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Review Article

Techniques of meat preservation- A review

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Abstract

Meat is the flesh of animals that is rich in protein, iron, zinc, fatty acids, and vitamins. Because of its nutrient and moisture concentrations, it is a highly perishable product. Because of its chemical composition and enzymatic activities, it is also very prone to spoilage. Because of the breakdown of fat, protein, and carbohydrates in meat, odors, putrefaction, and slime production occur, making the meat unsafe for human consumption. Moisture, temperature, microorganisms, ambient oxygen, and endogenous enzymes all have an impact on the shelf life and freshness of meat. Environmental bacteria are widely distributed and can adhere to meat from several sources, causing deterioration. Because of this, many technologies are used to preserve meat and meat products by inactivating or eliminating microbes. The goals of meat preservation are to enhance shelf life, eliminate microbes, and improve quality. Various preservation strategies are required to avoid the growth of bacteria that cause the physical and biochemical characteristics of meat to deteriorate. This review's goals are to discuss different methods and techniques for preserving fresh meat and meat products. This review also presents and discusses the benefits and drawbacks of these approaches.

Introduction

Meat is considered a complete protein because it contains all the essential amino acids, in addition to fatty acids, vitamins, and minerals (Alam et al., 2011; Azad et al., 2022; Hossain et al., 2023a, 2023b, 2021a, and 2021b; Rahman et al., 2022). Compared to many veggie diets, meat is a relatively concentrated source of high-quality, easily digestible protein. The slaughtering of a food animal is followed by a series of physiological and physical alterations that convert muscle to meat over the course of a few hours or days (Smulders et al., 2014). Diverse techniques for preserving meat have been developed in order to satisfy the demands of a growing human population. Since ancient times, humans have utilized a variety of food preservation techniques to preserve food for later consumption (Pal and Devrani, 2018). The canning of vinegar was introduced in 1782, and Nicolas Appert, a French chemist, patented the method of preserving food by canning. Later in 1837, French scientist Louis Pasteur used heat for the first time to eradicate harmful organisms in bears and wine. In 1980, the United States authorized the use of sodium benzoate as a preservative in certain goods. In 1990, the United States allowed the irradiation of poultry (Jay et al., 2005). Meat derived mainly from herbivorous animals, such as cattle, buffaloes, goats, sheep, camels, horses, and poultry, is widely consumed in developed as well as developing countries (Pal and Mahendra, 2015). Due to its rich nutritional matrix, meat is the best source of animal protein for many people around the world (Heinz and Hautzinger, 2005). According to the American Heart Association, the recommended daily intake of meat is six ounces. The conversion of animals into meat requires multiple processes, including the handling and loading of animals on the farm, the transportation of animals to slaughterhouses, the unloading and holding of animals, and the slaughtering of animals. Inadequate operational techniques and facilities in any of these operations will result in unnecessary animal suffering and injury, which can lead to meat loss, diminished meat quality, and meat deterioration. Therefore, preventing contamination during the cutting and processing of farm animals is of the greatest concern (FAO, 1991). The storage period can be prolonged through hygienic slaughtering and clean carcass processing (FAO, 1991). Due to its close to neutral pH, high moisture content, and abundance of nutrients, meat is more vulnerable to contamination by microorganisms than most other foods, making preserving it a greater challenge. The principle of food preservation is to create unfavorable conditions for the growth of microorganisms that cause food to spoil. Meat that becomes rotten loses its texture, flavor, and nutritional value, rendering it unsafe for human consumption. In the absence of appropriate preservation techniques, deterioration, microbial activity, enzymatic and chemical reactions, and physical changes are inevitable. However, it can be difficult to eliminate microorganisms from contaminated meat. Consequently, meat is preserved using a variety of methods, including chilling or refrigerating, freezing, curing, smoking, thermal processing, canning, dehydration, irradiation, chemicals, and pressure application (Cassens, 1994; Cheftel, 1995; Patterson et al., 1996; Zhou et al., 2010; Norton et al., 2009). This article is an attempt to present an overview of the different techniques applied to preserve meat around the globe.

Techniques of meat preservation

After the development and rapid expansion of supermarkets, meat preservation became essential for transporting meat over long distances without losing its texture, color, and nutritional value (Nychas et al., 2008). Traditional methods of meat preservation, such as dehydrating, smoking, brining, fermentation, refrigeration, and canning, have been replaced by chemical, bio-preservative, and non-thermal preservation techniques (Akhter et al., 2009; Akter et al., 2009; Zhou et al., 2010). The objectives of preservation techniques are to prevent microbial, oxidative, and enzymatic deterioration. The present techniques for preserving meat fall into three main categories: (a) controlling temperature; (b) controlling water activity; and (c) using chemical, biological, or physical preservatives. A combination of these preservation techniques can be used to slow down the process of decomposition. The preservation of meat and meat products has multiple goals, including i) controlling foodborne infections and poisonings, ii) ensuring the safety of food and food products from microorganisms, iii) preventing food spoilage, iv) extending the shelf life of raw and processed meat, v) enhancing the keeping quality of meat, and vi) reducing financial losses.

Chilling/refrigeration

Chilling or refrigeration reduces or inhibits the spoilage rate at temperatures below the ideal range, which can suppress microbiological growth and enzymatic as well as physico-chemical processes (Cassens, 1994). Fresh meat is kept refrigerated at temperatures ranging from 2 to 4°C. Chilling meat is essential for cleanliness, safety, shelf life, appearance, and nutritional quality (Akhter et al., 2022; Zhou et al., 2010). Carcasses are first placed in chilled cooling units (15°C) to eliminate body heat before being transferred to storing freezers (5°C). It is essential to maintain a sufficient distance between carcasses to allow for continuous air circulation. It can be chilled in two ways: (a) immersion chilling, which involves immersing the product in cooled (4°C) water; and (b) air chilling, which involves spraying the carcasses with water in a chamber with circulating cool air (Carroll and Alvarado, 2008). Meat chilling begins with the freezing of the animal carcass and continues through the entire process: holding, cutting, transportation, shopping centers, display, and even at the customer's home before the final usage. To avoid excessive shrinkage due to moisture loss, the relative humidity is usually regulated at 90%. Meat refrigerator storage varies by type of carcass, initial microbial load, packaging, temperature, and humidity throughout storage. Pork and poultry have a relatively high microbial load to begin with. Regardless of the species of origin, extreme caution should be taken while handling meat to prevent further microbial infection. Refrigerated temperatures promote the growth of psychrophilic microbes, resulting in the deterioration of meat over time. Fresh meat will generally keep in good condition for 5-7 days if kept refrigerated at 4 ± 1°C. Ultra-rapid freezing of pre-rigor beef may result in cold-shortening and toughening (Ockerman and Basu, 2004). It strongly suggests that processed meat remain chilled until it is finally consumed. When compared with fresh meat, well-preserved meat has a longer shelf life is also expressed by Akter et al. (2009).

