

EMERGING TECHNIQUES IN FOOD PROCESSING AND PRESERVATION

Abstract

The food industry is progressively moving towards innovative product development and implementing new ideas utilizing novel food processing methods that allow doing things that could not be done before. Different techniques are opted by food processing industries for providing processed and preserved foods for our daily consumption. In recent years; the increased interest towards novel thermal and non-thermal technologies for food processing has gained industrial importance. The non-thermal processing is used for all foods for its better quality, acceptance, and for its shelf life also reduces the operational cost. Since these technologies allow the food sector to meet product safety and fulfilling the shelf-life requirements. In this chapter, we shall discuss various non-thermal technologies that are widely employed for different food applications, e.g. pulsed electric field, high pressure processing, ultrasound etc.

Keywords: Consumer acceptance; food preservation; industrial adoption; non-thermal technology; technology diffusion; thermal technology.

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I. NEED FOR INNOVATIVE TECHNOLOGIES

Food processing is a method of converting raw food into final finished, well-cooked and well-preserved product consumable for both humans and the animals. The demand of fresh and minimally processed foods is increasing day by day. For this purpose, different techniques are opted by food processing industries for providing processed and preserved foods for our daily consumption. A Food Scientist studies the physical, microbiological, and chemical makeup of food. They are formulating various ways to process, preserve, package, or store food, according to industry and government specifications and regulations. Any food processing technique can affect its nutritional density. The loss of nutrients depends on the food and processing method. The food industry is progressively moving towards innovative product development and implementing new ideas utilizing novel food processing techniques that allow doing things that could not be done before.

Traditionally thermal treatments have been used earlier in the food industry to attain food safety and to enhance the shelf-life of the food product. But these thermal treatments result in destroying the heat-labile components creating loss of several organoleptic and nutritional properties of food products. To overcome these problems, innovative non-thermal methods like high power ultrasounds, pulsed electric fields, light technologies, cold plasma, etc. are developed in food industries to increase the production rate and profit. In recent years, the increased interest towards novel non-thermal technologies for food processing has gained industrial importance.

II. DIFFERENT EMERGING TECHNOLOGIES

Innovative food processing methods have better potential than other traditional food processing methods and still an evolving challenging field for the food processors. The cost of equipments used in various non-thermal food processing methods is high when compared to equipments used in thermal processing of foods. After minimizing the investment costs and energy saving potential of non-thermal processing methods, it can also be employed in small scale industries. The various emerging technologies in food processing and preservation are hurdle technology, irradiation, and ultrasonication and high-pressure processing, etc. The most extensively researched non-thermal processes for preservation of foods appear to be pulsed electric fields (PEF) and high hydrostatic pressure (HHP) (Ross et al., 2003), which are commercially applied for the processing of juices and other fruit-derived products. High hydrostatic pressure, pulsed electric fields, high-intensity ultrasound, ultraviolet light, pulsed light, ionizing radiation and oscillating magnetic fields have the ability to inactivate microorganisms to varying degrees (Butz and Tauscher, 2002). Novel non-thermal technologies such as pulsed light treatment (PL), ultrasounds (US), high pressure processing (HPP), pulsed electric fields (PEF) have the ability of preserving the nutritional and sensorial characteristics of fresh-like food products by inactivating the microorganisms at near-ambient temperatures.

III.DETAIL OF VARIOUS EMERGING TECHNOLOGIES

1. Hurdle Technology: Combining two or more non-thermal technologies in a single process is a better option of reducing the severity of each non-thermal treatment desired of achieving a given microbial inactivation level. This technique is known as “hurdle technology” which ensures food safety and better shelf life. Therefore, synergistic effects of different technologies alone are merged in a single technology. Hurdle technology also ensures complete elimination of all pathogens in food products.

