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Review

Trends and Innovations in Sterilization of Ready-to-Eat Food Products: Challenges and Future Directions

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Abstract: The growing demand for Ready-To-Eat (RTE) food products has significantly shaped the industry. RTE foods, including meat, dairy and vegetable-based products, offer convenience and practicality but are highly susceptible to contamination by pathogenic microorganisms. Sterilization, an essential process to eliminate viable pathogenic microorganisms, including spores, has become an important solution to ensure food safety and extend shelf life. Based on research data visualization focusing on trends over the past decade (2014-2024) analyzed using the VosViewer app, thermal sterilization processes such as using retorts and microwaves are effective methods in eliminating pathogenic microorganisms and prolonged shelf life. However, thermal processes can affect the quality of the resulting food products. Recent advances in sterilization technology aim to overcome this challenge by maintaining product quality while ensuring microbial safety through non-thermal sterilization in the form of irradiation, pulse electric field, cold plasma and high-pressure processing. These findings underscore the need for continuous innovation and optimization in sterilization processes to balance safety, nutrient preservation and industrial viability. By integrating advanced technologies and addressing existing challenges, the food industry can better meet consumer preferences for high-quality, safe and sustainable RTE products.

Keywords: Ready-to-Eat, Sterilization, Thermal Process, Non-Thermal Process, Product Quality

Introduction

There has been a significant increase in consumer demand for ready-to-eat foods that are practical and convenient. RTE foods refer to heat-processed, cooked meat, dairy, or vegetable products that can be consumed immediately with a short preparation time. Ready-to-eat foods, especially meat, with different nutritional values, compositions and sensory characteristics, have been widely produced in recent years. Meat is a type of product that is easily damaged by contamination of pathogenic bacteria such as *Listeria monocytogenes, Escherichia coli and Salmonella* spp, which is a challenge in the commercialization of products in the market (Dharma, 2023). Microorganisms can contaminate food products, resulting in foodborne illness when consumed. The presence and growth of these microorganisms must be prevented, one of which is by the sterilization process (Ayeni *et al*., 2022). In some regions, the quality of meat may be inconsistent due to supply chain issues, such as improper handling or storage conditions, which could affect the effectiveness of sterilization.

Sterilization is a process that aims to make the product free of all viable pathogenic microorganisms, including spores, to inhibit spoilage and extend the shelf life of the product (Rutala *et al.*, 2023; Chang *et al.*, 2024). Thermal death time, a kinetic parameter of the sterilization process, determines how long it takes to eliminate a particular microorganism at a given temperature. Based on the Indonesian Food and Drug Administration regulations, the commercial sterile process is a heat sufficiency number expressed as the equivalent of a minimum heating time of 3 minutes at 121.1°C (Saragih *et al.*, 2021). According to the United Nations Sustainable Development Goals, global food security should be achieved by 2030. In order to achieve this, it is necessary to produce food with better nutritional value and safety through thermal food processing (Rivera *et al.*, 2024). Thermal sterilization is the most commonly used technology due to its effectiveness in killing pathogenic microorganisms. Applying this sterilization process can affect the quality of the resulting product, such as physical and chemical changes (Gomez *et al*., 2020).

As a solution, many studies are developing advanced technologies in the sterilization process to preserve as much of the nutritional value and physical integrity of the product as possible. However, although various sterilization technologies have been developed, challenges still need to be overcome, such as limitations of application on a medium and industrial scale and potential environmental impacts. However, despite the development of various sterilization technologies, challenges remain, particularly in their application on a medium and industrial scale, as well as the potential environmental impacts. One of the main challenges in sterilizing RTE foods in emerging markets is the lack of access to advanced sterilization equipment and the high cost of modern technologies, which can be a barrier for small-scale food producers. Therefore, this article described and provided data visualization related to the latest research developments over the past ten years related to the sterilization process of food products, the methods used and the impact on product quality. A bibliometric analysis was conducted to help identify important information used as a data visualization that can help summarize the development of sterilization in ready-to-eat foods.

