**Chapter**

**Emerging techniques in food processing and preservation**

Pragati Kaushal\*

1Department of Food Science and Technology, Punjab Agricultural University, Ludhiana, Punjab, India

Corresponding author\* e mail: pragati88@pau.edu; pragati\_gndu@yahoo.co.in

1. **Need for innovative technologies**

Food processing is a technique of converting raw food stuff into final finished, well-cooked and well preserved product consumable for both humans and the animals. Consumers now days are demanding fresh, natural and minimal processed ready to eat food products. Different techniques are opted by food processing industries for providing processed and preserved foods for our daily consumption. Best quality harvested, slaughtered and clean constituents are used by different food processing industries for manufacturing nutritious and easy to cook food products. 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 methods that allow doing things that could not done before.

Traditionally thermal treatments have been used earlier in the food industry to provide the required food safety profiles and to enhance the shelf-life of the product. However, these thermal treatments results in damage of heat-labile compounds creating loss of organoleptic and nutritional properties of food products. In recent years, the increased interest towards novel thermal and non-thermal technologies for food processing has gained industrial importance.  The concern behind the thermal processing of food is loss of volatile compounds, nutrients, and flavor. To overcome these problems innovative methods are developed into food industries to increase the production rate and profit. 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, therefore they are having the ability to replace the existing traditional food preservation techniques. Therefore, various non-thermal technologies are widely employed for different food applications, e.g. high power ultrasounds, pulsed electric fields, light technologies, cold plasma, etc.  The term “non-thermal” is used for technologies that are effective at temperatures below the lethal temperatures of microorganisms, even though some of them may lead to indirect temperature raises in the product.

1. **Different emerging technologies**

Innovative food processing methods have better potential than other conventional 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, high pressure processing, ultrasonication etc. The most extensively researched and promising 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 being commercially applied mostly 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.

1. **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 that food products will be safe for consumption having good shelf life. Therefore, synergistic effects of different technologies alone are merged in a single technology. Hurdle technology also ensures that pathogens in food products will be eliminated.

Hurdle technology is used in food industry for the gentle and effective preservation of foods. The shelf life, sensory and nutritional quality of foods is based on applications of combined preservative factors (called 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 homeostasis of microorganisms. Food preservation can be achieved by disturbing the homeostasis i.e. balanced and stable internal environment of micro organisms. This can be successfully achieved by simultaneously controlling various mechanisms of homeostasis.

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 industrialized as well as in developing countries for the gentle and effective preservation of foods using two or more hurdles to an optimal extent without compromising the sensory quality of the food. Thus, hurdle technology will also be the key to future food preservation.

**3.1.2. 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. For example, Gram-positive bacteria include some of the more important spoilage bacteria, such as Clostridium, Bacillus and Listeria. A synergistic enhancement occurs if nisin is used against these bacteria in combination with antioxidants, organic acids or other antimicrobials. Combining antimicrobial hurdles in an intelligent way means other hurdles can be reduced, yet the resulting food can have superior sensory qualities (Malik et al., 2014).

**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 |
| 7 | Other preservatives | Nitrites, sulphites and sorbates |

Source: Leistner (1995)

Every hurdle could have both, positive or a negative effect on foods, depending on its intensity. For example, use of low temperature (chilling) below the critical limit of any food can lead to “chilling injury” whereas moderate chilling will be beneficial for their shelf life extension as it retards microbial growth. Similarly lowering the pH in fermented sausage inhibits the growth of pathogenic bacteria but lowering beyond the required limit can also impair the taste. Therefore, a balanced intensity of any hurdle should be used for food preservation.

**3.1.3. Principle**

The principle behind hurdle technology is the influence of various food preservation methods on the physiology and 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. The microbes can respond better to the hurdles at ambient temperature than at refrigeration and become metabolically exhausted. Disturbing the homeostasis i.e. internal balanced environment of the microorganisms by combining various hurdles result in the death of the micro organisms ensuring safety of food products (Pundhir and Murtaza, 2015).

**3.1.4. Mechanism**

The whole mechanism of preservation of food by using the concept of hurdle technology is comprised of various responses those are given by any microorganism. 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. If any of the hurdles used in food disturbs the homeostasis of these microorganisms, they will not be able to multiply and will remain constant in number or will die before the re-establishment of homeostasis. The type of hurdles and their combination varies for different food products.

