ISSN: 2319-6505

Available Online at http://journalijcar.org

International Journal of Current Advanced Research
Vol 5, Issue 4, pp 778-783, April 2016

International Journal of Current Advanced Research

ISSN: 2319 - 6475

RESEARCH ARTICLE

ULTRASOUND TECHNOLOGY IN FOOD PROCESSING: A REVIEW

Srinath D., [1] and Uma Maheswari K[2]

[1,2] Department of Foods & Nutrition, Post Graduate and Research Centre
Professor Jayashankar Telangana State Agricultural University, Hyderabad, Telangana-500030, India

A R T I C L E I N F O

Article History:

Received 16th January, 2016
Received in revised form 24th February, 2016
Accepted 23rd March, 2016
Published online 28th April, 2016

Key words:

Ultrasound, sonication, cavitation, food, sonolysis.

A B S T R A C T

Ultrasound is a non-thermal food processing technology. The sound wave in which the frequency is above the limit of human audibility i.e., greater than 20 KHz referred to as an ultrasonic wave. The energy generated by sound waves of 20000 or more vibrations per second. Ultrasonic vibrations can be produced in any sort of the material- gaseous, liquid and solid. Ultrasound is broadly classified into two group's as Low Power Ultrasound and High Power Ultrasound. Low Power Ultrasound uses frequencies higher than 100 kHz and intensities below 1 $W\cdot cm^{-2}$. Low Power Ultrasound cause no physical or chemical alterations in the properties of the material through which the wave passes. High Power Ultrasound uses frequencies between 18 & 100 kHz and intensities higher than 1 $W\cdot cm^{-2}$ (typically in the range 10-1000 $W\cdot cm^{-2}$). High Power Ultrasound is capable of altering material properties (e.g. physical disruption, acceleration of certain chemical reactions).Classic ultrasound equipment consists of three components: Electrical power generator, transducer and emitter. The power generator takes the energy from the electrical source. The transducer converts electrical energy into mechanical energy. The emitter is incharge of delivering sound energy into the medium through radiation of the waves. When sound waves enter a medium, sound is transmitted as sinusoidal waves and energy is propagated throughout the system in the form of vibration. This vibration is composed of cycles of compression and expansion moving in the media particles. When the energy (i.e. vibration) reaches an optimum level (depending on the characteristics of the medium such as volume, temperature, composition) an important increase of pressure takes place in the medium. This increase generates thousands of bubbles (cavitation). Cavitation can be transient or stable, a difference that depends on the size of the bubbles produced during cavitation and the speed of bubble growth. Cavitation is responsible for cell disruption, breakdown of microstructures, and production of free radicals in the medium etc.Cavitations create regions of very high temperature (5500° C) and peaks of pressure (50000kPa). (Zoran *et al*., 2013)

© Copy Right, Research Alert, 2016, Academic Journals. All rights reserved.

INTRODUCTION

The sound wave in which the frequency is above the limit of human audibility i.e., greater than 20 KHz referred to as an ultrasonic wave. The upper frequency limit is indefinite since it is continuously increasing as new techniques are discovered.The energy generated by sound waves of 20000 or more vibrations per second. Ultrasonic vibrations can be produced in any sort of the material- gaseous, liquid and solid (Bina *et al.*, 2012).

Ultrasound is one of the emerging technologies that were developed to minimize processing time, cost of processing, maximize quality and ensure the safety of food products (Mason *et al.,* 2011). Ultrasound technology has shown important advances in food processing in the last few years. This nonthermal technology, which is applied at low frequency (power ultrasound) in combination with heat, has been used successfully to inactivate pathogenic bacteria in a number of liquid foods, satisfying current pasteurization standards.The main reason for this technology's effectiveness is based on the cavitation generated by ultrasound in the food from sound waves passing through the medium, which in turn disrupt the cell membranes.

