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Review Article

Thermal and Nonthermal Food Processing Technologies for Food Preservation and their Effects on Food Chemistry and Nutritional Values

Osama O Ibrahim*

Consultant Biotechnology, Gurnee, IL, USA

***Corresponding Author**: Osama O Ibrahim, Consultant Biotechnology, Gurnee, IL, USA.

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Abstract

Food spoilage is a process where food products become unsuitable for consumption due to microbial contamination and biochemical reactions that change food color and texture causing unpleasant odor and taste. Food Preservation is the process to destruct (kill) or inhibit the growth of microorganisms in foods to maintain chemistry and quality of foods in the desired level and extend food products shelf life with maximum nutritional value for consumer health benefits. Drying, chilling and freezing are common methods for food preservation. Conventional methods for food preservation are thermal treatments such as pasteurization and sterilization, or chemicals such as the addition of organic acids or antimicrobial peptides to foods. In recent years food preservation became highly advanced technology by the application thermal and nonthermal process such as irradiation, high pressure processing (HPP), pulse electric fields (PEF), microwave volumetric heating (MVH) , and others technologies to impede microbial and chemical deterioration in foods while maintaining food products freshness, taste , color, flavor and nutritional value.

Keywords: *Food Preservation; Pasteurization; Sterilization; Autoclaving; Retorting; Thermal Sterilization; Nonthermal Sterilization; Food Irradiation; High Pressure Process (HPP); Pulse Electric Fields (PEF); Microwave Volumetric Heating (MVH); Ultraviolet (UV) Sterilization; Ultrasonic; Ozone; Hydrogen Peroxide; and Microfiltration*

Introduction

Foods are products of plants and animals contain protein, carbohydrates, lipids, and moisture, that are susceptible for spoilage by microbial, chemicals, or physical actions causing reduction of nutritional value, change food color, taste, odor, texture, and can be harmful to human consumption in the case of foodborne pathogens contamination and enumeration [1]. Therefore, foods are required to be preserved to retain their quality and safety for consumer benefits, in addition to extending food products shelf life [2]. In general, food preservation definition is a processes or techniques that must be undertaken in order to maintain internal and external factors that might cause food spoilage or harmful to human consumption [3].

Shelf life food items can be classified into three categories: perishable, semi-perishable and non- perishable [4]. Perishable food items are foods that have shelf life ranging from days to three weeks such as milk, dairy products, meats, poultry, and eggs. These items without preservations could spoiled in a very short time (less than one day). Semi- perishable are food items such as vegetable, fruits. chesses, that have long time shelf life for about six months. Non-perishable are food items such as dry beans, nuts, flour, sugar, canned foods, that have shelf life for over several years or longer.

Microbial, chemicals, and physicals are different factors that affect spoilage of foods. These factors are not necessarily mutually exclusive since food spoilage caused by one factor can stimulate another. In general, temperature, pH, air, nutrients, and presence of different chemicals are the major factors for food microbial spoilage. Food microbial contamination is also the most common cause of foodborne diseases. Perishable foods are often contaminated by different microorganisms causing spoilage or illness. The growth of these microorganisms in food can be prevented or inhibited by adjusting storage temperature, reducing water activity, lowering pH, apply food preservation methods, and proper packaging [5].

The primary factors of food spoilage with microbial (molds, yeasts and bacteria) enumeration and chemical/biochemical reaction are associated with intrinsic food properties such as endogenous enzymes, and food nutrients, Food nutrients are substrates for both microbials growth and enzymes reaction. Other factors are microbial cross contamination during crops harvesting, animal slaughtering and food processing in combination with temperature abuse. Microbial growth and its metabolites could cause food pH changes and formation of toxic compounds, off-odors, gas and slime-formation. Chemical and biochemical reactions in food are responsible to food color and flavor changes during processing and storage causing unpleasant food sensory. Other spoilage factors can be due to physical factors such as food sensitivity to light, or oxygen. Oxygen can cause food to spoil by enhancing the growth of spoilage aerobic microorganisms, activate oxidizes enzymes, speed up chemical reaction causing browning, and oxidizing fatty acids present in food (hydrolytic rancidity) resulting in off flavor and bad odors [6]. As an example, of enzymatic reactions that cause food spoilage includes microbial enzymes of proteolytic and pectinase. Proteolytic enzymes break down protein into short peptides and some of these generated peptides have bad taste which can be bitter or undesirable sweet. Pectinase enzymes cause pectin hydrolysis which soften the structure of foods from plant sources. Pectens are complex mixtures of polysaccharides that make up almost one third of plants cell wall. Metallic ions enhance pectinase enzymatic activity causing the color change for fruit James and jellies. Therefore, James and jellies are preserved in glass not metallic containers to inhibit pectinase enzymatic activity. In summary different factors are causing food spoilage, these factors are microbials, chemicals and physicals (Figure 1) and these factors must be controlled or deactivated to preserve foods.