**3.1.5. Advantages and disadvantages**

**Advantages:**

1. It can avoid the severity of one hurdle for preservation.
2. There is greater possibility of using natural preservatives in combination with synthetic preservatives.
3. It can give synergy of combination.
4. This appears to be a good tool of getting safe and tasty products of high quality.
5. Many of the hurdles come from past experience (i.e. tradition or culture).
6. It saves energy, money and several other resources.
7. It does not affect the integrity of food products.
8. It is applicable to both large and small scale industries.
9. Food remains stable and safe, high in sensory and nutritive value due to gentle process applied.

**Disadvantages:**

1. This technique could provide varying results depending upon various bacterial stress reactions.
2. The cross tolerance may not exist when combined hurdles are used.

**3.1.6. 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.

**3.2. High pressure processing**

**High Pressure Processing (HPP)** is a cold pasteurization technique by which 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. The pressure applied is isostatically transmitted inside a pressure vessel. Pressures above 400 MPa / 58,000 psi at cold (+ 4ºC to 10ºC) or ambient temperature inactivate the vegetative flora (bacteria, virus, yeasts, moulds and parasites) present in food, extending the product shelf life and ensuring food safety. 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. HPP of foods is of particular interest to food manufacturers because it permits microbial inactivation at low or moderate temperatures with minimum degradation. The energy required for compression with HPP is far less than that required in the thermal treatment process. HPP can be used not only for preservation but also for changing the physical and functional properties of foods, can be applied to a large number of food products (juices, milk, meat, seafood and many other liquid and solid foods).

Pressure processing is a lethal to microorganisms but at relatively low temperatures (0-40ᴼC) covalent bonds are almost unaffected. 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).

**3.2.1. 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 | If a food product contains sufficient moisture, pressure will not damage the product at the macroscopic levels as long as the 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 |

**3.2.2. 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 micro organisms. Only non covalent bonds are affected whereas organoleptic properties are unaltered. This process is product specific as inactivation of micro organisms is dependent on pH, RH, medium/food, exposure time, pressure level, etc.

**3.2.3. Advantages and disadvantages**

**Advantages**

1. Characteristics of the fresh product are retained
2. Excellent food quality
3. Destroys pathogens and ensuring food safety
4. Extends product shelf life
5. Lower returns, improved customer satisfaction
6. Reduces drastically the overall microbiological spoiling flora
7. Avoids or reduces the need for food preservatives
8. New innovative food propositions
9. Does not produce new chemical compound and radiolytic by-products
10. Inactivation of microorganisms and enzymes
11. Modification of biopolymers
12. Independence of size and geometry of the samples
13. Possibility to perform processing at ambient temperature or even lower temperatures
14. Quality retention, such as color and flavor
15. Changes in product functionality
16. Higher yields, fresh flavor, minimum hand labor
17. Only needs water and electricity
18. Environmentally friendly

**Disadvantages**

1. Bacterial spores are not inactivated by pressure alone
2. Most suitable for acid foods
3. Products need refrigeration for shelf-life and non acid foods for food safety without other preservation measures
4. Some food enzymes resistant to pressure
5. Can alter food products with high protein or starch contents
6. Batch process or semi batch process
7. Cost is a factor, but technological advances have brought equipment costs down & made commercialization feasible

**3.2.4. 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 |

**3.3. 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 to preserve the food. Pulsed electric field (PEF) processing is a novel, non-thermal preservation method that has the potential to produce foods with excellent sensory and nutritional quality and shelf-life. High intensity pulsed electric field (HIPEF) processing involves the application of pulses of high voltage (typically 20 - 80 kV/cm) to foods placed between 2 electrodes (Kumar et al., 2016). It is suitable for preserving liquid and semi-liquid foods, removing micro-organisms and producing functional constituents. PEF has not yet been used in Europe on industrial scale although it has been used in the US for orange juice, and it has considerable potential for improving quality and taste of pasteurized foods compared 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 (50-60ᴼC) |
| 2 | Treatment media | pH, antimicrobial and ionic compounds, conductivity, medium ionic strength |
| 3 | Microbial entity | Type, concentration and growth rate of micro organism |

**3.3.1. Principle**

The basic principle of the PEF technology is the application of short pulses of high electric fields with duration of microseconds to milliseconds and intensity in the order of 10- 80 kV/cm. The process is based on pulsed electrical currents delivered to a product placed between a set of electrodes; the distance between electrodes is termed as the treatment gap of the PEF chamber. The applied high voltage results in an electric field that causes microbial inactivation. Electroporation is the main principle behind the process in which a series of short, high-voltage pulses break the cell membranes of vegetative microorganisms in liquid media by expanding existing pores or creating new ones.

