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4. Advances in Food Technology

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Abstract:

The development of advanced food processing technologies has become increasingly crucial in meeting consumer demands for convenient, varied, nutritious and shelf-stable food products while addressing environmental concerns. Traditional methods such as pasteurization, sterilization, cooking and drying have been essential but are being supplemented and in some cases, replaced by newer, more environmentally friendly approaches. Novel non-thermal processing technologies such as High Hydrostatic Pressure (HHP), Pulsed Electric Field (PEF), Cold Plasma and Irradiation, offer advantages such as improved safety, extended shelf life and minimal impact on food quality. Each of these technologies possesses unique benefits and drawbacks, rendering them suitable for distinct applications. Moreover, emerging thermal processing methods such as Ohmic Heating, Radio Frequency (RF) Heating and Microwave Processing provide effective and uniform heating while reducing nutrient loss. Each of these techniques has its unique mechanisms and applications, catering to diverse food *processing needs. In general, the advancement and acceptance of sophisticated food processing technologies are essential for generating premium, safe and environmentally-friendly food items that align with changing consumer preferences and tackle ecological issues.*

Keywords:

Food processing; non-thermal processing; Thermal processing; Food safety and Sustainability.

4.1 Introduction:

Food processing encompasses a range of techniques used to transform raw ingredients into finished products, with a primary focus on preserving the quality and safety of foods. This commitment to quality and safety stems from consumer preferences for high-quality, nutritionally rich and technologically advanced food products. Throughout history, methods such as smoking, salting, drying and fermenting have been employed to preserve foods, making them suitable for consumption.

The ultimate goal of food processors is to ensure that processed foods meet safety standards while retaining their nutritional value and shelf stability. Modern consumers also seek informatively labelled, value-added foods that offer convenience beyond basic sustenance. owever, there's a growing awareness of the impact of processing on the functional properties of food, leading some health-conscious individuals to eat raw foods. Despite this trend, many foods require processing to be safe and accessible for consumption. This introductory chapter aims to provide an overview of both conventional and novel thermal and non-thermal processing methods available to the food industry, along with their efficiency and potential impact. Food processing methods are typically categorized into two main types: thermal and non-thermal. Thermal processing, being the conventional approach, is valued for its ability to deactivate harmful microorganisms and enzymes responsible for spoilage.

However, extensive heat treatments can lead to chemical and physical changes in foods, including the formation of toxic compounds and a reduction in nutrient bioavailability. Additionally, thermal processing can affect the organoleptic qualities of foods. In response to these concerns, there's a growing interest in softer processing techniques, including novel thermal and non-thermal methods. These approaches aim to balance the high quality and safety standards of industrial foods with improved functionality, catering to evolving consumer preferences and technological advancements.

4.1.1 Need for Development of Advance Technologies:

- Consumer preferences are shifting towards more convenient and diverse food options that offer both nutrition and extended shelf life.
- Meeting consumer expectations for premium food quality, amidst rising economic standards and growing ecological concerns, has spurred the emergence of innovative technological solutions in food processing.

- Traditional methods of food processing include pasteurization, sterilization, cooking, and drying.
- Emerging technological approaches in food preservation aim to minimize environmental impact.
- Certain promising new technologies show potential in terms of energy efficiency, water conservation and decreased emissions.
- The objective is to produce top-quality goods while enhancing heating efficiency, leading to energy savings, reduced processing expenses and increased product value.