Hurdle technology relies on the careful selection of combined preservative factors popularly known as hurdles (Leistner, 2000).In hurdle technology, hurdles are deliberately combined for improving sensorial and nutritional profile of food products and enhancing the microbial stability of foods. Thus, hurdle technology aims of achieving the total quality of foods by application of an intelligent and appropriate mixing of hurdles (Leistner, 2000).Examples of hurdles in a food system are low temperature during storage, high temperature during processing, increasing the acidity, lowering the water activity or redox potential, or the presence of preservatives. According to the intensity of the hurdles and the type of pathogens, the process can be controlled individually without affecting the safety of the food product. The most critical process in hurdle technology is disturbing the homeostasis of microorganisms i.e. their balanced and stable internal environment. This can be successfully achieved by simultaneously controlling various mechanisms of homeostasis (Kaushal and Sharma, 2018).

Multi targeted approach is the best way for controlling microbial population in hurdle technology. More than 60 different hurdles have been recognized till date which has proved beneficial in controlling microbial population. Hurdle technology is used in developing countries for effective preservation of foods using two or more hurdles without affecting the sensory quality of the food. Thus, hurdle technology will also be the key to future food preservation.

- **Different Hurdles and their Role:** Each hurdle aims to inactivate, eliminate unwanted microorganisms in food. The principal hurdles and their applications in food preservation are presented in Table 1. There can be significant synergistic effects between different hurdles.

Table 1: Principal hurdles in food preservation

S. No.	Hurdle	Application
1	High Temperature	Heating
2	Low Temperature	Freezing and chilling
3	Increased acidity	Acid formation and addition
4	Reduced water activity	Drying and curing
5	Reduced redox potential	Removal of oxygen and addition of ascorbate
6	Biopreservatives	Competitive flora such as microbial fermentation

Every hurdle involved in hurdle technology could have both, positive or a negative effect on foods, depending on its intensity. For example, lowering the pH in fermented sausage restricts the growth of pathogenic bacteria but lowering pH beyond the required limit can also affect its taste. Therefore, a balanced intensity of any hurdle is very important for food preservation.

- **Principle:** The principle behind hurdle technology is the effect of various food preservation methods on the behavior of microorganisms in foods, i.e. their homeostasis, metabolic exhaustion, stress reactions. For this purpose, the concept of multi-target food preservation played its important role in food preservation. Metabolic exhaustion deals with auto sterilization of food. Disturbing the homeostasis i.e. internal balanced environment of the microorganisms by combining various hurdles result in the death of the microorganisms ensuring safety of food products (Pundhir and Murtaza, 2015).
- **Mechanism:** The main mechanism involved in hurdle technology is the multi-targeting approach of controlling microorganisms. Rather than using single-targeting approach for micro-organisms, the multi-targeted approach allows low intensity hurdles for inactivating and killing micro-organisms thereby improving the product quality. Moreover, to disturb simultaneously all the mechanisms involved in disturbing homeostasis is the best approach used in this technology. The type of hurdles and their combination varies for different food products.
- **Advantages**
 - It can avoid the severity of one hurdle for preservation.
 - There is greater possibility of using natural preservatives in combination with synthetic preservatives.
 - It can give synergy of combination.
 - This appears to be a good tool of getting safe and tasty products of high quality.
 - Many of the hurdles come from past experience (i.e. tradition or culture).
 - It saves energy, money and several other resources.
 - It does not affect the integrity of food products.
 - It is applicable to both large- and small-scale industries.
 - Food remains stable and safe, high in sensory and nutritive value due to gentle process applied.
- **Disadvantages**
 - This technique could provide varying results depending upon various bacterial stress reactions.
 - The cross tolerance may not exist when combined hurdles are used.
- **Applications:** Hurdle technology has its wide applications in preservation of various food products like dairy products, fruits and vegetables, fruit derived products, meat and meat products etc.

2. High Pressure Processing: High Pressure Processing is a natural, environmentally friendly process which maintains the characteristics of fresh food. It is a real alternative to traditional thermal and chemical treatments. In this method, food products already sealed in its final package, are introduced into a vessel and subjected to a high level of isostatic pressure (300–600MPa/43,500-87,000psi) transmitted by water. Pressures above 400 MPa / 58,000 psi or ambient temperature inactivate the vegetative flora present in food, extending the product shelf life and ensuring food safety. The limited effect of HPP (at moderate temperature) on covalent bonds represents a unique characteristic of this technology because HPP has a minimal effect on food chemistry (Balny and Masson, 1993).

