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REVIEW ARTICLE

Developments in Radiofrequency Processing Applications on Food of Animal Origin

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ABSTRACT

Radio frequency (RF) treatment is one of the novel dielectric heating techniques for foods. It is an indirect process whereby electrical energy is initially transformed into electromagnetic radiation, which then generates heat within the food. Radiofrequency heating has been found some advantages like rapid heating or deep penetration into food compare to conventional methods. Traditional heat treatments applied to animal products can lead to quality losses, color and texture changes, overheating problems and other undesirable side effects. RF treatment has the potential to minimize these problems, improve organoleptic quality, reduce process time and save energy. Recently, the most investigated methods for animal origin foods are RF pasteurization/sterilization, RF-supported thawing methods, RF heating or cooking and the results obtained are promising. Radiofrequency technique is also investigated for following purposes; blanching, post-bake drying, roasting and disinfection. The new generation of RF studies explore other aspects, including the discovery of dielectric properties of foods, the evaluation of efficiency and quality effects, environmental sustainability of RF technologies and the improvement of RF system performance. Also combined systems are investigated such as radiofrequency-assisted cryogenic freezing. This paper reviewed principles of RF, overview situation of RF treatment methods and recent literature on RF applications on food of animal origin.

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1. Introduction

In recent years consumers demand that foods sold in markets have similar sensory properties to fresh foods and maintain their quality with minimal processing. Many new technologies have been and continue to be studied by researchers and industry to make the final products suitable for this demand. These technologies include both thermal and non-thermal processes. Microwave, high hydrostatic pressure, ultrasound, ohmic treatment and radiofrequency (RF) are some of the novel techniques applied in food technology.

RF is grouped together with microwave as non-ionizing radiation. RF is also called high frequency dielectric heating (Laycock et al., 2003). RF waves in the range of 1 to 300 MHz (Yao et al., 2022).

Radio frequency can heat food faster and more efficiently because it utilizes different parts of the electromagnetic energy spectrum. In contrast to conventional heating systems where heat energy is transferred from a hot medium to a cooler product resulting in large temperature gradients, electro-heating

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involves the transfer of electromagnetic energy directly into the product. This initiates volumetric heating due to frictional interaction between water molecules and charged ions. In this system heat is generated within the product. The efficacy of these modes of heating is generally higher than that of traditional conduction or convection heating modes (Koutchma, 2022). In traditional RF heating, such as in parallel plate electrode systems, the electromagnetic field is usually generated in a directional way between the electrode plates while the electromagnetic field of microwave heating might approach the material from different directions (Huang et al., 2018; Llave & Erdogan, 2022).

The potential of RF technology has been known since 1940s. Initial research attempts efforts laid the groundwork for the industrial application of RF technology by identifying its potential and associated constraints. RF heating has been shown to obtain effective pasteurization or sterilization. Microbial or pest inactivation by RF heating is based on reversible/irreversible deformation of cell members (Ștefănoiu et al., 2016). There are many studies investigating the use of the RF technique on meat products for pasteurization or sterilization (Ballom et al., 2021; Wang et al., 2022a; Wei et al., 2019) and pasteurization and disinfection (Bermudez-Aguirre & Niemira, 2023). Wang et al. (2022a) evaluated pilot-scale pasteurization system for beef sausages. Sausages were pasteurized only RF energy (27.12 Mhz, kW). They mentioned that result of the study showed RF system has a great potential to pasteurize solid foods like beef sausages.

Studies also showed that RF systems can preserve physicochemical components of foods better. As reported by Fiore et al. (2013), RF oven treatment preserved ascorbic acid and increased glucosinolates concentration in broccoli and it decreased the formation of acrylamide in roasted potatoes more than 50%. Similarly, the total amount of vitamin B in salmon was 30% and 50% higher in RF cooking system than those of conventionally cooking method. In addition to the use of RF for these purposes, it has also been investigated for drying (Chen et al., 2022; Huang et al., 2022), tempering (Han et al., 2022; J. Jiang et al., 2021), cooking or baking (Hussain et al., 2021; Q. Jiao et al., 2022; Saka et al., 2021). While studies on meat have predominantly centered on pasteurization/sterilization and thawing, the impact of the RF on product quality has been less explored. Wang et al. (2022b) was used to RF (27.12 MHz, 6 kW) combined superheated water (SW) system to inactivate *G. stearotherophilus* spores in ready-to-eat poached spicy pork slices. Result showed combined RF with SW under 170 mm electrode gap provides reduction in *G. stearotherophilus* spores and kept good sensory evaluation. Jantapirak et al. (2021) investigated effect of RF technology on the quality properties of vacuum-packed nitrite-free sausages and