Ultrasonic is a rapidly growing field of research, which is finding increasing use in the food industry for both the analysis and modification of food products. At present, ultrasound is a novel technology that has been explored in the lab with successful results, but it is still under development; current research is encouraging and has a promising future, but equipment manufacturers need to collaborate with food scientists to resolve specific issues related to this technology.A few commercial applications have used power ultrasound to perform homogenization, cutting, and extraction in the processing of food and bio-products (Feng and Yang, 2005). The use of ultrasound in combination with heat allows reducing the processing times considerably for some of the evaluated products and has the potential of energy and economic savings. Ultrasound equipment is easy to operate at lab and pilot plant scale and appears to be an environmentally friendly technology for processing food**.**Ultrasonic techniques used with food products form an entire field of applications, and provide the user with a wide variety of information about the properties of materials being processed (Povey, 1998).

History

Ultrasound has been used for a variety of purposes that includes areas as diverse as communication with animals (dog whistles), the detection of flaws in concrete buildings, the synthesis of fine chemicals and the treatment of disease.It has been known for many years that ultrasound can be employed as a method of inhibiting enzyme activity. Nearly 80 years ago Chambers (1937) reported that pure pepsin was inactivated by sonication probably as a result of cavitation.

Developments in the application of ultrasound in processing began in the years preceding the Second World War.By the 1960s the industrial uses of power ultrasound were accepted. The possibility of using low-intensity ultrasound to characterize foods was first realized over 60 years ago. However, it is only recently that the full potential of the technique has been realized.

Classification

The most important criteria for the classification of ultrasound are the amount of energy generated from the sound field, sound frequency and sound intensity. The sound ranges employed can be divided into high frequency, low energy diagnostic ultrasound and low frequency, high energy power ultrasound. The former is usually used as a non-destructive analytical technique for quality assurance and process control with particular reference to physicochemical properties such as composition, structure and physical state of foods (Zbigniew *et al.,* 2007). Nowadays, power ultrasound is considered to be an emerging and promising technology for industrial food processing.High power ultrasound can be applied using sonication baths or ultrasonic immersion probes with different lengths, diameters and tip geometries depending on applications.Ultrasound is broadly classified into two groups.Low Power Ultrasound and High Power Ultrasound

Table 1 Difference between Low Power Ultrasound and High Power Ultrasound

Low Power Ultrasound (LPU)	High Power Ultrasound (HPU)
Frequencies higher than 100 kHz	Frequencies between 18 & 100 kHz.
Intensities below 1 W·cm-2.	Intensities higher than 1 W·cm-2 (typically in the range 10-1000 W·cm-2).
Ultrasonic waves cause no physical or chemical alterations in the properties of the material through Which the wave passes.	Capable of altering material properties (e.g. physical disruption, acceleration of certain chemical reactions).
Non-destructive.	Destructive
They are successfully used for non-invasive monitoring of food processes.	Invasive and used to extract pigments etc.
Widespread application in analytical techniques for Providing information about the physicochemical properties of foods, such as composition, structure and physical state.	Used to generate emulsions, disrupt cells and disperse aggregated materials.

(Zbigniew *et al.,* 2007)

Principle

Ultrasound waves, like all sound waves, consist of cycle's of compression and expansion. When they travel through a fluid medium the elastic bonds between adjacent molecules are alternatively stretched and compressed (Roberts, 1991). Compression cycles exert a positive pressure on the liquid, pushing the molecules together; expansion cycles exert a negative pressure, pulling the molecules away from one another (Suslick, 1989).

When sound waves enter a medium, sound is transmitted as sinusoidal waves and energy is propagated throughout the system in the form of vibration.This vibration is composed of cycles of compression and expansion moving in the media particles.When the energy (i.e. vibration) reaches an optimum level (depending on the characteristics of the medium such as volume, temperature, composition) an important increase of pressure takes place in the medium. This increase generates thousands of bubbles (cavitation). (Povey and Mason, 1998)Cavitation can be transient or stable, a difference that depends on the size of the bubbles produced during cavitation and the speed of bubble growth. Cavitation is responsible for cell disruption, breakdown of microstructures, and production of free radicals in the medium etc;Cavitations create regions of very high temperature (5500°C) and peaks of pressure (50000kPa) (Zoran Herceg *et al.*,2013).

