Non-Thermal Processing Technologies for the Meat, Fish, and Poultry Industries

Edited by
M. Selvamuthukumaran
Sajid Maqsood

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Processed products obtained from meat, fish, and poultry play a predominant role in the food industry because of their nutritional profile and sensory characteristics. Usually, these products are highly perishable and therefore, the food industry has been using the traditional thermal methods of heat processing techniques in order to extend the stability of the product to the greatest extent. But this traditional method has several disadvantages, which include undesirable changes in organoleptic characteristics, denaturation of the good quality of animal proteins, and degradation of several nutritional components.

Non-Thermal Processing Technologies for the Meat, Fish, and Poultry Industries addresses the stability enhancement of the processed products of these types of foods by implementing a non-thermal approach. Currently, there are several innovative non-thermal processing techniques available that can be adopted for enhancing the safety quality of various meat-, fish-, and poultry-based food products. This book presents the various non-thermal processing techniques that can be successfully applied to meat, fish, and poultry, including high-pressure processing, ultrasound, irradiation, and pulse electric fields. It explains how these processes can minimize the quality changes significantly without posing any sort of threat to the consumers. These techniques can replace traditional thermal processing techniques, viz. roasting, frying, boiling, and grilling.

This book benefits food scientists, food process engineers, academicians, students, and food industrial professionals by providing in-depth knowledge about non-thermal processing of foods for meat, fish, and poultry product quality retention as well as for efficient consumer acceptability. It contains current and emerging trends in the use of non-thermal processing techniques for their application in these industries.

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M. Selvamuthukumaran and Sajid Maqsood

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Preface

The processed products obtained from meat, fish, and poultry have played a predominant role in the food industry because of their nutritional profile and sensory characteristics. Usually, these products are highly perishable and therefore, the food industries have been using the traditional thermal methods of heat processing techniques in order to extend the stability of the products to the greatest extent. But this traditional method has several disadvantages, which include undesirable changes in organoleptic characteristics, denaturation of the good quality of animal proteins, and degradation of several nutritional components. Currently, there are several innovative non-thermal processing techniques that are available and that can be adopted for enhancing the safety and quality of various meat-, fish-, and poultry-based food products. The various non-thermal processing techniques that can be successfully applied for meat, fish, and poultry include high-pressure processing, ultrasound, irradiation, and pulse electric fields, and these techniques can minimize the quality changes significantly without posing any sort of threat to the consumers, viz. roasting, frying, boiling, and grilling.

This book will introduce the various non-thermal food processing techniques, especially those employed in the fish, meat, and poultry processing industries. It describes the high-pressure processing techniques adopted for processing fish, meat, and poultry and their effects on maintaining quality and consumer acceptability. The text deals with the effects of several non-thermal processing techniques on the quality aspects of processed fish, meat, and poultry products. It also explains the safety aspects of using various innovative non-thermal–based technologies. The book describes cold plasma, ultraviolet (UV) irradiation, ultrasound and pulsed electric fields, pulsed light, and supercritical CO_2 techniques for fish, meat, and poultry, along with the advantages, disadvantages, process operations, mechanisms for microbes in activation, and more. In addition, commercially viable and economically feasible non-thermal processing technologies for these industries are illustrated.

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About the Editors

Dr. M. Selvamuthukumaran is presently a professor in the Department of Food Science & Technology, Hamelmalo Agricultural College, Eritrea. He was a visiting professor at Haramaya University, School of Food Science & Postharvest Technology, Institute of Technology, Dire Dawa, Ethiopia. He received his PhD in food science from the Defence Food Research Laboratory affiliated with the University of Mysore, India. His core area of research is the processing of underutilized fruits for the development of antioxidant-rich functional food products. He has transferred several technologies to Indian firms as an outcome of his research. Dr. Selvamuthukumaran received several awards and citations for his work and has published several international papers and book chapters in the area of antioxidants and functional foods. He has guided several national and international postgraduate students in the area of food science and technology.

Dr. Sajid Maqsood is a professor in the Department of Food Science at College of Agriculture and Veterinary Medicine, United Arab Emirates University (UAEU). He started his academic career in 2011 at the UAEU as a post-doctorate fellow and has been serving since 2021 as a professor. Since 2017, he has served in the strategically important role as Assistant Dean for Research and Graduate Studies, and since 2022 as Department Chair.

His research is dedicated and aligned exclusively to food and the nutritional needs of the UAE and the region. Dr. Maqsood has established an innovative research program at the UAEU that focuses on bioactive molecules (bioactive peptides) from camel milk and dates with two ongoing funded projects in this area. He is also working on food wastes and byproduct valorization generated at the farm and industry levels in the UAE and the utilization into food fortification, biodegradable packaging, extruded products, and more (two ongoing research projects). Moreover, Dr. Maqsood he is carrying out intensive research on alternative proteins (plant-based proteins, meat analogues, and more) and sustainable means of food processing (one ongoing research project). He is leading an active research group in the Food Science Department of the UAEU with multidisciplinary collaboration within the UAE and abroad.

Dr. Maqsood has published approximately 150 publications and edited 4 books and several book chapters. In addition, he has received several awards for his research in the UAEU and was listed in the Top 2% of Scientists released by Stanford University (2020-2022).

