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Advances in Non-thermal Technologies in Food Processing: A Review

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ABSTRACT: Consumers nowadays are demanding for clean and safe food without disrupting the nutritional and sensory qualities of food. To extend the shelf life of food, various thermal treatments are applied during processes. However, the nutritive and sensory qualities of the commodity may suffer as a result of these thermal processes. Consumers today demand food that is not only safe and wholesome, but also has good organoleptic qualities. This is why the development and advancement of non-thermal technologies that are secure, safe, and environmentally friendly have captured the attention of the food industry. In non-thermal processing technology the food is processed in room temperature, this reduces damage to food because heat-sensitive nutritious material stays intact in the food in contrary to thermal processing of food. These non-thermal technologies can be utilized for processing all kinds of food like fruits, vegetables, spices, pulses, meat, fish, etc. Non-thermal technologies have emerged largely in the last few decades in food sector. These methods of food processing achieve microbial inactivation without damaging the food's nutritional content or sensory qualities. They also increase product shelf life and preserve the fresh-like physical, nutritional, and sensory qualities of the food. These cutting-edge technologies, such as high hydrostatic pressure, pulsed electric fields, high-intensity ultrasound, ultraviolet light, pulsed light, ionising radiation, and oscillating magnetic fields, can inactivate microorganisms to varying degrees. With only minor nutritional losses, all food types, including fruits, vegetables, pulses, spices, meat, fish, etc., can be processed using these non-thermal technologies. Non-thermal technologies have grown in importance in the food industry over the last few decades. As a result, there is a need to research and develop these non-thermal technologies because they are becoming more and more important in the food industry.

Keywords: Preservation, Food Technology, Microorganisms, Food Safety and Inactivation.

INTRODUCTION

Due to the rising consumer demand for wholesome, all-natural, and simple-to-handle food products, the food industry is increasingly looking into replacing traditional food preservation methods (intense heat treatments, salting, acidification, drying, and chemical preservation) with new preservation techniques. Conventional food preservation methods subject food to high temperatures, which undoubtedly reduces contamination or microbial load from the food but also causes some unfavourable changes in the food, such as the loss of nutritional components that are temperature-sensitive, changes in the texture of the food brought on by heat, and modifications to the organoleptic properties of the food. Food is exposed to heat for an extended period of time during thermal processing, which results in observable changes in the food and the creation of low-grade food. The thermal preservation methods lead to the formation of chemically toxicants that are harmful to human health and carcinogenic in food (Jhadav *et al*., 2021). Food contains many heat sensitive nutrients which include vitamins, minerals, and nutrients having functional properties such as pigments, antioxidant, and bioactive compounds. Many processes during manufacturing of food cause detrimental effects on these nutrients. Retention of these nutrients in food products requires innovative approaches for process design because of their sensitivity to a variety of physical and chemical factors, which causes either loss of biological functionality, chemical degradation and premature or incomplete release. Hence, alternative methods for thermal processing of food are gaining importance; due to increased consumer demand for new methods of food processing that have a reduced impact on nutritional content and overall food quality. In non-thermal processing technology the food is processed in room temperature, this reduces damage to food because heat-sensitive nutritious material stays intact in the food in contrary to thermal processing of food. These non-thermal technologies can be utilized for processing all kinds of food like fruits, vegetables, spices, pulses, meat, fish, etc. Non-thermal technologies have emerged largely in the last few decades in food sector (Stoica *et* *al.,* 2013). In order to successfully differentiate products, emerging and improved technologies are increasingly being used in the food industry (Jan *et al*., 2017).

Among the most actively researched new preservation methods are non-thermal inactivation techniques like high hydrostatic pressure (HHP) and pulsed electric fields (PEF), packaging methods like modified atmosphere packaging (MAP) and active packaging, natural antimicrobial compounds, and biopreservation (Palmade *et al*., 2019). Due to rising consumer demand for nutritious, delicious food products with a long shelf life, non-thermal techniques have attracted a lot of research attention in the last ten years. A number of inactivation technologies are being studied, including ionisation radiation, high pressure homogenization, pulsed electrical fields, high pressure homogenization, UV decontamination, pulsed high intensity light, pulsed high intensity laser, pulsed white light, high power ultrasound, oscillating magnetic fields, high voltage arc discharge, and cold plasma. However, the food industry has only recently begun to use these technologies (Chacha *et al*., 2021). Non-thermal treatment can arrest the activity of enzymes, leading to the spoilage of fruits and vegetables. Moreover, by changing the structure of the membranes in bacterial cells and unfolding the helical structure of the DNA of the genetic material of microbial cells, these non-thermal treatments reduce the microbial load and cause microbial cells to start dying. These non-thermal treatments are used for a variety of purposes, including the extraction of bioactives from plant and animal sources for use in nutraceutical food applications, dehydration, enhancing the physical and chemical properties of food constituents, etc. in addition to reducing the microbial load (Rastogi, 2003). Non-thermal technologies for food processing have entered a new phase of minimally processed foods with high nutritional value that maintain the product's fresh qualities without sacrificing its safety and quality. To further reduce environmental impact, lower food processing costs, and increase the value of the products while maintaining the physicochemical properties, extending shelf life, and guaranteeing food safety, new methods of non-thermal preservation have been researched and encouraged these days (Pereira and Vicente, 2018). As the food is not exposed to higher temperatures, there is no chance for the formation of any undesirable products or by-products in the food or on the surface of the food, which increases the preservation effect of non-thermal technologies over thermal technologies. In spite of the numerous advantages possessed by these non-thermal technologies in the food sector, they are rarely used in food industries and remain at laboratory scale (Timmermans *et al.,* 2011). Therefore, this review, aimed to provide a technological overview on non-thermal food processing methods such as pulsed electric field, pulsed light, ultraviolet radiation, high-pressure processing, cold plasma, ozone treatment, ionizing radiation, dense phase carbon dioxide, non-thermal hybrid drying etc.