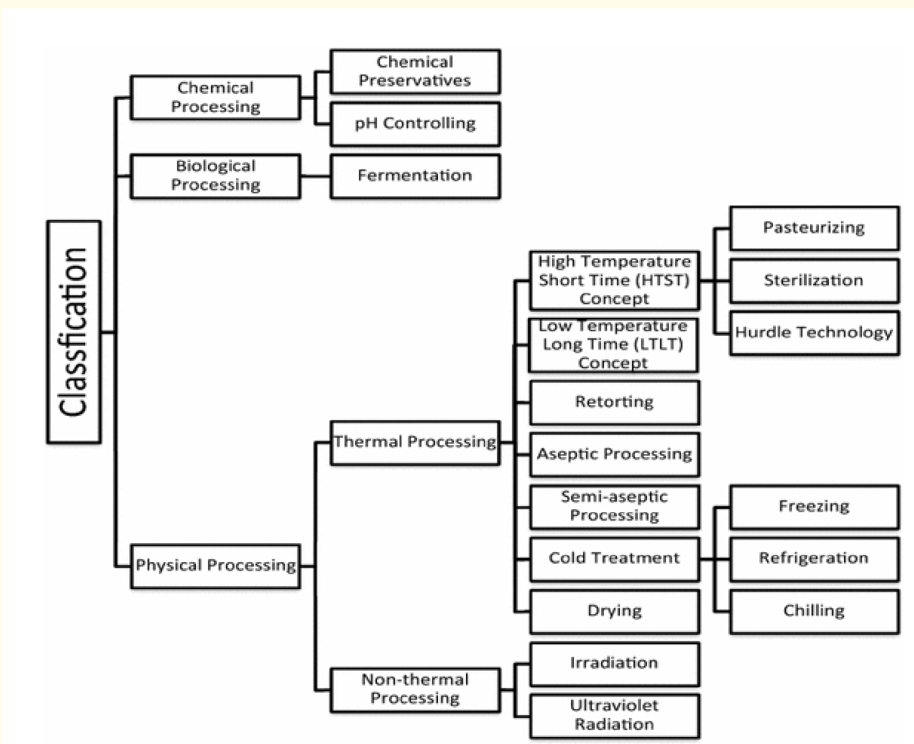

Figure 1: *Factors causing food spoilage and preservation methods.*

Inactivation of microbial growth in food or milk is by two different methods. These methods are partially or complete destructive (kill) microbial cells present in food or milk. The aim of partial microbial destruction in food or milk is to kill food-borne pathogens, and partially kill and inhibit the growth of nonpathogenic microorganisms that cause foods or milk to spoil. This method is known by the name pasteurization. The method that completely kill all pathogenic and nonpathogenic microbial cells including spore former bacteria present in foods or milk is known by the name sterilization.

Pasteurization and sterilization

Food pasteurization and sterilization processes are preservation methods to maintain foods at certain desirable properties and quality at a maximum nutritional benefit. These preservation methods involve controlling or preventing microbial growth in food and minimize food quality degradation due to microbial spoilage or due to unwanted chemical and enzymatic reactions that change food quality. These methods of preservation prevent food spoilage without damaging food product, and this can be achieved by optimization the process depending on the food type and the microbial types present in food or milk. The advantage of these preservation methods is not limited to prevent spoilage or foodborne illness, but also to extend the quality and shelf-life of foods specially to be consumed during off season of the year. In recent years, many new sophisticated preservation techniques have been developed for processing milk and variety of foods.

Food pasteurization

It is a preservation process that kills vegetative forms of microorganisms including pathogenic bacteria in milk or foods by heating at a certain temperature for a set period of time. After the pasteurization, the product has to be stored in a refrigerator to prevent the growth of survived saprophytic bacteria and germinate spore former bacteria. This process was named after the French scientist Louis Pasteur (1822 - 1895), who developed this process in 1862 and it was used for wine and beer production. Temperature range for pasteurization process usually in the range from 62 to 100°C and the time may vary from less than a second to thirty minutes depending on the method of pasteurization. The temperature and time in a batch (vat) pasteurization is 63°C for 30 minutes. For Higher temperature at 72°C a shorter time for 15 seconds is applied in pasteurization [7]. This 72°C pasteurization is known by the name High Temperature Short Time (HTST). Other pasteurization process is High Heat Short Time (HHST). This HHST is at the following temperatures and times: 89°C for 1.0 second, 90°C for 0.5 seconds, 94°C for 0.1 seconds, 96°C for 0.05 seconds and 100°C for 0.01 seconds (Figure 2).

Pasteurization Temperature vs. Time	
Vat (Batch) Pasteurization	
Temperature	**Time**
63°C (145°F)*	30 minutes
HTST Pasteurization	
Temperature	**Time**
72°C (161°F)*	15 seconds
89°C (191°F)	1.0 second
90°C (194°F)	0.5 seconds
94°C (201°F)	0.1 seconds
96°C (204°F)	0.05 seconds
100°C (212°F)	0.01 seconds

Figure 2: *Pasteurization methods. The higher temperature the lower the time.*

Pasteurization is widely used across food industries for the following reasons: kill all microbial pathogens in food, milk and other beverages, kill spoilage microorganisms which are not heat resistant, and decrease saprophytic nonpathogen microbial population in a heat sensitive food. Pasteurization has applications for both packaged and unpackaged liquid or solid foods. This pasteurization process is commonly applied for products such as, milk, beer, canned goods, dairy products, eggs, fruit juices, nuts, soup, water, etc.

Pasteurization is greatly reducing the risk of food poisoning and extends food products shelf life for days or weeks, and it does not affect the texture, flavor, and nutritional value of foods, milk or other beverages [8]. In the case of milk pasteurization, it increases the concentration of vitamin A, decrease vitamin B2, and has effect on other vitamins in milk which is not a major factor as nutritional source. In addition, the color of milk before and after pasteurization is the same and the only different in milk color is caused by the homogenization step prior to pasteurization. In the case of fruit Juices pasteurization, the process does not have any significant impact on color and does not result in the loss of aroma compounds, or reduce the level of vitamin C or beta carotene. Beta carotene is the precursor for vitamin A. In the case of vegetable pasteurization process sometimes may cause plant tissue softening and may decrease some nutrient levels and increase others [9].

The original method of pasteurization was a batch pasteurization in vats, by heating milk or other liquid food in a large tank (vat) at 63°C (145.4°F) for at least 30 minutes. This method is currently used in cheeses, yogurt, and in buttermilk industry for pasteurizing milk before adding starter cultures to the milk.

Currently, most common methods of milk pasteurization are; High Temperature Short Time (HTST), which use metal plates and hot water (Figure 3) to raise milk temperatures to at least 72°C (161°F) for not less than 15 seconds, followed by rapid cooling. Other method is Higher Heat Shorter Time (HHST) which is similar to HTST pasteurization, but slightly different in equipment used and use higher temperatures for a shorter time. Ultra-Pasteurized (UP) method is a new emerged pasteurization technology. In this UP pasteurization process the milk or other liquid food is heated at a minimum temperature of 138°C (280°F) for two seconds followed by rapid cooling. Products pasteurized by Ultra-Pasteurized (UP) method results in a longer shelf life, but the product still require refrigeration similar to other pasteurization methods [10].

