Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.5481

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **5 (6):** 363-371 (2017)

Review Article

International Journal of Pure & Applied Bioscience

OPEN ACCESS

Ultrasonication: An Advanced Technology for Food Preservation

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Received: 20.08.2017 | Revised: 26.09.2017 | Accepted: 1.10.2017

ABSTRACT

Pasteurization, sterilization and drying are the traditional methods used for food preservation. These methods pose problems like loss of nutrients and vitamins, enzymatic browning, prolonged processing time, fruit juice sedimentation and microbial spoilage. Increasing consumer demands for minimally processed high quality food products having natural flavour and taste which are free from additives and preservatives, paves the way for the development of non-thermal methods for food preservation. Sonication is one of the advanced technologies which can overcome these problems. Sonication is a non-thermal technology in which sound waves having frequency more than 18 kHz applied for processing and preservation of food without affecting the nutritional quality. Ultrasound proves its potential applications for fresh horticulture products in drying, fruit juice extraction, detection of foreign bodies, filtration and to control microbial contamination without compromising with their quality aspects. Thus, ultrasound can be one of the viable techniques for quality assurance and food safety.

Key words: *Ultrasounds, Sonication, Non-thermal, Cavitation, Preservation*

INTRODUCTION

Foods are complex materials containing proteins, vitamins, carbohydrates, fats, minerals, water and other organic ingredients with differing compositions[1]. Processing and preservation of food require different applications and precautions. Increasing consumer demand for high quality food products having natural flavour, taste and free from preservatives, encouraged the need for development of non thermal innovative approaches for food processing[2].

Traditionally, thermal treatments (pasteurization and sterilization) have been used to produce safe food products such as juice, milk, beer, and wine in which the final product has a shorter storage life (generally under refrigeration). However, vitamins, taste, colour, and other sensorial characteristics are decreased with thermal treatments. It is the adverse effect of high temperature which leads to loss of nutritional components and changes in sensory parameters of food. It often creates the need for additives to improve the products[3]. Non-thermal food processing methods such as high pressure processing, pulsed electric fields, cold plasma, ozonization and oscillating magnetic fields, offer maximum quality and safety to food products have attracted attention of the food industry[4].

Cite this article: Ravikumar, M., Suthar, H., Desai, C. and Sachin, Gowda, A.J., Ultrasonication: An Advanced Technology for Food Preservation, *Int. J. Pure App. Biosci.* **5(6):** 363-371 (2017). doi: http://dx.doi.org/10.18782/2320-7051.5481

In order to meet the consumer demand, new and innovative food processing methods, as well as novel combinations of existing methods, are continually being sought by industry in an effort to produce better quality food, economically. The non-thermal technologies are reported to have potential to be used for food processing as it offers microbial and enzyme inactivation at ambient or lower temperature. In recent years, there has been a significant increase in the research demonstrating novel and diversified uses of the non-thermal technologies for food processing, includes: more effective mixing and micro-mixing, faster energy and mass transfer, reduced temperature, selective extraction, reduced thermal and concentration gradients, reduced equipment size, faster response to process extraction control, faster start-up, increased production, and elimination of process steps[5].Ultrasound is considered as non thermal processing technology having potential to be suitable alternative of thermal food processing technologies[6]. Ultrasound is a form of energy, generated by sound waves of different frequencies that are too high to be detected by human ear, i.e. above 16 kHz[7].In last few years, ultrasound technology has gained wider applications in almost all fields including medical scanning ultrasonic therapy, mineral processing, nanotechnology, non-destructive testing, industrial welding, surface cleaning, and environmental decontamination applications and in food industry[8]. Ultrasound is also used as a processing aid in the mixing of materials, foam formation or destruction, agglomeration and precipitation of airborne powders, the improvement in efficiency of filtration, drying, and extraction techniques in solid materials, and the enhanced extraction of valuable compounds from vegetables and food products[6].A recent survey and market study of the possible future applications of ultrasound technology in the food industry has showing that there is a lot of scope due to the higher purity of the final products, eliminating undesirable sensory quality and consuming only a fraction of the time and energy normally needed for conventional processes[5].