Freezing

Freezing is the optimal technique for preserving the original qualities of fresh meat. Depending on the species, meat contains between 50 and 75% water by weight, and the chilling process converts the majority of this water into ice (Heinz and Hautzinger, 2007). It prevents microbial growth and inhibits enzyme activity. The most significant advantage of freezing involves the preservation of most of meat's nutrient content at storage, with only a tiny portion of nutrients lost during the thawing process. Before freezing, it is essential to wrap fresh meat with suitable wrapping paper; otherwise, the meat will be at risk from freeze burn. This abnormal condition is caused by progressive surface dehydration, which concentrates the surface pigments of meat. The freezing rate of frozen meat also affects its quality. Slow freezing results in the formation of large ice crystals, which may cause physical damage to muscle tissue and distort its appearance when frozen. Numerous small ice crystals develop uniformly throughout the meat tissue during rapid freezing. The freezing rate increases as the temperature decreases; nearly 98% of water freezes at -20°C, and crystal formation is complete at 65°C (Rosmini et al., 2004). Thus, the problem of muscle fiber contracting and appearance distortion is absent in meat tissue. As water solidifies within the muscle fiber itself, drip losses during thawing are significantly reduced. Numerous small ice crystals on the surface of fast-frozen meat are also important, as they produce a more desirable pale color compared to slow-frozen meat. Below -18°C, microbial proliferation ceases and cellular metabolism in animal tissues is completely stopped (Perez-Chabela and Mateo-Otague, 2004). Nevertheless, enzymatic reactions, oxidative rancidity, and ice crystallization will continue to play a significant role in deterioration (Zhou et al., 2010). Approximately sixty percent of the viable microbial population dies during freezing, but the remaining population increases progressively during frozen storage (Rahman, 1999). Yasmin et al. (2022) assessed the quality of goat liver and Akhter et al. (2022) studied the quality of beef liver under refrigerated storage and found minimal microbial load within seven days.

Drying

Drying is probably the oldest method of meat preservation. While drying solely or in conjunction with smoking could be done throughout the world, chilling and freezing were only appropriate during certain seasons or in arctic locations. When a huge animal's flesh and fat obtained from hunting it is too much to consume quickly, this strategy was extremely important to early people. During battles and sea transportation, dried meat, whether salted or unsalted, was extremely important. Due to advancements in general, drying started to be done on a larger scale, and easy methods of drying were developed and progressively improved. Before air conditioning, quality dried meat products were still manufactured. Fresh meat is a fantastic source of protein yet it spoils very quickly. Therefore, by drying the meat, people throughout the world have developed methods for preserving and enhancing the flavors of meat. Examples of dried meat products from around the world include "Pastirma" in Turkey, "jerky" in North America, "carne-de-sol" in Brazil, "biltong" in South Africa, "kaddid" in North Africa, and "cecina" in Spain. In order to dry meat, a variety of techniques are used, including vacuum drying, ultrasonic drying, freeze-drying, microwave drying, heat pump drying, pulsed electric field drying, and refractance window drying (Dinçer, 2021). Although these methods are efficient in drying meat, it is alleged that those that call for greater temperatures also reduce the quality of the dried meat by degrading the meat's vital components. However, several types of dried meat products exist depending on the type of meat, the drying process, and whether or not spices are used (Akter et al., 2009; Akhter et al., 2009; Mediani et al., 2022).

Curing

Historically, meat curing consisted of adding rock salt, sea salt, or ground salt to unheated pieces or small cuts of meat in order to reduce water activity, prevent microbial growth and chemical spoilage, soften the meat, and impart flavor to the product. Meat producers realized in the 19th century that some salts preserved meat better than others and that others enhanced and stabilized the product's red color. It was found that saltpeter (KNO_3) was the contaminant in these improved salts. However, the chemical reactions behind them remained unknown. Since ancient times, saltpeter has been recognized as an oxidative compound due to its oxidizing effect in gunpowder (carbon and KNO_3). So, how nitrate preserved or stopped oxidative rancidity was a mystery until Polenske (1891) of the German Imperial Health Office published experiments showing that when nitrate (saltpeter) was added to a pickling solution, nitrite was made, probably because of the actions of microorganisms in the brine. Lehmann (1899) and Kisskalt (1899) confirmed that nitrite was responsible for the red color and thermal stability of meat. Haldane (1901) shed light on the chemistry of the curing process by demonstrating that redox reactions took place during the curing of meat. In addition, he isolated NO-myoglobin as the pigment responsible for the bright red color of cured meat (Lacroix, 2007). Hoagland (1914) demonstrated that the nitrite anion was not the reactant; rather, the nitrous acid (HNO_2) or a metabolite of it, such as NO, reacted with myoglobin, as displayed in Figure 1. At the turn of the 20th century, the pigmentation of meat by nitrogen compounds was understood, but the antimicrobial and flavoring effects were still attributed primarily to the NaCl concentration. The action of nitrite on flavor and storage was not fully understood until the last two decades (Grever and Ruiter, 2001; EFSA, 2003; Lucke, 2008).

$$(KNO_3)\ \text{nitrate} \rightarrow \text{reduction by microorganisms} \rightarrow \text{nitrite}\ (KNO_2)$$

$$KNO_2 + H^+ \leftrightarrows HNO_2 + K^+$$

$$2HNO_2 \leftrightarrows N_2O_3 + H_2O$$

$$N_2O_3 \leftrightarrows NO + NO_2$$

$$NO + \text{myoglobin} \rightarrow \text{NO-myoglobin}$$

Figure 1. Action of nitrate in cured meat.