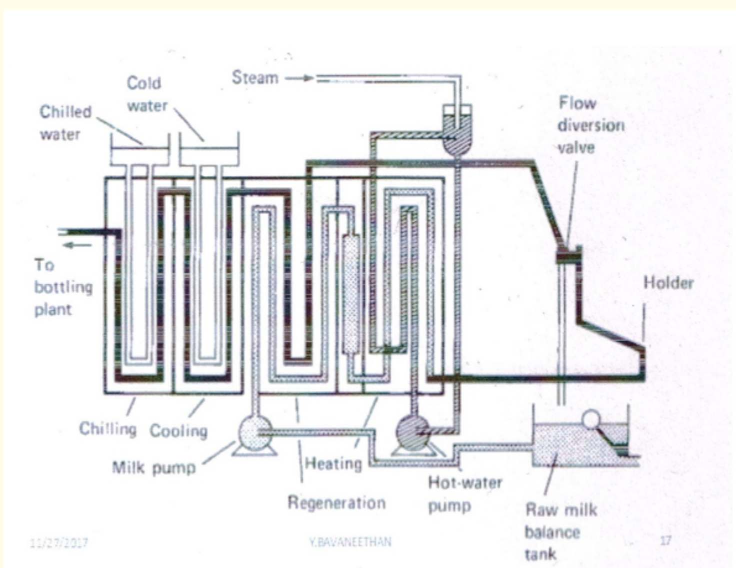

Figure 3: *Plate heat exchanger for milk pasteurization.*

Recent developed method of pasteurization is the aseptic processing, which also known by the name Ultra High Temperature (UHT) pasteurization. This UHT involves heating the milk in sterile equipment, then fill the pasteurized milk under aseptic conditions into sterile hermetically sealed packages. Milk processed by this aseptic processing (UHT) method is shelf stable and does not need refrigeration until the package is opened [11]. This UTH process requires establishing and validation the proper time and temperature based on the equipment used. Applications of this aseptic processing (UHT) method is mainly for food with low viscosity liquid products such as milk, juices, cream, wine, salad dressings and for foods with discrete particles such as baby foods, tomato products, fruits, vegetables juices and soups.

Food sterilization

Sterilization is a process used for completely eliminate all living micro-organisms, including thermoresistant spores in milk or other foods. Sterilization methods are divided into thermal processing (steam sterilization) and nonthermal processing. Nonthermal processes are such as Irradiation, and other newly preservation technologies. Thermal processing is widely used in food industry in spite of some disadvantages such as might reduce nutritional value or deteriorate the quality of food. Non-thermal processing considered most effective and does not cause nutritional value loss or food quality deterioration. Research on these nonthermal technologies are widely under evaluation, and large-scale food applications using some of these developed nonthermal technologies are pursued internationally.

Steam sterilization is the basic food method for thermal sterilization by exposing food product into direct steam contact at the required temperature and pressure for specific time. The pressure serves as a mean to obtain the high temperature necessary to kill vegetative and spore former microorganisms. Autoclaving is the basic principle of steam sterilization by exposing the product to direct steam contact at the required temperature and pressure at specific time. The two common steam sterilization temperatures are 121°C (250°F) and 132°C (270°F). These two common sterilization temperatures or sometimes higher must maintain at minimum time enough to kill microbial spores as indicator for a complete food sterilization. In large scale operations, solid foods are commercially sterilized after it has been placed into container and the container has been hermetically sealed. This food method of steam sterilization is known by the name retorting. In order to produce high quality and safe retorted foods such as ready-to-eat and shelf stable foods, it should not overcook or over processed to maintain the proper food taste and appeal. Food Package materials in food retorting is a rigid container such as glass, metal and plastics. Metal cans and glass jars are widely used in food retort processes because of their mechanical strength, thermal stability, resistance to pressure, and have good barrier properties. Package materials for food in pouches should be flexible, and not rigid, comparing to metal cans or glass jars, and should be thin film pouches that can sterilize food in a short time to maintain food color, taste and aroma.

Thermal destruction of microorganisms

Heat is lethal to microorganisms and each microbial genus, and species has its own heat tolerance. During thermal destruction process, such as sterilization, the rate of microbial destruction (killing) is logarithmic, as well as the rate of this microorganism growth is logarithmic. Thermal process is depending on both the temperature of food exposure and the time required at this temperature to destruct (kill) microorganism. To achieve the target microbial destruction thermal calculations is necessary and the initial microbial population in food for destruction (kill), must to know first. Also. the thermal resistance of this initial microbial population in food, and temperature time needed to destruct this microbial population in food must be known as well. In the case of pasteurization process, it is necessary to know the acceptable microbial population (nonpathogenic microbes) that can be remain after pasteurization and before cooling.

Thermal death curve (Figure 4) is a logarithmic (log.) given at the time interval of temperature, and the percentage of killed microbial population [12]. As an example, for a thermal process the time needed to kill one logarithmic cycle or 90% of the initial microbial population should be well known, to be able to calculate the time needed for microbial kill of 12 logarithmic cycle in the thermal process. In addition, if the initial microbial population in a food is very high, this will require higher temperature, and time for the thermal treatment to achieve the target microbial kill. Also, it is important to highlight that the heat process for thermal treatment process is usually based on

12 D concept. 12 D concept refer to the time required at the temperature of 121°C to reduce the most heat resistant spores *of Clostridium botulinum* by 12 logarithmic cycles. 12 D concept for pasteurization can be used to calculate the time required to reduce target microorganism in food or milk by 12 logarithmic cycle at a given temperature.

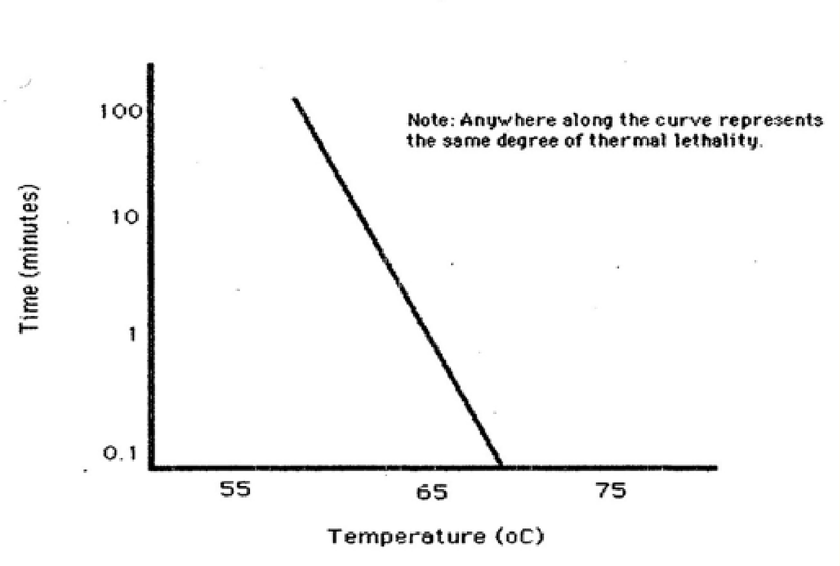

Figure 4: *Thermal death time curve for a single microbial species.*

There are two important parameters in thermal calculation for microbial destruction. These two parameters are D-value and Z-value, both are defined as the rate of thermal lethality [13]:

- **D-value:** Measure the heat resistance of a microorganism. It is the time in minutes at a given temperature required to destroy one logarithmic cycle (90%) of the target microbial population in a product. D-value can determine the microbial survival curve when the logarithmic (log.) population of microorganism is plotted against time (T). As an example, D-value at 72°C for one-minute, means that every minute at 72°C the microbial population in milk or food will be reduced by 90%. As shown the D-value is 14 minutes (40 minutes - 26 minutes) for pasteurization process at 72°C (Figure 5).
- **Z- value**: Measure the temperature change that is required to change the D-value by a factor of 10. As shown 100°C temperature required a shorter time of 3 minutes comparing to the original temperature of 90°C that was required for a longer time of 30 minutes (Figure 6).