4.2 Novel Food Processing Techniques Adopted by The Food Industry in Recent Times.

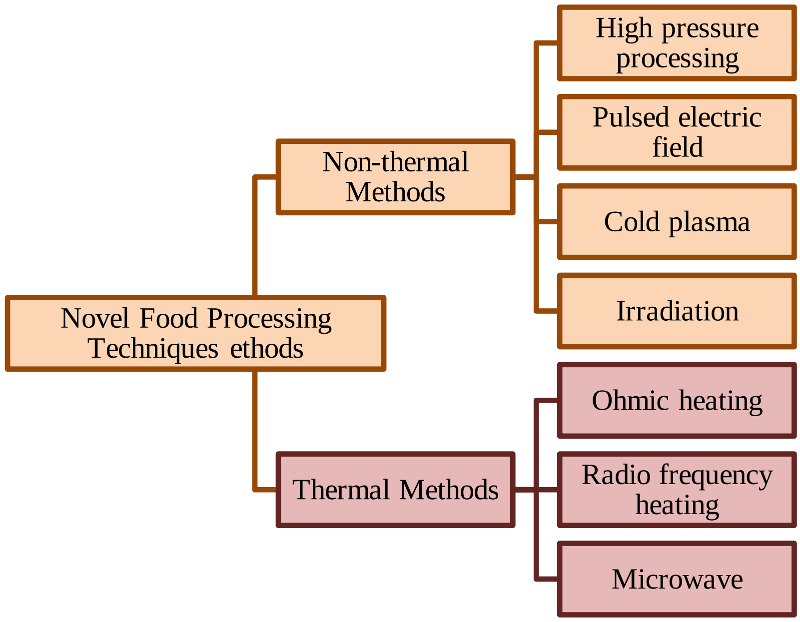

Figure 4.1: Novel Food Processing Techniques

4.2.1 Novel Non-Thermal Processing Technologies:

Non-thermal processing is frequently employed to describe technologies that function efficiently at room temperature or below.

A. High Hydrostatic Pressure (HHP):

High pressure processing of foods involves subjecting them to pressure ranging from 100 to 1000 MPa within a closed, degassed chamber. This method utilizes the isostatic principle, where pressure is uniformly applied throughout the food material, regardless of its mass, shape, or composition. Low or moderate HPP treatments typically target the destruction of microorganism cells and enzyme inactivation without significantly altering the food's sensory properties or vitamin content (Hugas *et al.*, 2002).

HPP primarily affects large molecules like proteins while leaving small molecules such as amino acids, vitamins and flavour compounds unaffected. This technique is particularly well-suited for fruit juices, pulps and other liquid products.

Features:

- High hydrostatic pressure processing, alternatively referred to as high pressure processing.
- Utilizes hydrostatic pressures typically ranging from 100 to 800 MPa to process different food items.
- Applies high pressure for durations ranging from 30 seconds to a few minutes.
- Neutralizes pathogenic bacteria, indigenous microflora, yeast and mould present in food.

Benefits:

- The uniform application of pressure throughout the food product ensures consistent treatment.
- It improves microbial safety and prolongs shelf life.
- It has minimal impact on heat (Pereira & Vicente (2010).
- Shelf life comparable to thermal pasteurization is achieved while preserving natural food quality attributes such as nutrients and sensory properties.
- Nonetheless, the upkeep and expenses associated with the system pose a notable limitation (Tappi *et al.,* 2020).

Advantages:

- Employed as a preliminary step to enhance the texture of food items while ensuring their safety, nutritional integrity and extended shelf life.
- Preserves the structural integrity of foods with high moisture content.
- Application of HPP to foods, particularly citrus fruits, boosts the levels of phenolic compounds.
- Enables food processing to occur at room temperature or lower (Escobedo-Avellaneda *et al*. 2011; Hogan *et al.* 2005).

Disadvantages:

- This technique applied to meat and fish may result in the release of metal ions into the tissues, potentially leading to heightened oxidation and adverse effects on flavor.
- HPP has the potential to induce protein denaturation in specific foods, altering the color of the processed food product, depending on the applied pressure and duration of exposure.

It could induce structural modifications in delicate foods like strawberries, causing softening and leakage of cell contents due to cell damage and distortion (Rastogi *et al.*, 2007).