**3.3.2. 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. Most proteins are unaffected by PEF, and the temperatures reached are lower than thermal pasteurisation, which means flavours are retained.

**3.3.3. Advantages and disadvantages**

**Advantages:**

1. Reduction in micro organisms (4-6 log)
2. Low treatment temperature
3. Less treatment time
4. Increased shelf life of foods
5. Maintaining food safety with low processing costs
6. Minimally processed foods of higher quality
7. It can be used to pasteurize fluids without using additives
8. It act as substitute for conventional heat pasteurization
9. Inactivates vegetative micro organisms
10. It kills microorganisms while better maintaining the original color, flavor, texture, and nutritional value of the unprocessed food
11. It improves the extraction rates of juices, sugars, coloring agents and other active substances and significantly extends shelf life.
12. Diffusion processes, like water removal from plant or animal tissue or the absorption of marinades, spices and auxiliary substances are accelerated, thereby saving valuable time in production processes
13. It can save time and money and create value by improving product quality
14. Juice or oil extraction yields are increased
15. Reduction of tumbling times in meat processing because of improvement of brining processes

**Disadvantages:**

1. It does not inactivate enzymes
2. Refrigeration is required for enhancing shelf life of food products
3. It is restricted to food products with low electrical conductivity and no air bubbles
4. It is effective for inactivation of vegetative bacteria only
5. Spores are able to survive
6. It has considerable added value for specific product ranges
7. It is not suitable for solid food products

**3.3.4. Applications**

Applications of PEF include mild preservation of beverages and semi-liquid food products, treatment of potatoes to replace thermal preheating, and extraction processes such as extraction of antioxidants, extraction of oil and protein from algae, extraction of sugar from sugar beets and extraction of nutrients or fibers from peels and stems. Furthermore PEF processing can be applied for the removal of acrylamide, concentration of protein from potatoes and enhancement of production processes for cooked ham and dry sausage.

* 1. **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. This oscillating motion of the blades produces 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). Recent advances in electronics helped to design ultrasound probes and instruments with high resolution and convenience, which diversified the applications of ultrasound 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 | It requires long treatment time to inactivate stable enzymes and/or microorganisms which may cause high energy requirement |
| 2 | Thermosonication (TS) | Combined method of ultrasound and heat | When thermosonication is used for pasteurization or sterilization purpose, lower process temperatures and processing times are required to achieve the same lethality values as with conventional processes |
| 3 | Manosonication (MS) | Combined method of ultrasound and pressure | Its inactivation efficiency is higher than ultrasound alone at the same temperature |
| 4 | Manothermosonication (MTS) | Combined method of heat, ultrasound and pressure | MTS treatments inactivate several enzymes at lower temperatures and/or in a shorter time than thermal treatments at the same temperatures |

* + 1. **Principle**

The main principle of ultrasonication is cavitation. The high ultrasonic intensity of the 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 and improve material transfer.

* + 1. **Mechanism**

Application of ultrasound to liquid systems causes acoustic cavitation which is the phenomenon of generation, growing and eventual collapse of the bubbles.  As ultrasound waves propagate, the bubbles oscillate and collapse which causes the thermal, mechanical, and chemical effects. Each bubble affects the localized field experienced by neighboring bubbles, which causes the cavitation bubble to become unstable and collapse, thereby releasing energy for many chemical and mechanical effects.