HIGH PRESSURE PROCESSING (HPP)

Application of extremely high pressures (100–900 MPa), whether or not heat is added, to achieve microbial inactivation, change the characteristics of the food to produce qualities that consumers desire, or both, in order to preserve food substance. Other names for this technology include high hydrostatic pressure processing and ultra-high pressure processing. HPP maintains the product's microbial shelf life, natural freshness, and food quality. This technology is now acknowledged by the USFDA for RTE foods. Processing heat-sensitive products at room temperature or in the refrigerator prevents thermal effects and cooked-off flavours from arising (Li *et al*., 2018). This technology was used to extend the shelf life of products by primarily eliminating deterioration and pathogenic microorganisms, as well as an alternative thermal treatment to packaged food materials.

Mechanism of Pressure Treatment. Every HPP processing cycle starts with a pressurisation phase where pressure is built up and the processing operation can be carried out using or without heat. The product should be packaged in a flexible or semi-flexible pouch that can withstand extremely high pressures. The final step involves submerging the finished product in a fluid that transmits pressure; water is frequently used in this procedure. Other liquids can also be used alone or in various combinations with water, including castor oil, silicone oil, ethanol or glycol, etc. This fluid can stop the inner vessel from corroding if it is chosen in accordance with the manufacturer's recommendations (Dong *et al*., 2020). During pressure processing, a procedure called adiabatic heating causes the product to warm up. The degree to which the temperature rises as a result of adiabatic heating depends on the type of fluid, rate of pressurisation, temperature, and pressure. As soon as the process is running, a pump pressurises the hydraulic fluid, and the pressure that is created is evenly transmitted into the packaged food from all sides. Because this processing is instantaneous and unaffected by the size or geometry of the food, the overall processing time can be reduced (Pereira *et al.,* 2010). The technique can be applied to both liquid foods and liquid foods with a certain amount of moisture. Due to the uniform and simultaneous application of pressure from all directions during transmission, food maintained its structural integrity even at high pressures.

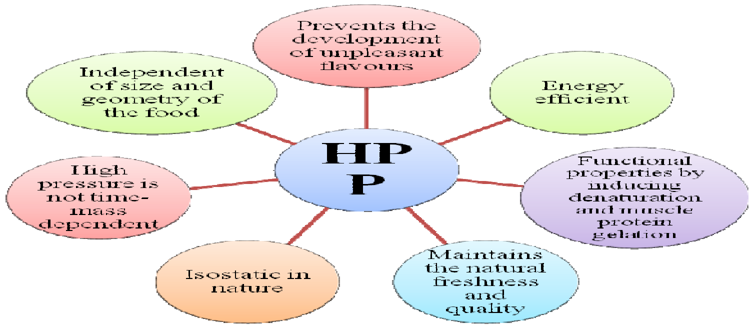

Fig. 1. Major advantages of HPP in food processing.

PULSE ELECTRIC FIELD

Pulsed electric field processing is a non-thermal method of food preservation that primarily uses microbe inactivation. In order to preserve food, PEF technology uses brief bursts of high electric fields with durations of microseconds to milliseconds and intensities in the range of 10-80 kV/cm. The number of pulses is multiplied by the effective pulsation duration to determine the processing time. The product is deposited between a set of electrodes, and the process is based on delivering pulsed electrical currents to the product. The PEF chamber's treatment gap is designated as the distance between the electrodes. The high voltage that is used creates an electric field that inactivates microorganisms (Garriga *et al.,* 2004). The poration of cell membranes caused by the palpitated electric field makes the cell membranes of microorganisms, industrial materials, or animal tissue permeable. A wide variety of food processing and bioprocesses that require little energy can use this electroporation technique. Because PEF technology kills microorganisms while preserving the undressed food's original colour, flavour, texture, and nutritional value, it has many advantages over heat treatments. It is appropriate for protecting liquid and semi-liquid foods while destroying microorganisms and creating useful ingredients (Gomez *et al*., 2007).

