Journal of Agricultural Engineering and Food Technology
p-ISSN: 2350-0085; e-ISSN: 2350-0263; Volume 5, Issue 3; July-September, 2018 pp. 158-162

http://www.krishisanskriti.org/Publication.html

Ultrasound Technology: A Non-thermal Approach to Fruit Juice Preservation

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Abstract—*Consumer demand for minimally processed and high-quality fruit juices has forced the food industry to search for a novel approach for the fruit juice processing and preservation. Traditional methods of thermal processing results in depletion of nutrients, antioxidants, compromise with the taste and flavor of the fruit juices. A need has arisen to search an alternative method for the processing and preservation of fruit juices. Ultrasound technology is an emerging non-thermal technology of low cost by its low energy consumption and reduced processing time. Ultrasound treatment is considered to be inexpensive, simple, reliable, environmentally friendly and highly effective in achieving microbial inactivation, enzyme inactivation with minimal effect on quality parameters of fruit juices. This paper gives an introduction to the technology and its recent application in food processing sector with specific focus on the fruit juice preservation. It gives you an in-depth insight into the technology.*

1. INTRODUCTION

Fruit juices are consumed worldwide on a large scale by all groups of the population. They are very popular in the summer season due to its refreshing and thirst quenching effect. Enzymatic and microbial spoilage limits its shelf life. Commercial fruit juice processing involves the use of pasteurization and sterilization techniques. These techniques result in loss of heat sensitive nutrients and loss of fresh like appearance and taste. Novel and non-thermal technologies are upcoming technologies which promise to provide a preservative effect with the minimal quality loss. These technologies aim to reduce the processing time, save energy and improve the shelf life and quality of food products. In recent years, ultrasound has been the subject of research and development in the food industry. There is a keen interest in ultrasound due to the fact that industries can be provided with practical and reliable ultrasound equipment. Nowadays, its emergence as green novel technology has also attracted the attention to its role in the environmental sustainability. Ultrasound offers an advantage in term of increased productivity and yield, lower processing time, improved quality, reduced physical and chemical hazards and is environment-friendly [1].

Ultrasound consists of mechanical waves at a frequency above the threshold of human hearing (>16 kHz). It is defined as a pressure wave oscillating between the frequencies 20 kHz and 10 MHz which includes the range of ultrasound applications. On the basis of the frequency applied, ultrasound can be divided into three distinct categories; power ultrasound (16–100 kHz), high-frequency ultrasound (100 kHz–1 MHz) and diagnostic ultrasound (1–10 MHz) [2]. In the food industry a similar division of ultrasound is made into two categories namely, low power, high-frequency ultrasound which uses frequency in the range higher than 100 kHz at intensities below 1 $W\cdot cm^{-2}$ and second category is the high power low frequency ultrasound which uses frequency in the range of 18-100 kHz and intensities above 1 $W\cdot cm^{-2}$ usually in the range of 10-1000 $W\cdot cm^{-2}$. Low power level used in the low-intensity ultrasound does not cause any physical or chemical changes in the properties of food materials. They are generally non-destructive in nature [3].

2. WORKING PRINCIPLE, MECHANISM, AND GENERATION OF ULTRASOUND

The principle used in low power ultrasound implies that when sound is propagated through food material as mechanical waves, it causes alternating compression and decompression [4]. These waves are characterized by specific wavelength, velocity, frequency, pressure and period. When sound waves strike the matter, it causes variation in the velocity and attenuation of the sound through absorption and scattering mechanisms [5]. Sound velocity is basically the product of frequency and wavelength. Shorter wavelengths are seen in high-frequency sound waves and longer wavelengths are seen in low-frequency sound waves. The Newton-Laplace equation gives us the ultrasonic velocity (V) determined by density (ρ) and elasticity (E) of the medium [6]. The sensitivity of ultrasonic velocity to the molecular organization and intermolecular interactions makes it possible for the ultrasound velocity measurements. Other ultrasound parameters that can be correlated with the physicochemical parameters of the material are the attenuation coefficient and acoustic impedance. Energy loss in compression and decompression of ultrasonic waves due to absorption and scattering phenomenon causes attenuation [7]. Homogeneous materials are been associated with absorption contribution of attenuation and heterogeneous materials are associated with scattering contribution of attenuation. Factors affecting attenuation are viscosity, compressibility, wall material, and scattering and adsorption effects [8], which can be used to get information about the physical and chemical properties of food materials such as molecular relaxation, microstructure, phase composition, bulk viscosity and rheology [9], kinetics of fast chemical reactions and droplet sizing and stability in emulsions [7]. Acoustic impedance is given by the product of density and sound velocity passing through the boundary of different materials, which causes changes in the reflection coefficient. The density of the material affects the acoustic impedances [9].