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Chapter 1

Scope for Implementation of Various Novel Non-Thermal Processing Techniques for Meat, Fish, and Poultry Industries

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CONTENTS

1.1 INTRODUCTION

The traditional form of food processing, thermal treatment, can kill bacteria but can cause physical, chemical, and sensory quality harm, especially to foods that are sensitive to temperature. Therefore, non-thermal technologies are increasingly being used today to protect food against germs while also enhancing their luxury appearance, flavour, and nutritional content and extending their shelf life. Due to their high nutritious value, food products, including fish, beef, and chicken, are in high demand. However, the food industry is experiencing significant losses since these items have a limited shelf life due to their perishability, and because microbiological decomposition and oxidation occur quickly, they are heavily reliant on post-harvest preservation. Applications of cutting-edge non-thermal food processing technologies, such as supercritical carbon dioxide, hydrodynamic shock waves, cold plasma, irradiation, pulsed light, and E-beams, can maintain the high sensory quality characteristics of fish, meat, and chicken while extending the shelf life through microbial inactivation. With a primary focus on sensory quality and microbial inactivation, we present in this chapter the significance of emerging non-thermal food processing technologies in the meat, fish, and poultry industries. The encouraging findings indicate considerable potential to retain the

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products' organoleptic qualities while preserving microbiological safety. Along with their technical advantages, these technologies' strengths and disadvantages are also explored. Under optimal treatment, combining various food processing technologies or using cutting-edge packaging techniques can increase antibacterial efficacy without adversely impacting other quality features.

1.2 HYDRODYNAMIC SHOCKWAVE

According to numerous studies (Lakshmikanth, 2009; Bolumar et al., 2014), hydrodynamic pressure processing or shockwave (HDP) treatment is an efficient post-harvest technique for improving the tenderness in fresh cuts without affecting the chemical and microbial stability. Shockwave-induced meat tenderization must result from mechanical stress and energy dissipation at the boundaries of materials with various sound velocities and acoustic impedances (Bolumar & Toepfl, 2016). Additionally, HDP can lessen the variance in softness across the entire beef portion (Spanier et al., 2000). Additionally, after HDP, turkey, beef, and pork may absorb more brine (Bowker et al., 2010).

Additionally, applying pressure to protein matrixes can have two additional effects: (1) altering the quaternary and tertiary structure of the proteins, which may impact their solubility and activity, and (2) inactivating bacteria. In a study of frankfurters made with meat following HDP treatment, no impact on the protein functioning of beef muscle was discovered (Schilling et al., 2002). Numerous studies have been done on microbial inactivation, but the findings of the various investigations are inconsistent. However, HDP merits additional scientific study as a physical alternative technique for improving functioning or microbial inactivation in meat and meat products.

By using shockwave therapy, tenderness can be improved by 25% or more. Since the middle of the 1990s, a lot of research has been done on the explosive-based hydrodyne process, with values of tenderness improvement ranging from "25 to 70% in various meats like beef, hog, and lamb". According to Solomon et al. (2004, 2008, 2011), the initial softness, treatment of "fresh or frozen/thawed meat, post-mortem time of treatment and storage duration, and specific HDP-treatment conditions" (such as shockwave container configuration, quantity, placement and shape of explosives, and position [distance] to the explosion) are all factors that affect how tender meat becomes over time. Although white meat or poultry doesn't typically have tenderness issues, HDP has also been used in specific circumstances where tenderness is an issue. In this regard, turkey breasts treated with HDP displayed improved brine absorption, processing yields, and textural qualities in comparison to the control, with no effect on the colour (Bowker et al., 2010). There is a significantly smaller body of literature on shockwaves caused by electrical discharge under water (Lukes et al., 2012; Bhattacharya et al., 2019). For several meats, including beef, pork, turkey, and chicken, a shockwave created by electrical discharges increased tenderness by 12%–29% (Table 1.1). Recently, Bowker et al. (2011) reported employing a high efficiency sparker to cut beef loins with a 20%–30% lower cutting force.

1.3 IRRADIATION

Irradiating the fish right away after they are caught, while the microbial load is still extremely low, and greatly prolonging the shelf life under crushed ice, had been a brilliant concept. The coastal cutter *Delaware* in the United States featured a portable Cobalt-60 irradiator that

TABLE 1.1 STRENGTHS AND WEAKNESSES OF DIFFERENT NON-THERMAL TECHNIQUES

Techniques	Strengths	Weaknesses
Hydrodynamic shockwave	• Helps in tenderization and reduced the ageing time of the product • Has no impact on the colour • Cost-effective • Low energy consumption	• Causes moisture loss • Not suitable for all packaging materials
Cold plasma	• Effective on inactivating a wide range of microorganisms like moulds, yeasts, pathogenic, or spoilage bacteria • Prevent cross-contamination • Rapidly effective • Low temperature	• Ineffective on endogenous enzymes as it's a surface phenomenon • Causes changes in organoleptic properties
Irradiation	• Less food spoilage • Does not affect significantly affect nutritional value, flavour, texture, and appearance of food • Less need for additives like preservatives and antioxidants	• Not effective for damaged or spoiled food • Low cost • Does not fully eliminate toxins
Pulsed light	• Low-cost technology • Does not form residues in food • Inactivation occurs rapidly on food surface and packaging materials	• Has less penetration capacity • Damages sensory quality when kept in close proximity to the food material
E-beam	• Uses low energy • Keeps the food highly safe	• Limited penetration depth • Not effective for damaged or spoiled food
Supercritical fluid	• Environmentally friendly • Best method for food preservation	• Capital cost is high • Limited to some food products

