EMERGING NON THERMAL TECHNIQUES OF MINIMAL PROCESSING OF FOOD

*Chaynika Verma[1], Priyanka Prajapati[2]
[1]Assistant Professor, [2] Student, B.Sc (Hons.) Department of Food Technology,
Shaheed Rajguru College of Applied Sciences for Women, University of Delhi,
VasundharaEnclace, Delhi -110096

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ABSTRACT- Various non-thermal technologies of minimal processing of food aims to inactivate microorganisms and halt the deteriorative reactions in the food without the application of heat. Non thermal technologies are said to guarantee the food safety and preservation as well as to maintain the fresh like characteristics of fruits and vegetables. The main objective behind minimal processing is to make the food chemically and biologically safe with minimum loss in their fresh like characteristics (flavor, texture, color, nutrients) that are associated with conventional heat processing method. Irradiation, High Hydrostatic Pressure, Ultrasound, Pulsed Electric Field, and High Intensity Light are some of the emerging non thermal techniques which are gaining importance for minimal processing of foods but still there is a wide scope of continued research for their commercial viability and widespread acceptance.

I. INTRODUCTION

The demand for high – quality foods with a marked degree of user convenience is gaining popularity in recent years. [9]Minimal processing of fruits and vegetablesadd convenience and keeps the product fresh without losing its nutritional quality. [4] Quality of fresh-cut fruit and vegetable products includes various parameters like appearance, texture, flavour, and nutritional value. [5]Modern day consumer makes a well informed choice for the processed food products with focus on superior quality of fruits and vegetables with lesser additives.[21][3]Traditionally prolonged shelf-life in foods has been associated with heat processing, alone or in combination with chemical or biochemical preservation methods but heat processingtends to reduce product quality and fresh like characteristics, as the price for extended shelf-life. [19]Therefore, the fresh-cut fruit and vegetable industry is still working to meet consumer's expectations for 'quick' and convenient foods that can very well preserve the nutritional quality without any significant change in color, flavor and texture, and contain fewer additives such as preservatives.[3] The ideal processing methodwould be one that inactivates microorganisms and halt the deteriorative reactions in the food without using heat treatment and thus can be called as a non-thermal method.[19]

Various stages are passed by fruits and vegetables during handling, storage and processing before they are consumed and might result in loss of nutrients and changes in other attributes.[4]Non thermal technologies are said to guarantee food safety and preservation as well as maintain the fresh-like characteristics of fruits and vegetables.[3]Hardly any non-thermal physical method of minimal processing is effective on its own in inactivating microorganisms and enzymes at intensities that will not reduce sensory and nutritional quality. Thus they need to be combined with other hurdles like refrigeration, MAP, chemical substances or other preservation techniques to increase shelf –life and product safety.[19]

II. NON THERMAL METHODS

A.Irradiation

Irradiation is the process of applying low levels of radiant energy to thefood to sterilize or preserve it by the destruction of food spoilage and pathogenic microorganisms.[2][17]The main aim of food irradiation is to increase the shelf-life of foods.[17]Gamma rays from radionuclides such as ^{60}Co or ^{137}Cs, or high energy electrons and X-rays are used for food irradiation. [8] Foodstuffs are generally irradiated with gamma radiation from a radioisotope source of ^{60}Co. [2]

When foods are exposed to ionizing radiation, the molecules of food start absorbing energy and form ions or free radicals which are highly reactive .[19] The ions or free radicals then react with water of food to form hydrogen,hydrogen peroxide, hydrogen radicals, hydroxyl radicals, and hydroperoxy radicals. [24]The radicals are extremely short lived but are sufficient to destroy bacterial cells. The major effect of radiation on microorganisms is the disruption of their genetic material (DNA, RNA)which are required for their growth and replication. [19][24]Irradiation dosage, expressed in kilograys (kGy), is a function of the energy of the radiation source and the time of exposure. One gray is equal to one joule of energy absorption per kilogram of a material. [2] Radicidation is carried out to reduce viable non-spore-forming pathogenic bacteria using a dose between 0.1kGy and 8kGylikeyeasts and molds.[19][24]Radurization has the objective of reducing viable spoilage organisms, using0.4kGy to 10kGy. [19] A dose up to 10kGy is required by herbs and spices because they are frequently contaminated by resistant spore-forming bacteria. Doses of 3-10 kGy are sufficient for destruction of food spoiling bacteria (salmonella typhimurium) as they are less resistant to radiation.[24] Dose levels from 10kGy to 50kGy are used in radappertisation to kill both vegetative bacteria and spores.[19]Radappertisation is used on a limited scale for wet foods as it affectssensory properties adversely, unless applied after freezing of the food. [19]