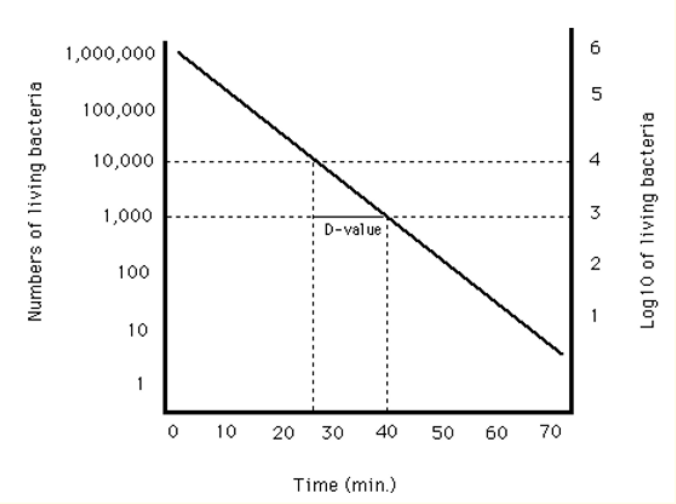

Figure 5: *D-value is 14 minutes (40 minutes - 26 minutes) for pasteurization process at 72°C.*

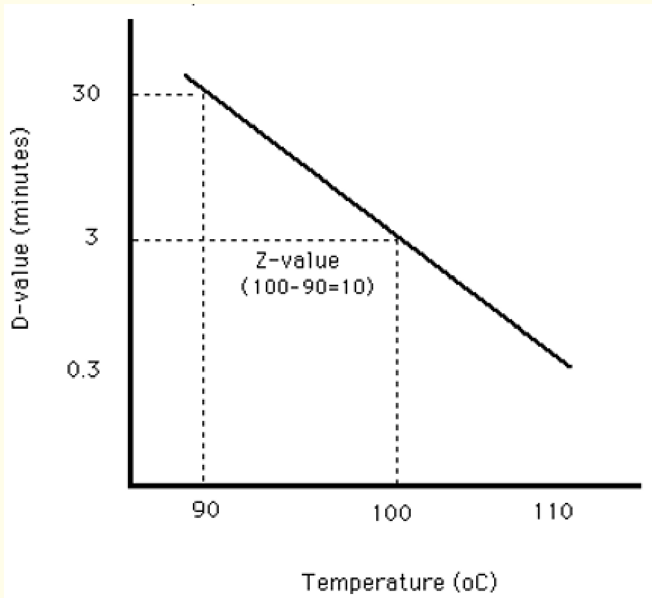

Figure 6: *Z value reflects the temperature dependence. Temperature at 100°C required a shorter time of 3 minutes comparing to the temperature of 90°C that required a longer time of 30 minutes.*

Emerging new pasteurization and sterilization technologies

Recent developed technologies that are applicable in food industry for pasteurization and sterilization processing's are focusing on low temperature systems, shorter cycle, expand process capability, reduced cost, and environmentally friendly. These emerging thermal and nonthermal technologies for both food pasteurization and sterilization are available in the market for food industries applications. Some of these emerging technologies are:

Irradiation: Food irradiation (Figure 7) is a nonthermal sterilization process commonly use gamma rays of Cobalt (Co60) or Cesium (Cs137) to penetrate the food and kill both microorganisms and insects [14]. The use of ionized irradiation for food preservation was investigated in the early 1920s, and in 1950s U.S. Army conducted food irradiation research at low and high dose on food military rations. Also, similar food irradiation experiments were studied in other countries. Since then the interest in food irradiation continue to grow. Research experiments demonstrated that food irradiation with proper application can be very effective in eliminating or reducing microbial contamination and kill insect infestations in foods along with foodborne pathogens improving the safety of many foods, plus extending food products shelf life. The effect of irradiation on foods depend on different factors. These factors are: the type of irradiation and its energy level, irradiation temperature, food composition, food physical state, and the atmospheric environment of the absorbing material. Irradiation mechanism is creating energetic electrons and free radicals in the treated food product. When food is irradiated the radiation energy breakdown target microorganism's DNA causing the death of microorganism in food. Irradiation of frozen foods required longer irradiation dose and time to kill the target microorganism in food. The unit of radiation energy is Gray (Gy), defined as 1 Joule/kg. 1 k Gy is about 0.4 BTU/lb., which is not enough thermal energy to raise the temperature of food to effective target. Typical values of radiation energy on food is in the range from 50 Gy to 4 kGy [15]. Food irradiation kill microbial pathogens and parasites in both raw meats and poultry, in addition to improve food safety. Other irradiation applications are reducing stored potato sprouting, extend shelf life of fruits such as strawberries. and reduce insect's infestation in tropical fruits such as mangoes, and papayas. Food irradiation processing under optimum conditions does not change color and food chemistry such as lipids, carbohydrates, proteins, minerals, and most vitamins remain unaffected. Higher irradiation dose may cause the loss of some food micronutrients, such as vitamins A, B1, C and E [16]. In United States, most imported spices, herbs, and dried vegetables is irradiated at the dose of 10 k Gy, to sterilize and sanitize spices and herbs from insects [17]. It is important to highlight that Irradiated foods sold to consumers must be labeled with the radula (radiation) label, which is a distinct symbol (Figure 8) adopted internationally. In the case of foodservice products or food ingredients does not need this irradiated label (radula). Currently consumer perception for marketed irradiated foods is not acceptable, and consumer education is needed to prove that food irradiation does not make food radioactive and it is safe for human consumption.