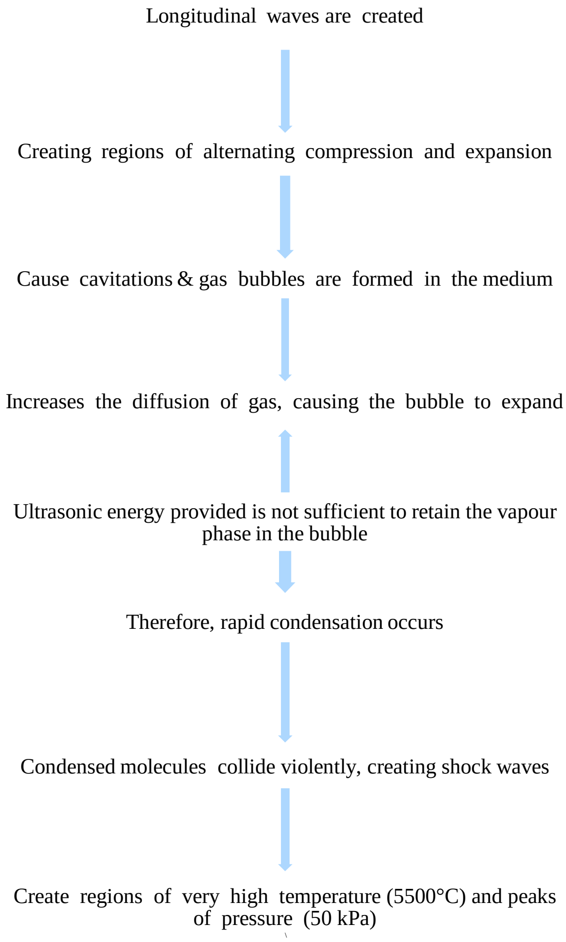

Figure 1 PROCESS FLOW CHART

Source: (Zoran Herceg *et al.,* 2013).

Chemical Reactions

Sonochemical reaction is the chemical manifestation of cavitation phenomena, and degassing of the medium enhances the yield of such a reaction and influences the phenomenon of radical formation by cavitation bubbles, which is the primary mechanism of a sonochemical reaction (Sivasankar *et al.*, 2007).Sonochemical reactions are related to new chemical species produced during cavitation, whereas for the latter, enhancement of the reactions could also be related to mechanical effects induced in liquid system by sonicationWhen ultrasound is applied, it will induce the sonolysis of water molecules and thermal dissociation of oxygen molecule, if present, to produce different kinds of reactive species such as OH•,H•,O• and hydroperoxyl radicals (OOH•).Reactive species production follows the following reactions, with ‘)))’ denotes the ultrasonic irradiation (Pang *et al.*, 2011).

$$H_2O +))) \rightarrow OH\cdot + H\cdot$$
$$O_2 +))) \rightarrow 2O\cdot$$
$$OH\cdot + O\cdot \rightarrow OOH\cdot$$
$$O\cdot + H_2O\cdot \rightarrow 2OH\cdot$$
$$H\cdot + O_2 \rightarrow OOH\cdot$$
$$OH\cdot + H\cdot \rightarrow H_2O\cdot$$
$$2OH\cdot \rightarrow H_2O + O\cdot$$
$$OOH\cdot + OH\cdot \rightarrow O_2 + H_2O$$
$$2OH\cdot \rightarrow H_2O_2$$
$$2OOH\cdot \rightarrow H_2O_2 + O_2$$
$$H\cdot + H_2O_2 \rightarrow OH\cdot + H_2O$$
$$OH\cdot + H_2O_2 \rightarrow OOH\cdot + H_2O$$
$$2H\cdot \rightarrow H_2$$

Source: Pang *et al.*, 2011.

Sonolysis of water also produces H_2O_2 and H_2 gas via OH• and H•. Even though oxygen improves sonochemical activities, its presence is not essential for water sonolysis as sonochemical oxidation and reduction process can proceed in the presence of any gas. However, presence of oxygen could scavenge the H• (and thus suppressing the recombination of OH• and H•), forming OOH•, which acts as oxidizing agents (Adewuyi 2001).