1) Applications: It can be used for packaging material and aids in aseptic processing of foods. [19]

- Inhibition of sprouting of tuber, bulb and root vegetables. It is found useful for inhibiting sprouting of potato , yam, Jerusalem artichoke, sweet potato ginger sugar beet , table beet, turnip, carrot onion garlic.[1]
- Inhibition of post- harvest growth of asparagus by applying ionizing energy inhibits their elongation and curvature.[1]
- Inhibition of post- harvest growth of mushroom byionizing radiation at 0.06-0.5 kGy inhibits cap opening and stalk elongation, reduce surface moulds and darkening of the gills and maintain the fresh appearance of mushroom.
- Irradiation is an effective method for insect disinfestation against various species of fruit flies, mango sweed weevil, potato tuber moth and other insects.
- Ripening of bananas is inhibited by applying irradiation doses of 0.25-0.35 kGy[1]
- Dosage range of 2.5-10 kGy increases digestibility and reduces cooking time of soya beans, broad beans , lentils, dehydrated vegetables.[20]

Table 1.Main potential applications and general dose requirements of food irradiation [13]

Application	Dose requirement(kGy)
Inhibition of sprouting	0.03-0.12
Insect disinfestation	0.2-0.8
Parasite disinfestation	0.1-3.0
Shelf-life extension ("radurization")	0.5-3.0
Elimination of non-spore forming pathogenic bacteria ("radicidation")	1.5-7.0
Reduction of microbial population in dry food ingredients	3.0-20
Production of meat, poultry and fishery products shelf-stable at ambient temperature("radappertisation")	25-60

2) Advantages: sensory and nutritional characteristics of food can be retained as it involves little or no heating of food. Packaged and frozen foods can be irradiated with minimum losses. Fresh foods can be preserved in a single operation without using chemical preservatives and requires less energy. Processing is automatic. [24]

3) Disadvantages: Elimination of high bacterial loads can be done to make unacceptable foods saleable. There might be a health hazard if toxin-producing bacteria are destroyed after they have contaminated the food with toxins. The development of resistance to radiation in microorganisms might lead to loss of nutritional value. A major disadvantage is high capital cost. [19]

B. High pressure processing

High pressure processing also referred as Ultra high pressure (UHP) or high hydrostatic processing (HPP) is a food processing method which has shown great potential in the food industry. [29][22] Generally high pressure is applied to liquid or solid food materials by compressing the surrounding water and transmitting pressure throughout the food material uniformly and rapidly. [6][16].The main principle behind HPPis based on the assumption that foods which experience high pressure in a vessel follow the isostatic rule which is nearly instantaneous regardless of the size, shape or composition of the food. [29]During pressure treatment the temperature can vary from 0˚C to 100˚C and the time of exposure of product can range from few seconds to 20 min. [22]. Applying high pressure in the range of 3,000-8,000 bars to food disrupt the large molecules of microbial cells such as enzymes, proteins, lipid or cell membranes without the degradation of small molecules such as vitamin and flavor components, thus, maintains the quality of food. [19][29]The rate of inactivation of food pathogens and spoilage microorganisms appears to increase in the temperaturerange of 45°C to 50°C .[14] Pressure ranging from 500 to 700 MPa in conjunction with temperatures of 90–110°C have been used to inactivate spore-forming bacteria such as Clostridium botulinum.[22]

Currently high pressure processes include two types of system; batch system, in which both liquid and solid pre-packed food can be processed and semi-continuous system, in which only pump able food products such as fruit juices can be treated.[6][22] Besides destruction of pathogenic and spoilage micro-organisms, there are other expected influences of pressure on the food product: protein denaturation or modification, enzyme activation or inactivation, changes in enzyme–substrate interactions, changes in the properties of polymer carbohydrates and fats. [22]

1)Applications: Combining high pressure with low temperature (HPLT) offers the new field of HP application, such as pressure-supported freezing, thawing and subzero storage. [29] HP is also used in applications, other than food preservation such as: tempering of chocolate, gelatinization of starches and proteins, blanching of vegetables ,tenderization of meats ,coagulation and texturisation of fish and meat minces, freezing and thawing (very rapid and without any temperature gradient.[19]

2) Advantages: One of the main advantages of this process is that the pressure transmission is almost instantaneous and uniform, independent of size, shape, and food composition yielding highly homogenous products. [28] It maintains quality and nutritional value of food. [6] This process modifies physiochemical properties of water. [6] The energy input is low.[25]