Sodium chloride, sodium nitrate, sodium nitrite, and sugar are the main curing constituents. In India, various methods of curing, including dried cure, pickle cure, injection cure, and direct cure, are utilized. The preservation of flesh through heavy salting is an ancient method. High concentrations of sodium chloride have a long history of use in food preservation (Dave and Ghaly, 2011). It was used as a rule of thumb because refrigeration facilities were unavailable in the past. Later, curing with table salt and sodium nitrate produced relatively superior products. By increasing osmotic pressure and decreasing water activity in the microenvironment, sodium chloride inhibits microbial growth (Dave and Ghaly, 2011). As little as a 2% concentration can inhibit some bacteria. A concentration of 20% of sodium chloride is high enough to inhibit many food spoilage yeasts, including *Debaryomyces hansenii, Yarrowia lipolytica, Kloeckera apiculata, Kluyveromyces marxianus, Pichia anomala, Pichia membranaefaciens, Saccharomyces cerevisiae, Zygosaccharomyces bailii, and Zygosaccharomyces rouxii* (Praphailong and Fleet, 1997). However, several bacteria from the genera Bacillus and Micrococcus have demonstrated tolerance to high salt concentrations. Sugars can bind with moisture and reduce water activity in foods (Dave and Ghaly, 2011). Dextrose, sucrose, brown sugar, corn syrup, lactose, honey, molasses, maltodextrins, and starches are commonly used in dry meat processing to increase flavor, minimize salt harshness, and lower water activity (USDA, 2008). Sugar is generally regarded as safe in Canada and the United States. The nitrites used in the meat preservation industry are always salts like sodium nitrite or potassium nitrite. Nitrites provide red meat color stability, cured meat flavor, and rancidity control. In addition to regulating anaerobic bacteria, nitrite salts are excellent at controlling color, lipid oxidation, and odor improvement (Roberts, 1975; Archer, 2002; Lovenklev et al., 2004; Sindelar and Houser, 2009). For meat products, the current limit for nitrite in food is 156 ppm in the United States and 200 ppm in Canada (Ryser and Marth, 1999). The use of nitrite as a food additive, on the other hand, may produce carcinogenic nitrosamines. Rather than bacteria, benzoic acid is typically used to inhibit yeasts and fungi. It has been reported that yeasts such as Saccharomyces and Zygosaccharomyces possess an innate resistance to benzoic acid within acceptable toxicological limits. It is suggested that the combination of benzoic acid treatment and nitrogen starvation conditions will effectively prevent food deterioration due to yeast.

The best method to preserve carcasses, meat, and meat products for an extended period is through energy-intensive freezing operations, which inhibit bacterial growth but not that of psychrophiles and spores. Neumeyer et al. (1997) reported that most of these organisms can survive at freezing and proliferate during thawing. Traditional methods for preserving meat through salting and curing are widely acknowledged. Other chemicals have been used as food additives for the preservation of livestock, but each country has established its own rules and regulations to prevent adverse effects on humans (Cassens, 1994; Jay et al., 2005). Freeze storage cannot prevent oxidative and microbial/enzymatic deterioration. Consequently, chemical preservation techniques are quite advantageous when combined with refrigeration in order to improve product stability, quality, and freshness while preserving nutritional value. Antimicrobial preservatives are substances used to extend the shelf life of meat by inhibiting microbial growth during slaughtering, transportation, processing, and storage (Rahman, 1999). Bacterial growth and meat decomposition are dependent on bacterial species, nutrient availability, pH, temperature, humidity, and the gaseous atmosphere (Cerveny et al., 2009). Antimicrobial compounds introduced during processing should not be used as a substitute for poor processing conditions or to hide a product that is no longer bad (Ray, 2004). In conjunction with refrigeration, they offer sufficient safeguards for livestock. Chlorides, nitrites, sulfides, and organic acids are common antimicrobial compounds (Archer, 2002; Chipley, 2005). Several organic acids are generally accepted as safe. Effective mold inhibitors include benzoic acid, citric acid, propionic acid, sorbic acid, and their salts. Lactic acid and acetic acid inhibit the growth of microbes, whereas sorbate and acetate inhibit the growth of yeasts in food. As meat preservatives, ascorbic acid, sodium ascorbate, and D-isoascorbate have been utilized. Their antioxidant properties can oxidize reactive oxygen species, resulting in the formation of water. It has been demonstrated that ascorbic acid increases the antimicrobial activity of sulfites and nitrites (Mirvish et al., 1972; Raevuori, 1975). In the meat industry, benzoic acid and sodium benzoate are also used as preservatives. The antibacterial activity of benzoic acid is due to its dissociated structure (Krebs et al., 1983; Brul and Coote, 1999; Feiner, 2006).

Smoking

Smoking meat is referred to as an approach for extending the shelf life of meat from animals. Smoke contains many wood decomposition products, including aldehydes, ketones, organic acids, phenols, and many others. Due to surface dehydration, a decrease in surface pH, and the antioxidant properties of smoke constituents, smoke can preserve meat and meat products. Meat curing and smoking are closely related processes. Currently, smoking usually occurs after curing. Smoke is produced in a specially constructed smoke house where sawdust, hard wood, or both are subjected to combustion at around 300°C (Pal, 2014). The production of smoke is accompanied by the formation of a variety of organic compounds and their condensation products. Aldehydes and phenols, which make up fifty percent of smoke components and account for most of the color of smoked meat products. Phenols are the principal bactericidal compounds. Currently, many liquid smoke formulations are accessible commercially in developed nations. Generally, liquid smoke is produced by removing polycyclic hydrocarbons from hard wood through filtration. Consumers greatly enjoy the smoky flavor that liquid smoke adds to products before cooking.