concluded that shorter process time of RF system promoted good texture and cooking yield safely for this products.

According to the US Food and Drug Administration (FDA), RF waves can be used to heat food safely if the radiation source must consist of electronic equipment that produces radio frequencies at specific frequencies determined by the FCC (Federal Communications Commission) and the radiation used or intended to be used in the production of food must have an effect on the process (Cakmak & Tavman, 2011).

An additional application area of the RF field is the utilization of radio frequency identification (RFID) technology. RFID technology is a non-contact automatic identification technology that enables the automatic identification and data acquisition of target objects through the use of radio frequency signals (Yiyang et al., 2019). RFID is an alternative technology with a potential to replace traditional universal product code (UPC) barcodes. This system is applicable to the food industry and meat products.

Current studies about RF technology mostly focus investigate pasteurization or sterilization potential, thawing freeze foods, tempering and discuss distribution during RF treatment. The new generation of RF studies explore other aspects, including the discovery of dielectric properties of foods, the evaluation of efficiency and quality effects, environmental sustainability of RF technologies and the improvement of system performance.

Thus, this review's purpose is to introduce RF technology, give basic information's about RF heating principle and summarize its novel application in food of animal origin.

2. History of RF

In 1873 James Clerk Maxwell mathematically predicted the existence and behavior of radio waves and after him Heinrich Henz experimentally proved Maxwell's theory in 1885. RF technique has been used for various food processes for over 80 years since the 1940s. At the beginning it was used or studied for blanching vegetables or thawing frozen foods. In the 1960s most of the studies focused on using RF energy for thawing or defrosting frozen foods. Some of the studies were successful and they applied to production lines. After a while RF has also been adapted for pasteurization of meat products (Marra et al., 2009). The next step in RF was post-bake drying of cookies and snacks in the 1970s. In the 1990s, the use of the RF technique for pasteurization became widespread, and studies on this subject were conducted with greater frequency. Subsequently, research into resolving technical issues associated with this technique intensified (Huang et al., 2018). Figure 1 shows the number of publications about radiofrequency on food of animal origin since 2017 according to Scopus Database.