Discription of the Equipment

Classic ultrasound equipment consists of three components: Electrical power generator, transducer and emitter. The power generator takes the energy from the electrical source. The transducer converts electrical energy into mechanical energy.The emitter is incharge of delivering sound energy into the medium through radiation of the waves (Povey and Mason, 1998).

Parameters Affect the Process

The mathematical treatment of cavity growth and collapse is complicated by the many factors involved: consideration should be given to surface tension, viscosity, liquid compressibility, gas and vapour transfer and diffusion, thermal transfers and time variations in the ambient pressure (Webster, 1963).Various parameters affect the process such as Sound wave frequency, Intensity of sound wave, Solvent characteristics, Gas properties, External pressure, Temperature (Wu *et al.*, 2013).

Applications in Food Processing

Fruits and Vegetables

Plant foods including fruits and vegetables are highly attenuating materials due to the scattering of sound from voids and pores, which complicates the interpretation of ultrasound data and thereby unsuitable for evaluating their tissues. The application of ultrasound for the quality control of fresh vegetables and fruits in both pre- and postharvest applications was highlighted in a recent review (Mizrach, 2008).

Mizrach (2008) explained the various physiological and physiochemical changes taking place during growth and maturation, and in the course of the harvest period, storage and shelf-life, and how linking the results of ultrasound measurements and other physiochemical measurements, such as firmness, mealiness, dry weight percentage (DW), oil contents, total soluble solids (TSS), and acidity enables the indirect assessment of the proper harvesting time, storage period or shelf-life. Ex: The amplitude of the ultrasound wave transmitted through fruit peels increased when the color changed from green to yellow indicating a good correlation between the ripeness and the acoustic attenuation.

Previous work on ultrasound processing has demonstrated that thermosonication is more effective in watercress peroxidase inactivation (Cruz *et al.*, 2006) and color enhancement (Cruz *et al.*, 2007).Textural attributes are among the main factors considered in quality assessment (Peacock *et al.*, 1986), and are regularly used for determination of the stage of maturity of various kinds of fruit and vegetables (Abbott, 1999).

Beverages

Foams are thermodynamically unstable colloidal systems in which gas is stabilized as a separate phase dispersed in a liquid matrix. De-foaming is the process of removing bubbles and air from liquids. In the food industry, it is important to remove air and oxygen from milk and drinks to prevent decay and oxidation, which enhance freshness, and quality, and extend shelf life. It is also important to avoid foams to maximize production and avoid problems in process control and equipment operation.Use in ‘fobbing’ of carbonated beverages, particularly, beer.In the production of bottled beer, it is important to remove all air from the bottle above the beer surface.If this is not done, then some bacteria present in air can produce certain reactions that will give taste to the beer (Bina *et al.*, 2012).

Inactivation of Staphylococcus *aureus* and *Escherichia coli* in milk containing 4 % milk fat was carried out using a 20 kHz power ultrasound. The experiments were planned and performed according to the statistical experimental design. Specifically, central composite design was used to optimize and design three experimental parameters: temperature (20, 40 and 60 °C), amplitude (60, 90 and 120µm) and treatment time (6, 9 and 12 min). It was found that Gram-negative bacteria (*Escherichia coli*; D120 µm=2.78 min at 60 °C) are more susceptible to the ultrasonic treatment than Gram-positive bacteria (*Staphylococcus aureus*; D120µm=4.80 at 60 °C). Nevertheless, all three parameters studied seem to substantially affect the inactivation of both *Staphylococcus aureus* and *Escherichia coli* in milk using ultrasonic treatment.

The results also indicate increased inactivation of microorganisms under longer period of treatments, particularly in combination with higher temperature and/or amplitude(Zoran *et al.,* 2012).Yogurt from themosonicated milk scored higher acceptability in sensory evaluation than the respective from conventionally treated milk (Chouliara *et al.,*2010).