Materials and Methods

Data Sources and Analysis

The data was reviewed from various journal sources, with ScienceDirect as the primary source. Data was collected by accessing a journal with a publication range from 2014 to 2024. The data qualification used only focused on research articles and review articles by analyzing information such as abstracts, keywords and relevant article titles. The keywords used included sterilization, commercial sterilization and food products. Research sources only collected articles in English. Research published in languages other than English is not well-represented in citation-tracking databases. The collected data was saved in RIS format and processed using an application called VosViewer version 1.6.19 and then used to export the data for additional bibliometric analysis (Eck and Waltman, 2020). Keywords that were not detected during data analysis using VosViewer were excluded from the data visualization process. The results are generated using parameters such as keyword occurrence networks and visualization overlays.

Recent Research on the Sterilization Process of Food Products

Food processing on an industrial scale aims to provide food on a large scale by applying the principle of food preservation through sterilization. The rapid development of industrialization has led to the emergence of a fast-paced lifestyle, including the cooking process on a household scale, thus encouraging the need for fast, ready-to-eat food. Ready-to-eat is processed food that is very practical and in great demand today because it has a long shelf life (Silaturahmi and Moentamaria, 2024). The demand for products has encouraged manufacturers and government regulators to meet consumer demand and fulfill specific nutritional and food safety requirements. Food preprocessing technologies such as preservation methods are applied to improve food safety quality by providing a long product shelf life and increasing the functional and nutritional value of food products (Koutchma *et al.*, 2021).

Based on the visualization of research trends related to sterilization in food products from 2014-2024, the relationship and interrelationship of sterilization with various factors that can affect the sterilization process, sterilization methods and the impact of sterilization were presented. In the production of ready-to-eat food, sterilization is an important point to maintain product safety in product commercialization. The visual network in Fig. (1). Provides an overview of the interrelationship between sterilization and various factors that must be considered, such as contamination, product quality, thermal stability, aseptic conditions and proper sterilization methods. Foodborne pathogens cause health issues for billions of people worldwide each year. To prevent this, food processing employs sterilization methods to ensure consumer safety (Jimenez *et al.*, 2023). Sterilization reduces pathogenic bacteria that can damage food, inactivates spores and helps prevent spoilage. In network visualization (Fig. 2.), shelf life is linked to sterilization, although the process can negatively impact product quality. When developing sterilization processes, ensuring adequate heat treatment at the product's coldest point (the least heated point) is essential to achieve the required lethality for the target pathogen (Gezahegn *et al*., 2024).

Several methods that can be used in the sterilization process of food products are described below.

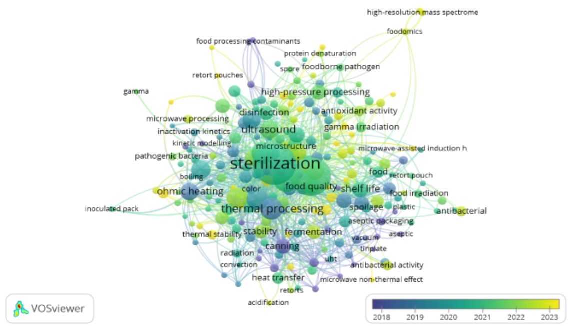


Fig. 1: Network visualization of recent research on sterilization

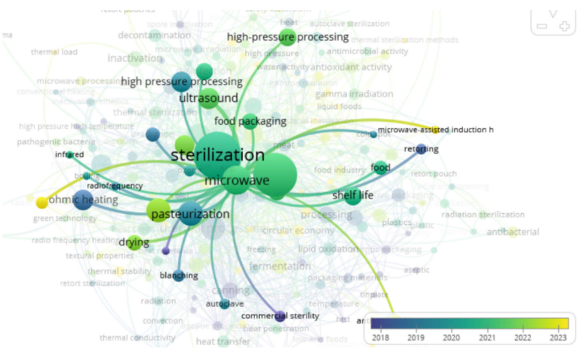


Fig. 2: Network visualization of sterilization method

Thermal Process

Sterilization can be done by applying heat treatment called thermal processing technology, which has been widely carried out in the food industry (Verheyen *et al.*, 2021). Based on the data visualization in Fig. (3), there is a relationship between the application of thermal processing in canning, commercial sterility, low-acid foods and canned foods in meat. Thermal processing has several advantages, such as its use is chemical-free, safe and cost-effective. This process is known as 'Commercial Sterility' (Jimenez *et al.*, 2023). The bacterial death rate follows a first-order semi-logarithmic rate, meaning that a product cannot be sterilized entirely but commercially. This implies that sterile products cannot be mass-produced, but commercially sterile products can be mass-produced based on an acceptable survival probability of no more than 1 in 10^{12} colonies (Jimenez *et al.*, 2023; Fardella *et al.*, 2021). Since 1965, the minimum 'botulinum cook' Fo value of 3 minutes has been discontinued and is still used today for canned products with low acid content.