History of ultrasound

Sound waves have been studied for many different reasons for hundreds of years, but the development of ultrasound had its beginning in 1790 with the discovery of echo sounding used by bats. In nature, dolphins and bats use low-intensity ultrasound waves to attack prey; while certain marine animals use high-intensity waves of ultrasound to set their victims before capture[9]. The most noticeable breakthrough was given by Curie brothers through their study on piezoelectric effect, which is the electric potential generated by a material in response to a temperature change[10]. They also studied the properties of the crystal structure to demonstrate a piezoelectric effect, a scientific basis of the first transducer. 60 years ago, low-intensity ultrasound methods were used to characterize foods, but it is only recently the potential of the method has been evaluated. Since the first real-world application of piezoelectricity for sonar in 1917, there has been substantial development in this industry[11].Thornycroft and Barnaby (1894) observed that vibrations were generated in the propulsion of missiles launched by a destroyer, which produced implosion bubbles and/or cavities in the water, a phenomenon known as cavitation[12]. Ultrasound was first used for clinical purposes in 1956 in Glasgow. Before World War II, applications of ultrasound were being developed for a range of technologies, including surface cleaning procedures. In the 1960s, ultrasound technology was well established and used in cleaning and plastic welding[12]. Despite the diverse applications and great development, ultrasound science is still considered a recent technology in the food industry. It because in recent times only food industries have started using this technology for food preservation, microbial inactivation, food drying and enzyme inactivation. The ongoing demand for low and high-frequency applications of ultrasound will bring many more new opportunities in future days[13].

Major advances have been made in last 5 years turning this laboratory-based prototype technology into fully operational commercial processes throughout Europe and the USA. The applications for which high power ultrasound can be used range from existing processes that are enhanced by the retro-fitting of high power ultrasonic technology, to the development of processes up to now not possible with conventional energy sources.

Commercialization

Ultrasonic processing is a significant food-processing technology with the capability for large commercial scale-up and good payback on capital investment. High-power ultrasound has become an alternative food processing technology applicable to large-scale commercial applications such as emulsification, homogenization, extraction, crystallization, dewatering, low-temperature pasteurization, degassing, defoaming, activation and inactivation of enzymes, particle size reduction, extrusion, and viscosity alteration[14]. Significant improvements in product quality, process enhancement and cost reduction can be achievable on a commercial scale using ultrasonic processing. Factors which need to be improved are (1) Availability of high amplitude/power units for large commercial operations (2) Improved energy efficiency of the equipment (3) Easy to install and/or retrofit systems (4) Low maintenance cost and (5) Higher reproducibility.

Types of sonication

Ultrasound can be used for food preservation in combination with other treatments to increase the efficiency of the technique. There have been many studies combining ultrasound with either pressure, temperature, or pressure and temperature.

a) Ultrasonication (US) is the application of ultrasound at low temperature. Therefore, it can be used for the temperature sensitive products where there is a concern about the loss of nutrients like vitamin-C, denaturation of protein, non enzymatic browning etc. However, it needs long period of exposure to kill/ inactivate stable enzymes and/or microorganisms which may cause high energy requirement. During ultrasound application there may be rise in temperature depending on the ultrasonic power and time of application and needs control to optimize the process[15].

b) Thermo sonication (TS) is a combination of ultrasound and heat. Here the product is subjected to ultrasound combined with moderate heat. As a result of additional heat, the ultrasound produces a high amount of cavitation which in turn gives a greater effect on inactivation of microorganisms than heat alone. Therefore, the combination of low frequency ultrasound with mild heat will help in reducing the time of processing by 55 % and temperature of processing by 16 % by reducing product sensory quality[16].

c) Manosonication (MS) is a combined method in which ultrasound and pressure are applied together. MS helps to inactivate enzymes and/or microorganisms by combining ultrasound with moderate pressures at low temperatures. Its inactivation efficiency is higher than ultrasound alone at the same temperature[17].

d) Manothermosonication (MTS) is a combined method of heat, ultrasound and pressure. Here, the applied temperature and pressure will maximise the cavitation and give greater efficiency for inactivation of enzymes and microorganisms. MTS treatments inactivate several enzymes at lower temperatures and/or in a shorter time than thermal treatments at the same temperatures. Microorganisms that have high thermo tolerance can be inactivated by MTS. Thermo-resistant enzymes, such as lipoxygenase, peroxidase and polyphenoloxidase are reported to be inactivated by MTS[1].

