all required to follow strict production standards and make sure that at least 75% of their cured ham qualifies as Parma Ham. The Consortium manages brand use, oversees compliance at each production stage through inspections and certification, and guarantees full traceability via the Parma Ham Ducal Crown stamp (Sargiacomo et al. 2016).

7.2. Raw Materials

Meat Source and Type

To ensure a high-quality Parma ham production, it is essential to have a specific selection of raw materials. As a product with Protected Designation of Origin (PDO) status, Parma ham must comply with strict production rules defined by the Consorzio del Prosciutto di Parma and European regulations, ensuring its authenticity, quality, and regional identity (Iotti et al., 2024). According to the PDO regulation, Parma ham can only be made from the hind legs of pigs raised in specific regions of Italy, primarily from the Large White, Landrace, or Duroc breeds (Bertolini et al., 2024). Following breed selection, the pigs are raised under highly controlled rearing conditions, which include well-defined feeding and growth protocols. To be eligible for Parma ham production, pigs must reach a minimum live weight of approximately 170 kg and be at least 9 months old at the time of slaughter (Vitali et al., 2021). Their diet typically includes grains, cereals, and whey derived from Parmigiano Reggiano cheese production, which enhances the flavor profile and contributes to the formation of the high-quality fat layer needed for proper aging and flavor development during the curing process (Grasse et al., 2017; Nevani, 2024).

The chosen meat must have a firm texture, accompanied by a thick, white layer of fat that protects the meat during curing, preventing spoilage and enhancing its flavor (Schiavon et al., 2024). Bruising and blood spots in meat can lead to potentially undesirable flavors and textures, which can negatively impact the sensory quality of the ham (Nannoni et al., 2023). Parma ham typically undergoes a curing process that ranges from a minimum of 15 months to more than 24 months, allowing for the development of complex flavors and aromas (Schivazappa et al., 2024).

Non-Meat Ingredients

Unlike many other cured meat, Parma ham is known by its natural curing process, which strictly excludes the use of nitrates, preservatives, or any artificial additives. The only additives applied during its production is pure sea salt (Bak et al., 2025). This traditional method emphasizes simplicity and natural preservation, relying on the intrinsic properties of salt to maintain the quality and safety of the meat. When sea salt is applied to the surface of the meat, it initiates osmosis, where water is drawn out from the muscle tissue (Manning, 2024). This dehydration effect concentrates the solutes within the meat, leading to an increased salt concentration in the extracellular environment. This change significantly alters the permeability of the muscle cell membranes and facilitates the release of heme protein from the muscle fiber. These proteins are essential for the development of color and flavor of the Parma Ham (Aminzare & Kay, 2024).

In addition to enhancing flavor and color, sea salt plays an important role in preservation. By lowering the water activity of meat, it creates an unfavorable environment for microbial growth. Additionally, the reduction in water content also slows down enzymatic activity, preventing premature degradation of protein and lipids that could potentially spoil the meat (Paredi et al., 2017).

Nutritional Profile

Since no artificial additives or preservatives are used, Parma ham offers a healthier option compared to many commercially cured meats. It is a good source of protein, vitamin B1, B6, B12, and PP, which are great for energy metabolism and red blood cell production (Pegg & Boles, 2024). The natural curing process of meat facilitates the enzymatic breakdown of proteins into free amino acids, making them more easily absorbed by the human body (Abril et al., 2023). Mineral content, such as zinc and iron, that is released during the curing process, can help to improve the metabolic process in the human body and the formation of haemoglobin (Schivazappa et al., 2024). However, excessive consumption of Parma ham can still have a negative impact due to the high sodium content. A high sodium intake can be linked to various health problems, including hypertension, high blood pressure, heart disease, and kidney failure (Fang & Zhu, 2025).

Alternative Meat Source

As stated by Italian Law Number 26 of 13 February 1990, titled “Protection of denomination of origin ‘*Prosciutto di Parma*’, the PDO status is granted to Parma ham, imposing strict regulation on every stage of its production. According to the law, only hind legs from pigs of specific breeds and regions of Italy are eligible for use in the production of *Prosciutto di Parma*. This quality control ensures the final products reflect their geographical heritage and traditional processing methods (Giacomini et al., 2016). Consequently, alternative meat sources such as lamb or beef, even when subjected to the same curing process or possessing similar sensory qualities, cannot legally be labeled as "Parma ham" (Gerboni et al., 2017).