3) Disadvantages: Although this technique is widely used but the main disadvantage of this technique is its initial installation and this limits its application to high-value products. [25]

C. Ultrasound

Ultrasound treatment can be regarded as both thermal and non-thermal. [19]Ultrasoundrefers to pressure waves with a frequency of 20 kHz or more.[26]Higher-power ultrasound or "power ultrasound", at frequencies (20 to 100 kHz) can cause cavitation, which can be used in food processing to inactivate microbes. [26] They can rupture cells and denature enzymes. Low-intensity ultrasound can also be used to modify the metabolism of cells.[7] Ultrasonic irradiation is applied to inactivate the bacterial populations. Microbial inactivation is due to thinning of cell membranes, localized heating and production of free radicals.[30]These vibrations produce cycles of compression, expansion and cavitation in liquids and wet biological material. When cavitation bubbles implode, spots of extremely high pressure andtemperature which can disrupt cell structure and inactivate microorganisms are generated.[19]The application of ultrasound and heat hasbeen termed as thermosonication.[19] Ultrasound reduces theheat resistance of microorganisms by causing physical damage to cell structures, due to extreme pressure changes, and disruption of cellular protein molecules.[19] Its emergence as green novel technology has also attracted the attention because of its role in the environment sustainability. [7]

1)Applications: There is large number of potential application of high intensity ultrasound in food processing such as freezing/crystallization, depolymerization, defoaming,drying, degassing, pasteurization/sterilization, filtration, and emulsification. [7] High intensity ultrasound is used for cleaning surfaces and for changing the properties of foods, such as meat tenderisation. [19] It is also used to inactivate microorganism, enzyme, spores that are present in food. [7]

2) Advantages: The advantages of ultrasound include: it minimize flavor losses, greater homogeneity; and significant energy savings.[7] Although High power ultrasound alone is known to disrupt biological cells, if this technique is combined with other heat treatments, it can accelerate the rate of sterilization of foods. It reduces both the duration and intensity of the thermal treatment and the resultant damages. [7]

*3) Disadvantages:*Currently the application of ultrasound in the food industry for bacterial destruction is unfeasible.[26] The method is highly complex and difficult to carry out practically. [22]

D. Pulsed electric fields

The application of pulsed electric fields (PEF) in food preservation seems to be an alternative and profitable non-thermal method and its use permits operation at low or moderate temperature. [15][23]During 1970s, the development of Pulsed Electric Field branched into two different fields namely reversible electro-permeabilisation for DNA transfer into cell and microbial inactivation and food preservation. [23] The term "thermization" has been applied to the combined effect of PEF and electrically induced heating.[32]

The PEF technology involves the application of short pulses of high electric fields with duration of microseconds - to milliseconds and intensity in the order of 10- 80 kV/cm which is based on pulsed electrical currents delivered to a product placed between a set of electrodes; the distance between electrodes is termed as the treatment gap of the PEF chamber. The electric field may be applied in the form of exponentially decaying, square wave, bipolar, or oscillatory pulses and at ambient, sub-ambient, or slightly above-ambient temperature. After the treatment, the food is aseptically packaged and refrigerated. Because of the presence of several ions, the food is capable of transferring electricity, giving the product a certain degree of electrical conductivity. [27]The factors that influence microbial inactivation by PEFs are duration of electrical treatment, type of microorganism, treatment temperature, pH, ionic strength, and conductivity of the medium containing the microorganisms. [15][11]

1) Applications: it involves non thermal microbial inactivation for food pasteurization, treatment of vegetable, animal and microbial cells to enhance the efficiency of mass transfer of water and other valuable compounds, in various processes like drying, extraction etc. [12]. PEF technology has recently been applied in drying enhancement, enzyme activity modification, preservation of solid and semisolid food products, and waste water treatment. PEF can be successfully used to enhance mass and heat transfer to assist drying of plant tissues. [27]

PEF does not involve the use of preservatives. The PEF treatment may also have no significant detrimental effects on heat-labile components present in foods such as vitamins. [11]This technology can be successfully applied to the citrus industry, which is concerned with the spoilage microorganismssuch as lactic acid bacteria and resultant production of off-flavor compounds. [27] PEF technology has been most widely applied to apple juice, orange juice, milk, liquid egg, and brine solutions. [27]