Thermal food processing depends on several variables, including surface heat transfer, package size and shape, product heating rate coefficient (thermophysical food attributes), the food's starting temperature, the heating medium, the Come-Up Time (CUT), the retort temperature (also known as the operating temperature) and the necessary lethality. The Arrhenius model, or more commonly, the z-value (temperature required to reduce the D-value in one log cycle) and D-value (time required to reduce the nutrient concentration or microorganism content at a specific temperature) are used to measure and characterize the thermolability of nutrients. Thermal food sterilization is often carried out under a CRTP. The usual temperature employed in a CRT procedure is 121.1°C and the processing time needed to get a lethality value F0 - which is defined as a thermal treatment that permits a decrease of 12 decimal (Fardella *et al.*, 2021; Yang *et al.*, 2022; Jimenez *et al.*, 2023).

Sterilization is key to ensuring meat products' safety and has a long shelf life (Yang *et al.*, 2022). Meat processed through thermal processing methods such as canning requires special attention to ensure food safety and maintain product quality during storage. In this process, meat is placed in airtight containers of high-quality packaging materials, such as metal cans or flexible packaging designed to withstand high temperatures. This packaging protects the product from outside contamination and ensures its integrity during the sterilization process. Thermal processing of canned food is usually carried out in a pre-arranged retort, where the food is heated by a heating medium (Zhu *et al.*, 2022).

The thermal sterilization process is essential for products with low acidity, such as processed meats, which are naturally more susceptible to the growth of harmful microorganisms, including Clostridium botulinum, which can produce deadly toxins under anaerobic conditions. Therefore, heating is carried out to a specific temperature capable of ensuring commercial sterility, which is a condition in which the food product has been processed thermally or through specific methods so that all pathogenic microorganisms, spoilage microorganisms and spores that can grow under normal storage conditions have been destroyed or inactivated.

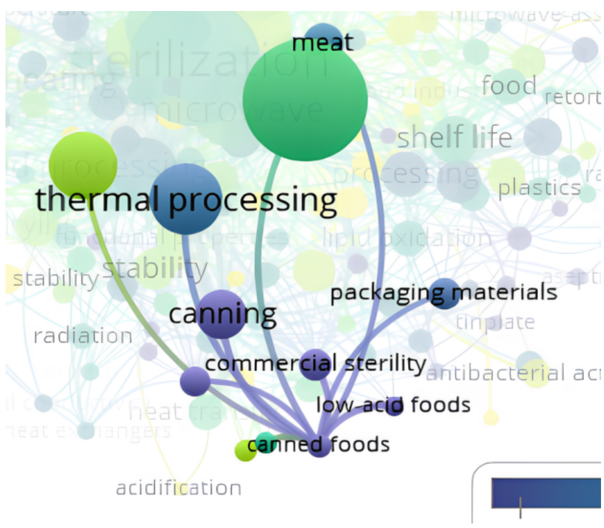


Fig. 3: Visualisation of thermal process in sterilization

Commercial sterility aims to ensure that food products are safe for consumption and have a long shelf life without refrigeration. By achieving commercial sterility, products can be stored at room temperature for long periods without the risk of spoilage or health hazards while maintaining flavor, texture and nutritional quality to the greatest extent possible.