Smoking meat likely began in prehistoric times as a byproduct of attempts to preserve meat. As with all scientific discoveries, ancient people may have investigated how various types of wood provided desirable or more markedly undesirable flavors and how temperature affected shelf life. Ostertag and Young (1934) postulated that the shrinkage of muscle fibers and the expansion of interstitial space were the causes of smoking's preservative effect in the 1930s. Jensen (1943) and Draudt (1963) theorized that the smoke's bacteriostatic compounds, such as resins, phenols, aldehydes, and aromatic hydrocarbons, reduced the surface microbial load. Smoke consists of multiple wood combustion products that are visible as gases and carry unburned solid particles (resin, tar, ash, etc.) as they move from the combustible heat source. The exact amount or ratio of gases and particulates within the smoke stream is determined by the type and moisture content of the wood, the rate and temperature of heating or burning, and other variables such as airflow. Meats are smoked at varying rates based on the flow of air into the smokehouse, the surface moisture of the meat, the temperature, and the relative humidity of the smokehouse.

Varieties of smoke

Cold smoking is one of the world's oldest preservation techniques and is typically practiced in cold regions. In order to achieve the desired shelf life, the humidity level can be decreased, as the process and function of cold smoking are to remove moisture, reduce water activity, prevent microbial spoilage, and attempt to prevent fat oxidation. Typically, cold smoking results in 15–20% weight loss. Typically, cold smoking is performed on foods that require minimal thermal processing, such as cold-water fish, dried or fermented sausages, and cured meat. Due to an extended smoking time, cold-smoked products are typically lighter in color (yellow to medium brown) and have a more distinct and uniform flavor throughout the product than warm and hot-smoked products. Warm smoking is typically administered between 23ºC-40 ºC and 75 to 85 percent relative humidity for four to forty-eight hours. Time, temperature, and humidity are dependent on the dimensions of the product and the final product that is wanted. Warm-smoked products have higher water activities than cold-smoked products and must be refrigerated because they are produced within the food's hazard zone (4–60°C). Due to a shorter smoke duration, warm-smoked products may have a greater external smoke coating with less smoke penetration than cold-smoked products. Salmon, mackerel, and other fish products are among the warm-smoked items. Hot smoking can begin at 40–60°C but can continue as the smokehouse temperature increases and can occur at temperatures as high as 90–100°C, depending on the product and desired flavor, with relative humidity ranging from 60% to 85% for up to four hours. This product must be refrigerated or fully cooked due to the shortened smoke time, as smoking will not significantly extend its shelf life. The following method of heated smoking can be used to increase color deposition in fully cooked meat products: (1) Smoking the meat product between 45°C and 65°C and potentially at higher temperatures. (2) In contrast, larger diameter products such as hams or barbecue may continue to be smoked at temperatures as high as 77–110°C; and is followed by (3) fully cooking the product to an internal temperature of between 60°C and 74°C. This is the most popular method of smoking meat.

Smoke chemistry

The direct application of smoke particles to the meat's surface results in the production of smoke flavor and color. In addition, smoke's ability to penetrate organic surfaces allows its flavor and color to penetrate the product's surface. According to Maga (1988), there is a chemical reaction between the carbonyls in the smoke vapor phase and the individual amino acids that make up the meat proteins during the heating process. Similar to the Maillard browning reaction, these chemical reactions result in nonenzymatic browning. The conversion of amino groups to hydroxyl groups through individual amino acids present in an organic casing as a result of Meat-Smoking Technology will reduce the number of chemical reactions, resulting in less smoke color deposition. Glycoaldehyde, glyoxal, and methyglyoxal are the carbonyls most associated with the formation of color in smoked foods. The carbonyls acetone, diacetyl, formaldehyde, furfural, and hydroxyacetone are less reactive (Anifantaki et al., 2002; Maga, 1988). The distinctive smoky flavor of smoked chicken is a major determinant of its sensory profile, which can influence consumer acceptability and intention to buy (Saldana et al., 2019). It is mainly due to volatile compounds produced during the combustion and decomposition of smoked materials (Jerkovic et al., 2007). Alcohols, aldehydes, acids, esters, phenols, furans, and ketones are the most common volatile compounds found in smoked chicken drumsticks (Zhang et al., 2022). Nevertheless, carcinogenic compounds such as polycyclic aromatic hydrocarbons (PAHs) and heterocyclic aromatic amines (HAAs) can be produced during the smoking process (Hitzel et al., 2013; Zhang et al., 2021). PAHs are composed of two or more condensed aromatic carbon rings produced by the incomplete combustion of burning materials. PAHs may be genotoxic and carcinogenic to humans due to a metabolic activation of diepoxides that causes DNA replication and mutation errors, which initiate the carcinogenic process (Skaliac et al., 2014 and 2018).

Antimicrobial and antioxidants in smoke

Meat products may develop antioxidative and antimicrobial properties from smoldering with wood or liquid smoke (Anastasio et al., 2004; Martinez et al., 2004; Kjallstrand and Peterson, 2001; Estrada-Munoz et al., 1998). The USDA has approved liquid smoke as a compound for use as an antioxidant and/or antimicrobial agent. The primary antimicrobial and antifungal compounds found in wood smoke are phenols and carboxylic acids. Carbonyls play a lesser role in inhibiting microbial growth, while hydrocarbons play no role. The antimicrobial potential of smoke compounds has varying degrees of efficacy, and smoke compound deposition alone is insufficient for ensuring food safety (Sunen et al., 2003). Smoke contains the polyhydroxyphenolic compounds pyrogallol and resorcinol. These substances are the most powerful antioxidants generated by smoked meats. Phenols can reduce oxidation by donating an electron to an oxidative radical without altering their structure. Guaiacol derivatives derived from methoxyphenols during the pyrolysis of lignin have less antioxidant activity than phenols because they contain fewer OH groups on a typical basis.