Classification of ultrasound application

Ultrasound applications are classified based on their mode of application and based on the intensity of sound waves. Classification based on mode of application includes 3 types: (1) Direct application to the product, (2) Coupling with the device and (3) Submergence in an ultrasonic bath[5]. Classification based on intensity of sound waves include 2 types: (1) High power ultrasound and (2) Low power ultrasound. In high power ultrasound, sound waves are having at low frequency (20 Hz to 100 kHz) which is having the ability to cause cavitation with sound intensity of > 1 W/cm2. It gives impact to physical, chemical and biological properties of food in processing, preservation and safety[18]. In low power ultrasound, sound waves are having higher frequency of > 100 kHz with an intensity of < 1 W/cm2. It is used in non destructive analytical measurements and monitoring of composition and physico-chemical properties of food for quality control.

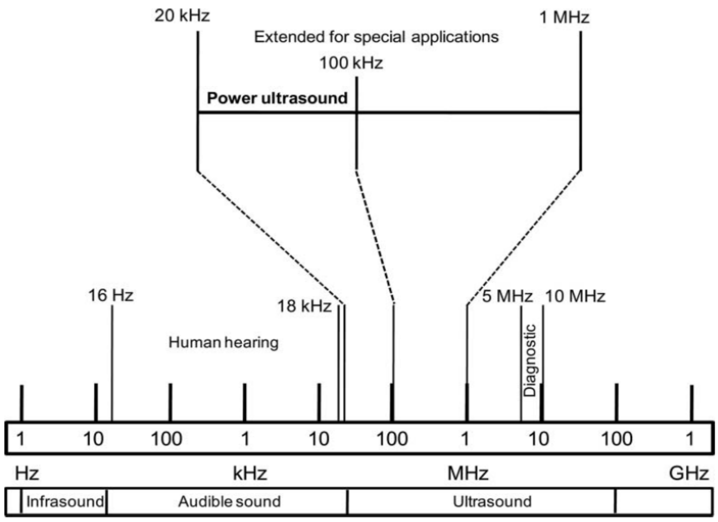


Fig. 1: Frequency ranges of sound indicating infrasound (1 Hz-16 Hz), human hearing (16 Hz-18 kHz), power ultrasound (20 kHz-100 kHz), extended for special applications (20 kHz-1 MHz) and diagnostic ultrasound (5 MHz-10 MHz) [6].

Principles of ultrasound

The basic principle on which the ultrasound can work is the cavitation. Ultrasound is a form of energy generated by sound waves having frequency that is in-audible to human ear s. When sound waves propagated through any product, there will be a production of high amount of energy due to compression and rarefaction of the medium particles. Thus, cavitation is the formation, growth and collapse of bubbles that generate a localized mechanical and chemical energy[19]. When ultrasound waves passes through a liquid medium, formation of gas bubbles inside a liquid due to cavitation occurs[20]. It is the interaction among sound waves, liquid and dissolved gas. It results in pressure change around the dissolved gas nuclei and lead to oscillations.