Bakery Products

Porosity is an important physical–mechanical property that is directly linked to the quality of bakery products. For optimizing the bread texture and rheology, it is necessary that air bubbles are incorporated during bread dough mixing and maintained until the dough is formed. However, air bubbles in bubbly media (like dough) have great effect on the sound velocity and attenuation, depending on wave frequency. A direct ultrasound measurement method at low frequency (to decrease attenuation) has been shown to be suitable, fast and nondestructive for evaluating the textural properties of bread products (Awad *et al.,* 2012).Many food products are made with batter such as pancakes, cupcakes, waffles, doughnut, tempura, etc. Ultrasound techniques are used to monitor the physical properties of batters (density, viscosity and rheology) and cakes (volume, symmetry, volume index, height and density).Ultrasound Technology is useful to the design and application of a low cost ultrasound system, to monitor specific quality of batters as it is mixed. Changes in compressibility in batters were monitored by measuring the acoustic impedance of the batter. In other ultrasound measurements, significant correlations were obtained between the acoustic impedance and the batter consistency.

Honey

The functional values of honey are highly dependent on the concentrations of its components including carbohydrates, amino acids, minerals, aromatic substances, pigments, waxes and pollen grains. Honey can be adulterated by adding amounts of sucrose, commercial glucose, starch, chalk, gelatins, water and other substances.

To ensure the quality and detect frauds, a variety of analytical techniques has been used to analyze honey composition such as sugar type by HPLC, differences in stable carbon isotope ratio between honey and its protein fraction by GC–MS system and adulteration by sugar syrups using NMR spectroscopy.

LPU has been used to determine the physical and mechanical properties of honey. Changes in the physical properties of honey such as density, viscosity and homogeneity, which were accompanied by changes in ultrasound velocity due to adulteration. For quality control, ultrasound velocity measurements can thus be an effective way to detect adulterated honey products or ensure the authenticity of natural honey products. LPU compares different honeys by measuring the high frequency dynamic shear rheology, viscosity and moisture content (Awad *et al.,* 2012).

Meat Products

Tenderness is influenced by composition, structural organization and the integrity of skeletal muscle (Jayasooriya *et al.,* 2004). Ultrasound-assisted process of meat tumbling caused the significant improvement of the yield, tenderness and juiciness of the end product (Dolatowski and Stasiak 1995).

Generally tumbling involves the meat particles with an aqueous liquor containing salt. Ultrasound assists the process by disrupting the meat myofibrils which releases a sticky exudate and this binds the meat together and leads to an increase in the strength of the reformed product. The binding strength, water holding capacity, product colour and yields were examined after treatment either with salt tumbling, sonication or both. Samples which received both salt treatment and sonication were superior in all qualities. Similar results were obtained from a study of the effect of sonication on cured rolled ham (Mason *et al.,* 1996).

Extraction mechanisms and process development

A major application of HPU is for facilitating the extraction process of a variety of food components (e.g., herbal, oil, protein, polysaccharides) as well as bioactive ingredients (e.g. antioxidants) from plant and animal resources.Extraction enhancement by ultrasound has been attributed to the propagation of ultrasound pressure waves, and resulting cavitation phenomena. High shear forces cause increased mass transfer of extractants (Jian-Bing *et al.,* 2006). The implosion of cavitation bubbles generates macro-turbulence, high-velocity inter-particle collisions and perturbation in micro-porous particles of the biomass which accelerates the eddy diffusion and internal diffusion. Moreover, the cavitation near the liquid–solid interface sends a fast moving stream of liquid through the cavity at the surface. Cavitation on the product surface causes impingement by micro-jets that result in surface peeling, erosion and particle breakdown. This effect provides exposure of new surfaces further increasing mass transfer.

The major advantages of ultrasound are minimum effect on extractable materials, avoidance of organic solvents as its action also works in GRAS solvents, reduction in extraction time, which can potentially enhance the extraction of heat sensitive bioactive and food components at lower processing temperatures and potentially in large industrial scales.

Although ultrasound assisted extraction can be used successfully for extraction proposes, it should be borne in mind that ultrasound conditions (including amplitude used and time) can lead to the destruction of bioactive compounds. It is also well know that ultrasound can lead to the production of free radicals within the cavitation bubbles and in some circumstances these free radicals can induce undesirable changes and /or destruction of the compounds extracted (Albu*et al.,* 2004).