Thermal processing or cooking

The destruction of spoilage and pathogenic organisms is the most essential function of cooking. The number of organisms destroyed will depend on the product's cooking temperature, the length of heating time, and the variety of bacteria present. Normal cooking conditions are unable to sterilize meat; the result is essentially a reduction in total bacterial load and an extension of storage life. Proper handling to prevent contamination of the product and refrigeration to prevent bacterial multiplication will lengthen the shelf life. The duration of storage will largely depend on the precautions taken to prevent recontamination and reduce conditions favorable to the growth of organisms that remain in the meat. Multiple pathogens can be troublesome. *Listeria monocytogenes* is currently the subject of extensive research into ready-to-eat meat products. The microbes are not very resistant to heat but prefer cold temperatures. If a ready-to-eat product becomes contaminated with Listeria during processing, packaging, or slicing and no post-packaging remedies are used to eliminate the bacteria, this can be problematic. This pathogen has resulted in a significant number of recalls of consumer goods. To control pathogens such as Salmonella spp., *Campylobacter jejuni*, and *Escherichia coli*, the internal temperatures of cooked food must meet certain requirements.

The primary purpose of cooking meat is to produce a suitable product for consumption. However, cooking also significantly extends the shelf life of such products. Although raw meat is susceptible to deterioration within a few days, properly packaged and refrigerated cooked and cured meat products can typically be stored for several weeks. Cooking enhances flavor and reduces the chance of spoilage by partially destroying microorganisms. As with meat curing, the history of meat cooking predates civilization, and it likely began by accident when fresh flesh was exposed to fire and/or heat. The case study is partially supported by Charles Lamb's classic poem Dissertation on Roast Pig. Cooking meat enhances its preservation qualities and extends its shelf life. Cooking not only helps meat products stay stable, but it also significantly contributes to the availability of a variety of meat products, which is possible just by changing cooking techniques. Therefore, flesh cooking has significantly contributed to the advancement of civilization. The following advantages of cooking meat and livestock products are realized: i) it kills a large number of microorganisms and extends the shelf life of meat products, assuming no further contamination; ii) it improves meat palatability by intensifying the flavor and altering the texture; iii) it develops color; iv) it decreases the water content of raw meat, particularly on the surface, which lowers the water activity; v) it improves the palatability of casings on cured meat products; and vi) it extends their shelf life, and vii) it destroys endogenous proteolytic enzymes and prevents the formation of undesirable flavors through proteolysis.

As a method of preservation, thermal processing is used to eliminate spoilage microorganisms. Pasteurization refers to heating at temperatures between 58 and 75 degrees Celsius, which is also the recommended temperature range for most processed meats. This heat treatment substantially extends the shelf life of meat. These products must also be stored in a refrigerated condition. Sterilization refers to the process that exposes meat to temperatures above 100°C, at which point all spoilage-causing microorganisms are destroyed or their microbial cells are permanently damaged. Due to the possibility of bacterial spore survival, this thermal treatment does not render the meat product commercially sterile. However, exposure to high temperatures gives foul flavors to canned meat and alters its texture. Different meat products vary in their water content, lipid content, and consistency. These parameters determine the thermal processing schedule. For instance, moist heat is more effective than dry heat at destroying microorganisms and spores. Consequently, a meat product with a high moisture content requires less heat to sterilize (Pal and Devrani, 2018).

Canning meat and meat products

Canning is the process of applying heat to meat kept in a jar in order to kill spoilage-causing microorganisms. The process is done by heating the meat and meat products for a specific period and thereby destroying these harmful microorganisms. Proper canning techniques prevent this type of spoilage. As the container cools and seals, air goes out, and a vacuum develops during the canning process. It is the procedure of preserving meat in sealed containers through thermal sterilization. The sensory attributes of meat products, such as appearance, flavor, and texture, are maintained to a great extent through canning. In addition, canned meat products have a minimum two-year shelf life at room temperature. There are several steps involved in the canning process, including meat preparation, precooking, filling, exhausting, seaming, thermal processing, cooling, and storage (Pal and Devrani, 2018).

The animals must be healthy, unstressed, and slaughtered properly; raw meat must be stored at a suitable temperature and time combination; recipes must be well-formulated; processing must be performed using good manufacturing practices; and thermal processing must be at the correct time and temperature combination to ensure a safe product. Various meat products are packaged in hermetically sealed containers (tins, glass jars, and retortable packages) and stored at room temperature after sterilization. In order to prevent the growth of pathogens and food-spoiling organisms under ambient storage conditions, certain cured meats must undergo additional tests to ensure that pathogens and spoilage organisms do not grow under ambient temperatures. Major challenges for meat canning include: i) High temperature: dry and moist heat treatment; ii) Water activity (Aw): Drying, curing, and fat addition; iii) Acidity (pH): acidification; iv) Redox potential: at low O_2 level, vacuum, and ascorbate added conditions; v) Preservatives: Sorbate, nitrite, and antioxidant added conditions. Meat and poultry processors must be knowledgeable about all relevant local regulations and laws governing meat processing and marketing. The machinery used in meat-processing facilities should be designed in such a way that it is simple to clean. All product-contacting surfaces should be free of cracks and have volume inside. Equipment must be fabricated from anti-corrosive metals, such as stainless steel, aluminum, or authorized plastics.

All tinned meat products must be thermally processed in accordance with a recommended authority on the use of thermal processing. There are variations in manufacturing and procedures in canning that may influence process relationships. Meat products should not be packaged without guidance from an authorized packaging authority. The sterilization processes mentioned here for tinned meat products should only be used as general guidelines and as approximations. Most of the thermal processes are not designed to kill all thermophilic microorganisms that may be present in a product. All canned meat products should be water-cooled to a centered can temperature between 37 and 42 degrees Celsius quickly after processing. The following categories of meat products are commonly available in canned form: i) Meat preparations, including corned beef, luncheon meat, pork chops, and preserved meat; ii) Cooked whole meat (for instance, ham or leg); iii) Sausages in brine (such as Frankfurters type, Vienna sausages, and chicken sausages) iv) Meat-based ready-to-eat meals, such as beef in gravy or chicken with rice, v) Meat-based soups, including chicken soup and oxtail soup, Thai soup, vi) Cold cuts or meat products are known as luncheon meats. They are prepared from finely ground or chopped meat and are usually served sliced condition. The luncheon meat may contain cereal, and it is possible to cure and sterilize luncheon meat.