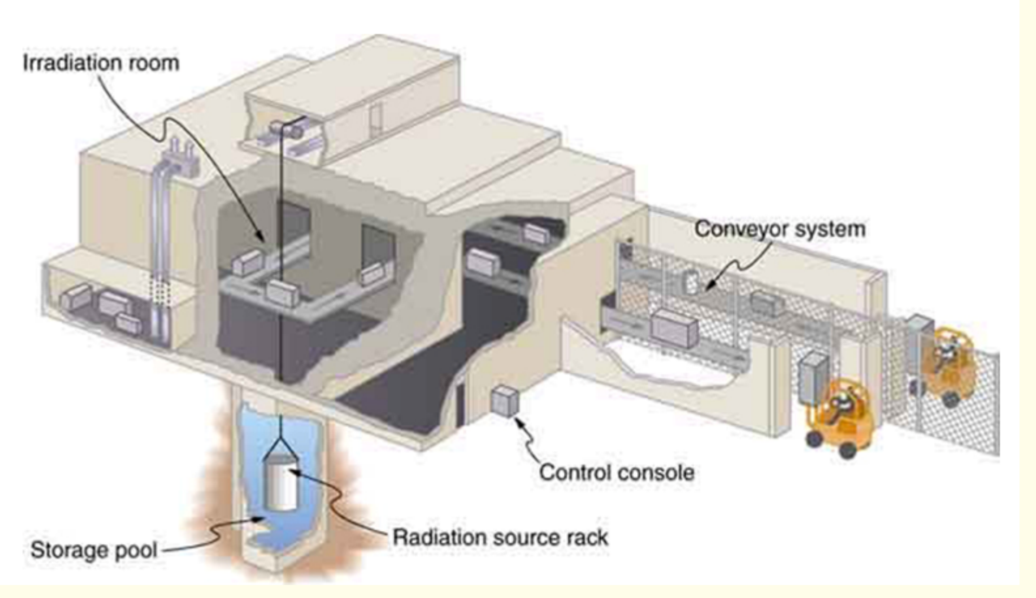

Figure 7: *Diagram for food irradiation plant. Packaged foods inter irradiation room via conveyor system and out for shipping.*

Figure 8: *International irradiation label for foods that have been processed via irradiation technology.*

High pressure processing (HPP): HPP is a cold (nonthermal) pasteurization for sealed food product in its final package (Figure 9). Sealed food packages are introduced into HPP vessel and subjected to a high level of isostatic pressure above 400 MPa (58,000 psi) at a cold temperature in the range of 4°C to 10°C or in some cases at ambient temperature [18]. This HPP inactivates vegetative microorganisms of bacteria, mold, yeast, virus and parasites, plus extend food products shelf life and guaranteed food safety of refrigerated foods. Because of the absence of heat treatment in HPP processing, food maintain its nutritional value, flavor and original freshness. Inactivation of bacteria spores in foods by HPP (food sterilization) can be achieved at high temperatures in combination with antibacterial agent incorporated into packaged food. The combination of antimicrobial agent and HPP inactivates bacteria spores, and improve food shelf life with natural sensory, quality, and nutritional attributes [19]. Currently, food and beverage companies in the United Stated and other part of the world applied HPP technology for beverages manufacturing. Other potential food applications for HPP are in the processing of fruits, vegetables, meat products, but the equipment cost for these type of food products are very costly.

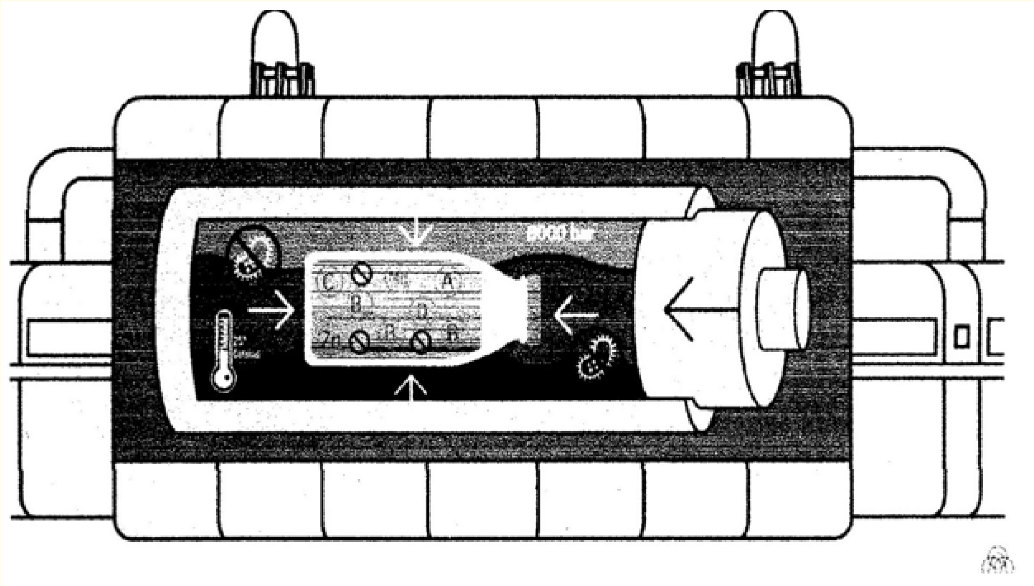

Figure 9: *Diagram for High pressure Processing (HPP) concept for bottled beverages.*

Pulsed electric field (PEF): PEF is nonthermal food processing technology used for pasteurization processing. The technology is based on using short and high voltage pulses to induce proration in microorganisms, plants, or animals' cells causing cell disintegration and microbial inactivation [20]. The process is based on delivering a number of electric pulses in the range of 10 - 80 kV/cm into food product which is held between two electrodes with specific gap between them. The gap between the two electrodes is known by the name treatment gap of the chamber. This nonthermal food preservation technology is preferred for liquid foods (Figure 10) because electrical current flow mor efficiently in liquid and electric pulses easy transfer from point to point due to the presence of liquid food molecules [40]. This pasteurization technology has applications in food products such as milk, dairy products, liquid eggs, and soups. It is important to highlight, that pulsed electric field (PEF) has some limitations such as the product must be free from air bubbles and the product must has lower electric conductivity [21]. Other PEF applications are in pharmaceuticals industry for the extraction of bioactive components from biological materials and in sugar industry for the extraction of sugar from plant cells.

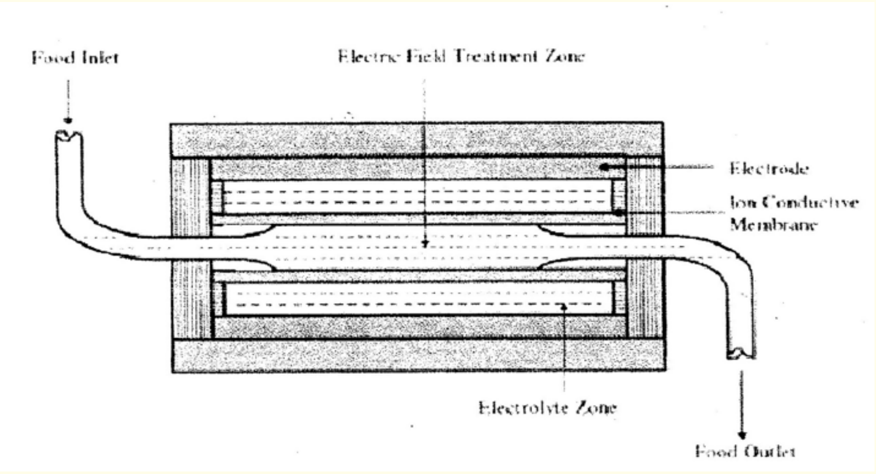

Figure 10: *Diagram for Pulse Electric Field (PEF) concept for liquid food products.*