The basic principle behind the high power ultrasound is that at higher intensities (low frequencies) it induces acoustic cavitation [10] due to the generation, growth, and collapse of large bubbles, which causes the liberation of higher energies [11]. Alternating compression and expansion create regions of a pressure change resulting into cavitation phenomenon. During the cavitation, bubbles are been formed, they have an increased surface area during the expansion cycle, diffusion of gases takes place which causes bubbles to expand, rapid condensation occurs when the ultrasonic energy is not sufficient to maintain the vapor phase in the bubble. Shock waves are been created when the condensed molecule collides violently creating regions of temperature and pressure change reaching up to 5500°C and 50 MPa. Microstreaming is caused due cavitation which enhances heat and mass transfer [12]. Acoustic cavitation is of two types namely transient and stable cavitation [13]. In transient cavitation bubbles formed undergo irregular oscillations creating regions of temperature and pressure change which results in the destruction of cells, inactivation of enzymes. The implosion of bubbles creates shear forces and microjets in the liquid causing disintegration of the cell membrane. Stable cavitation is characterized by bubbles which oscillate in regular fashion for many acoustic cycles resulting in a microstreaming phenomenon which induces stress to the microbes [1].

Cavitation phenomenon causes chemical, thermal and mechanical effects. Chemical changes consist of the formation of free radical as H+ and OH− due to the breakdown of the water molecule in aqueous solutions [14]. It also involves single electron transfer during the cooling phase and recombination of hydrogen atoms and hydroxyl radicals to form hydrogen peroxide (H_2O_2) which have bactericidal property [15]. Part of ultrasonic energy is absorbed and converted into heat. This thermal effect can be used to our advantage in thawing, drying and sterilization processes [16]. Mechanical effects are caused due to the generation of mechanical shocks which results in the destruction of cell structure resulting in cell lysis and inactivation of enzymes due to the depolymerization effect [17].

The efficiency of power ultrasound to inactivate microbes and enzymes is low at room temperature [18]. When sonication is combined with heat, the inactivation rate of microbes and enzymes is greatly enhanced [19]. Methods of sonication include ultrasonication thermosonication, manosonication, and manothermoson- action. Ultrasonication involves the use of ultrasound at low temperature, it requires a longer time for the destruction of microbes and inactivation of enzymes. Depending on the ultrasonic power and the treatment time employed, rise in temperature can be seen and hence requires process optimization [20]. Thermosonication involves the use of ultrasound with moderate heat. The efficiency of inactivation of microbes and enzymes is greater in thermosonication. An added advantage is the lower processing time and temperature employed in the process of sterilization and pasteurization. With thermosonication the same efficiency as that of the thermal treatment is obtained due to the synergistic effect of ultrasound and heat [21]. Manosonication involves the use of ultrasound in combination with pressure. It has the higher efficiency to inactivate microbes and enzymes than ultrasound alone at the same temperature [22]. Manothermosonication involves the use of ultrasound in combination with heat and pressure. It has higher efficiency in the inactivation of microbes and enzymes than thermosonication and utilizes lower processing temperature and time for the process [1].

During the processing of food, ultrasound treatment can be given either by use of an ultrasound probe system or the ultrasound bath system. In probe type of system, the probe is submerged in the product and in the bath type of system; the product is submerged in an ultrasonic bath to receive the treatment. Large volume can be used in bath type of system compared to the probe type of system [23]. Ultrasonic equipment basically consists of three parts namely generator, transducer, and delivery system. The generator is basically used to transform electricity into the desired alternating current at an ultrasonic frequency, Transducer than converts' electricity into mechanical vibrations. Commonly used transducers are the liquid-driven transducers, magnetostrictive transducers, and piezoelectric transducers [10]. The vibrations are then conveyed to the ultrasonic reactor by the delivery system.

3. APPLICATION IN THE FOOD SECTOR

Low power ultrasound has been widely used in the non-invasive monitoring of foods to determine composition, structure and physical state. It is been used in the pre and post harvest quality control of fruits and vegetables, quality control of cheese, cooking oils, bread and cereal products, bulk and emulsified fat based food products, food gels, aerated and frozen foods, to determine the honey adulteration, composition measurement in fish tissues, chicken and raw meat mixtures by the use of semi-empirical equations [24]. Power ultrasound has wide applications in the food sector. Some of the applications include generation of emulsions, cell disruption, and dispersion of aggregated materials. Recently it is been used in the control and modification of crystallization processes, degassing of liquid foods, enzyme inactivation, to enhance drying and filtration and the induction of oxidation reactions. It is used to enhance shelf life and quality of food products, microbial inactivation, freezing, thawing, freeze drying and concentration, drying and facilitating the extraction of bioactive components [1]. Effect of sonication on different fruit and vegetable juices has been explored such as apple, strawberry, cantaloupe melon, carrot, and orange [25-29]. It was observed that sonication retained most of the nutrients in juices and reduced the microbial load of the samples treated.