was run by the Gloucester Fisheries Institute at the time. This encouraged on-board research in Germany and the USSR, and even the United States ran two additional ships with on-board amenities. Unfortunately, there is no information about actual seafood irradiation in the United States accessible from the National Oceanic and Atmospheric Association (NOAA) or their National Marine Fisheries Service (NMFS). In the 1970s, Germany operated the *Walther Herwig* (later renamed the *Anton Dohrn*), a fisheries research vessel with X-ray equipment; shortly after capture, the gutted whole fish were irradiated and mixed with crushed ice. This strategy was particularly effective since the added 14 days of shelf life could be used for a longer fishing season or on farther-off fishing grounds, successfully filling the holds (Silva et al., 2006). However, at the same time, the 12–200 sm national maritime borders were raised, and Germany lost access, particularly to Iceland's fishing grounds.

In France, mechanically deboned, irradiated chicken meat used to be very popular. The new labelling rules limited further use and prevented the availability of complete and trustworthy information. Although the irradiator has been taken apart, SPI at Berric continues to generate a variety of recovered meat from animal remains. This facility was used to treat mechanically deboned poultry meat with radiation before it was utilized as an ingredient in another meat product. This use of ionizing radiation was hindered by the labelling requirements under the new EU legislation (down to the last molecule of any irradiated substance, effective after 1999).

Ionizing radiation processing of food is currently an undervalued and underutilized technique. Industry and governments should work to exploit food irradiation for the good of their populations because it has such huge potential. Such choices can be supported by science. The information gathered for this special issue ought to encourage more people to use this technology. The list of references should make assessing the state of the art easier. Ionizing radiation processing of food offers a variety of positive effects that cannot be achieved by other and – and in particular – traditional techniques. Some of these effects compete with conventional treatments in terms of effectiveness, while others are the ideal complement to methods that have been passed down to us over the years.

It's interesting to note that after being irradiated, spicy pickled chicken feet and wings have a flavour that consumers adore. The fact that all packages are marked "irradiated food" is noteworthy, because regular consumers receive this information favourably; for this product, a market norm has been created.

1.4 COLD PLASMA

A quasi-neutral ionized gas called plasma consists of ions, free electrons, atoms, and molecules in both their ground and excited states (Moore & Spencer, 2020; Volkov et al., 2021). Any energy that can ionize a gas can be used to create plasma, while most plasma species are created by electric or electromagnetic sources. "Thermal plasma and non-thermal plasma" are two different types of plasma. In order to maintain nutritional qualities while delivering effective "bio-decontamination resulting from reactive nitrogen or oxygen species, electric field, charged particles, and UV as elements of wide and varied systems of action, non-thermal or thermal plasma processes can be planned to deliver in a format that is cold or close to room temperature at the point of application" (Srivastava et al., 2019; Barjasteh et al., 2021; Mravlje et al., 2021).

"Cold plasma (CP) has a tremendous potential for regulating microbiological purity, extending shelf life, and preventing post-processing contamination, as is well known" (Schmidt et al., 2019; Fojlaley et al., 2020; Waghmare, 2021). It not only causes bacterial cleansing but also renders numerous microorganisms, such as fungi, viruses, and spores, inactive (Niveditha et al., 2021; Shahi et al., 2021). Numerous plasma components, including "NO_2, O, NO, OH, O_3, H_2O_2, charged particles, UV photons, and electric fields, play important roles in the process of microbial decontamination" (Chen & Wirz, 2021; Laroussi, 2021). The mechanisms of CP used to maintain microbiological safety in foods include erosion, bacterial cell etching, morphological modification, nucleic acid damage, loss of cell viability, and protein oxidation (Bermudez-Aguirre, 2020; Barroug et al., 2021). However, various variables and mechanisms affect how serious the harm is. How well CP kills microorganisms depends on the length of the treatment, the gas mixture, the exposure mode (direct or indirect), the intensity of the power source, and intrinsic product features (surface topology, type of sample treated [solid, liquid, or semisolid], and target cell characteristics) (Bigi et al., 2022; Obileke et al., 2022).

Ready-to-eat chicken products' toxicological safety was maintained, while post-process contamination was avoided thanks to in-package CP treatment arrangement (Gabrić et al., 2022; Onyeaka & Nwabor, 2022). No genotoxicity was detected using the *Salmonella* mutagenicity assay in chicken breasts treated with plasma (Lee et al., 2020; Jo et al., 2021; Mittag et al., 2021). Chicken samples were subjected to CP treatment (24 kV for 3 min), which significantly reduced the amounts of the Tulane virus (1.10 to 0.15 log CFU/cube), native mesophilic bacteria (0.90 to 0.22 log CFU/cube), and *Salmonella* (1.65 to 0.25 log CFU/cube), where increasing voltage (from 20 to 25 kV) and duration of treatment had a beneficial impact on the physicochemical parameters (Moutiq et al., 2020; Roh et al., 2020; Abdel-Naeem et al., 2022). Most cells displayed morphological changes (cell flattening and other distortions) at 3,000 Hz, but at 2,000 Hz, only observable cell aggregation and hollowed-out cells were present (Yu et al., 2021). *S. typhimurium* H7 and *E. coli* O157 monocytogenes counts dropped from 5.40, 5.78, and 5.85 log CFU/g, respectively, to 2.88, 3.22, and 3.84 log CFU/g after being exposed to plasma for 10 minutes in the chicken breast (Kim & Oh, 2020). In-package dielectric barrier discharge (DBD) (70 kV) has been shown to have the capacity to stop the growth of germs that ruin chicken breasts that have been treated and kept for five days at 4°C, according to another research study (Liu et al., 2021). In contrast to foodborne pathogens, the microbial decrease of psychrophiles was improved by prolonging the CP treatment time to over 60 seconds. The plasma process variables of plasma discharge frequency and residence time, where the concentration of plasma-generated reactive species of nitrite, peroxide, nitrate, hydroxyl, and ozone increased with the discharge frequency, were correlated with the in situ disinfection possibility of plasma-activated water (PAW) against *Pseudomonas fluorescens* ATCC13525 previously inoculated on chicken skin pieces.