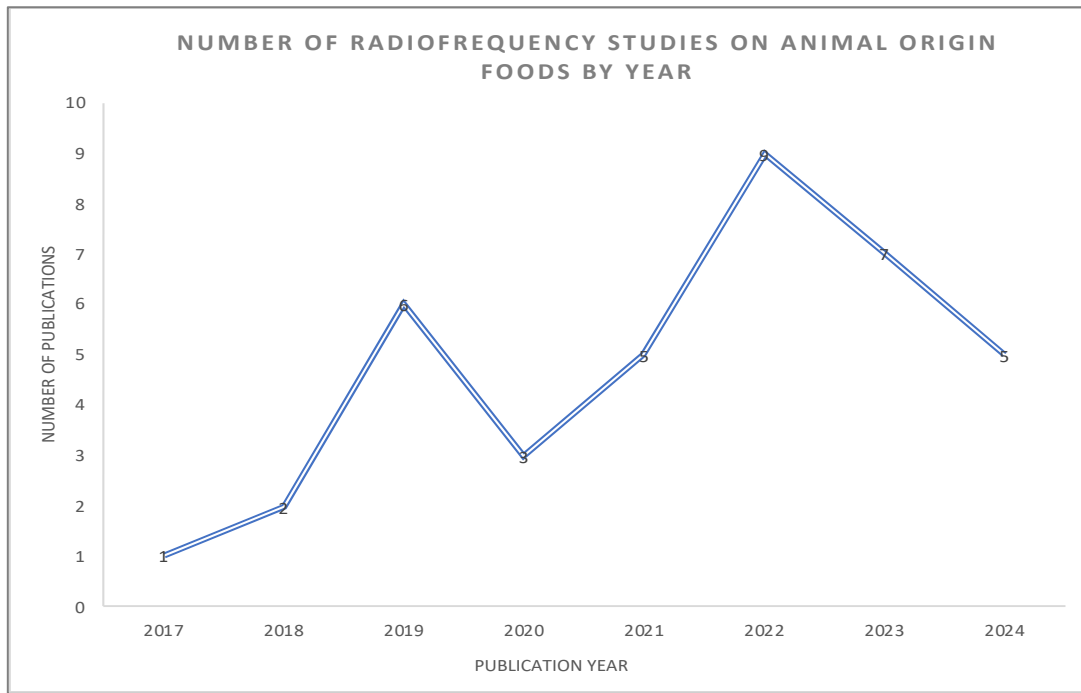


Figure 1. Number of publications about radiofrequency on food of animal origin since 2017 ((Information obtained from Scopus Database on 17 November 2024).

3. Principle and Mechanism of RF

RF is electromagnetic waves in the range of 1 to 300 MHz (Yao et al., 2022). Only certain values are used scientifically

and industrially in order not to affect other systems such as communication and military.

Figure 2 and 3 shows the electromagnetic spectrum and comparison of wavelengths with different objects respectively.

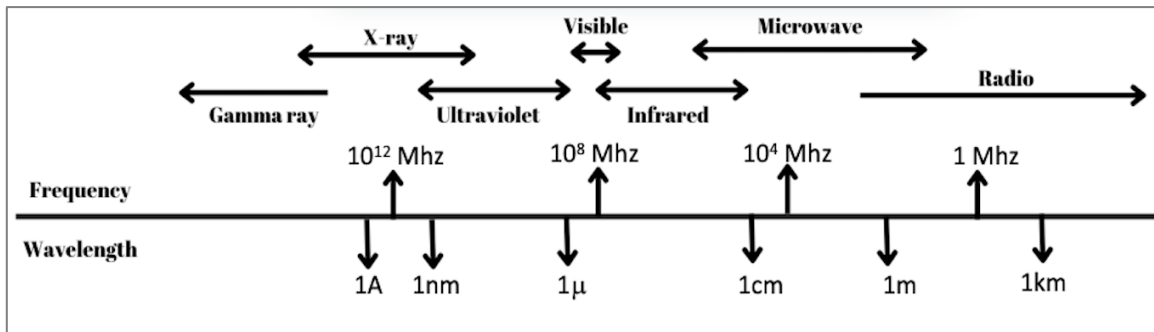


Figure 2. Electromagnetic spectrum (Yazar & İçier, 2013).

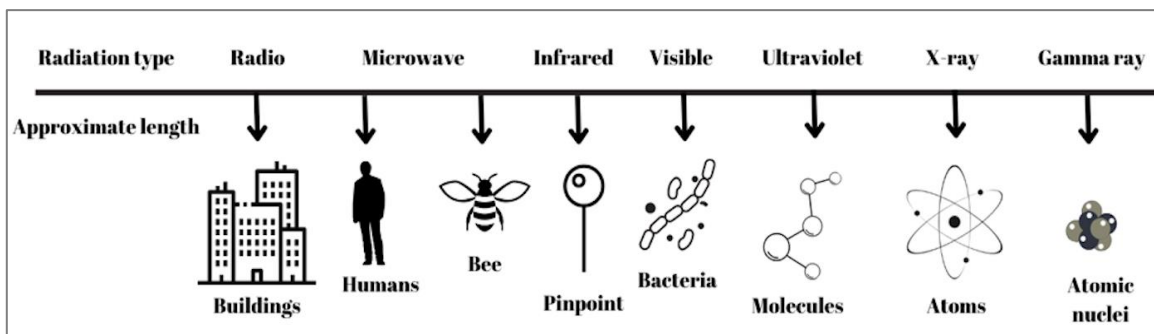


Figure 3. Comparison of wavelengths with different objects adapted by (STScI. "NasaHubblesite").

