Potential of Ultrasound in Food Processing: An Overview

Abstract

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Ultrasound is well known for its versatile processing in food industry. In industries it is used for variety of applications like filtration, pasteurization, sterilization, enzyme inactivation, cooking, depolymerization, meat processing etc. For rapid inactivation of microorganisms and enzymes, a combination of ultrasound with pressureor minimal temperature is been applied, it is a promising alternative technique for heat treatment. Ultrasound is mostly applied to overcome the time requirement for completion of various processes as it takes very less process time. Application of ultrasound in food will serve the benefits in several manners like conserve the nutrients for ultimate customer, improve physico-chemical characters of food along with sensory characteristics and responsible for preservation of food through different mechanisms. In this review the major applications of ultrasonic technique in food processing are discussed briefly. Applications of ultrasound during processing or as a pre-treatment show tremendous potential as a non-thermal technique for various purposes in food industries.

Keywords: *Applications; Food industry; Enzyme Inactivation; Microbial inactivation;Ultrasound..*

1.Introduction

Ultrasound

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Ultrasound, a form of sound waves with frequencies above 20 kHz that cannot be heard by humans, has a wide range of applications in various fields. In the field of human medicine, ultrasound is used to visualize internal organs, muscles, and tendons, allowing for the detection of flaws in concrete buildings. It is also utilized as non-contact sensors in industries such as medical, pharmaceutical, military, and general sectors for detection and ranging purposes. Furthermore, ultrasonic devices are commonly employed to detect objects and measure distances accurately. Interestingly, animals like bats and dolphins use low-intensity ultrasound to locate their prey while certain marine creatures utilize high-intensity ultrasound to stun their targets before capturing them. In the food processing industry, ultrasound finds its application in two categories based on frequency and intensity. Low-intensity ultrasound with frequencies above 100 kHz and energies below 1W/cm2 serves as a non-destructive analytical method to assess the composition and structure of foods. On the other hand, high intensity ultrasound ranging between 18 to 100kHz with energize above 1W/cm^2 can cause physical disruption of tissues, create emulsions, clean equipment, and promote chemical reactions.

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One remarkable characteristic of ultrasounds is their ability to propagate through solids, liquids and gases seamlessly. This property opens up a world of possibilities for further exploration and application in various scientific fields.(McClements 1997; Povey and McClements 1988).

2.Mechanism of ultrasound

During the sonication process, longitudinal waves are created,Longitudinal waves can travel in solids, liquids, or gases, and have short wavelengthsproducing sharply defined beams and high velocities. When a sonic wave meets a liquid medium, it creates cyclic succession of expansion (rarefaction) and compression phases due to mechanical vibration of food molecules(Tang 2003). Compression cycles exert a positive pressure and push the liquid molecules together, while expansion cycles exert a negative pressure and pull the molecules apart (Vajnhandl and Marechal2005). These regions of pressure change cause cavitations to occur and gas bubbles are formed in the medium. Once a bubble is created, two different cavitation phenomena that could take place in the liquid are: stable or transient cavitation. Stable cavitation occurs at low intensities where the size of the bubble oscillates in phase with expansion and compression cycles and the bubbles grow slowly over many cycles.Stable cavitation will accelerate heat and mass transfer (Thangavadivel et al. 2012). When high intensity acoustic field is introduced, transient cavitation usually occurs. This causes growing cavitation bubble to eventually become unstable after a number of cycle and collapse during the compression cycle of ultrasonic wave it shows in fig 1. In this cavitation phenomena, the size of a bubble drastically increases from tens to hundreds of times the equilibrium radius before it collapses violently in less than a microsecond (Destaillats et al. 2003;Vajnhandl and Marechal 2005).In this case, the instantaneous implosion of these bubbles can locally generate extreme temperature (up to 5000 K) and pressure (up to 100 MPa). Nevertheless, the classification of cavitation is vague as stable cavitation could lead to transient cavitation or transient cavitation could produce very small bubbles that undergo stable cavitation (Vajnhandl and Marechal 2005). In summary, phenomenon of cavitation consists of the repetition of three distinct steps: formation (nucleation), rapid growth (expansion) and explosion, violent collapse in the liquid (Pang et al. 2011). When ultrasonic frequency increases the formation of cavitation bubbles decreases this is due to insufficient time for the rarefaction cycle to allow the growth of the bubble so that disruption of the liquid can be produced (Bendicho and Lavilla 2000).