High intensity shock waves generates intense pressures, shear forces and temperature gradient due to the bubble of cavitation inducing the majority of ultrasonic effects with in a material, which can produce physical, chemical and mechanical effects (Mason *et al.,* 1996), making the chemical constituents dissolve in the solvent without heating.

Effect on the Quality of Food Products

The final characteristics in the quality of these sonicated products is akin to fresh products and sometimes it is even better (i.e. color) (Daniela and Gustavo 2011).Freshly squeezed watermelon juice was subjected to thermosonication treatments with processing variables of temperature (25–45 °C), amplitude level (24.1–60μm) and processing time (2–10 min) at a constant frequency of 20 kHz and pulse durations of 5 s on and 5 s off. Hunter color values (L*, a*and b*), lycopene (LC), phenolic content (TP) and ascorbic acid (AA) content were measured.Higher retention of AA and LC was observed at low treatment conditions. AA, LC & TP decreased significantly at higher amplitude levels and at the maximum processing time (Rawson *et al.,* 2011)

Microbial Applications

The bactericidal effect is reduced due to mechanical disruption of cells by very intense currents generated within the media by ultrasound. The main lethal effect is due to cavitation.It is generally agreed that the lethal effect of ultrasound is due to extreme pressure variations caused by implosion. It has been mathematically demonstrated that practically the whole of the lethal effect is due to the pressure changes responsible for the disruption of cellular structures (Scherba *et al.,* 1991).

Highly reactive chemical radicals and reaction product e.g. H_2O_2 of well known lethal capacity are liberated in the aqueous media during cavitations. Also there is extreme pressure variation caused by implosion which generates very high temperature.It has been observed that microorganisms can withstand high pressures but they are incapable of withstanding the quick altering pressures produced during cavitation (Bina*et al,* 2012). Ultrasound has been identified as a potential technology to meet the FDA requirement of a 5-log reduction in pertinent microorganisms found in fruit juices (Salleh and Roberts 2007).

Shelf-Life

As for the microbial inactivation observed in sonicated food, which also affects shelf life, the presence of free radicals such as OH− and H+ and others (depending on the kind of food) could be responsible for the delay of bacterial growth in some foods.So far, most of the sonication studies deal with the inactivation of microorganisms and enzymes, not the storage life of products. One of the few shelf-life studies on sonicated products showed that milk can be pasteurized using thermo-sonication and its storage life doubled with this technology, as compared with conventional pasteurization (Rawson *et al.,* 2011). Also, the degree of spoilage depends on the fat content of the milk. However, there is little scientific evidence verifying these facts and more research on liquid foods is needed.

Safety Concerns

Ultrasound equipment is safe and easy to operate, even though some of its small devices are noisy during regular operation. The bigger units are built inside special cabinets to cushion the noise and facilitate ease of operation (Daniela and Gustavo 2011).Avoid unnecessary exposure to air borne noise from ultrasonic equipment while locating the equipment in an area where personnel who are not working with the equipment. If necessary, workers who are in high noise region they should wear devices to keep away an excessive amount of sound from reaching their ear (Bina *et al.,* 2012).

Advantages

It has several advantages like improvement in mass transfer, food preservation, equipment is easy to operate at lab and pilot plant scale, environmentally friendly technology for processing food, viscosity alteration, degassing, spraying or coating and de-foaming etc. (Mathavi *et al.,* 2013). Potential of energy and economic savings, modifying the functional properties of different food proteins, inactivation or acceleration of enzymatic activity to enhance shelf life and quality of food products and microbial inactivation (Anet 2013).

Limitations

The limitations are that it will create considerable noise while performing the task it may cause noise pollution based health problems. The ill effects that may result from the operation of ultrasonic equipment might be hearing loss and other physiological effects such as: fatigue, nausea and pain etc. due to air borne noise radiated by equipment.