The principle of the RF system is based on high-frequency radio waves generated by two electrodes fed with high-voltage alternating current. In systems that generate radio waves, the electrical energy is converted into electromagnetic energy. This energy is absorbed by the food as internal energy and this internal energy creates heating procedure. At low frequencies, within the radio frequencies, ionic depolarization is considered to be the dominant mechanism of heating (Marra et al., 2009). Dielectric heating includes two primary mechanisms which are ionic depolarization and dipole rotation. Ionic depolarization means ions in the food material exposed to the swiftly oscillating in electrical field of RF waves and this situation caused heat occurrence. Dipole rotation means dipolar molecules like water molecules rotate incessantly to acclimatize with the changing electrical field. In RF heating, electrical field acts like a big magnet which that's incessant flipping its poles. So, the tinnier magnets try to catch up to stay in the right direction. This never-ending state of keeping up first creates friction and subsequently heat. (Altemimi et al., 2019; Di Rosa et al., 2019; L. Liu et al., 2024). Ionic depolarization is a more significant factor in RF heating than dipole rotation (Y. Jiao et al., 2018). General system specifications of RF system for use in foods are given in Table 1

Table 1. General system specifications of RF for use in foods (Y. Jiao et al., 2018).

Design characteristics of RF system use in foods	
System	Simple
Heating technique	Ionic depolarization has
Frequencies (MHz)	13.56 / 27.12 / 40.68
Wavelengths (in vacuum / m)	22.1, 11.1, 7.4
Penetration depth (in tap water /m)	1.58 / 0.79/ 0.53

RF waves applied in lower frequencies. Lower frequencies would always associate with larger wavelength according to:

$$c = \lambda v$$

Where *c* is the speed of light, λ is wavelength (m) and *v* is frequency of the wave (Hz). Lower frequencies are better to control of the absorbed power by material or product. Hence, RF creates more controllable and balanced temperature increase. Higher wavelength means larger penetration depth. Thus, RF can reach more larger area. The low frequency and large wavelength of RF systems make enable volumetric heating (Auwah et al., 2015; L. Zhang et al., 2021) This is the key of RF technique. RF technique heat volumetrically, while traditional techniques provide surface heating (L. Zhang et al., 2021). Figure 4 shows the schematic drawing of a radio-frequency heating (RF-H) system.

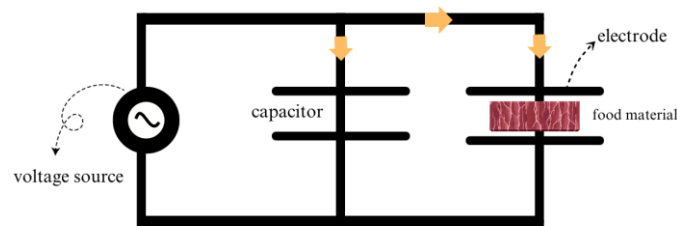


Figure 4. Schematic drawing of a radio-frequency heating (RF-H) system adapted by Altemimi et al. (2019).

RF heating has great potential to reduce the number of microorganisms. Electroporation generates pores in the cell membrane, and the electromagnetic impact may lead to the destruction of DNA and proteins (Guo et al., 2019; H. Zhang et al., 2020). Table 2 presents an overview of the advantages and disadvantages observed in the radiofrequency system.

Table 2. Advantages and disadvantages of radiofrequency system (Marra et al., 2009; Oibileke et al., 2022; Ravishankar, 2019).