3. Application of ultrasound in Food Industry

3.1 Filtration

Filtration is the process of separating useful solid or liquid from a mother mixture in which either can be useful as solid isolate or clear liquid. In filtration the membranes are acting as selectively permeable material which permits some selective material according to size to pass through. Membrane Filtration process depends on flux of processing that decreases with respect to time due to polarization and fouling (Huisman 1988.) Many have tried to improve the efficiency of membrane filters by applying magnetic or electric assistance (Bowenand Williams 1992;Shirato et al. 1998;Raats et al.2002) but the other problems like high power requirement raises its head (Huotari and Nystrom 2000) which restricted the popularity of these equipment's in the industries. The properties of ultrasonic waves such as cavitation, radiation pressure, acoustic streaming, dispersion, coagulation, and ability to change liquid properties can increase the flux of filtration by preventing the deposition of proteins and retarding the growth of filter cake on membrane which ultimately improves the life of membranes (Grossner et al.2005) as shown in fig.2

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Due to such properties many studies on have been conducted application of ultrasonic waves in filtration known as acoustic filtration of different food materials as shown in table no.1.

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According to a study conducted by Al-Juboori et al. in 2021, scanning electron microscopy (SEM) visualization revealed that ultrasound effectively eliminated membrane fouling. This finding suggests that the use of ultrasound filtration can address safety concerns and improve the efficiency of processed items, as stated by Bhargava et al. in 2021.

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The studies showed that acoustic filtration is having positive effects in increase in the flux which in this depends on properties like frequency, power intensity, feed properties, membrane properties, cross flow velocity, process temperature and pressure. Many researchershave been studied the effect of the above parameters on the flux changes and found that the flux increases at low frequencies rather than higher frequencies (Lamminen et al. 2004; Kobayashi et al.2003; Kyllonenet al. 2005). This may be happening because at higher frequencies the rate of cavitation is too high so the bubble formation and collapse rate will be higher which in terms not allowing the bubbles to grow, so these will not allow the formation of fouling. As we consider power intensity of the sound waves the increase in the intensity will also increase the fluidization of cake into liquid (Lamminenet al. 2004; Muthukumaran et al.2004; Kobayashi etal.2003). As the power intensity of the sound wave increases the wave pressure will goes on increasing which will increases the streaming that avoids the cake formation and protein deposition. Though the ultrasound gives positive results in filtration the power consumption is higher in case of the continuous processing so the equipment with timely application of ultrasound for rupturing of cake are designed for industrial use.

3.2Freezing and crystallization

In traditional method of freezing and crystallization it is difficult to obtain uniform size of crystal due to lack of uniform nucleation.There will be destruction of food material structure and loss in sensory quality, fluctuations in temperatures and pressure and non-uniform crystal growth due to uneven mixing (Ashokkumar et al. 2009; Lakshmisha et al. 2008). Acoustic cavitation can promote nucleation in a phenomenon referred to as sono-crystallization. Further, due to occurrence of microstreaming and general turbulence heat and mass transfer can be accelerated. the cutting-edge technology that harnesses the power of ultra-high pressure and cavitation bubbles to revolutionize various industries. With its ability to generate pressures up to 100 MPa, ultrasound sets a new standard in industrial processes. By leveraging rapid nucleation and primary/secondary nucleation processes, this remarkable device enables precise control and manipulation of transport media( ).

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Incorporating the latest research findings by Li et al. (2020) and Dalvi-Isfahan et al. (2017), ultrasound unleashes a world of possibilities. From enhancing chemical reactions to improving material synthesis, this innovative solution offers unprecedented efficiency and reliability.

Ultrasound has been proven to reduce oil migration in palm kernel fat and improve the properties of trans-free fats, such as elasticity. As the food industry seeks alternatives to partially hydrogenated oils, Ultrasound provides a way to achieve comparable techno-functional properties while promoting healthier options (da Silva et al. 2020, Lee et al. 2018).

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A wide range of foodstuffs have been successfully frozen under the influence of ultrasound (Delgado and Sun, 2011).

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Freeze preservation of fresh food stuffs

In immersion freezing of apple when ultrasound was applied from 0°C or –1°C for 120s in total, with 30 s intervals, the average freezing rate represented by the characteristic freezing time was significantly improved up to 8% ($P<0.05$). Freezing rates were enhanced ($P<0.05$) compared to the control treatment (Delgado et al. 2009). Immersion freezing of potato exhibited a better cellular structure because there is increase in the nucleation rate in extra cellular region, as less extracellular void and less cell disruption/breakage as compared to control (Sun and Li 2003).A comparison of freezing curves for potato with ultrasound (power level of 15.85 W, 2 min) and without ultrasound indicated that the application of power ultrasound reduced the freezing time required for bringing down the product temperature from 0 to −7◦C was reduced to 6.9 min instead of 8.7 min (Li and Sun 2002).