Microwave volumetric heating (MVH): MVH is a thermal process, with large scale applications for both food pasteurization and sterilization (Figure 11). The main mechanism of MVH on microorganism in food is due to its thermal effect. In addition to the selective heating effect on microorganisms, MVH cause microbial cells electroporation, cell membrane rupture, and microbial cell lysis due to electromagnetic energy coupling [22]. This microwave process is known by the name Microwave volumetric heating (MVH), because microwaves penetrate uniformly throughout the volume of the food product being treated, delivering the energy evenly into the food mass. This food preservation technology has other applications such as blanching, cooking, and baking. MVH is known for its operational safety and nutrients retention capacity with minimum loss of heat-labile nutrients such as vitamins B, vitamin C, antioxidant phenols, and carotenoids [23]. The use of shorter time and more uniform volumetric heating of MVH processing offers major advantages to MVH over the conventional food sterilization and retorting for producing high quality shelf-stable liquid, semi-solid and solid food products. As an example, food products such as salmon fillets, macaroni and cheese, mashed potato and beef in gravy have been processed by microwave volumetric heating (MVH) with good quality and safety [24]. This MVH processing is preferred for heat sensitive food products that when processed by conventional thermal treatments could result in food quality change and might be not acceptable to consumers.

Figure 11: *Picture for large scale Industrial Microwave heating (MVH) system.*

Ultra Violet (UV): Ultraviolet sterilization is a simple method, with high efficiency, and high speed, UV can be reflected by different surfaces, with weak penetrating power in liquid materials such as beverages, and milk. These liquid products processing (Figure 12) can be sterilized by passing through the ultraviolet irradiation zone in a thin layer [25]. In addition, UV sterilization can be applied to sterilize food surfaces, food packaging materials, production equipment's, appliances, work benches, and food processing environments. The UV sterilization efficiency is related to the irradiation intensity, time, distance, and air temperature. It is important to highlight that the efficiency of UV sterilization depends mainly on irradiation distance to food and time required according to the power of the ultraviolet lamp. In the case of packaged foods UV sterilization efficiency depends on packaged food surface material and conditions [26]. As an example, aluminum foil packaging materials with smooth surface, ultraviolet rays can kill bacteria, yeast mold, and viruses with higher efficiency [27], comparing to packaging materials with non-smooth surface that needs three times longer UV exposer to achieve the same rate of sterilization in killing microorganisms. In addition, the selection packaging material in food packaging should be considered when apply ultraviolet sterilization, especially for the inner layer of the composite material, such as PVC, PVDC, LDPE and other materials alike [28]. Combining UV with heated air, hydrogen peroxide or ethanol can enhance UV sterilization efficiency and shortening the treatment time.

Finally, it is important to highlight that UV time exposer optimization is very important because longer UV radiation time could reduce the package heat seal strength by about 50% [29].

Figure 12: *Picture for UV system for liquid food application.*

Ultrasonic: Sonication is a nonthermal technology in which a sound wave with a frequency greater than 18 kilohertz (18 kHz) applied in food processing and for food preservation is highly efficient without affecting food quality nutritional value (Figure 13). The interaction between the ultrasonic wave and the sound-transmitting medium contains enormous energy enough to kill microorganisms in a very short time via cell rupture mechanism. The pressure and temperature in ultrasonic process breakdown microorganism cell wall and damage cell DNA causing the destruction of the target microorganisms in food [30]. Ultrasonic is a one of the fast, versatile, emerging, and promising nonthermal technology used in food industry to improve food quality with shelf-life extension without affecting the quality and organoleptic properties of food products, plus ensuring food safety. There are four types of sonication which can be used for food preservation with or without the combination of other treatments to increase the efficiency. These methods are:

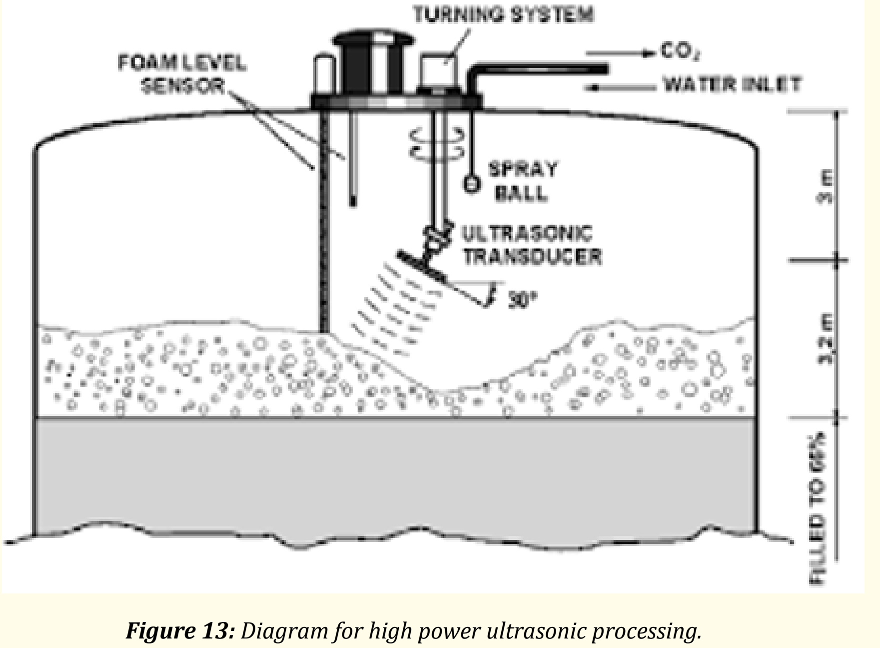

Figure 13: *Diagram for high power ultrasonic processing.*

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1. Ultrasonication (US): Is the application of ultrasound at low temperature [31] and can be used for temperature sensitive products with the concern in losing nutrients such as vitamin-C, protein denaturation, and inactivation of essential enzymes. This type of sonication needs long time of sonication exposure to kill microorganisms and/or inactivate undesirable stable enzymes that require high energy.

2. Thermo sonication (TS): Is a combination of ultrasound and heat [32]. Food product in this process is subjected to ultrasound combined with moderate temperature to improve killing microorganisms and/or inactivate undesirable enzymes. This combination reduces the TC process time and temperature to maintain food freshens, quality, and nutritional value.