Advantages of RF	Disadvantages of RF
High thermal efficiency	RF works well with large units, but not as well with small units as large units.
RF heating does not have any requirement for direct contact between product and electrode	The operating and equipment costs
More uniform heating over sample geometry	Users may need to know some high-level knowledge
RF can penetrate much deeper into samples without surface overheating	Slow heating rate
Hot/cold spot development observes less than MW	Information on dielectric properties of the target product may not be available
Can be applied inside packaging, it allows in-package pasteurization/sterilization	

There are studies which define RF technology as an alternative pasteurization or sterilization process. Several studies shown positive results of RF inactivation including *Enterococcus faecium* and *Salmonella* in wheat flour (S. Liu et al., 2018), *Salmonella* spp. in ground black paper (Wei et al., 2019) and *Salmonella typhimurium* in red paper powder (Hu et al., 2018). Hu et al. (2018) detected that in red pepper powders with a_w of 0.57, *S. typhimurium* were reduced 3.2, 3.9 and 5.6 log CFU/g after 180s RF treatment heated to 70°C, 80°C and 90°C, respectively. Initial a_w of food has effect on RF heating profile and pasteurization efficiency (Xu et al., 2019).

4. Application of RF on Food of Animal Origin

Meat and meat products play a crucial role in the human diet. Meat is a primer source of essential amino acids and supplies amino acid derived metabolites and peptides that have important bioactive properties. Iron bioavailability is highest when it is meat origin. Besides that, zinc is hard to consume in diets which include less animal-based foods (Geiker et al., 2021). Furthermore, there is no doubt that processed meat products, such as sausages, meatballs, meat cakes, and various other local delicacies, consistently enjoy high market demand. These products are favored by consumers due to their superior palatability, high nutrient content, and desirable aroma and taste (L. Liu et al., 2024). The most prevalent foodborne pathogens related to meat consumption are *Escherichia coli*, *Salmonella enterica*, and *Listeria monocytogenes* (Di Rosa et al., 2019). There is a mandatory requirement to take precautions against microbial risks. The RF system is used for melting frozen meats, processing meat products and preserving meat products (Altemimi et al., 2019). There are many studies related to the usage of the RF technique on meat and meat products for pasteurization or sterilization (Ballom et al., 2021; Wang et al., 2022b; Wei et al., 2019).

RF heating system is considered as a method to obtain uniformly heated foods. Besides that, in literature one of the significant issues of RF system mentioned as a lack of temperature uniformity. The main effective factors for uniform heat distribution are classified into three distinct categories food characteristics, RF system features, and application parameters. The primer factor is deflection of electrical field. Determine dielectric and thermal properties of meat products can be challenging due to their complex structure. Different components act differently under electrical field, so their capacity of absorbing electromagnetic energy will be different. Different components of meat could concentrate electrical field in a certain region. As result of this, certain regions heat quicker, the uniformity cannot provide, and hot-cold spots are existing (Goñi et al., 2022). Moreover, Even RF system can work in both batch and continuous, most of studies focus batch process. The meat processing industry relies on large units that must be processed in a shorter time. The absence of continuous process studies in the existing research may hinder the adaptation of this system to the meat industry (Bedane et al., 2017).

Another application area of the RF is the Radio frequency identification (RFID) technology and this system is applicable to the meat industry. RFID technology has the potential to replace traditional universal product code barcodes, enabling automatic identification of target objects and data collection through the use of radio frequency signals (Yiying et al., 2019). Three different type of RFID the near field communication (NFC), chipped RFID, and chipless RFID technologies are proposed. NFC systems are more suitable with shorter distance

(1-2 cm) (Fathi et al., 2020). The use of chip-based RFID technologies ensures high accuracy in the reading process; however, this may result in an increase in the complexity and cost of the tag, as well as a reduction in the tag's robustness and ease of integration with the package (Karmakar et al., 2016). Chipless RFID tags demonstrate enhanced functionality in hard and extreme environments. They can be printed on their support structure, similar to barcode tags, using conductive inks. Despite their current high cost, there is more potential for using and development (Vena et al., 2016). The implementation of an RFID system has the potential to represent a significant advancement the field of food traceability. Yiying et al. (2019) proposed a food traceability process and information model based on RFID system to animal origin foods. According to this system, consumers can get information about every step from the birth of the animal to the supermarket.

The majority of studies on meat and meat products concentrate on RF-based thawing/tempering and pasteurization/sterilization processes.