Retort

Retorts are commercial sterilizers that use heat to raise the temperature of the device while it is hermetically sealed. The temperature of the instrument is raised using heat in commercial sterilizing procedures. There are three steps in the sterilizing process:

1. The first step, known as Come Up Time (CUT), is the amount of time needed for the high-flow heating medium to attain a pressure of around 1-1.4 bar above atmospheric pressure and a retort temperature of roughly 115-121°C
2. Depending on the target microorganism or particular microbiological contamination, the retort maintains the following temperature and pressure during the second stage, Pt (holding or cooking stage), to ensure sterile conditions
3. Cooling water is injected during the third phase, known as Cool Down Time (CDT). The goal of cooling is to avoid overheating the product and stop the growth of thermophilic microbes. However, the retort bag could burst during the cooling process. Supplying high-pressure air throughout the chilling process may prevent this and package integrity and container deformation can be preserved (Jimenez *et al.*, 2023). To determine the lethality value of a sterilization procedure, this approach uses a computer to monitor the coldest point in the thermal process in real-time. Retorting has been shown to be a successful and economical method of food production

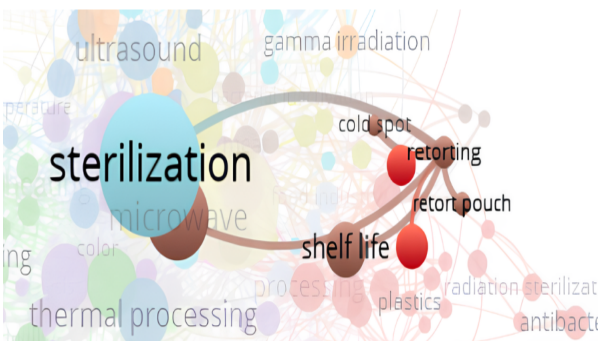


Fig. 4: Visualization of retort and the sterilization process

Based on the data visualization in Fig. (4). retorting is part of the sterilization process that is associated with shelf life. Retortable pouches combine the advantages of plastic and metal cans, making them more practical, convenient, economical, easy to open and energy-efficient in heat distribution and efficient. They can also withstand the high temperatures needed for thermal processing, including the operating temperature of the retort. During thermal processing, the compact cross-section of a retortable pouch allows for rapid heat transport to the most noteworthy point with little surface overcooking. Food products in retort pouches must thus cook for roughly half as long as those in conventional cans (Fardella *et al*., 2021; Azhari *et al*., 2023; Saragih *et al*., 2021).

In 2016, Regulation No. 24 on the requirements for commercial sterility standards was published by the Food and Drug Administration of the Republic of Indonesia (BPOM RI). F0, or equivalent heating time (in minutes) at 121.1°C (250°F), is a metric used to assess heat appropriateness for commercial sterilization. The F 0 value of commercial sterilizers against Clostridium botulinum must be at least 3.0 min. Acidity (pH) and water activity (aw) are the main factors that affect food danger. Foods with an aw of more than 0.85 and a pH of more than 4.6 are categorized as low-acid foods by the FDA. When kept at room temperature, these foods need to be sterilized (Saragih *et al.*, 2021).

Low-acid food items are frequently thermally sterilized at high Constant Retort Temperature Profiles (CRTPs) to guarantee the long-term shelf stability of packaged goods. Processing conditions sometimes include high temperatures (120-130°C) for prolonged periods (usually more than 60 minutes) in order to guarantee a low-acid product that is safe and shelf-stable. Extreme processing conditions (temperature and time) have a major effect on food's texture, flavor and nutritional value. They also damage the food's microstructure, which increases the loss of nutrients like carotenoids, amino acids, ascorbic acid, Polyunsaturated Fatty Acids (PUFAs), nonreducing sugars and amino acids into the medium. This leads to the formation of furans (Fardella *et al.*, 2021).

According to its thermal and physicochemical parameters, the food product's heat penetration determines the quality attributes of food produced by retort sterilization (Yu *et al.*, 2023).

Microwave

The US Food and Drug Administration (USFDA) has approved microwave-based thermal sterilization technology for commercial sterilization of pre-packaged foods, allowing for long-term room temperature storage. Fig. (5) shows a visualization of existing research related to microwave-assisted sterilization in extending product shelf life. Under the influence of a fluctuating microwave electromagnetic field, polar molecules rotate and collide, transforming electromagnetic energy into thermal energy. This process is known as microwave heating. Any food's electrical characteristics influence the energy levels in the high-frequency electric field used for heating in a microwave (Yang *et al.*, 2022; Soni *et al.*, 2020).