* + 1. **Advantages and disadvantages**

**Advantages:**

1. Increased productivity
2. Reduced down time
3. Improved cut quality
4. Multi–layers & densities are cut without smearing
5. Particulates such as nuts & fruits are cut cleanly without displacement
6. Minimized sticking of product to the blades
7. Ultrasonic components can be cleaned in place
8. Easily adapted into existing production lines
9. Reduced cutting force

**Disadvantages:**

1. Needs more input of energy
2. It can cause inactivation of released products
3. It induces physicochemical effects.
4. It results in the formation of free radicals which causes changes in food compounds
5. Frequency of ultrasound waves can impose resistance to mass transfer (Esclapez et al., 2011).
   * 1. **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.

* 1. **Irradiation**

Irradiation is one of the latest methods in food preservation. This technique makes the food safer to eat by destroying bacteria which is very much similar to the process of pasteurization. In effect, irradiation disrupts the biological processes that lead to decay and the ability to sprout. Being a cold process, irradiation can be used to pasteurize and sterilize foods without causing changes in freshness and texture of food unlike heat (Kalyani and Manjula, 2014). 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. 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 in over 40 countries worldwide.

Irradiation of food can control insect infestation, reduce the numbers of pathogenic or spoilage microorganisms and delay or eliminate natural biological processes such as ripening, germination or sprouting in fresh food. Food irradiation uses radiant energy electron beams, gamma rays or x-rays to rid food of harmful microorganisms, insects, fungi and other pests, and to retard spoilage. It does not make food radioactive. Irradiation kills pathogens and makes them incapable of reproduction. The principal types of irradiation sources are presented in Table 7. The general category and dose of treatment of irradiation are presented in Table 8.

**Table 7. Principal types of irradiation source**

|  |  |  |  |
| --- | --- | --- | --- |
| **S. No.** | **Type** | **Source** | **Energy** |
| 1 | Gamma radiation | From radionuclides such as 60Co or 137Cs | 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 dose | up to 1 kGy | Sprout inhibition, delay of ripening, insect disinfestations, parasite inactivation |
| 2 | Medium dose | 1 to 10 kGy | Reduction in numbers of spoilage microorganisms, reduction in numbers or elimination of non-spore-forming pathogens |
| 3 | High dose | above 10 kGy | Reduction in numbers of microorganisms to the point of sterility |

If a food has been irradiated or contains irradiated ingredients or components, it 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 Table 9.

**Table 9. Technical and scientific terms used in Irradiation**

|  |  |  |
| --- | --- | --- |
| **S. No.** | **Term** | **Meaning** |
| 1 | Ionizing radiations | The radiations whose energy is high enough to dislodge electrons from atoms and molecules and to convert them to electrically-charged particles called ions |
| 2 | Gamma rays and X-rays | The radiations that form part of the electromagnetic spectrum and occur in the short-wavelength, high-energy region of the spectrum and have the greatest penetrating power |
| 3 | Radioisotopes | Naturally occurring and man-made radionuclides 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 quantity of radiation energy absorbed by the food as it passes through the radiation field during processing. |
| 7 | Gray (Gy) | Unit of energy equivalent to 1 joule per kilogram. This unit of measure is based on the metric system |
| 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. |

* + 1. **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, food is exposed to a controlled amount of radiations from a radioactive source such as cobalt-60 and machine sources from electron beams and X rays. The radiations from any of these sources evenly penetrate the food, rapidly killing various food poisoning bacteria, harmful parasites or insects without altering the nature of the food. Irradiated foods are not radioactive since the rays do not remain in the food.

* + 1. **Mechanism**

Irradiation is carried out in specially contained areas where the food is exposed to a defined dose of radiation in a continuous or batch process. The level of exposure is designed to take into account interdependent parameters such as the type of operation (batch or continuous), the optimum energy requirement to successfully safeguard the food and the source of irradiation (gamma rays, X rays or electron beam).