*2) Advantages:*Vegetative micro-organisms including yeasts, spoilage micro-organisms and pathogens can be inactivated by using PEF. It can operate at room temperature and retains quality and heat-sensitive vitamins. PEF can be used as continuous process but, after processing, products have to be packaged hygienically and kept cool during storage. Juice yield can be improved as PEF causes the formation of large, permanent pores in cellular tissues, concentrations of functional components can be increased and the characteristics of dried produce can be enhanced. [10]

*3) Disadvantages:*Only homogeneous fluid foods without gas bubbles or large particles can be effectively processed. A proper range of electrical conductivity and viscosity is required for these fluid foods. Bacterial spores are not inactivated. Most PEF-treated non-acid foods require refrigerated storage and distribution after processing. There are chances of detrimental chemical changes if dielectric breakdown and electrochemical phenomena are not controlled. [23]

E.High intensity light

High intensity light is a fast and environment friendly non-thermal method of minimal processing [31][23].This method is also known by other names likeultraviolet light, pulse white light, and near infra-red light.[23] It uses the range of light in which non ionizing irradiation is emitted.

The main governing principle behind generating high intensity lightis that a gradual increase of low to moderate power energy can be harnessed and released in highly concentrated bursts of more powerful energy.[23] The electromagnetic energy is accumulated in storage capacitorand then released in the form of light within a millionth or billionth of a second which result in an amplification of power with minimum additional energy consumption.[23]In many food processing applications the pulses of white light which emit one to twenty flashes per second of electromagnetic energy within the range of 170 to 2600nm are used [23].Generally this technology is used for sterilizing or reducing the microbial load on packaging or food surface.[22] When the food material is exposed to high intensity light, it denatures the proteins of microbial cells, modifies or inactivate functional enzymes and disrupt the functional component of nucleoproteins.[23]Many insects including representatives from the phyla nematode and arthropoda, protozoan sporozoites and some algae, several genera of fungi (Mycetae) , gram positive vegetative cells , spores and gram negative bacteria as well as many viruses are inactivated to various degree through high intensity light treatments. [23]

*1) Application:*It is used for the decontamination of surface of foods and packaging materials. [8] This treatment is significantly applicable for surface disinfection [23]

*2) Advantages:*High intensity light is a fast and highly effective processing step in food preservation.The major advantage of this technique is that, it is cost effective, with minimal operating and maintenance costs once the equipment is in place. It is regarded as a relatively safe and non –toxic treatment. [23]. It can be applied to food products which have smooth surface like fresh whole fruits and vegetables commodities, hard cheese, or smooth surface meat cuts, such as steaks or chops where surface decontamination is a major concern.[23]

3) Disadvantages: High intensity light is unable to penetrate into opaque substances and irregular food stuff such as comminuted meats, spices, cereals, grains, dairy products or other emulsions. [23] Other disadvantage of High intensity light treatment is the possibility of occurring of shadow when microorganisms readily absorb the rays, and are present one upon another. This makes the organisms in the lower layers difficult to destroy in contrast to those in the upper layer (Hiramoto, 1984), although this shadowing effect can be overcome by using relatively high peak powers.[31] This type of technique is unsuitable for food with rough or uneven surfaces, cervices or pores because of the ability of microorganisms to harbor in small openings of food.

III. CONCLUSIONS

In recent years the demands of the consumer has shifted to processed foods which retain their natural flavour, colour and texture and are added with minimum additives. Thus minimal processing techniques are gaining importance because of their ability to increase the shelf life of foods without changing their fresh like qualities. Non thermal techniques of minimal processing include Irradiation, High Hydrostatic Pressure, Ultrasound, Pulsed Electric Field, and High Intensity Light. These techniques are based on specific principles and have own their merits and demerits. Irradiation treatment using gamma rays is mainly used to increase the shelf life of food products in fresh as well as in frozen conditions. High Pressure processing is becoming more popular because it is independent of food size, composition, and shape and can treat both pre packed and semiliquid food.In high intensity light technique non ionizing radiation are used particularly for surface decontamination. Ultrasound is used to inactivate enzyme and microorganisms along with bringing some desirable textural changes in thefood. Pulse Electric Field is used for increasing the shelf life of food products and can be successfully used as an alternative treatmentto conventional pasteurization and sterilization methods.

These techniques provide a means of minimally altering the food while improving their shelf life. They maintain the fresh like characteristics of food (flavor, texture, color) with minimum nutrient losses. But the main drawback with all these techniques is their high maintenance and installation cost, safety concern which limits their application. Due to lack of consistent information about these emerging technologies there is a requirement of continued research and developmentfor improvisation and overcoming challenges.

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