4.1. RF Thawing/Tempering

The traditional method of thawing in the refrigerator (4°C) is ineffective and problematic. It causes slow thawing, a large amount of drip loss and leads to bacterial growth (Y. Jiao et al., 2018). The inappropriate selection of a thawing method will result in a loss of quality, a change in colour, texture, flavor and provides an environment for microbial growth (Llave & Erdogdu, 2022). RF thawing represents a promising method for the thawing of meat and fish products, although it is currently employed only to a limited extent in industry. RF thawing is similar to microwave (MW) thawing. During the process, the product passes through the heater, whereby the heating occurs with radiofrequency energy (Ravishankar, 2019).

Bedane et al. (2018) revealed that RF thawing was 23 times faster than traditional thawing for chicken breast meat. Sun et al. (2023) detected that RF thawing method significantly reduced the thawing time for mutton in comparison to air thawing. RF thawing also preserved better texture, colour and thermal stability in samples. The findings of the study corroborate the concept that RF thawing is an effective approach for reducing thawing time while maintaining product quality. H. Jiang et al. (2023) investigated the potential implications of RF thawing on irregular sea products and the effect of layout position on thawing. The researchers used a 27.12 MHz, 6 kW free-running oscillator radio frequency (RF) heating system with parallel-plate electrodes. The findings of the study indicated that the upright position hairtail fish unevenly heated. In contrast, the flat position hairtail fish exhibited superior thawing performance. This result showed that geometrical structure and position of food material have important effect during RF thawing process.

It has been suggested that a thickness of 5 cm is the optimal dimension for fish block (Ravishankar, 2019). Li et al. (2016) used COMSOL Multiphysics® software to simulate the RF thawing process to 3 different thickness of beef (1.8cm, 3.8cm, 5.8cm); three different surface areas with constant thickness of 3.8 cm (original, 2 times, 4 times); three different shapes of beef (rectangle, trapezoid, step shape). The result of study showed best results given by 1.8cm, original surface area and step shape beefs. When other conditions remain constant, beef with a small dimension and a high surface area thaws at a faster rate.

As is the case with the majority of thermal thawing processes, the RF method is susceptible to the issue of runaway heat. Furthermore, the RF thawing system necessitates the implementation of rigorous sealing procedures. The system is susceptible to interference from nearby radio transmitters, necessitating the implementation of strong protection measures to ensure its functionality (Cai et al., 2019; Gao et al., 2023).

4.2. RF Pasteurization/Sterilization

RF is powerful method based on electromagnetic waves, has been investigated as a potential pasteurization method to inactivate food microorganisms, such as *Salmonella*, *Bacillus subtilis* spores, and *E. coli* O157:H7 (Uemura et al., 2010; Y. Zhang et al., 2020). Cui et al. (2022) investigated the cellular-level mechanism of action of RF pasteurization. The results of the study indicate that the cellular changes that occur during RF pasteurization include damage to the cell membrane, intracellular leakage of substances, changes in cell morphology, changes in intracellular structure, protein denaturation and changes in gene expression (on a smaller scale). These changes lead to damage to cells and the achievement of pasteurization.

RF system penetrates the inside of food package which allows in-package pasteurization/sterilization. RF pasteurization is particularly beneficial for ready-to-eat meat products as it can be applied after final packaging, reducing the risk of post-processing contamination (Aymerich et al., 2008). Wang et al. (2022b) used a novel device that simultaneously uses radio frequency (RF) energy (27.12 MHz, 6 kW) and superheated water (SW) with different electrode gaps and

different water temperatures to inactivate *G. stearothermophilus* spores in ready-to-eat spicy pork slices. They found that RFSW combine system with 190mm electrode gap results fastest heating rate but resulted in worst quality compared to the conventional method. RFSW combine system with 170mm electrode gap sterilization overall reduced the water loss and thermal damage to product. The results of the study demonstrated that a system combining radiofrequency and superheated water has substantial potential for use in the sterilization of ready-to-eat and in-package meat products.