- **Principle:** The basic principles that determine the behavior of foods using high pressure technology are principles of microscopic ordering, isostatic and Le Chatelier's principle. The difference in these three principles is summarized in Table 2.

Table 2: Different principles of high-pressure processing of foods

S. No.	Principle	Mode of action
1	Isostatic	Pressure will not damage the food product as pressure is applied uniformly in all directions
2	Microscopic ordering	At constant temperature, an increase in pressure increases the degrees of ordering of molecules of a given substance
3	Le Chatelier's	Any change in conformation and phase transition is accompanied by a decrease in volume which is enhanced by pressure as pressure is inversely proportional to volume

- **Mechanism:** High pressure processing of foods has lethal effects on microorganisms. This technology affects cell morphology, membranes, spore coats, and denatures proteins, enzymes leakage and permeability of membranes resulting in leakage leads to death of microorganisms. This process is product specific as inactivation of microorganisms is dependent on pH, RH, food, exposure time, pressure level, etc.
- **Advantages**
 - Characteristics of the fresh product are retained
 - Excellent food quality
 - Destroys pathogens and ensuring food safety
 - Extends product shelf life
 - Improved customer satisfaction
 - Reducing the need for food preservatives
 - New innovative food propositions
 - Does not produce new chemical compound and radiolytic by-products
 - Inactivation of microorganisms and enzymes
 - Modification of biopolymers
 - Quality retention, such as color and flavor

- Changes in product functionality
 - Higher yields, fresh flavor, minimum hand labor
 - Only needs water and electricity
 - Environmentally friendly.
- **Disadvantages**
 - Bacterial spores are not inactivated by pressure alone
 - Most suitable for acid foods
 - Products need refrigeration for shelf-life and non-acid foods for food safety without other preservation measures
 - Can alter food products with high protein or starch contents
 - Batch process or semi batch process
 - Very expensive technique.
 - **Applications:** High pressure processing has its wide applications in meat products, avocado products, ready to eat meals, seafood products, juices and fruit products, dips and salsa, salad and sandwich fillings, dairy products. The application areas of high-pressure processing of foods are summarized in Table 3. The different foods that can be and cannot be treated using high pressure technology are summarized in Table 4.

Table 3: Application areas of high-pressure processing of foods

S. No.	Application areas	Application
1	Pasteurization	Juices, milk & meat and fish
2	Sterilization	High and low acid foods
3	Functional changes	Cheese, yogurt, surimi
4	Texture modification	Fish, egg, proteins, starches
5	Specialty processes	Freezing, thawing, fat crystallization, enhancing reaction kinetics

Table 4: List of foods that are treated and cannot be treated using HPP

S. No.	Treatment	Foods	Technique	Examples
1	HPP treated	Solid foods	Vacuum packaging	Dry-cured or cooked meat products, cheese, fish, seafood, marinated products, ready to eat meals, sauces, fruits, marmalades / jams, vegetables
2	HPP treated	Liquid foods	Flexible packaging	Dairy products, fruit juices and nutraceutical formulations
3	Not treated using HPP	Solid foods	With inclusion of air	Bread, Mousse

4	Not treated using HPP	Packaged foods	Completely rigid packaging	In glass or canned foods
5	Not treated using HPP	Foods with very low water content		Spices, dry fruits

3. Pulsed Electric Field Processing (PEF): PEF is a non-thermal method of food preservation that uses short pulses of electricity for microbial inactivation and causes minimal detrimental effect on food quality attributes. Pulsed electric field (PEF) used short electric pulses of high voltage (typically 20 - 80 kV/cm) to preserve the food (Kumar et al., 2016). It is suitable for preserving liquid and semi-liquid foods, destroying micro-organisms etc. PEF technology has been used in the US for orange juice, and it has considerable potential for improving quality and taste of pasteurized foods in comparison with traditional preservation techniques. The critical factors in PEF processing are summarized in Table 5.