Microwave heating speeds up the sterilization process by heating the food from the inside, as opposed to traditional techniques like heating in a water bath. This allows the food to reach the desired core temperature faster. Furthermore, this technology's variable temperature heating produces a gradual, even dispersion of heat, which lessens the temperature differential between the food's inside and outside as compared to the conventional retort technique. This method lessens the detrimental effects of prolonged high temperatures on meat quality while simultaneously guaranteeing the best possible shelf life (Yang *et al.*, 2022). Microwave sterilization helps preserve milk protein quality by minimizing denaturation, particularly in whey protein, compared to traditional methods (Munir *et al.*, 2019). According to Xue *et al.* (2023), microwave sterilization preserves the color and texture of imitation crab meat more effectively than retort sterilization. Other process classified as thermal sterilization is ohmic heating which are associated as a part of processes in spore inactivation (Fig. 6.).

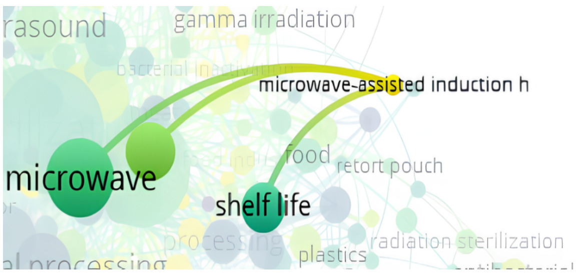


Fig. 5: Data visualization of the relationship of microwave sterilization in extending shelf life

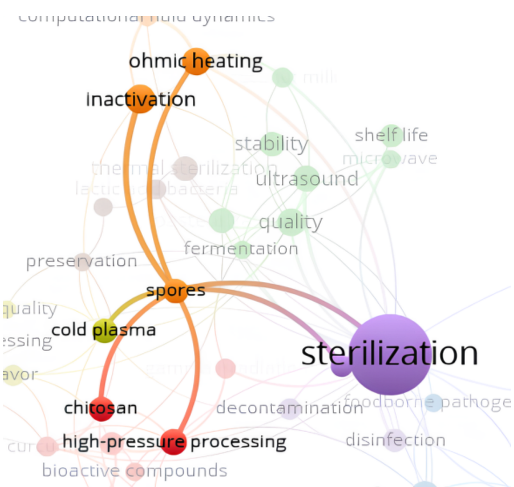


Fig. 6: Visualization of non-thermal process

Non-Thermal Process

Changes in consumer demands related to food safety, coupled with an increasing desire for food products that are free of microorganisms while maintaining nutritional value and sensory quality, have pushed food professionals to seek better solutions. In response to this challenge, non-thermal treatments are emerging as a promising alternative. Non-thermal technology is increasingly being applied in various food industries due to its ability to preserve nutrients, flavor, color and other sensory attributes with minimal damage. Various studies have shown that the freshness quality of food products, such as vegetables and dairy products, can be significantly preserved after non-thermal treatment. This is due to the fact that the food samples are only treated for a very short period of time, which does not have a major impact on the nutritional content and other characteristics. Non-thermal technology has proven to be effective in fighting microorganisms and inactivating enzymes (Safwa *et al.*, 2024).

Irradiation

Kr, β, γ, or accelerated electron rays (often Co60 and Cs137 gamma rays) are used in radiation sterilization technology to sterilize food. Irradiation is primarily used to sterilize beef, pig and other foods since it may permeate food, cause heat damage to DNA and RNA and destroy microbes and insets in food (Li *et al.*, 2021).

Cold Plasma

When it comes to inactivating harmful bacterial spores in powdered meals, cold plasma works well. Reactive oxygen and nitrogen species cause an etching process that deactivates bacteria in the suggested mechanism. Changes in the cytoplasmic membrane, metabolic proteins, DNA, or photo-oxidation may result from this process. Since cold plasma does not specifically target bacterial cells, the reactive species it generates can cause chemical interactions with lipids, proteins and carbohydrates that are present in the food matrix (Li *et al.*, 2021).

Pulse Electric Field

PEF is a non-thermal technique that kills bacteria with no harm to food quality by applying high voltage and brief electrochemical pulses to a liquid or semi-solid meal that is sandwiched between two electrodes. Although the exact method by which PEF inactivates bacteria is yet unknown, permeabilization of the microbial membrane is a widely accepted theory. Cell integrity gradually deteriorates with increasing electric field strength and the field is rendered inactive when it is above the original electric field threshold value. Food items with minimal electrical conductivity and no air bubbles are most suited for PEF.