RF enhances the target temperature faster than conventional methods. Heating time is much less than conventional so quality of meat product improves (Y. Jiao et al., 2018). On the other hand, RF pasteurization has not been commercialized yet due to limitations. While RF pasteurization shows promise at the laboratory and pilot scales, further research is needed to optimize protocols for industrial-scale applications (Calero et al., 2022) Combination with other antimicrobial treatments or technologies not investigated enough to apply industrial area (Nagaraj et al., 2016). Table 3 shows the summary of studies about RF technology used on animal origin products since 2017.

RF can positively affect the firmness of meat products by better preserving the water holding capacity of meat. It was stated that the changes in the hardness of meat during process is related to its water holding capacity (Y. Zhang et al., 2022). High-intensity radiofrequency (RF) treatments, particularly pasteurization, can vaporize the bound water inside the meat, allowing it to escape and thereby breaking the protein gel's three-dimensional network structure (Zhao et al., 2020). This results in a reduction in the hardness and chewiness of the meat products. RF thawing/tempering applications can be effective in reducing meat drip loss (Y. Zhang et al., 2022). Bedane et al. (2018) confirmed that RF thawing (10 kW, 27.12 MHz, electrode gaps of 65, 75, and 85 mm) had no significant effect on the texture (hardness, springiness, gumminess, and chewiness) of the thawed chicken breast meat, but markedly reduced drip loss as compared with thawing in a conventional method (refrigerator 4 °C).

Table 3. Summary of studies about RF technology used on animal origin products since 2017.

Product / Sample	Parameters / frequency	Aim of study	Conclusion	Reference
Pacific saury (<i>Cololabi ssaira</i>)	9kW – 27MHz	To investigate the effects of RF heating and conventional heating method on the elasticity, protein and collagen content of fish bones	The results support that RF heating is a suitable method for obtaining edible bony fish in a short time. The degree of softness achieved in 40 minutes using conventional techniques was attained in 18 minutes through the application of (RF) heating.	Kanafusa et al. (2018)
Marinated chicken breast	27.12 MHz	To develop the process for preheating marinated chicken breast meat in a pilot-scale radio-frequency oven and investigate its effect on marinade pickup, purge, cook yield and shear value.	RF preheating of chicken meat showed a great potential for preheating treatment.	Singh and Deshpand (2019)
Minced Fish	27.12 MHz	Using RF to find a thawing method which causes the least amount of damage possible with shortest time	RF system is considered a reasonable method for thawing minced fish. RF thawing at 27.12 MHz showed considerably greater penetration depth values from -15°C to -4°C .	Yang et al. (2019)
Pork Ham	27.120 ± 0.163 MHz	Developing a two-step (RF-tunnel and RF-steam oven) cooking system for pork ham. Also comparing new developed system with only steam-oven.	RF-Steam oven system gived similar results to conventional steam cooking. The RF-Steam oven system reduced necessary time %50.	Muñoz et al. (2020)
Nitrite-free sausages	27 MHz	To determine the effect of RF technology on the quality properties of vacuum-packed nitrite-free sausages. Conventional Retort heating method and RF method were compared.	The RF process was found safe for nitrite-free meat products. There are no significant differences between the inactivation of <i>B. Subtilis</i> . However, the shorter time of RF system promoted good texture and cooking yield comparing retort heating.	Jantapirak et al. (2021)
Tilapia (<i>Oreochromis mossambicus</i>)	27.12 Hz 600-800-1000 W Electrode gaps 10-12-14 cm	Determine the batch and continuous RF tempering processing parameters and compare the effects of RF technique to those of water tempering.	RF system provided uniform temperature distribution on the surface better than water-bath tempering. RF tempering parameters (800 W , 12cm) was more uniform than other parameters. Also, TBARS results and drip loss of RF treated samples were lower than water-bath treatment. No significant difference found in texture profiles.	Y. Zhang et al. (2021)
Salmon (<i>Salmo Salar</i>)	RF tempering: 40.68 MHz WT: $+10^{\circ}\text{C}$, $10 \pm 0.5^{\circ}\text{C}$ AT: $+10^{\circ}\text{C}$, $10 \pm 1^{\circ}\text{C}$	Compare effects of different tempering methods: radio frequency tempering, water tempering on the physiochemical properties of salmon fillets	The best overall quality of salmon found in Air Tempering application. However, it has long tempering time, RF is still promising as a new salmon tempering technology	Han et al. (2022)
Chicken meat	46.78 MHz two operative powers (225W and 300W)	Reveal the effect of load spatial configuration on heating rate, temperature uniformity and energy efficiency during RF heating of chicken meat at 40.68 MHz	During RF heating of chicken meat geometrical factors (shape of meat or gap between electrode and sample) were important on the major attributes.	Goñi et al. (2022)
Pork loin	27.12 MHz	Improve meat freezing by combining low-voltage radio frequency (RF) with cryogenic freezing.	In laboratory scale low voltage radiofrequency assisted technology for cryogenic freezing have a potential to obtain frozen meat with increased quality.	Manzocco et al. (2022)
Minced chicken breast	6Kw-27.12Mhz	Combine RF and traditional water bath (WB) for improved gel properties of minced chicken breast	Gel properties of chicken breast improved. Combined system required less time than traditional WB system.	L. Liu et al. (2024)