Table 5: Critical factors in PEF processing

S. No.	Critical factor	Depending factors
1	Process	Pulse width, shape, waveshape, polarity, electric field intensity, treatment time and temperature (50-60°C)
2	Treatment media	pH, antimicrobial and ionic compounds, conductivity, medium ionic strength
3	Microbial entity	Type, concentration and growth rate of micro-organism

- **Principle:** The basic principle of the PEF technology is electroporation. In this process, high voltage pulses (10- 80 kV/cm) create pores and expand existing pores in liquid media by breaking the cell membranes of microorganisms with duration of microseconds to milliseconds. The pulsed electrical currents delivered to a food product placed between a set of electrodes. The distance between set of electrodes is known as treatment gap of the PEF chamber. The applied high voltage results in an electric field that causes microbial inactivation.
- **Mechanism:** Cellular membranes have pores that control the flow of substances in and out of the cell. Application of a pulsed electric field causes these pores to enlarge and release the contents of the cell or allow substances to enter the cell more easily.
- **Advantages**
 - Reduction in microorganisms (4-6 log)
 - Low treatment temperature
 - Less treatment time
 - Increased shelf life of foods
 - Maintaining food safety with low processing costs

- Minimally processed foods of higher quality
 - It can be used to pasteurize fluids without using additives
 - It acts as substitute for conventional heat pasteurization
 - Inactivates vegetative micro-organisms
 - It kills microorganisms while better maintaining the original color, flavor, texture, and nutritional value of the unprocessed food
 - It can save time and money
 - It creates value by improving product quality
 - Juice or oil extraction yields are increased
- **Disadvantages**
 - It does not inactivate enzymes
 - Refrigeration is required for enhancing shelf life of food products
 - It is restricted to food products with low electrical conductivity and no air bubbles
 - It is effective for inactivation of vegetative bacteria only
 - Spores are able to survive
 - It has considerable added value for specific product ranges
 - It is not suitable for solid food products
 - **Applications:** PEF has its wide applications in following areas:
 - Extraction of oil and proteins from algae; sugar from sugar beets etc.
 - Preservation of beverages and semi-liquid food products.
 - Replacing thermal pretreatment in case of potatoes etc.
 - Enhancing production processes for sausages etc.
4. **Ultrasonication:** This method is an efficient way to cut, slice, form, divert, align or transfer a variety of food products. The ultrasonic blades vibrate at high-frequencies of 20 kHz, 30 kHz, or 40 kHz by creating a nearly friction-free surface. Ultrasound is applied to impart positive effects in food processing such as improvement in mass transfer, food preservation, assistance of thermal treatments and manipulation of texture and food analysis (Knorr et al., 2011). Ultrasonic technology has its wide applications in food science and technology as modifiers (high power ultrasound) or sensors (low power ultrasound) for enhancing food quality (Awad et al., 2012). The different methods of ultrasonication treatment are summarized in Table 6.

Table 6: Different methods of ultrasonication

S. No.	Type	Principle	Process comparison
1	Ultrasonication (US)	Application of ultrasound at low temperature	<ul style="list-style-type: none"> • Longer treatment time • Inactivate enzymes and microorganisms
2	Thermosonication (TS)	Combined method of ultrasound and heat	<ul style="list-style-type: none"> • Lower processing temperatures and processing time

3	Manosonication (MS)	Combined method of ultrasound and pressure	<ul style="list-style-type: none"> Inactivation efficiency is higher than ultrasound alone at the same temperature
4	Manothermosonication (MTS)	Combined method of heat, ultrasound and pressure	<ul style="list-style-type: none"> Shorter treatment time to inactivate several enzymes at the same temperatures