Working. The PEF technology works by delivering pulsing power to a product sandwiched between a set of electrodes that enclose the PEF chamber's treatment gap. The apparatus is made up of a high voltage pulsation generator, a treatment chamber, an appropriate fluid handling system, and the necessary monitoring and controlling impulses. Two electrodes are connected with a nonconductive material to prevent electrical inflow from one to the other and food product is placed in the treatment chamber, either in a static or perpetual design. The electrodes are subjected to electrical pulses with high voltage that are generated, and the electrodes conduct these electrical pulses with high intensity to the product that is sandwiched between the two electrodes. The so-called electric field, which is present in food products, exerts a force per unit charge that causes microorganisms to irreversibly break down their cell membranes. This causes the microbial cell membranes to dielectrically break down and opens the door to trade with the charged food molecules (Sunil *et al*., 2018).

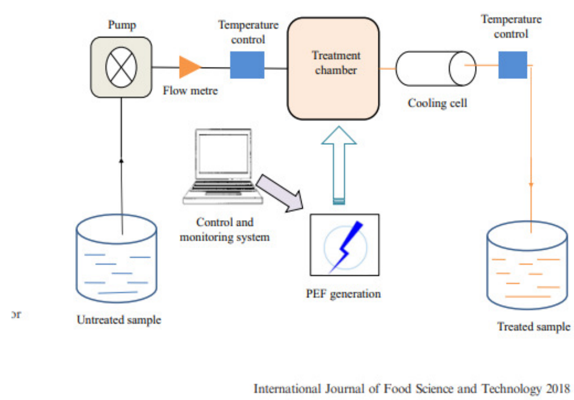

Fig. 2. Pulse electric field instrumentation (Kumar *et al.,* 2016).

Application of Pulsed Electric Field in Preservation. Fresh, frozen, dried, brined, and marinated fish can all be subjected to pulsed electric fields. The electroporation of fish tissue enhances mass transport processes, such as moisture transport and removal, leading to improved drying, brining, and marinating of fish. Fish cell disintegration requires a field strength of 1.0 to 3.0 kV/cm and an energy delivery of 3 to 10 kJ/kg. Cell disintegration in tissue is caused by the pulsed electric field that is being applied, which improves production methods and product quality. Additionally, it aids in the deactivation of parasites like nematodes (Gomez *et al*., 2007). Food product drying is accelerated by PEF technology, reducing processing times and energy use. Fruits, vegetables, potatoes, and meat can all be prepared using this method. Another benefit of electroporation is the improvement of extraction procedures. Increased extraction and pressing yields can be seen, for instance, in fruit juice, vegetable oil, and protein and algae oil. PEF technology shortens processing times and lowers energy consumption by accelerating the freezing of food products (Perera *et al.*, 2010). The freezing rates are accelerated by cell disintegration. Ice formation outside the cell begins as the cellular water easily exits the cell. The quality of the frozen food product also improves as smaller ice molecules are created (Ekezie *et al*., 2018).

PULSE LIGHT TECHNOLOGY

One such researched non-thermal technology in the food industry is pulse light, particularly for decontaminating food packages and food surfaces. The inert gas in the lamp is exposed to a high-voltage, high-current short electrical pulse that causes strong collisions between electrons and gas molecules, which excite the latter and cause them to emit an intense, extremely brief light pulse to decontaminate and sterilise food. In the food industry, short light pulses—one to twenty per second—are typical. The term "light" is typically used to refer to radiations with wavelengths between 180 and 1100 nm. These radiations include visible light (400–700 nm), ultraviolet (UV) rays (180–400 nm, roughly divided into UV-A, 315–400 nm, UV-B, 280–315 nm, and UV-C, 180–280 nm), and visible light (400–700 nm). Using this technology, microorganisms on food surfaces, equipment, and packaging materials can be quickly rendered inactive. The photochemical action of the ultra violet portion of the light spectrum, which results in thymine dimerization in the DNA chain, which prevents replication and ultimately causes cell death, is the primary cause of the effect on microorganisms (Rosario *et al*., 2020).

Principle and working. A gradual increase in low to moderate power energy can be released in intensely concentrated bursts of more powerful energy, according to the principle behind the production of high intensity light. A flash lamp that is filled with an inert gas is the main part of a Pulse Light device. The inert gas in the lamp is subjected to a high-voltage, high-current electrical pulse, which excites the gas molecules and causes them to emit an intense, extremely brief light pulse. It is widely acknowledged that UV is essential for the inactivation of microorganisms. Therefore, the delivery of UV-C to bodies using pulsed light has been modified and is said to be improved.

Medium-pressure UV lamps have been in use more recently due to their significantly higher germicidal UV power per unit length. A polychromatic output from medium-pressure UV lamps includes germicidal wavelengths between 200 and 300 nm.