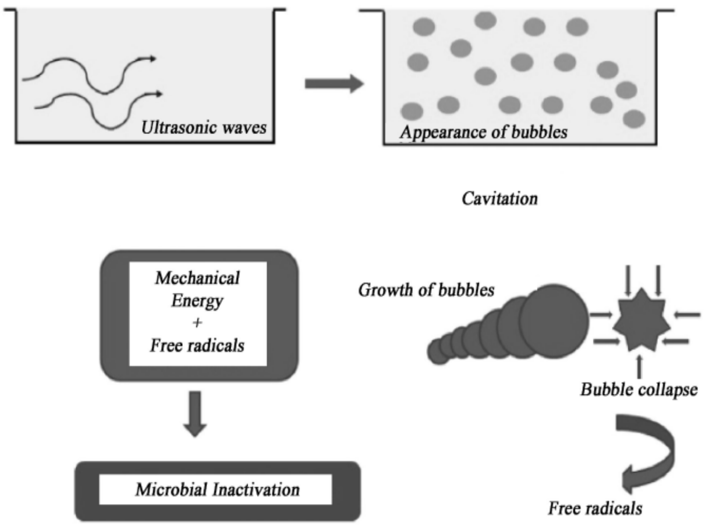


Fig. 2: Ultrasonic waves and the cavitation phenomenon[13]

Further, the dissolved gas and solvent vapour spread in and around the oscillating bubbles. Then the bubbles will get expanded in successive cycles to an unstable size and burst. Bursting of bubbles release very high pressure and heat around the collapsing bubbles which break the compounds in the liquid. It cause particle dispersion and cell disruption and provide localised sterilisation or pasteurization effect depending on the intensity of applied sound[16].

Solid, semisolid and liquid food preservation by ultrasound waves

When ultrasound is applied in a solid–fluid system, it produces a series of effects that can affect both internal and external resistance to mass transfer between solid and fluid[21]. In solid foods, when ultrasound is allowed to pass through them, product drying at higher rate at lower solution temperature occurs. It also protect product from case hardening, non-enzymatic browning, poor appearance and preservation of natural flavour, colour and heat sensitive nutritive components. It is due to increased cell wall permeability owing to the formation of microscopic channels which facilitates the transport of water out and solute in. Thus, the micro jets hitting the solid food surface may produce an injection of fluid inside the solid and affect the mass transfer between the solid and the fluid[12]. In the solid, ultrasonic waves produce a series of rapid compressions and expansions of the material that can be compared to a sponge squeezed and released repeatedly[22]. This effect, known as the "sponge effect," helps the liquid to flow out of the samples[23]. On the other hand, the compressions and expansions of the material can create micro channels which are suitable for fluid movement[24]. The effects described, can affect both internal and external resistances to mass or heat transport and are the reason why high-intensity ultrasounds are applied to improve some transport operations. In heat transfer processes, high-intensity ultrasound can be used to improve the convective heat transfer coefficient in a similar way to mechanical agitation[25].

APPLICATION OF ULTRASONICATION IN FOOD INDUSTRY

Microbial inactivation

The common techniques currently used to inactivate microorganisms in food products are conventional thermal pasteurization. Sterilization in liquid foods and in solid foods drying, freezing, blanching and irradiation techniques are commonly used. Thermal processing does inactivate/kill vegetative microorganisms and some spores but unable to inactivate/kill heat resistant organisms. However, if treatment with increase in the temperature and time of heat exposure is given to kill heat resistant organisms, the food will lose important nutrients. The magnitude of treatment, time and process temperature is proportional to the amount of nutrient loss, development of undesirable flavours and deterioration of functional properties of food products. So, in order to replace these traditional methods of food preservation, ultrasound is emerged as a green technology to destroy the harmful microorganisms without affecting beneficial organisms by retaining the sensory qualities of food products. Power ultrasound has multifunction in reducing spoilage and pathogenic microorganisms and removing other harmful substances and ultimately preserves the food products for a longer period. Actually, microorganisms are directly destroyed or removed by cavitation, which is generally a combination of the following effects: (1) Mechanical effects, includes the generation of turbulence, compression, rarefaction and shearing effect, (2) Chemical effects, includes cavitation and production of free radicals (H^+ and OH^-). Free radicals formed in aqueous medium attack the chemical structure of cell wall of microorganism and weaken the cell wall to the point of disintegration. However, these free radicals are short lived and there is no adverse effect on human beings consuming these Ultrasound treated foods and (3) Physical effects, includes extreme temperature and pressure in and around the food products locally which preserve the food for longer period[26].The effectiveness of an ultrasound treatment is depends on the type of bacteria being tested. Other factors are amplitude of the ultrasonic waves, exposure time, volume of food being processed, the composition of food and the treatment temperature. Bactericidal effects of ultrasound were observed while suspended in culture medium[27].