- Principle:** The main principle of ultrasonication is cavitation. The high intensity of ultrasonic waves can generate the growth and collapse of bubbles inside liquids, a phenomenon known as cavitation. Ultrasonic cavitation creates shear forces that break cell walls mechanically.
 - Mechanism:** Cavitation is the main mechanism in ultrasonic technology. In other words, oscillation and collapse of bubbles is known as cavitation. As ultrasound waves propagate, the collapsing of bubbles causes thermal, mechanical, and chemical effects. This results in releasing energy for many chemical and mechanical effects.
 - Advantages**
 - Increased productivity
 - Particulates such as nuts & fruits are cut cleanly without displacement
 - Minimized sticking of product to the blades
 - Ultrasonic components can be cleaned in place
 - Easily adapted into existing production lines.
 - Disadvantages**
 - Needs more input of energy
 - It can cause inactivation of released products
 - It induces physicochemical effects.
 - It results in the formation of free radicals which causes changes in food compounds
 - Applications:** Ultrasonication has its wide applications in disintegration of cells, extracting intracellular components or obtains cell-free bacterial enzyme, inactivation of enzymes, meat processing, crystallization, stimulation of living cells, microbial inactivation. dispersion of a dry powder in a liquid, mixing and homogenizing, acceleration of fermentation, activation of an enzyme reaction in liquid foods, emulsifying of oil/fat in a liquid stream, spraying etc.
5. **Irradiation:** Food irradiation is a technology that can be safely used to reduce food losses due to deterioration and to control contamination causing illness and death. This technique makes the food safer to eat by destroying bacteria which is very much similar to the process of pasteurization. Being a cold process, irradiation can be used to

pasteurize and sterilize foods without affecting the freshness and texture of food unlike heat (Kalyani and Manjula, 2014). Irradiation is a physical treatment where food is exposed to a defined dose of ionizing radiation and is used on more than 60 food types worldwide. Irradiation treatment helps in controlling and reducing pathogenic microorganisms eliminate sprouting in fresh foods etc. The principal types of irradiation sources are presented in Table7. The general category and dose of treatment of irradiation are presented in Table8.

Table 7: Principal types of irradiation source

S. No.	Type	Source	Energy
1	Gamma radiation	From radionuclides such as ^{60}Co or ^{137}Cs	Energies of 1.17 and 1.33 MeV
2	Machine sources	From electron beams	Energies up to 10 MeV
3	Machine sources	From bremsstrahlung (X rays)	Electron energies up to 5 MeV

Table 8: Category and dose of treatment of irradiation

S. No.	Type	Dose	Benefits
1	Low dosage	up to 1 kGy	Inhibiting sprouts, delay of ripening, insect disinfestations, inactivating parasites
2	Medium dosage	1-10 kGy	Reducing spoilage microorganisms and non-spore-forming pathogens
3	High dosage	>10 kGy	Reducing microorganisms to the point of sterility

An important thing that must be kept in mind while irradiating food is its labelling. An irradiated food must be labeled with a statement that the food, ingredients or components have been treated with ionizing radiation. The different technical and scientific terms used in irradiation are presented in Table9.

Table 9: Technical and scientific terms used in Irradiation

S. No.	Term	Meaning
1	Ionizing radiations	The radiations whose energy is high enough to convert them to electrically-charged particles called ions

2	Gamma rays and X-rays	The radiations that occurs in the short-wavelength, high-energy region of the electromagnetic spectrum and have the greatest penetrating power
3	Radioisotopes	Naturally occurring and man-made radionuclide's which emit radiation as they spontaneously revert to a stable state.
4	Half-life	The time taken by a radionuclide to decay to half the level of radioactivity originally present
5	Becquerel (Bq)	It is unit of radioactivity and equals one disintegration per second
6	Radiation dose	The dosage of radiations absorbed by the food while passing through the radiation chamber.
7	Gray (Gy)	Unit of energy equivalent to 1 joule per kilogram.
8	1 kilogray (kGy)	It is equal to 1,000 grays (Gy)
9	Radura	It is the international symbol indicating a food product that has been irradiated. The Radura is usually green and resembles a plant in circle.