3. Mansonication (MS): Is a combination of ultrasound and pressure [33]. MS helps in killing microorganisms and/or inactivate undesirable enzymes with moderate pressures and at low temperatures, at the same low temperature applied in ultrasonication (US) method.

4. Manothermosonication (MTS) is a combination of ultrasound, heat, and pressure [34]. The application of temperature and pressure in sonication kill thermotolerant microorganisms, and inactivate thermostable enzymes such as lipoxygenase, peroxidase and polyphenol oxidase.

Ultrasonic methods have multiple advantages in efficiency that are difficult to obtain by other physical food processing methods such the application for homogenization, emulsification, dispersion, hydrogenation, meat tenderization, fruits ripening, oxidation, dissolution, crystallization and cleavage of macromolecular substances.

Ozone: O_3 is a chemical sterilization technology. The mechanism of ozone sterilization is the formation of ozone and water, this O_3/H_2O form is strong oxidizing electrode potential with destructive effect on microbial cell membrane by increasing cell membrane permeability to deactivate microbial cell inner enzymes and degrade cell genetic material (DNA), causing microbial destruction and death [35]. Advantages of ozone sterilization processing is in its highly efficient, safe for food application, inexpensive, and fast in time. Its efficiency about 300 to 1000 times faster than chlorine sterilization method. Ozon is listed by FDA as General Recognized as Safe (GRAS), with properties such as powerful oxidizing agent, lethally effective against vegetative bacteria, yeast, molds, viruses and parasites. Plus, O_3 degrades pesticide residue in water and on fruits, vegetable surfaces [36]. The most advantage of ozone comparing to chlorine is its molecule breakdown in the atmospheric oxygen resulting in negligible ozone residue on treated foods or liquid. Currently, ozonated water is used to sterilize aseptic packages before the filling with sterile food or beverage, and O_3/H_2O applied as antimicrobial agent for washing raw meat and poultry [37]. It is important to must consider using safely ozone concentration of 3 to 8 ppm in water. Ozone gas is also used to sterilize food storages and food processing facilities and is important to use permissible exposure levels of 0.04 ppm ozone gas that is allowed by Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA). This 0.04 ppm ozone gas is efficient to provide antimicrobial benefits for food storages and facilities [38].

Hydrogen peroxide: Hydrogen peroxide (H_2O_2) is a chemical sterilization, that has broad-spectrum effect on microorganisms. Its sterilization power is related to its concentration and temperature. Higher sterilization efficiency of hydrogen peroxide is at the concentration of 25 - 30% and at the temperature of 60 to 65°C [39]. At normal temperature, the sterilization efficiency of hydrogen peroxide is very poor. Hydrogen peroxide is usually used for the sterilization of food packaging containers (aseptic packaging before filling). All packaging materials can be treated by soaking or spraying with hot hydrogen peroxide, then heated to decompose the remained hydrogen peroxide on the package surface [40]. Also, H_2O_2 has application for semi-viscous and viscous food products such as milk and milk products by direct integrating aqueous solution of hydrogen peroxide into these food products as antimicrobial agent to kill or inhibit microbial activity. Hydrogen peroxide advantages are nontoxic when used in food applications at a minimum effective concentration, and any excess of hydrogen peroxide used in direct integration with food is normally decomposes into oxygen and water in subsequent processing stages, such as drying, or by adding catalase enzyme. Catalase enzyme break down hydrogen peroxide into water and oxygen. Because hydrogen peroxide has the ability to gain or lose electrons, its mechanism on microorganisms is due to its oxidizing property by causing disturbances in microbial structure and increase the permeability of microbial cell wall, and microbial cytoplasmic membrane, to induce ribosomal lesions and the breakdown of bacterial DNA. This mechanism lead to microbial cell destruction and death [41]. In addition, hydrogen peroxide has a wide food application in United States, Canada, Australia and New Zealand. As a bleaching agent in food processing such as wheat flour, edible oil, and the application as antimicrobial agents for foods such as in egg white processing.

Membrane filtration: It is a physical sterilization by separation. Various types of membranes are used for sterilization or for materials separation, with wide applications in industrial production such as food [42], biopharmaceutical and other industries. The membrane separation process can be divided into two types based on the driving force. One type is a membrane process that uses pressure as a driving force, such as ultrafiltration [43], the second type is a membrane process that is driven by electricity, also called ion exchange, such as electrodialysis [44]. The pressure uses in filtration divided membrane filtration process into microfiltration [45], ultrafiltration and reverse osmosis [46] according to the pore size and retention capacity of the membrane. Typically, the pore size of the membrane is in the rage from 0.0001 to 10 microns, comparing to microbial size which is in the range of 0.5 to 2 microns. Membranes that having a pore size smaller than microbial size are used to separate microbes from liquid foods through a membrane filtration process. Applications of membrane filtration in food sterilization has advantages such as low energy consumption, operate at normal temperature, suitable for heat sensitive materials, and strong process adaptability. Food application of membrane filtration processes are used for filtration (remove particles), sterilization (remove microorganisms), and bleaching (remove color) from liquid foods, dairy products and juices.

Discussion

The history of food preservation dates back to ancient civilization when ancient people felt the necessity to preserve food after hunting a big animal and could not be able to eat it in a short time. Early methods of food preservation became very important for survival and was the first step toward civilization. Drying food for preservation was the oldest and the simplest method dated far back to 12,000 B.C. Drying by removing water from food inhibit the growth of spoilage microorganisms (bacteria, mold, and yeast). Drying meats, fish, fruits, and vegetables in ancient times was achieved by leaving food out in the sun to dry. This drying method have negative effects on texture and taste and it is still applied today in developing countries [47].

Food smoking by exposing meats, and fish, to wood smoke, was probably discovered back early by burning fires in caves without chimneys, causing the cave to be filled with smoke, and preserved meat from microbial spoilage was due to burned wood antimicrobial activity effects. Later people learned to pretreat food with salt before smoking, and this smoking methods is more effective for microbial inhibition and for better taste. Today food smoking method is currently used as food flavor enhancement rather than for food preservation.

Preservation by food fermentation was observed by accident dated back to 10,000 B.C. when unknowingly microbial contamination caused food spoilage, and sometime creating a new edible food taste and extended food storage. Currently foods fermentation is advanced technology and are applied in foods such as cheeses from milk, sauerkraut from cabbage, and breads from flour dough by using selected industrial microbes (bacteria mold and yeasts). Today microbial fermentation is sophisticated technology for the production of foods bio-ingredients, organic acids, antibiotics, therapeutic proteins, etc.