Sterilization

Low-acid foods, such as meat, necessitate a thorough sterilization process unless other obstacles are included. By measuring and quantifying the total amount of heat treatment to which a canned product is subjected throughout the sterilization process, thermal processing specialists developed the temperature and time combinations recommended for achieving this balance between food safety and food quality requirements. From a microbiological standpoint, it would be optimal to use an extreme heat treatment that would eliminate any chance of any microorganisms surviving. Most canned meat products, however, cannot be subjected to intense heat without suffering loss of sensory quality (e.g., texture breakdown, jelly and fat separation, discoloration, undesirable flavors) and nutritional value. To comply with the preceding factors, an understanding must be reached in order to keep the heat sterilization sufficiently strong for the microbiological safety of the products and as moderate as possible for product quality. The products and recipes provided in this section are intended to provide ideas and instructions for preparing canned meat dishes that have been sterilized.

Canning

Meat in a jar and meat products in a jar can be prepared from a variety of sources. The procedures are numerous and adaptable. Fresh or cured beef and pork trimmings, tripe, hearts, lips, lungs, cracklings, etc., can be used alongside trimmings, scraps, and small portions of product from other canning operations. In general, potted meats are heavily seasoned with white spice, nutmeg, paprika, mustard, and cardamom seeds. The shippers' personal preferences and line of work have a significant influence on the seasoning. The cost of the various ingredients and the availability of meats both have a significant impact on the recipe. Cereal can be incorporated into the dish with potted meat. Any quality sausage binder or maize flour can be used. Utilizing processed flour is advantageous because it absorbs water when cold, making it simpler to control the product's consistency. Processed flour absorbs roughly twice as much as water unprocessed flour. When the product is mixed and processed through the cutter, the cereal is added to the potted meat (Figure 2). Dry-processed flour may be added.

Figure 2. Canned meat.

Irradiation

Irradiation is known as "cold sterilization" as well. It is the emission and propagation of energy through substances. Continuous waves constitute electromagnetic radiation. They can ionize molecules in their path. These radiations can kill microorganisms by fragmenting their DNA molecules and ionizing the water contained within them. It is important to keep in mind that microbial destruction of foods occurs without substantially raising the temperature of the food. Gamma radiation generates the desired action only during food irradiation and is unaffected by source removal. These are frequently employed in food preservation. UV radiations are the most bactericidal of the known ionizing radiations, but they lack effective preventing ability, so they are only used for the surface sterilization of meat. Recently, irradiation technology has become popular due to its effectiveness in microbial destruction and increasing the shelf life of meat and meat products (Islam et al., 2022 and 2019; Rima et al., 2019; Sadakuzzaman et al., 2021). Food is irradiated with ionizing radiation, such as gamma rays, X-rays, or high-energy electrons (Ehlermann, 2014). The wavelength of ionizing radiation is depicted in Figure 3a. In general, food irradiation is determined by the dose absorbed, which is expressed in Gray (Gy) or kilo Gray (kGy), with 1 Gy equating to 1 J/kg of product. Considered a safe, and effective method for reducing or eliminating harmful microorganisms, prolonging expiration lives, and improving the quality and safety of food products (Arvanitoyannis, 2010). Erkmen and Bozoglu (2016) and Farkas and Mohacsi-Farkas (2011) stated that the principles of food irradiation are determined by the ability to disrupt the genetic material of microorganisms, preventing them from propagating or causing death. Figure 3b depicts the direct and indirect effects of irradiation on the genetic material of microorganisms. Irradiation can disrupt the bonds between base pairs in a cell's genetic material, destroying its ability to reproduce. Then, damage to water molecules generates free radicals and reactive forms of oxygen, which indirectly harm genetic material. Irradiation also aids in the destruction of enzymes and proteins that contribute to food deterioration, thereby extending its shelf life (Munir and Federighi, 2020).

The United States, Canada, and several European and Asian nations permit food irradiation with Cobalt-60, cesium-137, and electron-beam accelerators (Maherani et al., 2016; Indiarto et al., 2020). Cobalt-60, the most common source of ionizing radiation for food irradiation, is a radioactive isotope that originates gamma rays that are capable of penetrating directly into food products and destroying pathogenic microorganisms. Moreover, electron-beam accelerators are used to irradiate food. These devices generate high-energy electrons capable of penetrating food products to eradicate pathogenic microorganisms and extend shelf life (Shahi et al., 2021).