B. Pulsed Electric Field (PEF):

It is recognized as an eco-friendly innovation within the food processing sector. It entails applying an external electric field, typically ranging from 20 to 80 kV/cm, to living cells for a brief period, typically measured in nanoseconds or milliseconds. This application causes pores on the cell membrane, a phenomenon known as electroporation or electro-permeabilization (Saulis, 2010).

However, the high costs associated with PEF have hindered its widespread adoption in industrial settings, limiting its use primarily to wastewater treatment. Furthermore, PEF technology is more suited to processing of liquid foods (Sampedro *et al.*, 2013).

Advantages:

- It serves as an efficient preservation technique for liquids with low-ionic-strength and low-conductivity, effectively eliminating vegetative cells.
- Improved outcomes including higher yield and preservation of quality attributes such as color, flavor, and nutrients are noted during fruit juice and vegetable oil extraction.
- By reducing temperature elevation, it minimizes processing duration, resulting in eco-friendly practices and lower processing expenses.
- It facilitates enhanced mass transfer in meat and fish at lower temperatures, accelerating protein digestion.

Disadvantages:

- It incurs a high initial investment, presents difficulties when dealing with conductive materials, and shows limited effectiveness against certain enzymes and spores.
- Operational issues arise from the formation of bubbles and the presence of dissolved gases.
- Additionally, there is a lack of comprehensive operational protocols for food products, coupled with insufficient economic and engineering evaluations for scaling up the process (Arshad *et al*., 2020).

C. Cold Plasma:

Cold plasma technology has garnered global attention across various industries and is increasingly recognized for its promising applications. It has drawn interest from both scientists and industrial sectors as an eco-friendly method that minimally impacts food properties while offering an alternative approach to conventional decontamination techniques (Pignata *et al.,* 2017).

Cold plasma treatment leaves no chemical residue and operates without thermal effects. Plasma, a partially ionized gas mixture consisting of charged particles and neutral species, is the key component in this process. The effectiveness of plasma processing relies on several parameters, including input energy, gas composition, and the nature of the food matrix (Ekezie *et. al*. 2017; Ahangari *et. al*. 2020).

Features:

- Plasma comprises ionized gas components, encompassing photons, free electrons, excited or non-excited atoms, and positive or negative ions and molecules.
- Furthermore, the processing generates UV light and oxidants like ozone and hydrogen peroxide.
- Cold plasma also known as nonthermal plasma or atmospheric cold plasma, is generated at room temperature under standard atmospheric pressure.
- Various factors influence the effectiveness of cold plasma, including the generating device, power input, exposure mode and duration, gas composition, temperature and relative humidity.

Advantages:

- Cold plasma offers cost-effective equipment and operations while ensuring reliability.
- It enhances the microbiological safety of treated foods.
- While it generally preserves the sensory properties of processed food products, there are occasional contradictions in this regard (Gavahian *et al.*, 2019).

Disadvantages:

- The presence of non-uniform surfaces on food products can support the growth of microorganisms, consequently reducing the effectiveness of the process. Therefore, ensuring evenly and adequate penetration depth becomes crucial factors to consider during cold plasma treatment (Niemira 2012).

D. Irradiation:

This processing has been utilized for the decontamination of various food commodities, offering an efficient physical method involving ionizing energy. A significant benefit of this method is its ability to treat large quantities of materials both before and after packaging. Food decontamination through irradiation is widely acknowledged as a safe, efficient, eco-friendly, and energy-saving process (Mir *et al*., 2021). This approach operates by damaging the genetic material, resulting in the elimination of fungi that produce mycotoxins. Ionizing radiations also interact with mycotoxins, disrupting their molecular structure through mechanisms involving free radicals and oxidation. Furthermore, the indirect effects of water radiolysis and free radical reactions contribute to the breakdown of pathogens and mycotoxins. Crucially, irradiation does not raise the temperature or leave any residues on the food (Akhila *et al.*, 2021).

How Do You Irradiate Food:

- The irradiation process is conducted within a shielded irradiation chamber, enclosed by thick concrete walls measuring 1.5 to 1.8 meters.
- Food items, either pre-packaged or bulk, are placed in appropriate containers and conveyed into the irradiation chamber using an automated conveyor system.