7.3. Processing and Conditions

Preparation of Parma Ham

The preparation of Parma ham involves several steps that begin long before the curing process, starting from the selection of the pigs to the initial handling of the meat. This phase plays a role in determining the quality and consistency of the final product, as it ensures that only hams with the ideal characteristics, such as appropriate fat distribution, muscle structure, and weight. The preparation steps are illustrated in Figure 7.2.

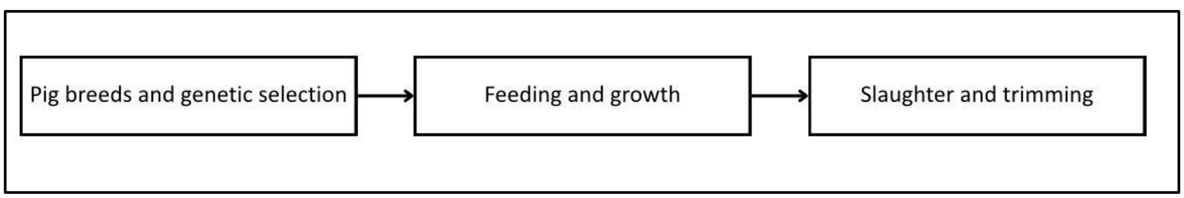

Figure 7.2. Initial preparation steps of the pig for making Parma Ham

According to Bertolini et al. (2024), the process starts long before the actual curing, with the meticulous selection of pig breeds and genetic lines. These crossbreeds are specifically chosen for well-developed muscle structure, balanced intramuscular fat, and overall carcass uniformity, all of which are crucial for meeting the strict quality standards established by the Consorzio del Prosciutto di Parma (2022). Following breed selection, the pigs are raised under highly controlled rearing conditions, which include well-defined feeding and growth protocols. To be eligible for Parma ham production, pigs must reach a minimum live weight. The feeding regimen during this period determines the fat composition and muscle development of the pigs (Hu et al., 2025).

Once the pigs have reached the appropriate age and weight, they are humanely slaughtered under hygienic conditions. Only the hind legs that meet specific physical criteria are selected for Parma ham production. These legs must weigh a minimum of 12-14 kg and achieve proper conformation, firmness, and an adequate fat cover to protect the meat during the lengthy curing process (Consorzio del Prosciutto di Parma, 2022). Legs that fail to meet these standards are excluded to maintain product consistency and prevent defects during aging.

The selected hind legs then undergo a meticulous trimming process, where excess fat, skin, and connective tissue are removed. This step serves to shape the leg into its traditional rounded form and facilitates uniform salt absorption and moisture evaporation during the curing stage (Bosse et al., 2017). The trimming process is carried out with precision to ensure homogeneity across all hams, which helps control microbial growth, enhance texture, and ultimately produce a uniform final product in terms of flavor, aroma, and appearance (Harkouss et al., 2015).

Main Processing of Parma Ham

Once the hams have been properly prepared, they enter the main processing phase, which transforms the raw meat into the distinctively flavored and textured Parma ham. This stage includes a series of traditional yet scientifically controlled procedures such as salting, resting, drying, and aging. The processing steps can be seen in Figure 7.3.

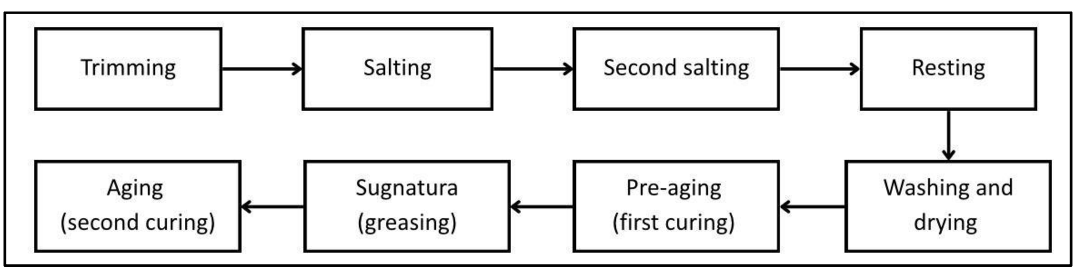

Figure 7.3. Main processing steps of Parma ham

The transformation of raw pork into Prosciutto di Parma involves a series of carefully monitored processing stages that span over a year, combining tradition, craftsmanship, and strict environmental control. Based on Parolari's (1996) and Bonfatti and Carnier's (2020) research, the process begins with trimming, during which the rind and excess subcutaneous fat are removed from the surface of the selected hind legs. This step is crucial for standardizing the shape of the hams, promoting uniform dehydration and salt penetration during curing (USDA, 2024). By exposing more of the muscle tissue, trimming ensures that the salting phase is more effective and consistent across all hams.