Meat that has myoglobin in it may become discoloured due to the hydrogen peroxide and choleglobin interaction. As the breast of the meat was coated with extensible thin-layer DBD (Cheng et al., 2021), both L* and b* values increased; in contrast, when DBD was applied to chicken breast (100 kV, 50 kHz), the L* value decreased mostly due to slime development after storing for 9 days at 4°C (Sujiwo et al., 2019; Lee et al., 2022). Zhuang et al. (2019) did not note any appreciable changes in L*, a*, or b* values when chicken breast was exposed to 70 kV, in contrast. Lipid peroxidation may be brought on by the reactive species produced by the plasma. No changes were observed in the fat content of the chicken breast after CP treatment, according to (Lee et al., 2019; Zhuang et al., 2019, and Moutiq et al., 2020). This was attributed to the fact that plasma reactive species are less harmful to chicken breast than red meat due to variations in fat content.

Choleglobin-induced beef colouring may occur as a result of myoglobin and hydrogen peroxide interaction. While flexible thin-layer DBD when applied to chicken breast increased both L* and b* values, DBD applied to chicken breast (110 kV, 60 kHz), however, revealed a drop in L* value after 9 days of storage at 4°C, mostly because to slime development. However, Zhuang et al. (2019) found that following 70 kV treatment of chicken breast, there were no appreciable changes in L*, a*, or b values. Lipid peroxidation may be brought on by the reactive species that the plasma produces. After CP treatment, there were no variations in the cholesterol level of chicken breast, which Lee et al. (2019), Zhuang et al. (2019), and Moutiq et al. (2020) attributed to the fact that red meat is more susceptible to plasma reactive species than chicken breast is because of differences in fat content.

The combination treatment impact of rosemary (*Rosmarinus officinalis*) extract (1%), as well as in-package DBD-CP, on chicken ground meat was examined by Gao et al. (2019). The highest population densities of treated samples were equivalent to those at day 0 by day 5 of storage at 4°C, indicating that the treatment resulted in a decrease in the diversity of bacterial communities

(Liu et al., 2019; Los et al., 2020). Chicken patties that had previously received plasma treatment, as well as chicken patties that hadn't had plasma treatment, had significantly lower total microbial counts after being exposed to rosemary extract (Zhuang et al., 2019). CP-treated silk fibroin nanofibres/thyme oil were suggested as an active packaging strategy with promising antibacterial activity and vaccination against *Salmonella typhimurium* on poultry flesh (duck or chicken meat). Silk fibroin nanofibres and thyme essential oil (EO) treated with CP were found to have stronger inhibitory potential than untreated silk fibroin nanofibres/thyme EO, with a notable increase in the rate of thyme oil release (23.5%–25%) after plasma treatment (Sakai et al., 2020). According to Sahebkar et al. (2020), treating chicken breast fillets with *Streptococcus pneumoniae* with both CP (10 min at 32 kHz) and EO (in marinade solutions) results in improved survival rates. Up to 3–4 log CFU/g of considerable microbial reductions are caused by *Escherichia coli* challenge populations (Zhu et al., 2020; Mohammadi-Aragh et al., 2022). Three different EOs (*Crocus sativus L., Zataria multiflora Boiss.*, and *Allium sativum L.*) were combined with CP therapy to create a synergetic effect, and the benefit of doing so persisted after 14 days of storage (Cimino et al., 2021; Rout et al., 2022).

1.5 PULSED LIGHT

A technique for food preservation known as pulsed light (PL) uses powerful, brief bursts of broad-spectrum "white light" (ultraviolet to the near infrared region) (Baysal & Taştan, 2022). For the majority of applications, a few flashes applied in a split second are sufficient to effectively inactivate bacteria. At various wavelengths, the light pulses have varying degrees of mortality. Foods undergo photochemical or photothermal reactions when exposed to light pulses (Sunita et al., 2022). The high peak strength and wide spectrum of the flash are said to have special effects that explain how the PL process works. Nucleic acids are a main target for cells (Favaudon et al., 2022). Numerous processes, such as chemical alterations and DNA cleavage, result in inactivation of *E. coli* and other bacteria that are present such as *Staphylococcus aureus, Bacillus subtilis*, etc. Using 1–35 pulses of light with an intensity of 1–2 J/cm^2, *Saccharomyces cerevisiae* was rendered inactive (Katsigiannis, 2022; Katsigiannis et al., 2022). After receiving PL treatment, *Listeria innocua* was found to have decreased by 2-log units on hot dogs (inoculated with 3 or 5 log per wiener) (Alonso et al., 2022; Vidovic et al., 2022). In samples infected with either 5 or 2 log per cm^2, the number of *Salmonella serovars* was reduced by 2-log units on chicken wings (Inanoglu et al., 2022). The primary use of this technology is to sterilize or drastically reduce the bacteria population on packaging or food surfaces (Figure 1.1). It is necessary to conduct in-depth independent study on the inactivation kinetics under a wide range of realistic food system and surface characteristics (Cai et al., 2022; Martin et al., 2022).