- The conveyor system navigates through a maze of concrete walls to prevent radiation exposure to the work area and operator room.
- During periods of non-use, the radiation source is stored beneath 6 meters of water.
- To treat food, the radiation source is raised to the irradiation position above the water level once all safety measures are activated.
- Food items within aluminium carriers or tote boxes are mechanically positioned around the source rack and rotated to ensure both sides are irradiated.
- The absorbed dose is calculated based on the length of time the carrier or tote box stays in the irradiation position.
- To monitor absorbed dose levels, dosimeters are positioned at different locations within a tote box or carrier.

How Irradiation Works:

- Radiation disrupts the biological processes responsible for decay.
- Radiation energy is absorbed by molecules in food and living organisms when they interact with water and other molecules.
- These interactions with DNA result in the demise of microorganisms and insects, as well as hinder the ability of potatoes and onions to sprout.

Table 4.1: Different Doses of Irradiation

Level	Range	Purpose of application
Low dose	< 1 kGy	1. Preventing the growth of sprouts in potatoes and onions. 2. Controlling insects in stored grains, pulses, and related products. 3. Eliminating parasites in meat and meat-based items.
Medium dose	1 to 10 kGy	1. Removing spoilage microorganisms from fresh fruits, meat, and poultry. 2. Getting rid of foodborne pathogens in meat and poultry. 3. Sanitizing spices and herbs to ensure hygiene.
High dose	>10 kGy	1. Sterilizing food to meet specific needs. 2. Creating shelf-stable foods that don't require refrigeration.

Advantages of Irradiation

- Eliminating insect pests in stored goods.
- Eradicating quarantine pests in fresh produce.
- Slowing down the ripening or aging process of fruits and vegetables.
- Preventing sprouting in tubers, bulbs and rhizomes.
- Eradicating spoilage-causing microbes in food, thereby eliminating foodborne parasites and pathogens**.**