Enhancing fruit juice quality and shelf life

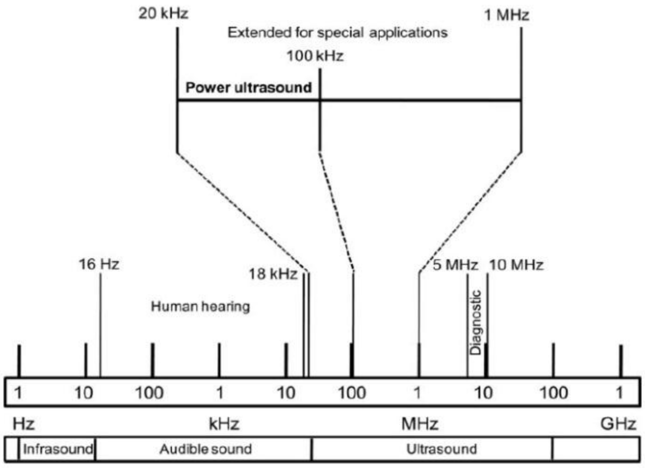
Ultrasound is more effective in fruit-juice processing because of many actions such as microbial inactivation, enzyme inactivation, prevention of juice sedimentation, degassing effect, juice yield and quality enhancement. Many beverages and concentrated juices are vital food products due to their massive demand in the global market[28]. Over the last few years, the consumption of fruit juices has been rapidly increasing[29], making the fruit-juice industry among the largest agro-based industries worldwide[30].Generally, the pigments present in the mesocarp of the fruit. Using traditional preservation methods like pasteurization and sterilization, it is not possible to disturb the cell structures in juice suspension, but when sonication is applied to fruit juice, it will affect juice's macrostructures and convert them into micro structures there by reduces fruit sedimentation and increases and enhances the nutritional compounds in fruit juices[31]. Due to the production of high temperatures, pressures and high shearing effects, it brings about a localized pasteurization effect without causing a significant rise in product temperature[29].The lethal effect of ultrasound is reported to be very much dependent on type of microorganism, processing parameters and sonication medium[32]. Thermo sonication treatment has efficiency to decrease the microbial load in fruit juice. Efficiency of microbial inactivation can be affected by many factors like intensity of ultrasound waves, processing time, treatment temperature; quantity of juice to be processed and juice composition like acidity, pH, water activity and nutritional value. As all microorganisms do not react in the same way to ultrasound treatment, optimization of the process is required. The mechanism of microbial inactivation is mainly caused by the thinning of cell membranes, localised heating, pressure increase and production of free radicals. Combination of ultrasound treatment with heat could give extensive cell damage and breakage of *Escherichia coli* K12 cells[33]. Prolonged treatment time and high acoustic energy density are needed to achieve the 5-log decrement in the number of pathogenic cells[33].

Ultrasound assisted drying

The aim of ultrasound-assisted drying is to overcome some of the limitations of traditional convective drying systems, especially by increasing drying rate without reducing quality attributes in a short period of time[21]. Drying rate of a product depends on the factors such as composition of the product, intensity of ultrasound, time of expose and environmental conditions. Removal of bound water in a product requires longer time and high temperature exposure in traditional methods of drying. While US facilitates fast removal of bound water from the product and achieve effective drying. When ultrasounds pass through the product, mass transfer can be effectively achieved by cavitation phenomenon which creates micro streaming channels in the food product, and gives better results compare to traditional methods[34].Ultrasonic osmotic dehydration technology uses lower solution temperatures to obtain higher water loss and solute gain rates. Due to the lower temperatures during dehydration and the shorter treatment times, food qualities such as flavour, colour and nutritional value remain unaltered. A hydrodynamic mechanism of mass transfer is observed, significantly increasing the water losses and solute gain. Ultrasound has also been used as a pre-treatment prior to the drying of a range of vegetables. The treatment produced a reduction in subsequent conventional and freeze-drying times and also in rehydration properties[5].