The Food and Drug Administration authorized high-power PL to decontaminate food surfaces in 1999. They proposed the decontamination of surfaces by intense and brief pulses of broad-spectrum light (Paskeviciute et al., 2011; Cai et al., 2022). This employs brief, strong bursts of broad-spectrum light with wavelengths between 200 and 1,000 nm. The many-fold multiplication of the flash power results in PL (Di Benedetto et al., 2010). The absence of mercury in the radiation, low energy costs, high adaptability, and brief exposure times are some of the main advantages of this approach. Furthermore, there was no evidence of microbial resistance for this treatment (Shen et al., 2020). The absence of applied chemicals that could harm persons or the environment and the absence of leftover compounds are further benefits of PL

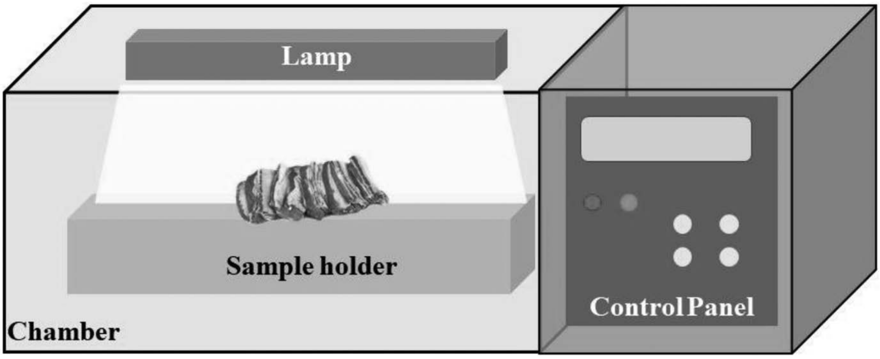

Figure 1.1 Schematic diagram of PL on meat products.

(Luksiene et al., 2007). Pulsed ultraviolet (UV) radiation has been shown to be effective in vitro at reducing the bacteria population by numerous researchers. This method is effective against *Listeria monocytogenes*, *Salmonella enteritidis*, *E. coli*, *Pseudomonas aeruginosa*, *S. aureus*, and *Bacillus cereus* and can inactivate them by 2–6 log (Rajkovic et al., 2010; John & Ramaswamy, 2018). Due to the more complex light-surface interaction, the decrease in microbial population on food surfaces is typically not consistently significant (Zarzuela et al., 2021; Ezzatpanah et al., 2022). For instance, salmon fillets that have been cooked have less *E. coli* O157:H7 on their surface (not more than 1 log). According to Keklik et al. (2008), PL may successfully disinfect chicken breast from *S. enterica* by 2.4 log under different experimental circumstances. High-power PL's bactericidal and sensory attribute effects on chicken breast during non-thermal treatment conditions were not thoroughly studied at the time.

An efficient method for inactivating germs on various food surfaces is high-power PL (Figure 1.1). Additionally, it offers certain useful advantages over traditional UV light in circumstances where quick and efficient disinfection is needed (Wang et al., 2005). According to our research, bacteria are primarily affected by UV light (260 nm) from a broad spectrum of emitted light (200–1,000 nm). Its germicidal effect has been principally linked to the photochemical dimerization of pyrimidine nucleotides in bacterial DNA. The development of such connections renders the bacterium incapable of reproducing because PL prevents DNA from unzipping for replication (Elmnasser et al., 2007). *Listeria* and *Salmonella* were inactivated by high-power PL by 6.5 and 7.0 log, respectively, in vitro. The outcomes are consistent with earlier reports (Gomez-Lopez et al., 2005), in which it was found that gram-positive and gram-negative bacteria were susceptible to this therapy differently.

After applying pathogens to the surface of chicken breasts, they were illuminated with PL, which decreased the deactivation mechanism of the pathogens. The more complicated light-surface interaction may provide an explanation for that. A significant amount of light energy is lost due to the opaqueness and uneven structure of the chicken surface. When any light technology is used, by no means do certain shadow effects contribute to the decontamination of chicken breasts. This phenomenon undoubtedly lowers the antibacterial effectiveness of light-based technology. Therefore, to obtain 2–3 log inactivation of *Salmonella*, *Listeria*, or aerobic mesophiles on chicken breast, greater light doses of 5.4 J/cm^2 are required. This disadvantage shouldn't be overstated either, as washing techniques (sodium hypochlorite) used to disinfect solid foods can frequently have a surface antibacterial impact (Gomez-Lopez et al. 2005). By using standard UV light to disinfect fresh beef, Guerrero-Beltrán and Barbosa-Cánovas (2004) showed that the bacteria load was reduced by 2–3 log. According to Lyon et al. (2007), UV light treatment was successful in reducing the number of infected, uncooked, skinless, boneless chicken breasts with monocytogenes. In the meantime, a lengthy exposure period is necessary to provide an adequate UV light dose using traditional light sources, which is occasionally unacceptable for industry. In addition, ordinary UV light bulbs release mercury into the air, which is bad for the environment. Eventually, the bacterial photoreactivation mechanism makes it possible to heal the damage caused by conventional UV light to bacteria (Otaki et al., 2003).