- **Principle:** Irradiation is a direct, simple, and efficient one-time process. It works by disrupting the biological processes that lead to decay. In this process, controlled dosage of radiations from a radioactive source such as cobalt-60 is exposed to food product. The radiations from any of these source results in destroying all food poisoning bacteria, insects etc. by penetrating evenly inside the food product. This mechanism does not alter the nature of food product.
- **Mechanism:** Irradiation process is carried out under controlled conditions inside a chamber where adequate dosage of radiations entered the food product without affecting the basic nature of food. This process may be batch or continuous. The dosage of irradiation depends on numerous factors like the nature of food product, mode (batch/continuous) and the source of irradiation (electron beam, X rays and gamma rays).
- **Advantages**
 - They undergo minimal changes in texture, flavor, odor, and color
 - We can put fresh like food on the plate of the consumer on land, under the waters, in the air, and in outer space
 - It can be used to preserve a wide variety of foods in a range of sizes and shapes
 - Simplicity in preparation
 - Reduction of labor in the kitchen.
 - Shelf-life extensions without refrigeration

- Spoilage losses from insect infestation, sprouting, or refrigeration breakdown will be minimized
 - Foods high in nutritive value
 - Less need for pesticides
 - Reduced sprouting in potatoes, onions, herbs and spices
 - Reduced risk of food-borne diseases caused by micro-organisms
 - Less need for some additives, such as preservatives and antioxidants
 - Reduced spoilage in global food supply.
- **Disadvantages**
 - It causes changes in flavor or texture e.g. in dairy foods and eggs
 - It affects the nutrient content of some foods because it reduces the level of some of the B-group vitamins
 - High capital cost of irradiation plant
 - There will be a health hazard if toxin-producing bacteria are destroyed
 - Inadequate analytical procedures for detecting whether foods have been irradiated.
 - **Applications** Irradiation technology has its wide applications in controlling mould growth, disinfestations, destruction of pathogens, sterilization of packaging materials, inhibition of sprouting, inactivation of parasites, extension of shelf life of foods like fruits and vegetables, meat, poultry etc.

6. Ohmic Heating: Ohmic heating uses the electrical resistance of foods to directly convert electricity to heat. The most commonly used heating techniques for liquids and slurries rely on heat transfer from a hot surface. Heat can be generated directly (using an electrical heating element) or indirectly from hot medium (using heat exchangers).

This process requires temperature gradient so as to transfer heat for processing liquids and to the surfaces that are at high temperatures than the food product. Ohmic heaters resolve various problems by removing hot surfaces from the heating of the fluids. The different terms used in ohmic heating are presented in Table 10.

Table 10: Terms used in ohmic heating of foods

S. No.	Term	Meaning
1	Alternating Current (AC)	Electrical current whose magnitude and direction vary cyclically
2	Hertz (Hz)	Unit of frequency, waves of energy expressed in cycles per second
3	Direct Current (DC)	It is one directional flow of electric charge, sources include batteries and solar cells.
4	Joule (J)	Unit of measurement of heat, electricity and mechanical work
5	Coulomb (C)	It is the amount of electrical charge, measured in one ampere per second.
6	Electrical	It is measure of the degree to which an object opposes an

	resistance-	electric current through it, expressed in ohms
7	Electric current-	It is the movement of electric charge, expressed in amperes (A)
8	Voltage-	It is the difference of electrical potential between two points of an electrical or electronic circuit, expressed in volts
9	Electrical conductivity	It is a measurement of ability of the material to conduct an electric current.
10	Electroporation	It is a significant increase in the electrical conductivity and permeability of the cell membrane by an externally applied electrical field.