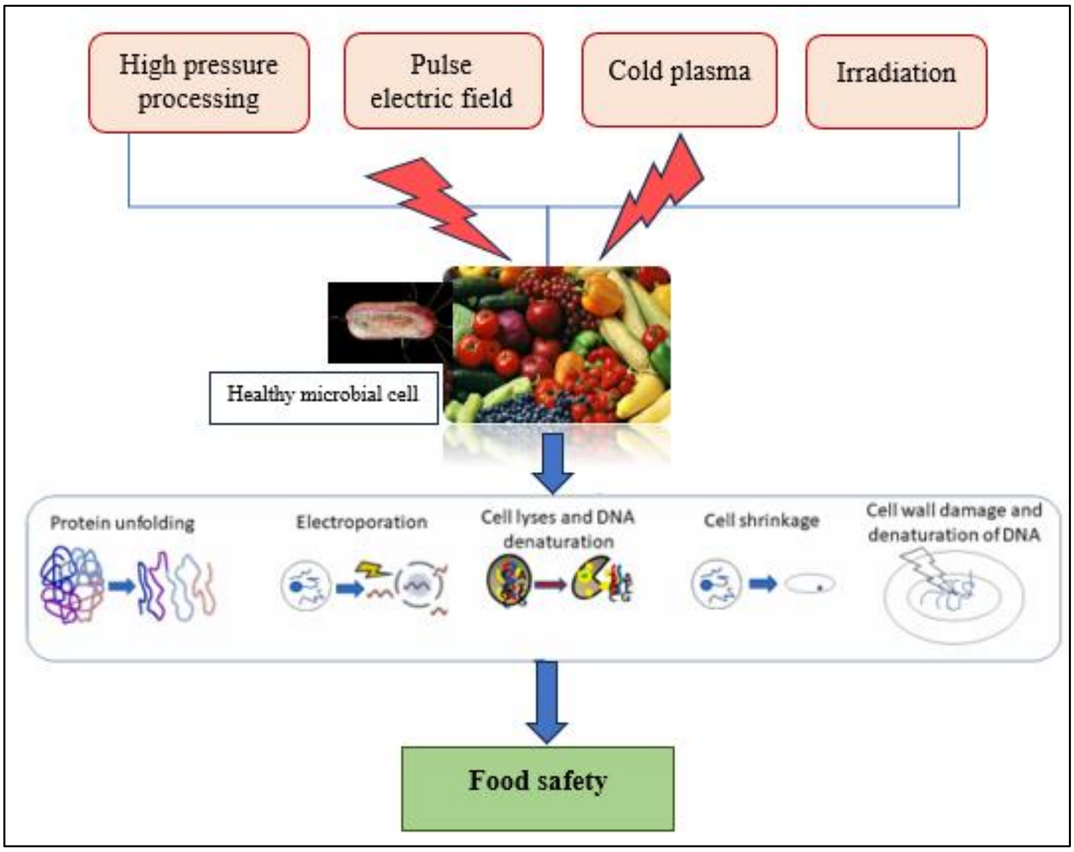

Figure 4.2: Action Mechanisms of Chosen Non-Thermal Methods to Ensure Food Safety.

4.2.2 Novel Thermal Processing Technologies:

Traditional methods of food preservation typically involve subjecting food to high temperatures to reduce microbial contamination. While thermal processing remains the primary method for prolonging the shelf life of foods and safeguarding against microbial contamination, it frequently induces unfavourable alterations in food quality.

These alterations may include the degradation of temperature-sensitive nutrients, modifications in texture, and alterations in taste and aroma. Furthermore, thermal preservation may contribute to the development of chemical toxins in food, some of which pose carcinogenic risks and potential harm to human health. The nature and amount of these toxins differ depending on the food variety and the particular thermal technique employed. Moreover, questions persist regarding the nutritional advantages of thermally processed foods, given that heat treatment can substantially modify the nutritional composition and overall quality of the items. Heat-sensitive vitamins, including vitamins A (in the presence of oxygen), D, E, β-carotene, vitamin C, B1, B2 (in acidic environments), nicotinic acid, biotin and pantothenic acid, are particularly susceptible to degradation during thermal processing.

To address these concerns, innovative thermal processing techniques have been developed, featuring alternative heating methods that offer faster heating rates, thereby minimizing nutrient loss and undesirable reactions.

A. Ohmic Heating:

It is often classified as a modern processing technique and is considered an alternative to conventional thermal processing techniques. This technology has been acknowledged since the 19th century, initially utilized for milk pasteurization. Unlike microwave and radio frequency heating, which are forms of indirect electro-heating, ohmic heating involves direct electro-heating, where electrical current is directly applied to the food. Various ohmic heating processes utilizing electrical current for food heating have been developed and extensively studied, with numerous scientific inquiries dedicated to this field. Research has primarily focused on frequencies of either 20 kHz or 50 kHz. The primary food matrices studied concerning ohmic heating include meat, processed meat items, and liquid foods like fruit and vegetable juices, as well as milk and milk substitutes. However, a major drawback of this technology is that even with proper optimization of the ohmic process conditions, it can still lead to changes in the textural properties of food.

Working Principle of Ohmic Heating:

The principle of ohmic heating, also known as Joule heating or resistive heating, involves passing an electrical current through a conductive material, typically a liquid or semi-solid food product. This process relies on the resistance encountered by the material to the flow of electricity, which results in the conversion of electrical energy into heat energy.

In ohmic heating, the electrical impedance generates heat directly within the food material, uniformly raising its temperature throughout. Unlike conventional heating methods where heat is transferred from an external source, ohmic heating heats the food from within. This uniform heating distribution is advantageous for preserving the quality of the food, as it minimizes temperature gradients and reduces processing times.