1.6 ULTRASOUND

In the meat sector, the application of ultrasound (US) (28 W/L, 25 and 130 kHz, 5–30 minutes, 10°C) was primarily employed to enhance the cooling of broiler chickens (Mendez-Flores et al., 2018) and the tenderness of the meat (Henchion et al., 2014; De Hooge et al., 2017). The most crucial quality characteristics for consumer approval are quality, flavour, and tenderness, all of which are now frequently improved by low-intensity US (Alarcon-Rojo et al., 2018; Kim et al., 2021). Furthermore, a number of recent studies have shown the beneficial effects of high-intensity US waves on fresh meat (Haughton et al., 2012; Firouz et al., 2022). Numerous studies have been published on the potential use of US in the meat industry across a variety of domains, including bacterial inhibition (Caraveo et al., 2015), thawing (Mason et al., 2011), cooking (Miles et al., 1999), freezing (Zheng & Sun, 2005), and meat brining (Cárcel et al., 2007). The most crucial meat quality characteristics that have a big impact on industrial settings are texture, pH, water holding capacity (WHC), oxidative stability, and sensory qualities (colour) (Abdalhai et al., 2014). The protein structure of chicken meat changes as a result of US treatment, enhancing the emulsification and gelling properties (Li et al., 2014).

Group B vitamins are abundant in chicken meat but can be lost or degraded during processing and cooking (Lombardi-Boccia et al., 2005). The duration of exposure, moisture, pH, light, temperature, and oxygen are only a few of the variables that contribute to degradation (Lešková et al., 2006). The efficacy of using US and supercritical carbon dioxide (SC-CO_2) to preserve the vitamin content (vitamins B_1, B_2, B_3, and B_{12}) of chicken breast was demonstrated (Morbiato et al., 2019). The authors contrasted the use of SC-CO_2 alone or in conjunction with high-power US with the use of traditional processing methods like steaming or boiling, frying, and oven drying. As B vitamins are water soluble, steaming and boiling samples caused a drastic decrease in their retention (1% to 25%). However, when SC-CO_2 was employed, the retention (for vitamins B_1, B_2, and B_3) was between 75% and 85%, and with the aid of the US, the retention was complete (100%). No matter whether US was used or not, SC-CO_2 had the highest retention in the case of vitamin B_{12} (around 20%).

The quality of the meat is impacted by intrinsic (such as pH, water availability, and nutrients) and extrinsic (such as processing, storage, and transportation of meat) characteristics. As a result, the meat is more likely to spoil and become infected by pathogenic microorganisms like *E. coli*, *S. aureus*, *Campylobacter* spp., *Salmonella* spp., lactic acid bacteria, and *Pseudomonas*. The type of bacteria, the intensity, frequency, and duration of the US wave treatment, as well as the characteristics of the meat, all influence how high-intensity US affects bacteria (Joyce et al., 2011). According to Altemimi et al. (2017) mechanisms involving the elimination of microorganisms by US are carried out through the cavitation phenomenon, which alters the potential for microbial growth. Morild et al., 2011 reported that the high-intensity US decreased the counts of *S. typhimurium* and *Yersinia enterocolitica* 3.3 log CFU/cm^2 for 4 seconds. The skin of chicken can be decontaminated with US waves, as well as in conjunction with lactic acid (Kordowska-Wiater & Stasiak, 2011). Using steam and US to treat chicken corpses can reduce the amount of *Campylobacter* on contaminated animals (Musavian et al., 2014). According to Huerta-Jimenez et al. (2021), after 7 days of storage, chicken breasts were subjected to sonic treatments (40 kHz, 9.6 W/cm^2 at 0, 30, and 50 min), which resulted in an increase in *S. aureus*, mesophilic bacteria, psychrophilic bacteria, and lactic acid. The variations in US time were insignificant. After 50 minutes of US therapy, the quantity of microorganisms such as *Salmonella*, *E. coli*, and *Staphylococccus coli*, Lactic acid bacteria (LAB), and psychrophiles was dramatically decreased. However, it was observed that treating chicken breast with an ultrasonic bath for 20 minutes revealed both *Salmonella* and *E. coli* weren't impacted. Using ultrasonics (2.5 W/cm^2, 40 kHz, 3 or 6 minutes), Kordowska-Wiater and Stasiak (2011) treated the surface of chicken wings. They discovered that the treatment reduced bacteria but also discovered that the US medicines were more effective on *E coli*. According to Kordowska-Wiater and Stasiak (2011), US (2.5 W/cm^2, 40 kHz, 3–6 minutes) completely removes *Salmonella enterica*, *E. coli*, *Pseudomonas fluorescens*, and *Proteus species*" from the surface of chicken skin in 3 minutes (1.0 log CFU/cm^2). The scientists found that increasing the duration of treatment to 6 minutes resulted in a 1.5 log CFU/cm^2 reduction in bacteria. Without changing the hue or texture of chicken skin, 30% ethanol and US were able to lower *Salmonella typhimurium* by a >1.0 log CFU/g (Seo et al., 2019). The same authors did note that the US was unable to defeat the S. typhimurium on its own. According to Vetchapitak et al. (2020), the US treatment (1,200 W/130 Hz/15 min) lowers the amount of Campylobacter in contaminated chicken carcasses from 0.94 to 1.19 log10 MPN (most probable number)/10 g. The impact of US application on the reduction of microorganisms is summarized in Table 1.2.