Table 1: Merits and Demerits of Pulsed light technology.

MERITS	DEMERITS
— The inactivation of microbes by Pulse Light is very fast process and cause rapid disinfection in a very short period.	Pulse Light application in meat industry has some constraints as the low penetration power and chances of lipid oxidation.
— It is a green technology as the consumption of energy is very less during its application.	The packaging materials showing high penetration of light should be used while treating the packed food by this method.
— Pulse Light has been proven as a safe technology for living being and their environment without producing harmful residuals, chemicals and toxic by-products in the treated foods.	The limited control of food heating still remains the main concern in Pulse Light technology.
— It does not affect the nutritional and sensory quality of the products.	
— The concerns of ionized radicals and radioactive by-products in foods by consumers are removed in Pulse Light due to its non-ionizing spectrum	

RADIATION PROCESSING

Ultraviolet light: Ultraviolet (UV) light processing is one of the most promising non-thermal technologies created in recent years because it is simple to use, lethal to most microorganisms, and a dry cold process that can be efficient at a low cost in comparison to other preservation techniques.

The UV light used for food processing has a wavelength range of 100 to 400 nm and is divided into UV-A (320-400 nm), UV-B (280-320 nm), and UV-C (200-280 nm). Since the United States Food and Drug Administration (USFDA) approved the use of UVC light for the pasteurisation of fruit juices, this technology has primarily been used to prepare liquid foods and beverages, where it is believed to be the germicidal region lethal to the majority of microorganisms (Lazaro *et al*., 2014).

Gamma Irradiation: The large 60 Co radionuclide sources from which the rays for food processing are derived. In essence, this kind of radiation is mono energetic (60Co emits simultaneously two photons per disintegration with energies of 1.17 and 1.33 MeV). Even when very complex source geometries, such as extended plaque sources, are used, it is possible to compute the dose distribution in irradiated food products using analytical techniques like the point kernel (Kadam *et al.,* 2012).

Historically, food irradiation (GI) has been recognised as a reliable method for lowering food-borne microorganisms. The primary cause of microorganism inactivation by GI is DNA damage. Particularly in the case of vegetative cells, a number of variables, including the makeup of the medium, moisture content, presence or absence of oxygen, could affect the resistance to radiation (Ekezie *et al*., 2018).

ULTRASOUND PROCESSING

Another area in non-thermal approaches that takes advantage of the high intensity sound waves' ability to preserve food is the use of ultrasound. The preservative effect is achieved by mechanically inactivating microbes and spoilage enzymes. The mechanism is that as ultrasonic cavitations spread through biological structures, shear forces are produced. This results in mechanical cell breakage and permits material transfer from cell into solvents. Cavitation reduces particle size, which expands the surface area in contact during compound extraction.

Titanium dioxide-ultraviolet photocatalysis: Pathogens can be rendered inactive by titanium dioxide-ultraviolet photocatalysis (TUVP) in aqueous environments by producing potent oxidising agents. These substances, which react with biological macromolecules and ultimately cause cell death, include hydrogen peroxide and hydroxyl/hydroperoxyl radicals.

The technology is used to extract proteins, lipids, and their functional modifications. It is also used to emulsify, improve viscosity, homogenise, and enhance dispersion stability in liquid foods. Because it uses physical and chemical phenomena that are fundamentally different from those used in traditional extraction, processing, or preservation techniques, this technology is used in the fields of processing, preservation, and extraction. In food industry, the application of ultrasound can be divided based on range of frequency:

1. Low power ultrasound: Uses a low power level so that the waves don't change the physical or chemical characteristics of the material they pass through. To ensure the quality and safety of various food materials during processing and storage, this property is used for non-invasive analysis and monitoring.

2. High power ultrasound: Uses ultrasonic waves with high energy (high power, high intensity) at 20 and 500 kHz. Foods' physical, mechanical, or biochemical properties are disrupted and enforced as a result. In terms of food processing, preservation, and safety, these effects are promising (Sorio and Villamiel, 2010).

IRRADIATION

Irradiation is the process of sterilising or extending the shelf life of any food product by exposing it to low doses of radiation. It is a physical process that involves gamma, x, or electron exposure to the prepackaged or bulk foodstuffs. Foods are typically exposed to gamma radiation from a radioisotope source, electrons produced by an electron accelerator, or x-rays. These rays can treat food for the purposes of preservation and quality improvement because they have a high penetration power. The amount of ionising radiation that is absorbed while food is exposed to radiation is known as the "radiation absorbed dose" (rad) and is calculated in rads or Grays (Liu *et al.,* 2011).

Cobalt-60, a radioactive element, is used as a primary source of high energy gamma rays to irradiate food. Electromagnetic waves or photons known as gamma rays are released from an atom's nucleus. These gamma rays have enough energy to knock electrons out of food molecules and change them into electrically charged ions. The rays can't cause radioactivity in the treated food because they don't have enough energy to knock the neutrons out of the molecules' nuclei. The radiation dose varies according to the foods' thickness, moisture content, and other factors. The efficiency of radiation is also affected by outside variables like temperature, the presence or absence of oxygen, and subsequent storage conditions (Barbosa-Canovas and Bermudez-Aguirre 2016).