In general, radiofrequency thawing/tempering can help achieve a color that closely approximates that of the original meat product due to its fast and homogeneous heating process (Han et al., 2022). The difference in color attributes under different RF conditions and applications had a relatively strong correlation with pH, migration of bound water to immobilized water, content of immobilized water, and drip loss during process (J. Jiang et al., 2021). Color differences (ΔE) were lower in sausage samples heated with RF and SW (105°C, 110°C, 115°C and 120°C) compared to samples heated with SW alone (105°C). This was explained by the fact that RF energy shortens the heating time and provides a more uniform heat distribution (Wang et al., 2024). Results of study by Han et al. (2022) showed that the L^* value of radiofrequency tempered (RT) salmon fillets was significantly increased compared to those of control samples. While the a^* value of samples showed no significant difference compared to control samples, b^* value was lower than control samples. Wang et al. (2024) observed that with an increase in temperature during RF process, the L^* values of the sample increased while a^* values decreased and there were no significant changes in b^* values. The researchers attributed the decrease in a^* value to the myoglobin content affected by increased oxidation.

The effects of RF applications on properties of meat and meat products may vary depending on the RF application parameters such as frequency used, power, application time and also the characteristics and composition of the meat and meat product. Therefore, it is crucial to ascertain the specific conditions associated with each product and to implement the appropriate RF parameters.

5. Future Perspectives

The RF technology has been proven as a safe and effective method for various food products and has potential to replace traditional methods in the industry. Studies showed that RF system is successful to protect nutritional and beneficial components of foods after treatment. It has advantages like rapid heating and short processing time. Some studies have indicated that RF method is more effective than conventional techniques in enhancing the organoleptic characteristics of food products.

Current studies have proven that RF is a promising technology for animal origin food products and RF systems are safe and efficient for the following purposes: thawing meat and seafood products, tempering meat, heating ready-to-eat foods, pasteurize animal-origin foods, and sterilizing/pasteurizing in-package. A variety of combination technology trials are conducted with diverse systems with the objective of enhance the impact of the system on the foods. Recent studies support the exploration of combined RF systems, such as radiofrequency-assisted cryogenic freezing. Quality characteristics of products following the application of radio

frequency (RF) treatment, the effects of disparate geometries and the influence of different pre-applications are also subjecting of current research.

However, it was clear that the RF system has its own limitations. Even though this technology has been available for many years, its total adaptation to industry is relatively slow. One of the limitations is nonuniformity heating capacity especially for small-irregular shapes. There are not enough studies to determine dielectric properties of a variety of foods. Based on the parameters, there is a possibility that certain meat or meat product textures may deviate from the norm. Future studies should focus on exploring different methods and combinations to design a proper RF system. Further investigation is required to ascertain the impact of RF treatment on the quality and sensory properties of the products. To conclude, while the RF system presents certain limitations, its potential benefits shows its promising future applications in both domestic and industrial area.

Conflict of Interest

The authors declare no conflict of interest.

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