SUMMARY & CONCLUSION

The growth of the ultasonics is following a natural pattern for any fledging field.Initially, ultrasonics was found to be extremely efficient for the production of an oil and water emulsion.Its applications have broadened considerably and now it is believed that ultrasonics is set to make a considerable impact on the food industry over the next decade. Several factors viz. new materials which can reduce the cost of ultrasonic equipment, methods for producing vibrations of sufficient intensity and consequently, more powerful sources of vibrations, improvement in basic designing and finally the availability of trained personnel, have to be explored in depth to make the application of ultrasonic more meaningful and significant in food industries.

Nowadays, power ultrasound is considered to be an emerging and promising technology for industrial food processing. The use of ultrasound in processing creates novel and interesting methodologies which are often complementary to classical techniques. Various areas have been identified with great potential for future development: crystallisation, degassing, drying, extraction, filtration, freezing, homogenisation, meat tenderization, sterilization, etc. There is a wide scope for further research into the use of ultrasound in food processing both from an industrial and academic viewpoint.

References

1. Abbott, J.A., 1999. Quality measurement of fruits and vegetables. PostharvestBiol. Technol. 15, 207–225.
2. Adewuyi YG (2001) Sonochemistry: environmental science and engineering applications. Ind Eng Chem Res 40:4681–4715.
3. Albu, S., Joyce, E., Paniwnyk, L., Lorimer, L. & Mason, J. P. (2004). Potential for used of ultrasound in the extraction of antioxidants from Rosmarinu sofficinalis for the food and pharmaceutical industry. Ultrasonic Sonochemistry, 11, 261-265.
4. Anet RezekJambrak (2013) Application of High Power Ultrasound and Microwave in Food Processing: Extraction, *Journal of Food Process Technology*, 4:1.