The pulse number, pulse breadth, pulse shape, pulse length, pulse specification and pulse frequency all have an impact on the PEF effect. In the meat and fish business, the PEF method primarily seeks to lengthen the curing period and enhance the final product's muscular structure's softness. Additionally, PEF treatment improves meat's protein digestibility (Li *et al*., 2021).

High-Pressure Processing

There is a link between high-pressure processing as part of the sterilization process and the process of removing contaminants in food (Fig. 7.). Food is often processed using Ultra High-Pressure sterilization (UHP) at pressures between 100 and 1000 MPa and temperatures between 0 and 100°C for a few seconds to more than 20 min. Regardless of sample mass and shape, UHP may spread instantly and continuously throughout the food system. UHP makes it possible to inactivate the majority of vegetative bacteria, yeasts and molds, protecting food nutrition and odor while maintaining flavorings and vitamin C. Meat may be sterilized with this method (Li *et al*., 2021).

Sterilization is difficult since spores are known to be resistant to heat, radiation and other substances. High-pressure conditions (>1000 MPa) can be used to eliminate certain bacterial spores, whereas thermal processing can weaken the spores. Unfortunately, due to practical constraints, such high-pressure conditions are not possible in the food industry.

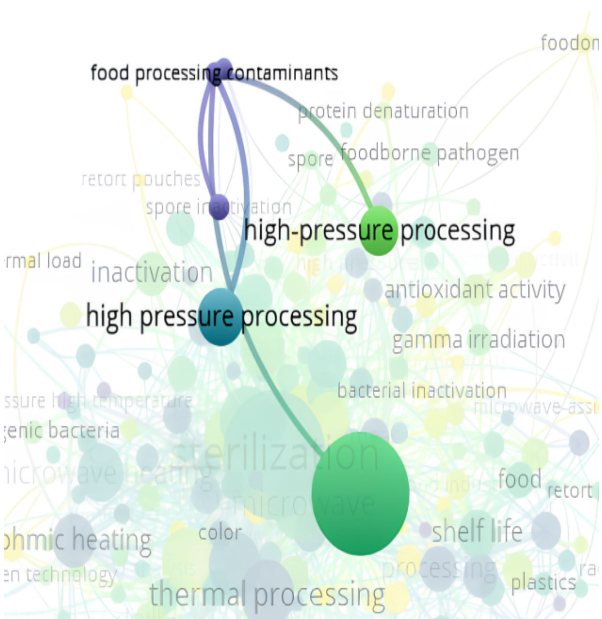


Fig. 7: Visualization of sterilization process in high-pressure processing

Effect of Thermal Sterilization Process on Product Quality

Based on Fig. (8). there is a relationship between the thermal sterilization process and product quality. Thermal processes such as color, texture and flavor can affect nutrient content and food quality. Different thermal sterilization techniques have different effects on the quality of meat products. Optimization of sterilization minimizes changes in food quality and nutrient composition at the same time (Mutma'innah *et al.*, 2022; Yang *et al.*, 2022). The type of food and the dimensions and form of the package will determine if the decrease of Clostridium botulinum spores is more than three minutes (Fardella *et al*., 2021).

Research shows that specific vitamins are degraded during the process due to their heat resistance, while others may be more bioavailable. Thus, sterilization suggests a complex interaction between nutrients (Jimenez *et al.*, 2023).

One of the most crucial markers for determining the quality of meat is its color. Oxidative denaturation of myoglobin may be the cause of metmioglobin synthesis, which is linked to the coloring of duck breast flesh. Meat may develop dark deposits due to myoglobin and hemoglobin, which can be impacted by microwave radiation. Under the presence of a microwave electromagnetic field, polar molecules like water and ions are guided in their rotation and collision by microwave heating. Rapid heating results from this process, which enables the surface of the duck meat to absorb microwave energy and transform it into thermal energy. Additionally, the Maillard process is accelerated by this quick heating, producing brown or even black macromolecules that cause the flesh to darken (Yang *et al.*, 2022).