Thermal heat treatment of foods has been used widely for food preparation since ancient time and lately scientifically applied for food preservation. Heat treatment at 60° to 90°C for 10 - 15 minutes was suffusion to kill vegetative bacteria, yeast and mold cells, but is not suffusion to kill spore former bacteria. Microbial spores are heat resistant and can be inactivated at 100°C or higher temperature at time varied from one minute to twenty hours depending on spore former bacteria genus and species. Thermal treatments are highly effective for microbial destruction in acidic foods, or by adding organic acids, salt or sugar to food before thermal treatment.

Today thermal treatments for food preservation involve controlling or preventing microbial growth to minimize food spoilage and inactivate unwanted enzymatic or chemical reactions that changes food quality over time. Currently, foods thermal treatment is no longer simple and straightforward as in the past. It involves highly inter-disciplinary field of science in order to produce food with acceptable quality, extend food shelf-life, minimize health risk, protect environment, and maintain food nutritional properties. Many emerging thermal and nonthermal preservation technologies have been developed and already reached commercial adoptions in specific food applications while other sophisticated preservation techniques remain promising.

Food manufacturers are responsible to select between food product pasteurization or sterilization for commercialization. This choice depends on food type, the desired food shelf life, and storage temperature, (ambient or refrigerated). Pasteurization technology is a process designed to reduce food microbial count to increase refrigerated food shelf life and maintain the organoleptic characterization of the food. The moderate heat treatment of pasteurization allows the destruction of pathogenic bacteria, and a large number of spoilage microorganisms present in vegetative forms in food that might change food organoleptic characterization and shelf life. Temperature applied in pasteurization process is generally below 100°C in a short time heat exposer, followed by a rapid cooling. At this temperature below 100°C in a short time does not inactivate spore formers bacteria present in the food or milk. Marketed pasteurized food or dairy products produced by pasteurization process must be stored at ≥ 4°C cooled temperature to prevent food spoilage by limiting the growth of microorganisms that is still present in the food or milk products after pasteurization. Some examples of pasteurized food products are ready-made meals in trays, vegetable in trays, vacuum-packed roasted meat in pouches, sauces in pouches, and vegetable or soups in jars.

Milk Pasteurization [48] is widely practice in United States and other Countries and requires temperatures of about 63°C (145°F) for 30 minutes, followed by rapidly cooling the milk down to 4°C (39°F). Other two alternative methods of pasteurization are High temperature Short time (HTST) and Ultra-High Temperature (UHT). High temperature Short time (HTST) method is heating the milk at a temperature of 72°C (162°F) for 15 seconds, followed by rapid cooling down to 4°C (39°F). Ultra-High Temperature (UHT) method is heating the milk to approximately 132°C (280°F) for just 2 seconds and then rapidly cooled down the milk to 4°C (39°F). The selected time and temperature in these two pasteurization methods in milk are designed to kill pathogenic bacteria specially *Mycobacterium tuberculosis*, other food-borne pathogens, and non-spore-forming spoilage microorganisms that might present in raw milk.

Sterilization is intended to destroy all microorganisms present if food or milk including spores. The temperature in sterilization process is higher than 100°C. This sterilization process makes it possible to store food products at room temperature permanently and obtain a long shelf life varied from few months to a few years depending on the sterilization method and the food product. Some examples of sterilized food products are canned fish, baby food in jars, baby food in pouches, vegetables in cans, vegetable in jars, sauces in pouches, bottled milks, and pet food in pouches.

Retort process which is also known by the name autoclave or sterilizer process is a pressure vessel used in food manufacturing to sterilize food after it has been placed in its container and the container has been hermitically sealed. The high temperatures in retort process for food present in sealed container is well above the boiling point of water at normal atmospheric pressure. Retort processing is designed to kill all microorganisms including microbial spores that may be present in the food placed in containers, or pouches.

Recently, food sterilization methods are divided into two categories: sterilization by heat (thermal process) and sterilization without heat (nonthermal process). Thermal sterilization process is widely practiced worldwide in spite of some disadvantages such as the loss of food nutritional value and quality deterioration due to high temperature treatment. Steam sterilization (moist heat) is by using saturated steam under pressure and is the most widely used process. This steam sterilization process is nontoxic, inexpensive, rapidly destructive (kill) microorganisms, inactivate spores, and the heat rapidly penetrates food product.

New thermal processes are emerged such as microwaves. Microwave volumetric heat (MVH) process is defined as a part of electromagnetic waves. Microwave heating has considerable advantages over conventional heating methods, especially with regard to energy efficiency, and the heat penetrate through food in a short time which is different than steam sterilization. In steam sterilization the heat penetrates food gradient from outside to inside in a long time, while in MVH the rapid heating in a short time minimize temperature difference between the surface and interior food product, and produce food with good taste like-fresh, with nutrients retention, and long shelf life. Other advantages of MVH is more precise control process, with better energy use and cleaner working environmental in food processing facilities. This microwave technology has broad range of food processing such as drying, tempering, blanching, cooking, and baking.

Nonthermal processes such as irradiation, High-pressure processing (HPP), Pulsed electric fields (PEF), and Ultraviolet (UV). Microorganism's inactivation mechanism of action is different for these methods. Irradiation method damage microorganism's genetic materials (DNA). This damage prevents microbial growth and terminate most microbial enzymatic reaction in irradiated food. High pressure processing (HPP) method cause deprotonation of charged groups and chemical structure in microbial cells, plus causing disruptions of salt bridges and hydrophobic bonds in the microbial cells structure. These changes in cell morphology cause the collapse of microbial intercellular gas vacuoles, anomalous cell elongation, and cessation of movement of microorganisms leading to its destructive (kill). Pule electric fields (PEF) method increases microbial cell transmembrane permeability by accumulating compounds of opposite changes in microbial cell membrane surroundings, causing pore formation in microbial cell membrane leads to microbial cell leakage and death. In the case of Ultraviolet (UV) process, the UV wavelengths are primarily mediated through absorption by highly conjugated carbon-to-carbon double-bond system of proteins and nucleic acids in the microorganism chemical structure, plus breakdown the microbial cell DNA, causing microbial cell destruction and death. Other methods used for food sterilization and shelf life extension are chemical processes such as ozone or hydrogen peroxide and physical processes such as physical separation or by membrane filtration methods.

Conclusion

Advanced technology in pasteurization and sterilization processes offer great opportunities for food industry to develop new food products, with high nutritional values which have not been able to produce before due to the limitation of severe heat in conventional methods. Today, food industry became advanced technology moving toward improving food products quality, nutritional value and shelf life through the application of these newly, and highly advanced pasteurization and sterilization sophisticated emerging technologies.

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