- **Principle:** Ohmic heating of foods is based on Ohm's law. According to Ohm's law, the current passing between two points in a conductor is directly proportional to potential difference across the points and inversely proportional to resistance between the points at constant temperature. During ohmic heating, AC voltage is applied to the electrodes at both ends of the product body. The strength of electric field can be controlled by adjusting the gap between the electrodes or the applied voltage, while the electrical conductivities of foods vary greatly, but can be adjusted by the addition of electrolytes (Ruan et al., 2002).
 - **Mechanism:** Electroporation is the basic mechanism involved in ohmic heating of foods. In addition to this, low frequency (50-60 Hz) of ohmic treatment creates pores by concentration of charges at cell surface.
 - **Advantages**
 - Low capital cost
 - Due to uniform heating, it is suitable for liquid foods
 - Protection of heat-sensitive foods
 - Even heating of solid and liquid foods if resistance is same.
 - Suitable for continuous food processing operations
 - No risk of surface fouling and burning of product is associated with the process
 - Temperature sufficient for UHT processing can be achieved
 - **Disadvantages**
 - Cannot apply for all foods
 - High installation cost
 - Increased electrical conductivity of food materials
 - **Applications:** Ohmic heaters has its wide applications in production of dairy products, tomato products, milk-based foods, fruit juices, liquid egg, jams, soups etc.
7. **Atmospheric Pressure Plasma Technology (APP):** Atmospheric pressure plasma (APP) is an emerging non-thermal technology for the improvement of food safety. Plasma exists over a massive range in temperatures and densities. Plasma is considered as the fourth state of matter. The concept of the fourth state of matter results from the phase transitions that occur by progressively providing energy to the matter, such as the one from the solid state to liquid up to the gas state. Formerly, plasma treatments were carried

out under vacuum conditions, but researchers have now developed an atmospheric pressure plasma system, resulting in reduced cost, increased treatment speed, and industrial applicability (Yun et al., 2010). The different terms used in APP are presented in Table 11.

Table 11: Terms used in AAP technology for foods

S. No.	Term	Meaning
1	Plasma	Ionized gas containing free electrons, ions and neutral particles
2	High temperature plasma (HTP)	Electron, ions and neutral species are in a thermal equilibrium state
3	Thermal plasma (TP)	Existence of a thermodynamic equilibrium between the electrons, ions and neutral particles.
4	Non thermal plasma (NTP)	It has different electron and gas temperatures
5	Direct plasma	Plasma is in direct contact with substrate
6	Semi-direct plasma	Distance between plasma and substrate is much larger than the mean free particle path.
7	Indirect plasma	No contact with plasma particles

- **Principle:** This technology uses high reactive and energetic gases to inactivate microorganisms present in foods. It uses electricity and carrier gases. Microorganisms are destroyed due to UV light and reactive chemical products generated in cold plasma ionization process.
- **Mechanism:** Several mechanisms are considered to be responsible for inactivating microorganisms using this technology which are summarized as follows:
 - Rupturing of cell membrane by accumulation of charged particles at its surface.
 - Complete killing of microorganisms by direct contact with active species of antimicrobials.
 - Microbial death occurs due to oxidation of lipids, amino acids etc.
 - Modification of DNA of microorganisms by UV photons resulting in disturbing cell replication (Afshari and Hosseini, 2012).
- **Advantages**
 - Environment friendly
 - Low running cost
 - Does not affect nutrients within the food
 - Novel, ultra-fast sterilization process
 - Inactivate all types of pathogens
 - It operates at ambient temperatures
 - Readily adaptable to food manufacturing environment
 - Requires short treatment time
- **Disadvantages**
 - Energy efficiency of NTP is not so good.

- Special care is required in case of sensitive foods containing high amounts of vitamins and lipids.

- **Applications:** This technology has been applied in the food industry including decontamination of raw agricultural products (mangoes, lettuce, almond, etc.), kill bacteria on raw chicken, inactivate contaminating microbes on meats, poultry, fruits, and vegetables and production of composite packaging.

8. Microwave Heating: Microwave heating has an excellent potential for fast and efficient food processing, with large possibilities for reducing energy consumption, while achieving high product quality. The technology can be used separately or combined with existing treatments, and can increase production capacity for a range of purposes, such as heating, thawing, drying, baking, pasteurization and sterilization of foods. The list of safe and unsafe materials for microwave heating is listed in Table 12.

Table 12: Food contact and non-contact materials for microwave heating

S. No.	Type	Material
1	Safe material	Any utensil labeled for microwave use, heatproof glass, glass-ceramic, oven cooking bags, most paper plates, wax paper, parchment paper etc.
2	Unsafe material	Cold storage containers: margarine tubs, cottage cheese and yogurt cartons, brown paper bags and newspapers, metal pans, foam-insulated cups, bowls, plates or trays, Chinese “take-out” containers with metal handles, Metal “twist ties” on package wrapping, food completely wrapped in aluminum foil, food cooked in any container or packaging that has warped or melted during heating.