Table 1.1 gives us an idea about the different non-thermal techniques used in meat, fish, and poultry industries.

1.7 ELECTRON BEAM

Frankfurters in particular have seen a significant growth in production and consumption in recent years, primarily as a result of changes in lifestyles and eating habits. Convenience, time effectiveness, minimum packaging, improved handling, and improved quality can be credited for this. A high level of safety is not always upheld, though. More recently, a number of foods have been pulled from shelves due to *Listeria monocytogenes* contamination, including chilled ready-to-eat meats, frankfurters, prepared sandwiches, meat salads, and meat spreads. Consequently, due to a moral commitment to the general public, preventive measures have been put into effect. The FDA approved and upheld the "zero tolerance" policy for the involvement of *L. monocytogenes* in ready-to-eat foods in 1989. If customers do not accept irradiation as a processing technology, maintaining the quality and safety of chilled, ready-to-eat meats is useless. For this technology to be used and its benefits to be realized, consumer acceptability is essential. Although there are still certain issues with food irradiation that may lead consumers to feel uneasy, more people are now prepared to accept it in order to have a safer product (Hunter, 2000). The fate of radiation-resistant infections, vitamin degradation, the development of lipid oxides and off tastes, the potential toxicity of radiolytic products in irradiated foods, and the impact of irradiation on packing materials are some of the worries raised. Although decades of research have

TABLE 1.2 EFFECT OF NON-THERMAL TECHNIQUES ON DIFFERENT MEAT AND FISH PRODUCTS

Treatment	Meat and Fish Matrix	Effects on Matrix	Treatment Conditions	Reference
HDP	Beef	Increase in tenderization of the muscle	25 kV for 8 pulses	McDonnell et al. (2021)
HDP	Chicken	Cooking loss was higher in shockwave-treated meat. Shockwave facilitated early deboning and provided tenderness-enhanced fillets.	Electrical discharge Energy setting (72%), pulses (2)	Claus et al. (2001)
CP (atmospheric air)	Chicken breast	Malondialdehyde (MDA) content increased with increase in treatment time, indicating formation of secondary oxidation products. MDA increased from 0.48 to 0.87 mg malondialdehyde/kg.	1–3 minutes	Moutiq et al., (2020)
CP (dielectric barrier discharge)	Mackerel (fish)	Lipid oxidation reduced and protein oxidation increased	80 kV for 5 minutes, kept at 4°C for 24 hours, followed by storage at 4°C, 8°C, and –20°C	Pérez-Andrés et al. (2020)
CP (high-voltage dielectric barrier discharge)	Asian sea bass (*Lates calcarifer*)	a. Decreases total viable count, psychrophilic bacteria count, *Pseudomonas*, hydrogen sulphide–producing bacteria, and *Enterobacteriaceae* b. Increases protein and lipid oxidation	Input of 230 V at 50 Hz and output of 80 kV for 2.5, 5, 7.5, and 10 minutes	Olatunde et al. (2019)
Irradiation	Spanish mackerel (*Scomberomorus commerson*)	Amino acid content increased or decreased with increasing irradiation dose with no clear trend of the change	Gamma irradiation 1.5 kGy	Al-Kahtani, et al. (1998)
Irradiation	Horse mackerel (*Trachurus trachurus*)	No significant effect on proteins of this species	Gamma irradiation 1, 5, and 10 kGy	Silva et al. (2006)
Pulsed light	Chicken	a. Decrease in microbial loads and total aerobic count b. Maximum temperature <42°C, no significant increase in lipid peroxidation and no impact on sensory attributes under non-thermal conditions	0.78, 2.7, 4.05, and 5.4 J cm^{-2}; 0–1,000 pulses; 0–200 seconds; 5 Hz	Paskeviciute et al. (2011)

(Continued)

TABLE 1.2 EFFECT OF NON-THERMAL TECHNIQUES ON DIFFERENT MEAT AND FISH PRODUCTS *(Continued)*

Treatment	Meat and Fish Matrix	Effects on Matrix	Treatment Conditions	Reference
Pulsed light	Seafood	a. Decrease of *L. monocytogenes* in shrimp, salmon, and flatfish b. Temperature rises by maximum 5°C; no immediate impact on colour	0–17.2 J cm^{-2}; 0–9,800 pulses; 0–1,960 seconds; 0.11–1.75 J cm^{-2} per pulse	Cheigh et al. (2013)
E-beam	Shrimp (*Litopenaeus vannamei*)	a. Shrimp irradiated at above 2.5 kGy dose had a lower hardness b. L* value showed a decreased trend during storage c. b* and a* values showed a gradual increase during storage significant ($p < 0.05$) reduction in *Brochothrix thermosphacta* and *Lactobacillus* count	2.5, 5.0, 7.5 and 10 kGy	Annamalai et al. (2020)
E-beam	Frozen duck meat	a. Reduction in total bacterial count b. Increase in thiobarbituric acid reactive substances (TBARS) values, peroxide value, and total volatile base nitrogen but no effect on the sensory parameters c. Lowering of L* and a* values but elevation of metmyoglobin content	3 and 7 kGy	Arshad MS et al. (2020)
Supercritical fluid extract	Frozen chicken meat	Reduced lipid and protein oxidation	2 mL/kg of *Echinacea angustifolia* extract	Gallo et al. (2012)
Supercritical fluid extract	Fish patties	Reduced cholesterol oxidation	1 and 3 g/kg of oregano extract	Tarvainen et al. (2016)