Salting marks the beginning of the preservation and flavor development process. The trimmed hams are moved to cold rooms maintained at temperatures between 1°C and 4°C with approximately 80% relative humidity. In this process, salt is generously applied to the surface of each ham, drawing moisture out of the tissue and forming a brine that gradually penetrates into the muscle (Tsai et al., 2022). This initial salting phase typically lasts for 6 to 7 days. Afterward, the hams enter a second salting phase, during which excess surface salt is brushed off, and a smaller amount of fresh salt is reapplied. The hams remain under the same temperature and humidity conditions for an additional 15 to 18 days, bringing the total salting duration to approximately 23 days. This prolonged salting not only dehydrates the meat but also stabilizes it against microbial spoilage and begins to influence its flavor profile (Mafe et al., 2024).

Following salting, the hams undergo a resting or pre-curing phase, where they are stored in specially designed rooms at 1°C to 5°C and 75% relative humidity for 60 to 90 days. During this time, salt continues to diffuse uniformly into the deeper muscle layers, ensuring balanced seasoning and preservation throughout the ham (Sharedeh et al., 2015). This phase also allows for further moisture loss and helps the meat acclimate to the slower pace of enzymatic and microbial activity that will define the later stages of curing (Tsai et al., 2022). Once resting is complete, the hams are thoroughly washed with warm water to remove any residual surface salt or impurities. They are then dried in rooms with controlled airflow for several days to prepare them for the next phase.

The hams then enter the pre-aging or first curing stage, which lasts around 3 months. This takes place in ventilated chambers that simulate the seasonal climatic conditions typical of the Parma region. Temperatures range from 15°C to 24°C, with relative humidity maintained between 60% and 80%. In this environment, controlled enzymatic breakdown of proteins and fats begins, initiating the complex biochemical processes that develop the characteristic flavor, aroma, and texture of Parma ham (Abril et al., 2023). Moisture continues to evaporate at a steady pace, contributing to the firming of the meat and enhancing shelf stability.

A distinctive step in the Parma ham production process is known as sugnatura, which involves applying a mixture of minced pork lard and salt to the exposed muscle surfaces of the ham (Piasentier et al., 2021). This traditional greasing technique prevents the outer portions from drying too quickly, helping regulate the pace of moisture loss and promoting a slow, even maturation. It also protects the meat from surface cracking and excessive hardening during the long aging period.

The final and most important phase is aging, or second curing, which must last a minimum of 12 months from the date of first salting, though some hams are aged for up to 24 or even 36 months for enhanced complexity and depth of flavor. Aging takes place in well-ventilated rooms that rely on natural air circulation, allowing the internal conditions to change gradually with the seasons. This mimics the traditional curing environment of Parma, where air from the Apennine mountains develops the ham's unique character (Consorzio del Prosciutto di Parma, 2022). During this time, the enzymatic and microbial actions intensify, contributing to the breakdown of complex molecules and generating volatile aroma compounds associated with high-quality dry-cured meats.

Before a ham can be officially labeled as Prosciutto di Parma, it must pass a rigorous quality inspection. One of the traditional inspection methods involves inserting a horse bone needle into several points of the ham and sniffing it to evaluate its internal aroma (Blanco et al., 1996). The porous bone absorbs the scent without altering the product and allows trained inspectors to detect any off-odors or defects. Only hams that meet the strict sensory and physical criteria established by the Consorzio del Prosciutto di Parma receive the prestigious Parma Crown seal (Figure 7.4), certifying them as authentic Parma ham.

Figure 7.4. Parma crown seal

Effect of Processing on Quality of Parma Ham

The development of flavor in Parma ham is largely driven by enzymatic and microbial activity during the aging process. Enzymatic proteolysis breaks down muscle proteins into free amino acids and small peptides, which are responsible for the ham's distinctive umami and sweet flavors (Afzal et al., 2022). Lipolysis of fat releases free fatty acids that may undergo oxidation or esterification, contributing to the rich aroma and subtle nutty notes (Tatiyaborworntham et al., 2022). Additionally, the natural microbial flora present on the ham's surface produces complex, savory, and slightly fruity flavor compounds, adding depth and uniqueness to the final product.