- **Principle:** Microwave is comprised of electric and magnetic fields oriented perpendicularly. Electric field play primary role in heating by promoting rotation of polar molecules. Heat is generated by molecular friction. This technology involves electromagnetic waves and heat transfer; any material that is exposed to electromagnetic radiation will be heated up. A time-varying magnetic field applied to a conductive material will also induce current flow.
- **Mechanism:** Microwave heating takes place in dielectric materials such as foods due to the polarization effect of electromagnetic radiation at frequencies between 300 MHz and 300 GHz. The most prominent characteristic of microwave heating is volumetric heating, which is very different from traditional heating. Volumetric heating means that materials can absorb microwave energy directly and internally and convert it to heat.
- **Advantages**
 - Rapid heating of foods reduces processing time

- Large potential for reduced energy consumption
 - Higher product quality
 - Increased production capacity and flexibility
 - It has potential for reducing the acryl amide content in certain products
 - This technique can be used in the development and production of innovative products
 - Volumetric and selective heating
 - Compactness of equipment
 - No products of combustion are generated
- **Disadvantages**
 - Need a lot of knowledge and experience to understand
 - Very expensive
 - Limited to small quantities
 - Eliminating deep frying
 - Microbial hazard
 - Requires high input of engineering intelligence
 - **Applications:** Microwave heating has its wide applications in pasteurization, and sterilization of readymade meals, tempering and thawing of blocks of meat, fish and berries. Other applications include continuous microwave heating of pumpable foods, such as meat emulsions, particulate-containing soups, microwave-convective drying of vegetables, fruits and spices, microwave baking of cookies, loaves, rolls, and other bakery products, microwave scalding of flour, and swelling of starches.

9. Radio Frequency Electric Fields (RFEF): Radio frequency electric fields (RFEF) processing is a new, advanced and emerging food processing technology that inactivates bacteria in orange juice, apple juice, and apple cider at moderately low temperatures. Unlike thermal pasteurization, where heat conduction is a slow process, the lethal effect of the high intensity radio frequency (RF) field combined with the very fast and efficient dielectric heating caused by the radiofrequency wave is instantaneous.

- **Principle:** There is complex interaction between the RF field, the food material, the hydrodynamic pattern on the inactivation chamber. Heat is generated due to ohmic and dielectric heating which has lethal effect on microorganisms.
- **Mechanism:** During the RFEF treatment, it is believed that the membrane potential of microbial cells is exceeded, leading to the formation of pores, causing a release of intracellular liquid. However, the mechanism is not completely elucidated. Basically, electromagnetic energy directly transfers into product which induces volumetric heating due to frictional interaction between molecules. Due to high frequency of the field, heat is generated within the food. Radio frequency heats at molecular level therefore, it heats from within the material, middle and the surface.
- **Advantages**
 - Inactivation of micro-organisms
 - Energy efficiency
 - Selective heating

- Contactless heating
 - More uniform heating and drying
 - Faster heating and drying time
 - Moisture leveling and profiling
 - Increased throughput
 - Improved control
 - Increased power penetration
 - Simpler construction
- **Disadvantages**
 - RF heating equipment is more expensive than any other conventional method.
 - Operating cost is high
 - Reduced power density
 - **Applications:** RFEF has wide applications in thawing, tempering, baking, drying, defrosting, pasteurization and sterilization of the food products.

IV. CONCLUSIONS

Emerging technologies in the food processing and preservation areas offers natural alternatives for processing of large number of food products. With the application of various thermal and non-thermal technologies, we can successfully inactivate enzymes, microorganisms and modify structures without affecting the nutritional and sensory parameters of food products. To provide excellent quality of food products to the consumers having good shelf life, these technologies play the major role. The development and implementation of new emerging technologies enhances food quality and safety. New and innovative products, some with unique product attributes, have been developed through the use of these new emerging food processing and preservation technologies.

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