4. ULTRASOUND IN ENZYME INACTIVATION

Among the food enzymes, peroxidase (POD) and polyphenol oxidase (PPO) is associated with many deteriorative changes such as enzymatic browning resulting into loss of sensory and nutritional properties of fruit and vegetables [30]. These enzymes are usually inactivated by thermal treatments involving a large amount of energy besides imparting several quality losses [31]. Ultrasound technology has found to be effective in the inactivation of enzymes. In a study, 14% and 16% inactivation in PPO was been observed in ultrasound treated cantaloupe melon juice and pineapple pulp treated for 10 minutes at temperature ≤23^{o}C ,19kHz frequency, 0.6W/mL acoustic power [27,32]. Ultrasound technology has been explored for the partial and complete substitution for thermal processing of fruit juice [33]. Thermosonication uses moderate heat with sonication and higher inactivation rate of enzymes and microbes is obtained by thermosonication. It could thus serve as novel non-thermal preservation technique in pear juice [34], apple juice [35], tomato juice [36], watermelon juice [37], orange juice [38] and grapefruit juice [39]. Rate constant increased from 0.04 min^{-1} at 55^{o}C to 2.617 min^{-1} at 75^{o}C in thermosonicated mushroom crude extract for the inactivation of PPO at a 25kHz frequency and acoustic power of 0.43W/mL. They found that the inactivation rate for PPO was higher at 60^{o}C than 50^{o}C [40]. Ultrasound treated coconut water at 25^{o}C observed a 27% reduction in peroxidase enzyme activity [41]. Other enzymes have been inactivated by sonication and thermosonication namely pectin methylesterase in lemon extract and tomato juice [42, 43], polygalacturonase (PG) in tomato juice [36]. The basic principle involved in the enzyme inactivation is the depolymerization effect. It generally involves two possible mechanisms: degradation of the polymer due to the cavitation effect [44] and the instability phenomenon which occurs due to the binding of free radical to the enzyme substrate resulting in instability of enzyme and loss of enzyme activity [45]. Free radicals formed due to the sonolysis of water attack specific sites such as disulfide bonds that destabilizes enzyme conformation and can oxidize amino acid residues such as tryptophan, tyrosine, histidine, and cysteine that are responsible for catalytic activity and stability of several enzymes. Cavitation causes temperature, pressure changes and increases shear stress in the enzyme environment resulting in the breakdown of hydrogen and van der Waals bonding resulting into loss of enzyme activity [46].

5. ULTRASOUND IN MICROBIAL INACTIVATION

Ultrasound has proved to be effective in obtaining the 5 log microbial reduction criteria set by FDA for fruit juices to obtain the pasteurization effect [47]. Reduction in the microbial count was observed for ultrasound treated (61 µm amplitude, 15 min at 25 ^{o}C) pomegranate juice inoculated with *Escherichia coli* [48]. Patil et al (2009) reported the effective inactivation of E. coli. inoculated in apple and orange juices by applying ultrasound at 37.5 µm amplitude for a period of less than 14 min at a temperature below 30 ^{o}C [47]. Significant reduction of *Pichia fermentans* inoculated in tomato juice treated with ultrasound [50]. The mode of action involved in microbial inactivation is the cell rupture caused due to the intracellular cavitation [51].

6. EFFECT ON PHYSICAL PROPERTIES OF JUICES.

The quality parameter of orange juice comprising color degradation, have been studied of the ultrasound treated sample [29]. Other to add to the list is the cloudy quality of apple juice [35], colour stability and apparent viscosity of pineapple juice [32], color stability, solid deposition and apparent viscosity of cactus pear [52], color and sensory quality (appearance, texture, taste, and aroma) of soursop juice [53], has been studied. These studies have highlighted the fact that ultrasound technology can be effectively used to improve properties such as the consistency (apparent viscosity), color, cloudy stability and its sensory acceptance.

7. CONCLUSION

Ultrasound is an upcoming technology that can be used to substitute traditional thermal technology for the processing of juices. It has found to be effective in enzyme inactivation, microbial inactivation, preservation of quality parameters in different juices and purees. Lower processing time employed is an added advantage offered by this technology. It is an inexpensive, reliable and cost-effective technology compared to the existing non-thermal technologies. The focus should be drawn towards the pilot plant studies. Efforts should be taken to commercialize this technology. Effect of sonication and thermosonication technology have been extensively explored for the preservation of juices, but scarce literature is available which explores the effect of manothermosonication on shelf life enhancement of juices and purees. This need to be explored which would provide us with a clear vision of the synergistic effect of heat, sonication, and pressure on the quality parameters of the juices and purees. The limiting factor for the manothermosonication study involves the unavailability of the customized monothermosonication instrument which would successfully be used for laboratory studies. It still remains an area unexplored.

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