The texture of Parma ham is achieved through slow drying and prolonged aging, which leads to a firm yet tender consistency. Salt and enzymes break down myofibrillar proteins in the muscle fibers, softening the tissue without compromising its structure (Karam et al., 2025). This transformation results in a smooth mouthfeel and an enjoyable chewiness characteristic of high-quality cured meats.

In terms of color, the salting process inhibits microbial growth and enzyme degradation, and it facilitates the release of heme protein from muscles (Paredi et al., 2017). After approximately 1 month of curing, the heme protein (mainly myoglobin) in meat naturally degrades, releasing protoporphyrin IX and iron (Lebret & Čandek-Potokar, 2022). Over time, the available iron may become limited due to oxidation, which can increase the availability of zinc that is already present in the muscle tissue. Due to this condition, ferrochelatase can catalyze the conversion of zinc into protoporphyrin IX, forming Zinc Protoporphyrin (ZnPP). As the curing progresses, ZnPP will gradually accumulate in the tissue. This compound is responsible for the purple-red pigment found in Parma ham (Vegni et al., 2023). This vibrant muscle color contrasts with the surrounding creamy white fat, enhancing its visual appeal and consumer desirability.

Parma ham also undergoes nutritional changes throughout processing. Moisture content decreases from approximately 75% to around 55%, which concentrates the nutrients in the meat (Jens et al., 2003). Protein becomes more digestible due to the breakdown into smaller peptides and amino acids (Guo et al., 2021). Although the sodium content increases because of salting, it remains within the typical range for traditional dry-cured meats. These transformations not only preserve the ham but also enhance its nutritional and sensory qualities.

Stability of Parma Ham (flavor development, physical properties)

The flavor stability of Parma ham is largely maintained through the effects of salt and dehydration, which significantly inhibit microbial spoilage and enzymatic degradation (Amaral et al., 2018). Lipid oxidation, a common cause of off-flavors in meat, is effectively controlled by natural antioxidants present in the meat as well as careful regulation of oxygen exposure during the aging process (Sohaib et al., 2017). Furthermore, the volatile flavor compounds formed through lipid and protein breakdown remain stable over time due to the product's low moisture content and the consistent temperature and humidity conditions maintained throughout curing (Kumar & Sharma, 2024). These factors help preserve the ham's rich aroma and complex flavor profile over extended storage periods.

Physical stability is another key feature of Parma ham's quality. The drying process gives the ham a firm, resilient texture, while the fat content acts as a barrier to further moisture loss and oxidative damage (Amaral et al., 2018). In some traditionally aged hams, a layer of non-pathogenic mold forms on the outer surface. This mold not only protects against external contamination but also helps regulate humidity around the product, further contributing to its long-term stability and preservation (USDA, 2023).

Natural Fermentation in Parma Ham

Parma ham undergoes a subtle form of natural fermentation primarily driven by endogenous enzymatic activity. Proteases and lipases naturally present in the muscle tissue break down proteins and fats, leading to the development of free amino acids and fatty acids that contribute to the product's complex flavor (Bosse et al., 2017). Additionally, the native microflora, including yeasts and bacteria such as *Staphylococcus* and *Micrococcus* species, contribute to flavor development through their enzymatic functions. However, because Parma ham has a low sugar content and does not utilize added starter cultures, the fermentation process is slow and understated. As a result, the biochemical changes are predominantly enzymatic rather than microbial, leading to a gradual and controlled flavor evolution during aging

7.4. Regulatory and Labelling Requirements

Specific Rules and Related Regulatory Needs

According to EU Regulations 1151/2012 and 668/2014 on quality systems for agricultural products and foodstuffs, to be labelled PDO or PGI, these specialities must adhere to strict requirements throughout the whole production cycle. Overall, this comprehensive regulatory framework aims to achieve specified high-quality features, primarily related to the compositional and sensory properties of cured hams (Albuquerque et al., 2018).