Advantages of Ohmic Heating:

- Uniform Heating: It ensures consistent quality by evenly heating the entire food product, thereby reducing temperature variations.
- Rapid Heating: It enables rapid heating as heat is generated directly within the food material, leading to shorter processing times and increased throughput.
- Preservation of Quality: Ohmic heating preserves the organoleptic qualities, nutritional content and quality of food products by minimizing heat exposure and reducing the risk of thermal degradation.
- Flexibility in Control: Ohmic heating allows for precise control over temperature profiles, enabling tailored processing to achieve specific objectives such as pasteurization or sterilization.
- Energy Efficiency: It can be energy-efficient, particularly in comparison to traditional heating methods, as heat is produced directly within the food material, reducing heat loss.

- Reduced Processing Costs: Ohmic heating can lead to reduced processing costs due to shorter processing times, energy efficiency and minimal need for additional equipment.

Disadvantages of Ohmic Heating:

- Equipment Complexity: Ohmic heating systems can be complex and require specialized equipment, including electrodes and power sources, which may increase initial investment costs.
- Electrical Conductivity Requirement: Ohmic heating is most effective for food products with high electrical conductivity, limiting its applicability to certain types of foods.
- Potential for Electrolysis: In some cases, ohmic heating may lead to electrolysis, which can cause changes in pH and chemical reactions within the food material, affecting taste and quality.
- Limited Penetration Depth: Ohmic heating may have limited penetration depth, particularly in dense or heterogeneous food products, leading to uneven heating.
- Safety Concerns: There may be safety concerns associated with the use of electrical currents in food processing, such as the risk of electric shock or equipment malfunctions.
- Regulatory Considerations: Regulatory approval may be required for the use of ohmic heating in food processing, which could impact its adoption in certain regions or markets.

B. Radio Frequency (RF):

Radio frequency (RF) heating entails directly transmitting electro-magnetic energy into a food item, leading to volumetric heating induced by the frictional interaction among its molecules. Frequencies typically utilized for RF heating range from 1 to 300 MHz, featuring a substantial penetration depth. The extended wavelengths characteristic of radio frequencies, in contrast to those of microwave heating, underscore the considerable benefits of RF heating, especially in food processing contexts.

Working Principle:

Radio frequency (RF) heating operates based on the principle of transferring electro-magnetic energy directly into food products. This energy is delivered at frequencies typically ranging from 1 to 300 MHz. RF heating induces volumetric heating within the food material by causing molecules to rapidly oscillate due to the alternating electric field created by the RF energy.

The working principle involves the following steps:

- Energy Transfer: RF energy is emitted from an antenna or electrode and directed towards the food product. The RF energy penetrates the food material and interacts with its molecules.

- Molecular Friction: As the RF energy encounters the molecules in the food, it causes them to rapidly oscillate. This oscillation results in frictional forces between the molecules, generating heat throughout the volume of the food product.
- Volumetric Heating: Unlike conventional heating methods, which rely on heat transfer from external sources, RF heating heats the food material uniformly from within. This volumetric heating ensures that the entire product reaches the desired temperature evenly.
- Efficient Processing: RF heating offers advantages such as rapid and uniform heating, precise temperature control, and energy efficiency. These characteristics make it suitable for various food processing applications, including cooking, drying, thawing, and pasteurization.

Overall, RF heating involves directly transmitting electro-magnetic energy into a food product, resulting in efficient and uniform heating through volumetric heating caused by molecular friction.

Similar to ohmic and microwave processes, RF heating offers several advantages over conventional heat-processing technologies.

However, it also presents some specific benefits over these alternative volumetric technologies. Nevertheless, there are also some disadvantages associated with RF processing:

Advantages:

- RF heating offers similar benefits to ohmic and microwave processes, including efficient and uniform heating of food products.
- RF heating is particularly advantageous due to its longer wavelengths compared to microwaves, which can penetrate more deeply into food materials, resulting in more uniform heating.
- The volumetric heating characteristic of RF processing can lead to faster heating rates and reduced processing times compared to conventional methods.