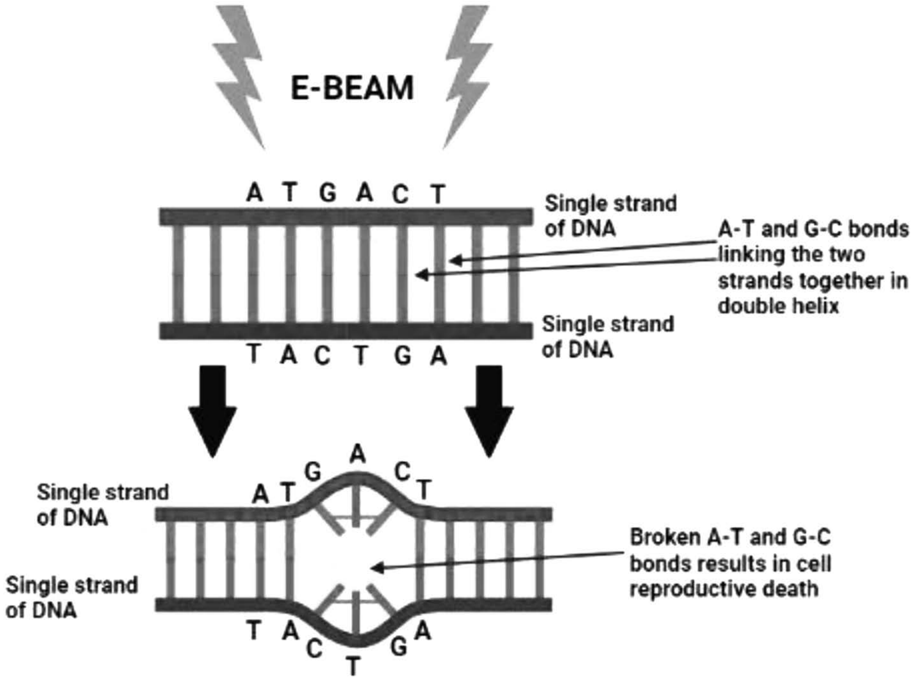

Figure 1.2 Mechanism of E-beam on a single strand of DNA.

demonstrated the effectiveness and safety of the food irradiation process to improve food safety, reduce common food-spoilage organisms, extend shelf life, and reduce the likelihood of illness due to post-processing contamination, there are some drawbacks associated with the procedure, as with any technology (Figure 1.2). The issue with food irradiation is that when done at room temperature, most meats have perceptible off-odours. The threshold dose for irradiating chicken at 5–10°C is 2.5 kGy, which results in a mild irradiation flavour with an intensity of 2.0 on a scale of 1–5 (where 1 is no irradiation flavour and 5 is a very strong irradiation flavour) (Sudarmadji & Urbain, 1972). It was found that doses between 2.5 and 5.0 kGy produced a faint irradiation smell that vanished after 4 days of storage before returning on the fifth day. Irradiating high-moisture items like beef in the frozen condition, however, can preserve their sensory qualities (Sales et al., 2020).

To achieve a longer shelf life, several poultry products are being packaged under changed atmospheres. Because there isn't any oxygen present during the anaerobic irradiation of poultry items, off tastes and aromas are somewhat reduced. However, these items are only permitted to be irradiated in oxygen-permeable packaging in order to protect the irradiated poultry products that are immune from contamination with *Clostridium botulinum* (https://www.usda.gov/sites/default/files/sarc1997_1.pdf). To assess the quality and consumer acceptance of meals treated with irradiation at dosages necessary to ensure safety, more sensory research on ready-to-eat foods is needed (Doyle, 2000).

The sensory texture, flavour, and palatability of frankfurters manufactured from beef and pork (8 to 32 kGy) and chicken or turkey (Terrell et al., 1982) are affected by high dosage levels of irradiation. The effects of sodium nitrite, meat formulation, and sodium acid pyrophosphate on the characteristics of irradiated (0, 8, and 32 kGy) frankfurters were investigated by Terrell et al. in 1982. The frankfurters exposed to radiation at 0 and 8 kGy did not differ significantly from one another, but they did from the frankfurters exposed to radiation at 32 kGy. The off flavours in the frankfurters exposed at 0 and 8 kGy were minimal, but the off flavour in the frankfurters exposed to 32 kGy was significantly more potent.

Table 1.2 provides us a glimpse of the different non-thermal treatments on fish, meat, and poultry products.

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High-Pressure Processing of Meat, Fish, and Poultry Products

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Commercial Viability of Non-Thermal Processing Applications for Meat, Fish, and Poultry Processing Industries at Global Perspectives with Its Regulatory Aspects

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