Effect of Irradiation on food: The quality of the food's proteins, lipids, and carbohydrates are not significantly impacted by irradiation. Irradiation of food has no effect on minerals. Irradiation causes only modest overall chemical alterations in food, which has little impact on nutritional value. Irradiating moist food while it is frozen and without oxygen significantly reduces the overall chemical yields by about 80 %. So, irradiating to a cumulative dose of 50 kGy at 30°C is essentially equivalent to irradiating to a dose of 10 kGy at room temperature or below. Trichinosis-causing food-borne parasites can be controlled with a dose of 1–10 kGy. Dried fish can avoid developing an insect infestation with a minimum dose of 0.15 kGy. If certain agricultural products are to be exported, irradiation is frequently regarded as a phytosanitary requirement. The ability to perform radiation decontamination on packaged foods even when they are frozen is its special quality (Zhang *et al*., 2018).

Applications: By eliminating the different pathogens and parasites, irradiation has the potential to make meat and meat products safe. By better preserving the nutritive quality, this improves food preservation and storage life. This procedure is also referred to as "cold sterilisation" or "electronic pasteurisation." The use of lower dose irradiation can inactivate more than 90% of bacteria and extend the shelf life of meat. applications involving low dose rates (10 Gy) Irradiation in the dose range of 20 to 150 Gy can prevent the sprouting of potatoes, onions, garlic, shallots, yams, and other plants. Such products are biologically altered by radiation in such a way that sprouting is significantly reduced or entirely avoided. Such products are biologically altered by radiation in such a way that sprouting is significantly reduced or entirely avoided. The ripening of fruits is one of the physiological processes that can be delayed in the dose range of 0.11 kGy. These actions are a result of enzymatic modifications to the tissues of plants.

PULSED UV-LIGHT

A method known as pulsed UV-light uses brief bursts of intense, broad-spectrum "white light" in the spectral range between 200 and 280 nm to inactivate surface microorganisms (Gomez-Lopez *et al.,* 2007). Even though each pulse or flash of light is only a few hundred million or thousands of times as intense as sunlight at sea level, it also contains some ultraviolet light. When this happens, the deoxyribonucleic acid (DNA) in the cells absorbs the UV light and produces photoproducts that prevent DNA transcription and translation and ultimately cause cell death.

The power unit that generates high power electrical pulses, the treatment chamber that converts the light source into high power light pulses, the timing control, and the trigger generator are the three basic components of pulsed UV-light technology. Pulsed UV light technology can be used to effectively remove microorganisms from a variety of foods during processing and packaging (Rodrigues et al., 2016).

UV-C radiation

For the disinfection of water, air, and packaging surfaces, ultraviolet radiation-C (UV-C) is an established NTPT. In the year 2000, the FDA approved the use of UV-C radiation for food decontamination. However, there are still few applications for meat products and food processing. Due to the low cost, simple installation and maintenance requirements, non-production of off-flavors, and effective application in meat products, the use of this technology in food processing has been viewed as promising (Mysan *et al.,* 2002). Between 200 and 280 nm, the broad spectrum of UV-C was considered to have a germicidal effect, with a maximum response at 253.7 nm. Low-pressure mercury lamps produce UV-C, and the radiation they emit has been shown to be effective against bacteria, viruses, protozoa, yeasts, and algae (Dong *et al.,* 2020). UV-C radiation works by damaging DNA and RNA through the induction of thymine and cytosine binding, which impairs transcription and replication processes and inhibits the growth of microorganisms. Due to the formation of pyrimidine dimers, UV-C radiation can therefore prolong the latent microbial phase and speed up the process of microbial generation (Cheigh *et al.,* 2012). Additionally, unsaturated organic molecules can absorb UV light, which results in the production of free radicals as a result of photochemical reactions that indirectly inactivate microorganisms. (Lazaro *et al.*, 2014). Therefore, the effectiveness of UV-C radiation depends on a number of variables, including the type of microorganism, the amount of microbes present, the composition of the matrix, the reactor's geometry, the amount of energy emitted, the wavelength, the permeability of the product, and its topography.

COLD PLASMA

The fourth state of matter, distinct from the solid, liquid, and gaseous states, has been referred to as plasma. When matter absorbs energy, its state can be altered. When the intramolecular and intraatomic structures are broken, free electrons and ions can be released. One way to conceptualise plasma is as an ionised gas made up of neutral molecules, electrons, and positive and negative ions. Plasma can transfer energy by crashing into other gas molecules, which produces a variety of highly reactive species that can interact with the surface of food, including reactive hydroxyl radicals, hydrogen peroxide, ozone, nitrogen oxide, and UV radiation (Thirumadas *et al*., 2015). The composition of plasma is different due to various type of the carrier gas (air, oxygen, helium, nitrogen and argon), the plasma generator (radiowave, microwave, plasma jet and dielectric discharges) and the operating conditions (pressure and temperature).