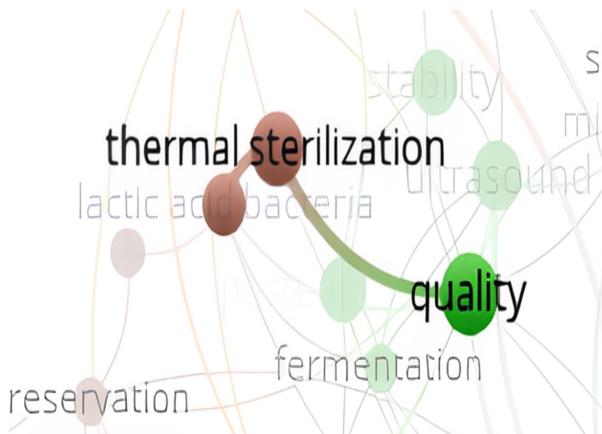


Fig. 8: Visualization of the link between product quality and thermal sterilization

Hardness, chewiness, compactness, pliability and resilience are some of the textural characteristics that are crucial for evaluating the quality of meat products. Products made from cooked meat may undergo structural changes as a result of sterilization, including reactions brought on by temperature that lower the product's quality. The degree of treatment and influence that various sterilizing techniques have on the structure of meat causes variations in the textural qualities of the meat. More intensive heat treatment may be the cause of the textural deterioration in sterilized meat groups, which can result in loosening muscle structure, reduced cross-linking levels of myofibrillar proteins and alterations in the spatial structure of proteins (Yang *et al.*, 2022).

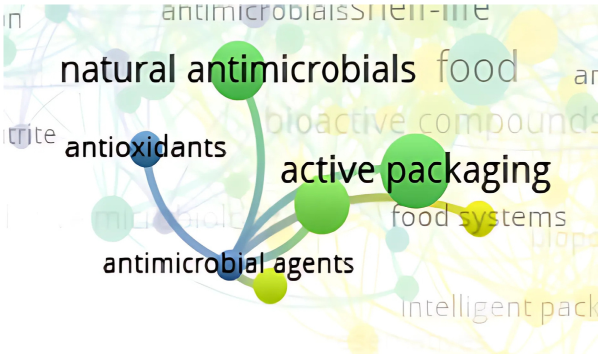
In order to minimize quality loss and enhance the quality of sterilized food, the food industry is dedicated to ongoing research and development of several innovative sterilization processes. The food business has seen the emergence of several innovative sterilizing methods (Yang *et al.*, 2022).

Food Preservative

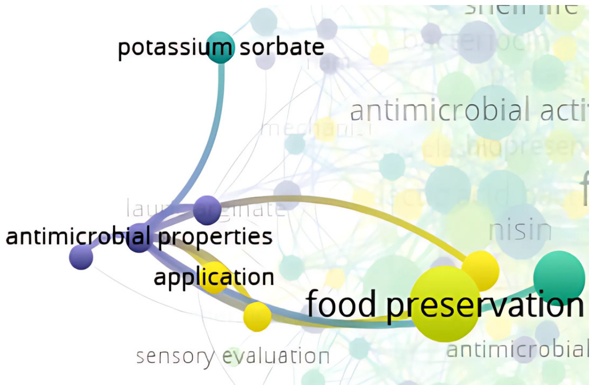
There are various ways to extend the shelf life of ready-to-eat foods. In addition to thermal and non-thermal sterilization, the process is applied to a series of physical processes to obtain conditions free of spoilage microbes so that the shelf life can be extended. Another way to extend shelf life is by adding food preservatives to the product. Based on data sources, there is a relationship between product shelf life and the addition of preservatives from both natural and synthetic sources (Fig. 9).

The addition of antimicrobial agents to food preparations can effectively inhibit the growth of *L. monocytogenes*. These antimicrobial additives primarily include organic acids, bacterial metabolites (bacteriocins) and plant extracts (antioxidants). Among organic acids, lactic acid, acetic acid and their salts, whether used individually or in combination, have shown significant potential for food preservation (Necidová *et al.*, 2019). The food industry primarily utilizes potassium sorbate as a preservative to prevent microbial spoilage, typically applying it as a sprayed solution at the final stage of production after tenderizing. However, its potential toxicity at doses exceeding recommended limits has been noted. Therefore, it is crucial to monitor its application levels and persistence in food products (Cárdenas *et al.*, 2024).