* + 1. **Advantages and disadvantages**

**Advantages**

1. They undergo minimal changes in texture, flavor, odor, and color
2. We can put freshlike food on the plate of the consumer on land, under the waters, in the air, and in outer space
3. It can be used to preserve a wide variety of foods in a range of sizes and shapes
4. Simplicity in preparation
5. Reduction of labor in the kitchen.
6. Shelf-life extensions without refrigeration
7. Spoilage losses from insect infestation, sprouting, or refrigeration breakdown will be minimized
8. Foods high in nutritive value
9. Less need for pesticides
10. Lower risk of importing or exporting insect pests hidden inside food products
11. Reduced sprouting in potatoes, onions, herbs and spices
12. Reduced risk of food-borne diseases caused by micro-organisms
13. Less need for some additives, such as preservatives and antioxidants
14. Reduced need for toxic chemical treatments, such as those used to kill bacteria found in some spices
15. Reduced spoilage in global food supply

**Disadvantages**

1. It causes changes in flavor or texture e.g. in dairy foods and eggs
2. It can alter the nutrient content of some foods because it reduces the level of some of the B-group vitamins
3. High capital cost of irradiation plant
4. There will be a health hazard if toxin-producing bacteria are destroyed
5. Inadequate analytical procedures for detecting whether foods have been irradiated

**3.5.4. 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, fish and seafood

* 1. **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. This heat can be generated directly via an electrical heating element or indirectly from a hot medium (e.g. steam) via a heat exchanger (e.g. shell and tube, plate). These methods require a temperature gradient to transfer heat to the process liquid and as such the surfaces are at a higher temperature than the product. This can cause fouling of the surfaces for certain products which become burnt onto the hot surfaces reducing heat transfer rates and adversely affecting the product. A further issue with heat transfer is found when heating very viscous fluid and fluids with particulates where effective, even heat transfer is difficult to achieve. Ohmic heaters address the aforementioned problems by removing hot surfaces from the heating of the fluids. The fluid is heated directly by passing an electrical current (normally AC) through the product, its own electrical resistance causes heating throughout giving a uniform temperature rise (Sakr and Liu, 2014). This effect is seen independently of turbulence effects, so there is no loss in performance for low flow rates or high viscosity. Particulates in the stream will also be heated evenly. 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, sources include standard electricity |
| 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 resistance- | It is measure of the degree to which an object opposes an electric current through it, expressed in ohms |
| 7 | Electric current- | It is the flow (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 measure of a material's ability to conduct an electric current. |
| 10 | Electroporation | It is a significant increase in the electrical conductivity and permeability of the cell plasma membrane caused by an externally applied electrical field. |

* + 1. **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 rate of heating is directly proportional to the square of the electric field strength, the electrical conductivity, and the type of food being heated. The electric field strength can be controlled by adjusting the electrode gap 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).

* + 1. **Mechanism**

A mild electroporation mechanism may occur during ohmic heating. The principal reason for the additional effect of ohmic treatment may be its low frequency (50 - 60 Hz), which allows cell walls to build up charges and form pores.

* + 1. **Advantages and disadvantages**

**Advantages**

1. Low capital cost
2. Due to uniform heating, it is suitable for liquid foods
3. Protection of heat-sensitive foods
4. Even heating of solid and liquid foods if resistance is same.
5. Suitable for continuous food processing operations
6. No risk of surface fouling and burning of product is associated with the process
7. Temperature sufficient for UHT processing can be achieved
8. Minimum mechanical damage
9. High energy efficiency

**Disadvantages:**

1. Cannot apply for all foods
2. High installation cost
3. Increased electrical conductivity of food materials
   * 1. **Applications**

Food production is a major use for ohmic heaters. Common foods which use ohmic heaters are dairy products, milk based foods (e.g. rice pudding), tomato products, fruit pieces/whole fruit, fruit juice, liquid egg, jams, compotes, mincemeat, soups, casseroles and ragouts. Often food based processes integrate the ohmic heater into pasteurization lines incorporating the heater, heat recovery, cooling, storage and filling.

**3.7. Atmospheric Pressure Plasma Technology (APP)**

Atmospheric pressure plasma (APP) is an emerging non-thermal technology for the improvement of food safety. Non-thermal plasma (NTP) is a neutral ionized gas that comprises highly reactive spices including, positive ions, negative ions, free radicals, electrons, excited or non excited molecules and photons at or near room temperature. Plasma exist 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 idea that phase transitions occur by progressively providing energy to the matter, such as the one from the solid state to liquid up to the gas state. A further phase transition may be thought as the one from the gas state to plasma state, even if these states is reached gradually by providing more and more energy to the system (Mishra et al., 2016). 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 |

**3.7.1. Principle**

This technology uses high reactive and energetic gases to inactivate micro organisms present in foods. It uses electricity and carrier gases. Micro organisms are destroyed due to UV light and reactive chemical products generated in cold plasma ionization process.