The different carrier gases (air, oxygen, helium, nitrogen, and argon), plasma generators (radiowave, microwave, plasma jet, and dielectric discharges), and operating factors each affect the composition of plasma (pressure and temperature).

As it doesn't rely on a thermal effect to kill the pathogens and is generated at or near room temperature, cold plasma preserves the quality of food products during the treatment period (Fernandez et al., 2013). The cold plasma system comprises a discharge device, treatment chamber, gas control system and/or pressure control system.

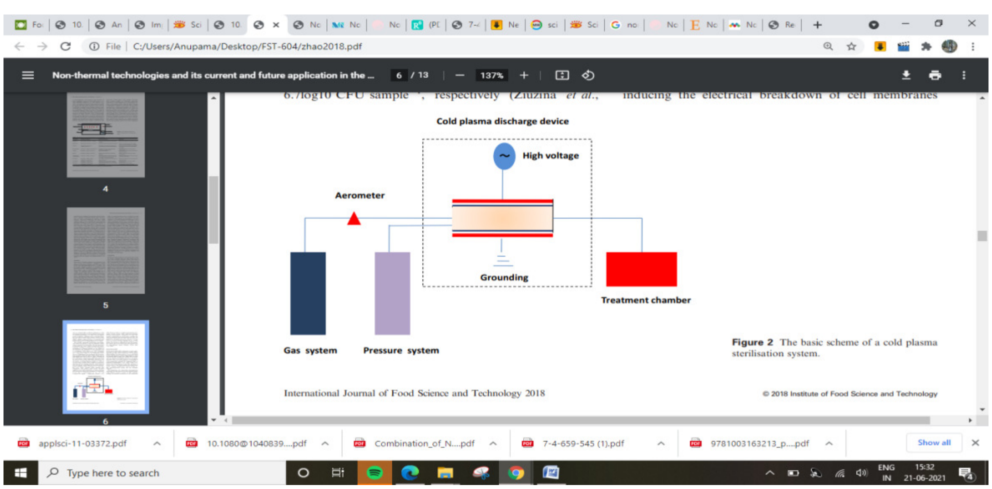

Fig. 3. Basic scheme of a cold plasma sterilisation system (Zhang *et al*., 2019).

Mechanism: The mechanism for inactivating microorganisms using cold plasma is the generation of various reactive oxygen free radical which affects the macromolecules of microbial cell, such as DNA, proteins and macromolecules, resulting in the oxidation of cell components due to accumulation of charged particles on the surface of the microbial cells, leading to the breakdown of the membrane.

Cold plasma in food packaging : The most common operations of plasma in packaging is in the area of labelling whether labelling jam jars, printing on glass holders, or sealing liquid packaging, a crucial factor in the packaging industry is the capability to reuse materials reliably and at low cost. Pre-treatment with atmospheric pressure tube makes it possible to reuse different materials and coatings that are occasionally very thin, for instance, in the product of compound packaging. Where packs are reprocessed at high speed and an tenacious bond is needed, recesses in the area of the relating exteriors generally have to be taken into account, especially in the case of high- buff plastic-carpeted shells. By using Open- air tube technology, similar high- gloss unsticking points are directly and widely pre-treated inline so that dependable bonding is secured. In labelling glass bottles, atmospheric-pressure tube is employed for pre-treating glass. This allows the use of a universal and low- cost water based adhesive (Dasan and Boyaci 2018).

OZONE PROCESSING

Ozone has a largely biocidal effect and a wide antimicrobial range for food preservation technology. In the food industry, ozone has been routinely used for washing and storehouse of fruits and vegetables by gaseous treatment. With the recent FDA approval of ozone as a direct cumulative to food, the possibility of ozonation in liquid food operations has increased (Cullen *et al*., 2009). Ozone as an antimicrobial agent has multifold possible operations in the food industry because of its advantages over traditional antimicrobial agents similar as chlorine and potassium sorbates. Ozone processing within the food industry has been carried out on solid foods by either gassy treatment or by washing with ozonated water. However, with the FDA approval of ozone as a direct cumulative to food, the eventuality of ozonation in liquid food operations has begun to be exploited. A number of marketable fruit- juice processors in the USA have begun to employ ozone to meet the recent FDA obligatory 5 log reduction of the most resistant pathogens in their finished products (Grimi *et al.,* 2011). Ozone is considerably applied in the treatment of water and wastewater due to its important oxidation and disinfection capabilities. Ozone as an oxidant is used in natural water treatment, washing and disinfecting of fruits and vegetables and juice processing to inactivate pathogenic and corruption microorganism (Sunil *et al*., 2018).