In addition to adding preservatives to food, the shelf life of ready-to-eat products can also be extended with the use of proper packaging. Research suggests that edible films and coatings can greatly extend the shelf life of food products.



(a) Antioxidant as a natural food preservative



(b) Potassium sorbate as a chemical food preservative

Fig. 9 (a-b): Food preservative application

Recently, edible films made from various natural materials have been developed to encapsulate active ingredients, including antimicrobial agents, anti-browning agents, colorants, spices and nutrients, in a range of food products such as seafood, poultry and meat (Fang *et al.*, 2025). It is important to note that the use of nisin is currently limited by the US Food and Drug Administration to 15 ppm in meat. Selecting the appropriate food preservative for each product type can serve as an effective alternative for extending the shelf life of ready-to-eat food products.

Future Consideration

Based on the findings presented in the article, it can be seen that there is a significant difference between thermal and non-thermal sterilization methods. Thermal sterilization has been widely used in every layer of small-scale and industrial-scale processes. Thermal sterilization has the advantages of being chemical-free, safe and cost-effective (Jiminez *et al.*, 2023)), but there are drawbacks that are enough to affect consumers' views on the quality of products that decrease or bias against heat sources such as steam (Zhu *et al.*, 2022). As stated by Gomez *et al.* (2020), Changes in the chemical structure of compounds responsible for flavor, texture and nutritional value, such as protein denaturation, hydrolysis and gelation due to boiling and prolonged heating, can affect consumer acceptance and disrupt dietary balance. To address this, technologies are needed that ensure food safety while preserving the nutritional integrity of traditional meat products to meet consumer expectations.

This limitation marks the beginning of the development of non-thermal sterilization for food products, particularly RTE foods. Non-thermal sterilization addresses the drawbacks of thermal sterilization, offering the advantage of preserving food quality. However, at an industrial scale, non-thermal sterilization presents several challenges, including high production costs and the need for a thorough understanding of sterilization mechanisms. Moving forward, businesses and industries must focus on understanding these mechanisms, selecting the appropriate equipment and maintaining tools to optimize the sterilization process for effective application.

Optimizing the procedural mechanisms of each technique and educating consumers about the benefits and potential of non-thermal technologies can enhance awareness. This should precede any modifications to their design, particularly if the goal is to improve cost-effectiveness and scalability for industrial applications. Ultimately, both the implementation and selection of these technologies are crucial (Chacha *et al*., 2021).

The primary challenge in adopting non-thermal processes is the high production cost. Future research should focus on evaluating ways to enhance and maintain food quality and safety for more efficiency, along with conducting cost comparison analyses of various non-thermal food processing technologies that currently lack optimization. These analyses can help the food industry and stakeholders select the most suitable non-thermal technology based on their production requirements, capacity and operational needs.

Conclusion

Based on data visualization related to current research over the past ten years in the sterilization process of food products, it can be concluded that food products, especially ready-to-eat foods, require special attention to be marketed and have a long shelf life for the safety of consumers. Commercial sterilization can be achieved by paying attention to the heat adequacy number, the main parameter regulated in product marketing regulations, namely the equivalent of a minimum heating time of 3 min at a temperature of 121.1°C. Thermal sterilization processes are widely used and proven to be effective in eliminating pathogenic bacteria such as c botulinum but can affect the physicochemical quality of the resulting product, so there is a development of non-thermal sterilization technology that can maintain the nutritional value and physical properties of food products. However, this advanced technology has other challenges, such as needing to be more applicable to the small and food sectors.

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Author's Contributions

Daimon Syukri: Wrote the manuscript.
Rini: Wrote the manuscript and research supervisor.
Risa Meutia Fiana: Data analysis.
Jonrinaldi: Literature review for engineering aspects.
Ratni Prima Lita: Literature review for economics aspects.
Quratul Aisyah: Community observation.
Hiyang Hidayati Sukma: Community observation
Yasmin Azzahra and Aurelia Amaliyah Tarumiyo: Figure editing.
Deden Dermawan: Industrial perspective.

Ethics

There are no ethical issues in this study.

Reference

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