**3.7.2. Mechanism**

Several mechanisms are considered to be responsible for microbial inactivation. During plasma treatment, killing microorganisms are result of direct contact to antimicrobial active spices. Accumulation of charged particles at the surface of the cell membrane can rupture the cell membrane. Oxidation of the lipids, amino acids and nucleic acids with reactive oxygen and nitrogen spices cause changes that lead to microbial death or injury. In addition to reactive spices, UV photons can modify DNA of microorganisms and as a result disturb cell replication (Afshari and Hosseini, 2012).

**3.7.3. Advantages and disadvantages**

**Advantages:**

1. Environment friendly
2. Low running cost
3. Does not affect nutrients within the food
4. Novel, ultra fast sterilization process
5. Inactivate all types of pathogens
6. It operates at ambient temperatures
7. Readily adaptable to food manufacturing environment
8. Requires short treatment time

**Disadvantages:**

1. Energy efficiency of NTP is not so good
2. Special care is required in case of sensitive foods which has high amount of lipid and vitamins

**3.7.4. Applications**

NTP has been applied in the food industry including decontamination of raw agricultural products (Golden Delicious apple, lettuce, almond, mangoes, and melon), kill bacteria on raw chicken, egg surface and real food system (cooked meat, cheese), inactivate contaminating microbes on meats, poultry, fruits, and vegetables and production of composite packaging.

**3.8. 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, baskets (straw and wood) for quick warm-ups of rolls or bread, most paper plates, towels, napkins and bags, wax paper, parchment paper, heavy plastic wrap. |
| 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. |

**3.8.1. 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. The rapidly varying electric and magnetic fields lead to four sources of heating. Any electric field applied to a conductive material will cause current to flow. In addition, a time-varying electric field will cause dipolar molecules, such as water, to oscillate back and forth. A time-varying magnetic field applied to a conductive material will also induce current flow. There can also be hysteresis losses in certain types of magnetic materials. These phenomena will lead to current flow and oscillation of the molecules in the material.

**3.8.2. 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 quite different from conventional heating where the heat must diffuse in from the surface of the material. Volumetric heating means that materials can absorb microwave energy directly and internally and convert it to heat.

**3.8.3. Advantages and disadvantages**

**Advantages:**

1. Rapid heating of foods reduces processing time
2. Large potential for reduced energy consumption
3. Higher product quality
4. Increased production capacity and flexibility
5. It has potential for reducing the acryl amide content in certain products
6. This technique can be used in the development and production of innovative products
7. Volumetric and selective heating
8. Compactness of equipment
9. No products of combustion are generated

**Disadvantages**

1. Need a lot of knowledge and experience to understand
2. Very expensive
3. Limited to small quantities
4. Eliminating deep frying
5. Microbial hazard
6. Requires high input of engineering intelligence

**3.8.4. 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.

**3.9. Radio frequency electric fields (RFEF)**

Radio frequency electric fields (RFEF) processing is a new, advanced and emerging food processing technology that has been shown to inactivate bacteria in apple juice, orange juice and apple cider at moderately low temperatures. Unlike thermal pasteurisation, 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.

**3.9.1. 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.

**3.9.2. 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.

**3.9.3. Advantages and disadvantages**

**Advantages:**

1. Inactivation of micro organisms
2. Energy efficiency
3. Selective heating
4. Contactless heating
5. More uniform heating and drying
6. Faster heating and drying time
7. Moisture leveling and profiling
8. Increased throughput
9. Improved control
10. Increased power penetration
11. Simpler construction

**Disadvantages:**

1. RF heating equipment is more expensive than any other conventional method.
2. Operating cost is high
3. Reduced power density

**3.9.4. Applications**

RFEF has wide applications in thawing, tempering, baking, drying, defrosting, pasteurization and sterilization of the food products.

**4. Conclusions**

Emerging technologies in the food processing and preservation areas offers natural alternative for processing of large number of food products. With the application of various thermal and non thermal technologies, we can successfully inactivate microorganisms, enzymes and modify structures having little or no effects on nutritional and sensory quality aspects of foods. 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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