Disadvantages:

- RF processing generally involves higher equipment and operational expenses in contrast to traditional heating systems.
- RF heating might exhibit lower power density when compared to microwave heating.
- There is a scarcity of research on identifying the dielectric properties of foods treated with RF, which can impact process optimization and effectiveness.

C. Microwave Processing

Microwave processing, a modern thermal treatment method, has witnessed growing adoption in both the food industry and households in recent times. Household microwave ovens generally work at a frequency of 2.45 GHz, whereas industrial microwave systems operate within a range of 915 MHz to 2.45 GHz. Microwave technology is characterized by its ability to generate heat instantly, resulting in significantly reduced processing times and operational expenses compared to traditional dry-heating techniques. Microwave heating finds widespread application in both pasteurization and sterilization processes.

Pasteurization involves eliminating pathogenic microorganisms in their vegetative state through thermal treatment, thereby enhancing food safety and extending shelf life.

In microwave processing, microbes are destroyed at low temperatures through various mechanisms, including selective heating, disruption of cell membranes, electroporation and coupling with magnetic fields.

Working Principle:

Microwave technology employs electromagnetic waves in the microwave frequency range to induce heat within food products.

These waves cause polar molecules within the food, such as water, fats and sugars to rapidly oscillate. This oscillation generates friction and heat, leading to the heating of the food.

Magnetrons are commonly used to generate microwaves by converting electrical energy into microwave radiation. These microwaves are emitted into the processing chamber, where they penetrate the food and induce heating from within. This is in contrast to conventional heating methods, which primarily heat the food from the outside.

Advantages of Microwave Processing

- Shorter processing time
- Efficient heating
- Improved product quality
- Preservation of nutritional and sensory attributes
- Reduced drying time
- Thawing
- Tempering of fish meat and poultry
- Pasteurization, sterilization and blanching
- Baking and cooking

Disadvantages of Microwave Processing

- Deterioration of processed food items resulting from dry heating and dehydration.
- Uneven temperature distribution, resulting in areas of both high and low temperatures in products treated with microwaves.
- Low penetration depth.
- Less energy efficient than ohmic heating.

Table 4.2: Major Differences

Ohmic heating	Radio frequency	Microwaves
Uses the electrical resistance of foods	Uses electromagnetic energy	Uses electromagnetic energy
Direct approach and heat are generated due to electric current	Heat is generated indirectly as infrared energy is absorbed and then transformed into heat	Direct approach and heat is produced through the molecular friction within water molecules.
Relies on the electrical resistance of the food	Relies on the surface properties and coloration of the food	Relies on moisture content of the food
Primarily employed for food preservation	Mostly utilized to enhance the sensory attributes	Mainly used for food preservation
Penetrates uniformly throughout the food	Has restricted depth of penetration	Has limited depth of penetration
Thermal conductivity does not pose a restriction	Thermal conductivity poses a limitation	Thermal conductivity does not pose a restriction
Require liquid or particulates food	Can be applied to both liquid and solid food items	Foods having moisture can support efficiently

4.3 Conclusion:

The development and adoption of advanced food processing technologies play a crucial role in meeting consumer demands for convenient, nutritious, and environmentally sustainable food products. Traditional methods such as pasteurization and sterilization are being supplemented or replaced by novel thermal and non-thermal processing techniques to address evolving consumer preferences and environmental concerns.

Non-thermal processing technologies offer advantages such as improved safety, extended shelf life and minimal impact on food quality. Each technology has its specific applications, catering to diverse food processing needs. Similarly, novel thermal processing technologies offer efficient and uniform heating while minimizing nutrient degradation.

These technologies provide rapid heating, precise temperature control, and energy efficiency, contributing to reduced processing costs and improved product quality. Overall, the development and adoption of advanced food processing technologies are essential for producing high-quality, safe and sustainable food products that meet the evolving demands of consumers while addressing environmental concerns.

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