Table 2: Applications of some non-thermal technologies in food processing.

Technique	Conditions	Product	Observations	Reference
High Hydrostatic Pressure in combination with TiO_2-UV Photocatalysis (TUVP)	500 MPa for 1 min at 25°C TUVP dose- 8.45 J/cm^2	Commercial apple juice	Gram-positive bacteria, *Listeria monocytogenes* and *Staphylococcus aureus*, were inactivated; microbial load decreased to 4.8 and 2.4 log cfu/mL, respectively	Shahbaz *et al*. (2015)
High pressure processing	400 MPa for 3 min at 5°C	Acai juice	*Salmonella* spp. and *Listeria monocytogenes* inactivated	Gouvea *et al*. (2020)
High pressure processing	14kBar pressure for 2 min	oranges, apples, peaches, mixed citrus juices, carrots, tomatoes, strawberries and raspberries	No significant effect on sucrose, vitamin C, carotenoids, anti-mutagenic and anti-oxidative factors	Butz *et al*. (2003)
Pulsed electric field-temperature treatment	0.55-1.11 kWh/kg at 55°C	Extraction of intracellular component from microalgae (*Chlorella vulgaris*)	Release of intracellular components, carbohydrates and proteins.	Postma *et al*. (2015)
Ultrasound coupled with irradiation	150 W ultrasound power, Irradiation time (10 min)	Sour orange	Pectin extraction yield- 28.07%; Extracted pectin contained 65.3% galacturonic acid	Hosseini *et al*. (2018)
Pulsed UV light	8 light pulses at dose of 4J/cm^2	Egg shells	*Sallmonella enteritidis* reduced by 8 log_{10}	Dunn (1996)
Pulsed UV light	60 sec treatment at 5.6 J/cm2 per pulse energy	Salmon fillets	*E. coli* O 157:H7 and *Listeria monocytogenes* was reduced by 1 log_{10} cfu/g	Ozer and Demirci, (2006)
Cold plasma	Generated with a 60 kV dielectric barrier discharge pulsed at 50 Hz	Strawberry	Decrease in total mesophilic count by 85%, yeast and mould count by 44-95%	Misra *et al*. (2014)
Ozonation	Flow rate of 0.12 L/min; ozone concentration- 0.048 mg O_3 min^{-1}/mL at 20°C	Apple juice	5 log reduction in *E. coli* achieved within 5 min	Patil *et al*. (2010)

Dense phase carbon dioxide. Dense phase carbon dioxide (DPCD) processing, a collaborative term for liquid carbon dioxide (LCD) and supercritical carbon dioxide(SCCD – CO_2 above the critical point of 31.1°C and 7.38 MPa) or high- pressure carbon dioxide (HPCD), is an surfacing, non- or mild- thermal preservation system, alternative to high pressure processing or traditional heating of fruit juices. HPCD near-critical CD and SCCD can be used at temperatures and pressures, which are fairly safe for heat- labile composites, as well as sufficient for the inactivation of microorganisms and tissue enzyme.

The CO_2 used in this process is quite inert, affordable, nontoxic, noninflammable, recyclable, and readily available in high chastity, and leaves no remainders when removed after the treatment process. The effectiveness of DPCD for microbial inactivation depends on a number of factors, including exposure time, pressure, temperature, pressure cycling, original medium pH, water activity, cell growth phase or age, species of microorganisms, and treatment system type. The majority of DPCD inactivation studies that are presently published in the scientific literature were conducted on putrefied or invested foods (Khan *et al*., 2017). High pressure makes it easier for CO_2 to dissolve in water and pass through cell walls. It also increases viscosity, which boosts birth power. By enhancing cell membrane fluidity, which makes them easier to access, and by enhancing CO_2 diffusivity, advanced temperature improves deactivation. Advanced temperatures, still, might make CO_2 less effective at rooting low- volatility substances and less soluble in aqueous media. likewise, it's considered a generally honored as safe (GRAS) substance, meaning it can be used safely on food products(Vanga *et al*., 2016).

Non-thermal hybrid drying. Non-thermal processes are processes that don't involve the generation of heat, but can induce a change in temperature inside a product. In other words, these processes don't depend on the temperature of source. Non-thermal methodologies involve technologies that are effective at room or lesser intense temperatures. These technologies could affect in the rise in temperature during processing. Hybrid drying involves the combination of two or further different processing unit operation or drying system either as a single unit or multistage arrangement. The combination of NT (Non-Thermal) and combined convective hot- air drying(CHAD) can ameliorate and control the vital influence of CHAD, minimize the inflexibility of each technology due to the synergetic effect, enhance the final quality of dried product, and advanced overall drying effectiveness as compared with utilising just combined convective hot-air drying(Zhon *et al*., 2016).