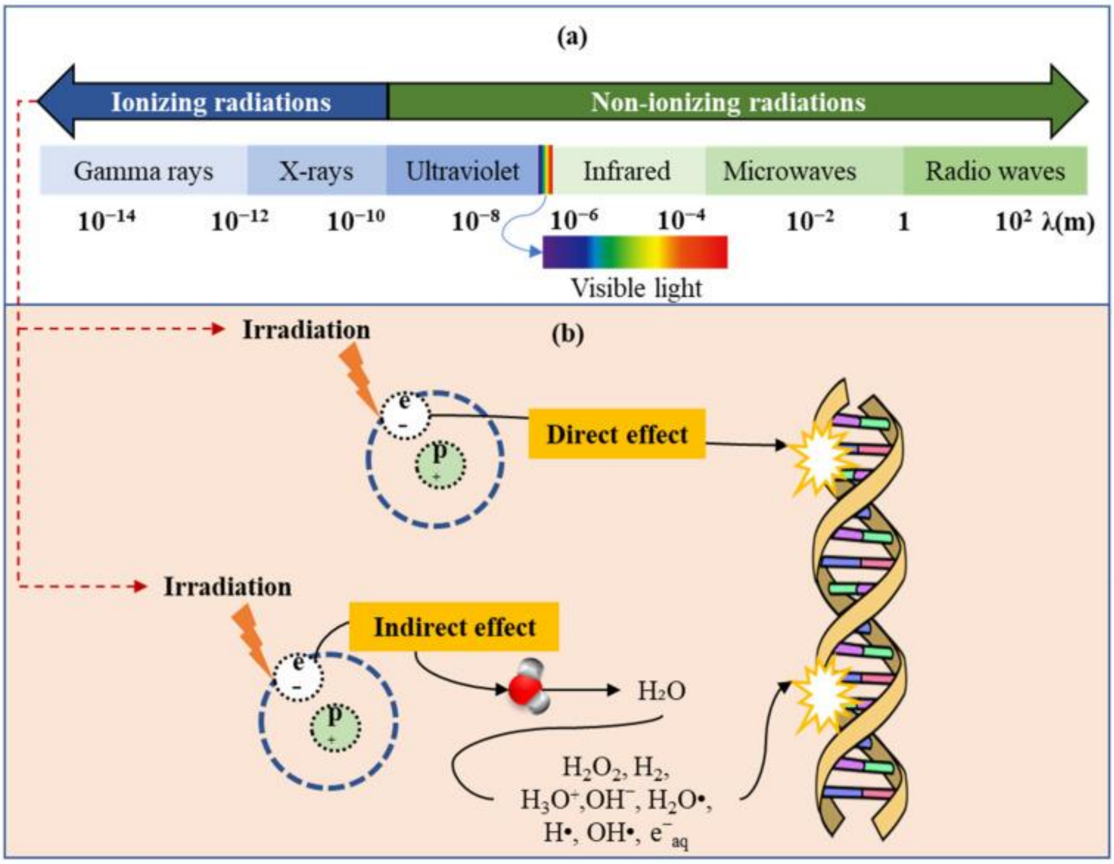

Figure 3. (a**)** Electromagnetic spectrum; **(**b**)** schematic of the effect of irradiation on nucleic acids.

Source: Indiarto et al. (2023).

There are numerous advantages to irradiating food, including multifunctional applications and safety and security assurances (Bachir and Mehio, 2001; Indiarto et al., 2020). The spectrum produced is beneficial against a wide range of bacterial spore concentrations. Due to the absence of heat during processing, the method is safe for food, does not substantially reduce nutrient levels, provides no chemical residues, and is easy to control. According to Ehlermann, the following principles must be observed to extend the shelf life of irradiated food products: (1) Radurization depends on low levels between 0.1 and 1 kGy. The amount being used inhibits respiration, delays ripening, kills parasites, and eradicates the Trichinella parasite. (2) A moderate dose of radiation is referred to as irradiation. This radiation consumes approximately 1–10 kGy, which reduces spoilage and pathogens such as Salmonella spp. and *Listeria monocytogenes*. This dose is commonly found in refrigerated foods, and its application is identical to that of pasteurization, with the exception that irradiation does not rely on thermal energy. (3) Extremely high doses greater than or equal to 10 kGy that extend between 30 and 50 kGy are used in radopertization. This dose is typically used in the sterilization process because its effect can kill all microorganisms in foods up to the spore level. In general, the sources and principles of food irradiation depend on the ability of ionizing radiation to disrupt the genetic material of microorganisms, enzymes, and proteins in food products, resulting in enhanced food safety and quality. National and international authorities regulate the use of irradiation to ensure its safety and efficacy.

The effectiveness of irradiation in reducing microbial contamination of meat has been extensively studied (Bachir and Mehio, 2001). By exposing food to ionizing radiation, hazardous microorganisms that can cause foodborne illness are reduced or eliminated. Previous research (Chun et al., 2021; Yemmireddy et al., 2022) showed that irradiation could effectively reduce the levels of pathogens like Salmonella and *Escherichia coli* as well as spoilage organisms. This led to a higher level of microbial safety and a lower risk of foodborne illness. The effectiveness of various forms of ionizing radiation, such as gamma rays and e-beams, on meat has been investigated (Park et al., 2010). According to Park et al. (2010), gamma ray irradiation inhibits microbial proliferation in meat more effectively than e-beam irradiation. Yeh et al. (2018) discovered that UV light effectively destroys Salmonella spp., Pseudomonas, Micrococcus, and Staphylococcus on meat. By eradicating these contaminant microorganisms, the shelf life of meat products is extended. Low-dose gamma irradiation can improve microbiological safety, and extend the shelf life of chicken meat without diminishing its quality. Sedeh et al. (2007) discovered that bovine meat irradiated with 3 kGy of gamma rays inhibited the proliferation of mesophilic bacteria, coliforms, and Staphylococcus aureus. Schevey et al. (2013) determined that a gamma ray irradiation dose of 3.5 kGy effectively eliminates pathogenic microorganisms from raw meat. Radiation had the effect of retarding bacterial cell proliferation and deactivating their metabolism. Bacteria are naturally resistant to the effects of irradiation, and their resistance increases during the latency phase, or inactive state. Those who are in the development phase will be more vulnerable.

Addition of essential oils (EO) for meat preservation

Due to their diverse content of antimicrobial and antioxidant compounds, essential oils (EOs) have the potential to serve as natural food preservatives (Conner, 1993; Oussalah et al., 2007). EOs have long been used as flavoring agents in food and beverages. EOs are secondary metabolic products of the plant and are utilized in numerous spice and food industry applications. Russo et al. (1998) found that each variety has a unique physiological and biochemical form, with enzymatic mechanisms that are coded in its DNA and guide biosynthesis by forming its parts in a certain way. Commonly, they are concentrated in a single region, such as the leaves, bark, or fruit, and when they occur in different organs of the same plant, they frequently have distinct chemical identities. Due to their diverse content of antimicrobial compounds, EOs have the potential to serve as natural food preservatives (Conner and Beuchat, 1984; Connor, 1993). Burt (2004) stated that steam distillation is the most common commercial process for producing essential oils. Extraction by liquid carbon dioxide under low temperature and high pressure seems to produce a more natural organoleptic profile and may also influence antimicrobial properties (Moler, 1998), and the use of hexane for the extraction has been demonstrated to have greater antimicrobial activity than steam distillation (Packiyasothy and Kyle, 2002). It was also determined that the antioxidative properties of most plant extracts were highly dependent on the solvent used for extraction (Yanishlieva et al., 2006), and that supercritical carbon dioxide extraction can also preserve the extract's antioxidant properties (Tipsrisukond et al., 1998). Terpenoids and phenolic compounds are the most common active compounds in EOs (Oussalah et al., 2007). When tested against different EOs and different microorganisms (Skaltsa et al., 2003; Helander et al., 1998; Kim et al., 1995), the minimum level of inhibitor ranged from 1 mM for active compounds to 3% for less active compounds. Inhibiting the growth of pathogenic bacteria and expanding food's shelf life by using EOs as natural antibacterial agents is a novel idea. Das et al. (2022) stated that mustard oil may be used for meat marination and preservation to extend the shelf life of refrigerated meat rather than soybean and flax seed oils. The pattern of EOs in the mustard oil might reduce the microbial load more effectively, and it is recommended that mustard oil be used in the preservation of raw broiler meat in refrigerated storage.