Advantages and disadvantages

Ultrasound applications offer numerous advantages in the food industry: (1) Ultrasound waves are chemical free, safe, and eco-friendly. Ultrasonication can be combined with many thermal and non-thermal methods are considered an effective means of microbial inactivation, (2) Use of ultrasound in juice extraction will be more efficient in enhancing juice yield as compared to other juice extraction methods, (3) Reducing the time of processing by 55 % and temperature of processing by 16 % (Chin and Abdullah, 2014), (4) Ultrasound treated products will get minimum loss in flavour, colour and other nutritional compounds during processing, (5) Ultrasound has gained huge applications in the food industry such as preservation, processing, extraction, emulsification, centrifugation homogenization, *etc*. Despite having lot of advantages, use of ultrasound waves has some disadvantages such as: (1) The free radicals formed during cavitation may cause harmful effect on the consumer, (2) Budding technology, (3) Ultrasound may cause physic-chemical effect which may be responsible for off-flavour, discoloration and degradation of components, (4) High initial investment and (5) Frequency of ultrasound waves can impose resistance to mass transfer[8].



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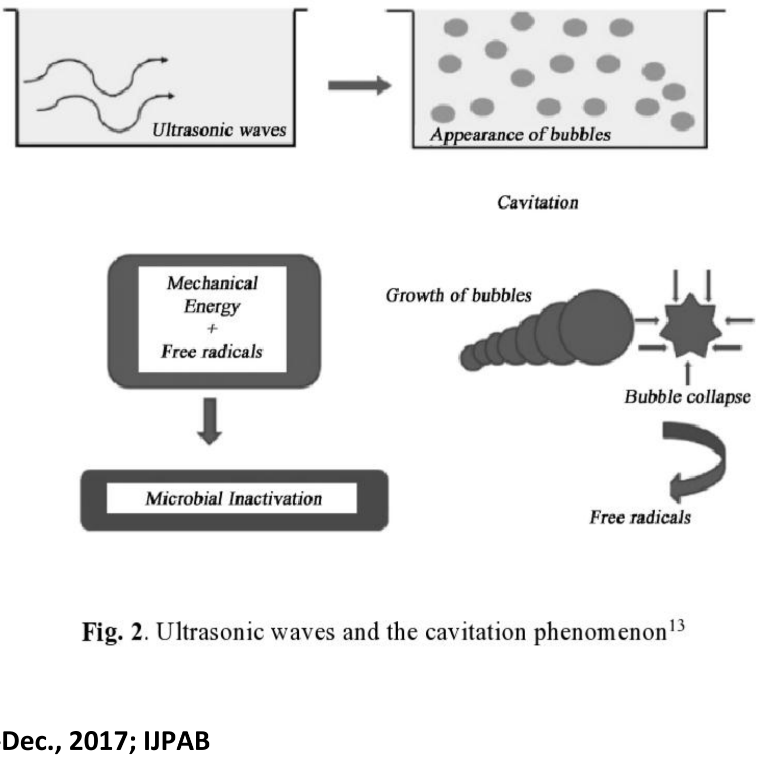

Fig. 2. Ultrasonic waves and the cavitation phenomenon[13]

CONCLUSION

Considering all these aspects, it can be concluded that ultrasound technique may become a new path to improve the nutritional quality of different foods, enhance the shelf life and at the same time minimizing the effect on the product sensory properties.US efficiency can also be enhanced by combining with other non thermal and thermal technologies. The technology is more effective in inhibition/killing of harmful enzymes and microorganisms without affecting the beneficial one. The technique may not able to get 100 % success in replacing the traditional methods of food preservation, but they can certainly best complement or be integrated with the existing ones.

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