Combined ultraviolet and hot-air drying. Ultraviolet (UV) radiation falls in the electromagnetic range with wavelengths between 100 and 400 nm. Traditionally, the UV light is substantially classified into UV- A (315 – 400 nm), UV- B (280 – 315 nm), UV- C (200 – 280 nm) which is considered the germicidal range, and the vacuum UV (100 – 200 nm. UV technology is anon-thermal technology that's free of chemicals and waste discharges, making it a veritably ecological friendly energy source. Although UV treatment has been associated with the term “irradiation ”, still UV light is anon-ionizing radiation and it mustn't be associated with other types of irradiation (e.g. gamma radiation) (Zhang *et al*., 2019). The scanning electron microscope results of their exploration further revealed that samples dried using UV- C combined CHAD showed deeper shell layers which caused advanced rate of humidity evaporation as compared to drying using CHAD. Generally, during UV- C treatment process, microorganisms that are exposed to the UV- C light are affected at the DNA, thereby inhabiting microbial growth. The conformation of pyrimidine dimers changes the structure of DNA helix and block microbial cell replication. Therefore, the injured reproductive systems of cells come unfit to repair which leads to the death of cells. This process could ultimately affect in increased severance conformation, thereby adding the rate of humidity transfer on the operation of other sources of heat (Canto *et al*., 2019).

UV combined CHAD is a promising non-thermal technology especially for artificial operations. This technology, when completely developed, has the implicit to come an environmental friendly, easy to operate, cost and energy effective drying technology.

Table 3: Merits and demerits of using combined UV and CHAD technology in the drying of fruits and vegetables Applications of some non-thermal technologies in food processing.

MERITS	DEMERITS
Higher drying rate	Drying mechanism is not yet understood
Reduction in drying time	No specified process conditions for achieving optimum result
Reduction in energy consumption	Still in the early stages and needs further research before acceptability
Easy and affordable to design and install	
Enhanced colour when compared with drying using CHAD	

Combined pulse electric field (PEF) and hot-air drying. In the operation of PEF to agricultural crops, the electrical parcels must be determined because PEF is frequently applied on accoutrements with low electrical conductivity, high electrical resistivity, and those free of bubbles, although it can also be efficiently applied on accoutrements with high conductivity only for a short period (micro-pulses). In corresponding to thermal drying, the combined goods of PEF and CHAD may results in improvement of the drying kinetics due to the synergistic effect (Onwude *et al*., 2017). This mongrel or chain fashion may represent an volition to conventional drying styles. A continues increase in the cells trans- membrane increases the pressure on the cell, dwindling the membrane consistence and ultimately results in severance conformation. On the other hand, the bibulous lump of cell results in the decaying of the membrane until it burst. This process is due to electroporation in the protein channels and lipid disciplines called this conception the poration proposition (cell death by PEF) (Zhang *et al*., 2019).

The potentiality for combined PEF and CHAD in the food and agricultural processing industries is advantageous due to the following reasons

1. Improves the colour of fruits and vegetables
2. Causes invariant rise in product temperature
3. Works better for thermal sensitive products at moderate temperatures
4. Saving energy and minimising product quality damage. For illustration, in the bakery industry, the energy of consumption in the product of crackers and cookies can greatly be reduced and the final product quality is highly increased. This could restate into lower price of decoration products for the consumers.
5. Moderate electric field strengths at lower temperature leads to advanced quality of products, in terms of microorganism inactivation, nutritive and functional properties. This is also authentically useful in the artificial product of decoration foods.
6. Uniform moisture distribution leads to uniform drying
7. Useful in the artificial product of decoration snacks and cookies.

Limitations of Combined PEF and CHAD

1. Insufficient proper processing conditions
2. Complex outfit design and installation
3. Suitableness and electrical properties of fruits and vegetables
4. Increased product damage electrically, with increased resistance of smaller cells.

CONCLUSION

New preservation technologies are an interesting option to produce high quality food products with an extended shelf life. The starting point of an evaluation of the possibilities of new technologies will thus be the effect on quality combined with the safety of the product after processing. Irradiation, ultrasound under pressure, HHP and PEF are effective procedures to inactivate vegetative micro-organisms in foods, but the high adaptability of spores limits their use as a sole system for food preservation. Thus, these new technologies are chancing usages as hurdles that assure food safety through microbial inactivation in minimally reused high quality products. To completely exploit their potentiality, further exploration work is demanded to clarify mechanisms of inactivation, especially for HHP and PEF, to more understand the effect of environmental factors, and the circumstance of stress adaption and sub-lethal injury, aspects of great applicability regarding food safety. Further, interest in non-thermal food processing technologies has increased appreciably in the once decade. Also, minimum processing ways similar as ultraviolet (UV) light treatment meet these conditions. The use of UV- C light treatment proved to be effective at reducing microbial loads of pathogens on fresh fruits and vegetables. Current limitations of arising non-thermal technologies can be overcome when they are combined with conventional preservation styles. Especially using advanced or lower temperatures than room temperature is an intriguing option to increase the effectiveness of new technologies.

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