Ismail et al. (2001) found that using a solution made of 100% sage (Santolina sp.) or thyme dramatically decreased the number of *Yersinia lipolytica* on chicken. Manderfeld et al. (1997) reported on the antimicrobial activity of furocoumarins in parsley against *Listeria monocytogenes*, *Escherichia coli*, and spoilage bacteria. Carrots have phenolic compounds and EOs with considerable anti-listeria activity. These EOs include eugenol, cinnamaldehyde, thymol, citronellol, limonene, and geraniol. Essential oils are antimicrobial as well. Chicken can become tainted with Candida and Rhodutorula when antibiotics are not used. Essential oils (EOs) with concentrations between 50 and 500 ng/ml were more effective at killing *Staphylococcus aureus*, *E. coli*, and *Klebsiella pneumoniae* than those with concentrations lower than 50 ng/ml. This was the case for clove, cinnamon, cardamom, thyme, tea tree, marjoram, ho leaf, and sage. A key component of vanilla beans, vanillin, significantly inhibits spoilage yeast in apple puree, including *Saccharomyces cerevisiae*, *Zygosaccharomyces rouxii*, and *Debaryomyces hansenii* (Cerutti and Alzamora, 1996). Moore and Atkins (1977) found that cultivating garlic stunted the development of Candida, Cryptococcus, *Thodotorula torulopsis*, and Trichosporon. *Aspergillus parasiticus* can't make aflatoxins (B1 and G1) if ground oregano and thyme and their extracts are added to the growth environment. At pH 5.5, thymol and carvacrol completely stop the growth of *Aspergillus flavus*, *Aspergillus niger*, *Geotrichum candidum*, Mucor spp., and Penicillium spp. on potato dextrose agar (Akgul and Kivanc, 1988). Inhibition of *Aspergilus parasiticus* growth and aflatoxin generation by concentrations of 0.02, 0.2, 2.0, and 20% cinnamon, respectively (Bullerman, 1974). Pickles and sauerkraut made with mustard oil have been shown to be resistant to spoilage from the yeasts *Saccharomyces ellipsoideus*, *Saccharomyces cerevisiae*, and *Mycoderma vini* (Shelef, 1984). Essential oils from spices can hinder the recovery of heat-injured yeasts by damaging structural and metabolic enzymes (Conner and Beuchat, 1984). Because of their lipophilic nature, the compounds found in EOs have antibacterial properties that can be used to attack the membrane's integrity, reduce the cell's energy supply, and cause significant damage to the cell's outer membrane (Rhayour et al., 2003) or plasmic membrane (Lambert et al., 2001). Essential oils high in phenolic compounds have better antibacterial effects than terpenoids, as reported by Cosentino et al. (1999). However, even very small elements might contribute through their synergistic interactions with one another. Sage, some types of thyme, several varieties of oregano, and clove have been found to have antibacterial properties (Paster et al. 1995). Ali et al. (2022) stated that bee honey also contains some antioxidants that reduce the microbial load and increase the shelf life of meat and meat products.

Antioxidants in meat preservation

Due to their diverse content of antimicrobial and antioxidant compounds, essential oils (EOs) have the potential to serve as natural food preservatives (Conner, 1993; Oussalah et al., 2007). EOs have long been used as flavoring agents in food and beverages. EOs are secondary metabolic products of the plant and are utilized in numerous spice and food industry applications. Russo et al. (1998) found that each variety has a unique physiological and biochemical form, with enzymatic mechanisms that are coded in its DNA and guide biosynthesis by forming its parts in a certain way. Commonly, they are concentrated in a single region, such as the leaves, bark, or fruit, and when they occur in different organs of the same plant, they frequently have distinct chemical identities. Due to their diverse content of antimicrobial compounds, EOs have the potential to serve as natural food

preservatives (Conner and Beuchat, 1984; Connor, 1993). Burt (2004) stated that steam distillation is the most common commercial process for producing essential oils. Extraction by liquid carbon dioxide under low temperature and high pressure seems to produce a more natural organoleptic profile and may also influence antimicrobial properties (Moler, 1998), and the use of hexane for the extraction has been demonstrated to have greater antimicrobial activity than steam distillation (Packiyasothy and Kyle, 2002). It was also determined that the antioxidative properties of most plant extracts were highly dependent on the solvent used for extraction (Yanishlieva et al., 2006), and that supercritical carbon dioxide extraction can also preserve the extract's antioxidant properties (Tipsrisukond et al., 1998). Terpenoids and phenolic compounds are the most common active compounds in EOs (Oussalah et al., 2007). When tested against different EOs and different microorganisms (Skaltsa et al., 2003; Helander et al., 1998; Kim et al., 1995), the minimum level of inhibitor ranged from 1 mM for active compounds to 3% for less active compounds. Inhibiting the growth of pathogenic bacteria and expanding food's shelf life by using EOs as natural antibacterial agents is a novel idea. Das et al. (2022) stated that mustard oil may be used for meat marination and preservation to extend the shelf life of refrigerated meat rather than soybean and flax seed oils. The pattern of EOs in the mustard oil might reduce the microbial load more effectively, and it is recommended that mustard oil may be used in the preservation of raw broiler meat in refrigerated storage.

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