Pigs must come only from specific genotypes included in the production specifications, such as Italian Large White, Italian Landrace, Italian Duroc crossbreeds, and hybrids derived from crossbreeding programs with aims consistent with those pursued by the Italian Herd Book for heavy pig production. The type and quantity of feedstuffs permitted include all raw materials that can be used in diets at various stages of the production cycle, along with the inclusion levels. The requirement for a minimum age at slaughter and a maximum weight for each batch necessitates moderate weight gains. Therefore, the animals must receive rationed feed. The quality of raw thighs referred to as "green hams" and the meat processing procedures, preparation, and curing of the thighs are the key qualitative criteria for the finished product. The ham undergoes two phases: cold (salting and resting) and maturation (drying and aging), each with specific temperature and humidity requirements (Merialdi et al. 2016; Vitali et al. 2021).

Labelling for Commercial Products

The product is clearly labeled as "Prosciutto di Parma" or "Parma Ham" to reflect its authentic origin. A "best before" or "use by" date is provided to ensure freshness and guide proper consumption. Relevant warnings, such as allergen information or specific storage instructions, are included to safeguard consumers. The net quantity indicates the exact weight of the ham contained in the package. If the ham has been cooked with additional ingredients, a complete list of ingredients is provided. The country of origin is specified as Parma, Italy, highlighting its protected designation of origin. A unique lot number is assigned for traceability purposes. Lastly, storage conditions are clearly stated to maintain the product's quality and safety (Iotti et al., 2023).

Authentication

According to Fontanesi et al. (2024), authentication of Parma ham, or Prosciutto di Parma, is necessary to ensure that the product originates from the Parma region of Italy and meets the stringent criteria established by the European Union under its Protected Designation of Origin (PDO) system. Following an examination by the Consorzio del Prosciutto di Parma, authentic Parma ham must bear the PDO designation and be fire-branded with the characteristic Parma crown logo. Each ham leg is labelled with a unique producer ID and curing date, ensuring complete traceability.

7.5. Recent Studies and Future Improvements

Scientific Advancement

The proteolysis and flavour development process is one of the most exciting scientific aspects of Parma ham manufacture. Proteolysis is the enzymatic breakdown of muscle proteins into smaller peptides and free amino acids that act as precursors for flavour and fragrance components. This process occurs naturally over the extended curing phase, which typically lasts 12 to 36 months, and is influenced by endogenous enzymes such as cathepsins and calpains, which remain active after slaughter. These enzymes gradually break down muscle proteins, such as actin and myosin, resulting in a soft texture and a nuanced, savory flavor. Furthermore, lipolysis, which is the breakdown of fat by lipases, produces free fatty acids that can be oxidized or transformed by microbes into aroma compounds, such as aldehydes, ketones, and esters (Mora et al., 2016).

Emerging trends

Mazzocchi et al. (2022) reported that Parma ham, also known as Prosciutto di Parma, is making a comeback as consumer tastes and global food trends evolve. One of the most significant new trends is the premiumization of cured meats, in which consumers are increasingly drawn to high-quality, artisanal products with historical roots. Parma ham effectively satisfies this demand, particularly with its PDO classification and natural, additive-free curing process. Additionally, a growing awareness of sustainability and animal welfare is prompting businesses to implement more open procedures, such as traceable sourcing and environmentally friendly agricultural practices. Parma ham is particularly popular among health-conscious consumers due to its high protein content and natural production process, which aligns with clean-label and low-carb diets, such as the keto diet.

Sustainability

Parma Ham has strengthened its sustainability commitment by launching a two-year plan to reduce its environmental impact. This resulted in eligibility for the "Made Green in Italy" accreditation, a national voluntary initiative for environmentally friendly products. A specific software (ENERSEM) was created to assist producers in calculating their footprint and receiving tailored improvement ideas. Many producers have already implemented this instrument, indicating strong industry participation in the ecological transition and meeting worldwide market demand for sustainable products (Cossu et al., 2023).

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Back Cover

World of Preserved Meats: An Introductory Review offers to enrich readers about the diverse range of preserved meat products worldwide. Each chapter explores the history, raw materials, processing steps and conditions, as well as the emerging advancement of these products. The book spans a wide variety of examples. Starting from the iconic Italian Parma Ham to Japan's distinctive Katsuobushi. It demonstrates the remarkable diversity of meat preservation traditions.

The book presents preliminary and basic information of each product to accommodate all readers. It is designed to be a starting point for the general population and food enthusiasts alike. In an era of scientific and technological advancements, this book presents an opportunity for readers to rediscover traditional preserved meats that have been part of various cultures since ancient times.