5. Awad T.S., Moharram H.A., Shaltout O.E., Asker D., Youssef M.M. (2012) Applications of ultrasound in analysis, processing and quality control of food: A review. Food Research International 48: 410–427.
6. Bina Rani, Upma Singh, Magan Prasad, Chauhan A K and RaazMaheshwari (2012).Utilization of ultrasound technological advances in food industry, *International Research Journal of Pharmacy.* 3:125-127.
7. Chambers, L. A. (1937) the influence of intense mechanical vibration on the proteolytic activity of pepsin. *Journal of Biological Chemistry*.117, 639-649.
8. Chouliara E., Georgogianni K.G., Kanellopoulou N. &Kontominas M.G. 2010.Effect of ultrasonication on microbiological, chemical and sensory properties of raw, thermized and pasteurized milk. *International Dairy Journal*, 20, 307-313.
9. Cruz, R. M. S., Vieira, M. C., & Silva, C. L. M. (2006).Effect of heat and thermosonicationtreatments on peroxidase inactivation kinetics in watercress (Nasturtium officinale). *Journal of Food Engineering*, 72, 8−15.
10. Cruz, R. M. S., Vieira, M. C., & Silva, C. L. M. (2007).Modelling kinetics of watercress (Nasturtium officinale) color changes due to heat and thermosonication treatments. Innovative Food Science & Emerging Technologies, 8, 244−252.
11. Daniela Bermudez-Aguirre and Gustavo V. Barbosa-C anovas (2011) Power Ultrasound-Fact Sheet, Appendix 7 Power Ultrasound, Nonthermal Processing Technologies for Food, Edited by H. Q. Zhang, G. V. Barbosa-Canovas, V. M. Balasubramaniam, C. P. Dunne, D. F. Farkas, and J. T. C. Yuan. Blackwell Publishing Ltd. 621-625.
12. Dolatowski Z.J., Stasiak D.M., (1995).”Tumbling machine with ultrasound”. In: The 9th Congress of Food Science and Technology. Budapest, 153.
13. Feng H. and Yang W. (2005).Power ultrasound. In: Hui Y.H. (ed.), Handbook Food Science, Technology and Engineering. New York: Marcel Dekker.
14. Jayasooriya S.D., Bhandari B.R., Torley P., D’Arcy B.R., (2004). “Effect of high power ultrasound waves on properties of meat: a review”. *Int. J. Food Prop*. 7, 2, pp301-319.
15. Jian-Bing, J., Xiang-hong, L., Mei-qiang, C., &Zhi-chao, X. (2006).Improvement of leaching process of Geniposide with ultrasound.*UltrasonicsSonochemistry*, 13, 455−462.
16. Mason T.J., Chemat F, Vinatoru M (2011) The Extraction of Natural Products using Ultrasound or Microwaves. Curr Org Chem 15: 237-247.
17. Mason, T.J. Paniwnyk, L. and Lorimer, J.P. (1996) the uses of ultrasound in food technology, Ultrasonics Sonochemistry 3:253-260.
18. Mathavi V, Sujatha G, BhavaniRamya S and Karthika Devi B (2013) New Trends in Food Processing-Ultrasonics, International *Journal of Advances in Engineering &Technology*, 5(2):183-184.
19. Mizrach, A. (2008). Ultrasonic technology for quality evaluation of fresh fruit and vegetables in pre- and postharvest processes. Postharvest Biology and Technology, 48(3): 315–330.
20. Pang YL, Abdullah AZ, Bhatia S (2011) Review on sonochemical methods in the presence ofcatalysts and chemical additives for treatment of organic pollutants in wastewater. Desalination 277:1–14
21. Peacock, B.C., Murray, C., Kosiyachinda, S., Kosittrakul, M., Tansiriyakul, S., 1986. Influence of harvest maturity of mangoes on storage potential and ripe fruit quality. ASEAN Food J., 99.
22. Povey M. and Mason T. 1998. Ultrasound in Food Processing. Blackie Academic & Professional. London. Phys. 39, 467–478.
23. Rawson A, Tiwari B K, Patras A, Brunton N, Brennan C, Cullen P J and O'Donnell C. (2011) Effect of thermosonication on bioactive compounds in watermelon juice, Food Research International 44: 1168–1173.
24. Roberts, T. (1991) High intensity ultrasound in the processing of food.Proceedings of theConference of Process and Raw Material Development for Confectionary, Bakery and Snack Products. Solingen, Germany.
25. Salleh-Mack S.Z. and Roberts J.S. (2007) Ultrasound pasteurization: The effects of temperature, soluble solids, organic acids and pH on the inactivation of *Escherichia coli* ATCC 25922, *Ultrason.Sonochem*.14: 323–329.
26. Scherba, G., Weigel, R. M. and O’Brien, J. R. (1991) Quantitative assessment of thegermicidal efficacy of ultrasonic energy.*Applied and Environmental Microbiology*. 57, 2079-2084.
27. Sivasankar, T., Paunikar, A. W., &Moholkar, V. S. (2007). Mechanistic approach to enhancement of the yield of a sonochemical reaction. *AIChE Journal*, 53, 1132−1143.
28. Suslick, K. S. (1989) the chemical effects of ultrasound. *Scientific American*.260 (2), 80-86.
29. Webster, E. (1963) Cavitation. *Ultrasonics*.**1**, 39-48.
30. Wu, T.Y. Guo, N. Teh, C.Y. Hay, J.X.W. (2013) Advances in Ultrasound Technology for Environmental Remediation,SpringerBriefs in Green Chemistry for Sustainability, Chapter 2, Theory and Fundamentals of Ultrasound 6:1-13.
31. XuYuting, Zhang Lifen, ZhongJianjun, ShuJie, Ye Xingqian and Liu Donghong (2013) Power ultrasound for the preservation of postharvest fruits and vegetables. *International Journal of Agriculture & Biological Engineering*, 6(2): 116-125.
32. ZoranHerceg, Anet Reek Jambrak, VesnaLelas and Selma MededovicThagard (2012) The Effect of High Intensity Ultrasound Treatment on the Amount of Staphylococcus aureus and Escherichia coli in Milk.Food Technological Biotechnology. 50(1): 46–52.
33. Zoran Herceg, Ksenija Markov, Brankica Sobota Salamon, Anet RezekJambrak, TomislavaVukusic and JankoKaliterna (2013) Effect of High Intensity Ultrasound Treatment on the Growth of Food Spoilage Bacteria, FTB-3224. 1-5.

****