In partial freezing of ice cream power ultrasound has several benefits inside a scraped surface freezer e.g. reducing crystal size, preventing incrustation on freezing surface (Mortazavi and Tabatabaie 2008).

The study states that in liquids samples creation of bubbles could be a promising and feasible approach to improve the effectiveness of ultrasound irradiation on the initiation of nucleation. This approach could have great potential for the frozen food industry (Hu et al.2013a). In case of carrot juice freezing there was reduction in freezing time after the application of ultrasound (Janiszewska and Sakowski2013). Application of ultrasound assisted freezing on the quality and microstructure of frozen dough, were investigated results showed that crystal nucleation enhanced by ultra sound and formation of a large number of tiny ice crystals inside the frozen dough, and the maximum penetration force of ultrasound-assisted frozen dough increased due to ultrasonication (Hu et al. 2013b). Finally it concluded that the potential of power ultrasound to aid food freezing is promising, especially for high value food (ingredients) and pharmaceutical products.

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3.3 **Thawing**

Freezing is one of the most accepted food preservation technique to increase the shelflife but the process of thawing should be done before using the product. Thawing can be explained as conversion of the frozen food into unfrozen state at thawing temperature. This could be a problem at industrial level due to more process time and could be more expensive (Chemat and khan 2011) however it depends on the conditions at which the process has been done(Rouillé et al. 2002). As being a slower process it can cause physico-chemical changes as well as microbial decay of food so instead of applying conventional method different thawing techniques are employed like high pressure, microwave, ohmic but there are still several disadvantages due to the rate at which thawing can be accomplished (Li and Sun 2002). The application of ultrasound for the thawing of food was tried nearly 50 years before but due to the limitations like poor penetration in frozen food, localized heating and high power requirement became hurdle in industrial acceptance (Brody and Antenevich 1959). Liu et al 2019 states that ultrasound shortens thawing time in mango pulp while preserving sensory and nutritional quality. With adjustable ultrasound intensity, you have complete control over the thawing process.But Kissam et al.(1982) reported good results when studies are conducted on thawing of frozen fish and reported that the process of the ultrasonic thawing done at relaxative frequencies will give good results. An experiment on blocks of cod has shown that, compared to simple immersion thawing the energy requirement will reduce upto 71% when acoustic wave at 1500 Hz at 60W was applied in water immersion thawing. Miles et al.(1999) noticed that rate of heating in the thawed region increased with intensity and frequency (above 430 kHz), and was greatest when transmission was parallel to the muscle fibersrather than perpendicular or mixed which is the reason for the surface overheating. To overcome this problem one should adjust the frequency to relaxative frequency of (500 kHz) and intensity (0.5W·cm−2) for frozen beef, pork and cod, which were thawed to a depth of 7.6 cm within.

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3.4 Extraction

Issues related withexisting extraction issues are increased the consumption of energy and longer period of extraction. Ultrasound in combination with conventional extraction is potential technique to enhance the rate of yield and can accelerate heat and mass transfer. A phenomenon of ultrasound extraction is attributed by ultrasound pressure waves, and results in cavitation.

Cavitation, which generates high shear forces and micro-bubbles that enhances surface erosion, fragmentation and mass transfer resulting in high yield of extracted materials and fast rate of extraction. Cavitation on the product surface causes impingement by micro-jets that has the ability to punch holes through the cell walls result which in turns in surface peeling , erosion and particle break down as shown in fig.3 Extraction yield varies with the hardness of the seed structure, ultrasound frequency and intensity.

By these mechanisms many products have been extracted and some of the applications are as follow.In extraction of oil samples like soybean oil, flaxseed oil, rice bran and edible oil, ultrasound extraction increases the yield and reduces the time compared to conventional extraction (Li et al. 2004; Zhang et al. 2008; Vilkhu et al.2008).

Comment [H15]: Li and Weiss, 2004, correct it in references

By GC-MS analysis percentage of the unsaturated fatty acid is more in ultrasound extraction compared to conventional extraction for rice bran oil (Krishnan et al.2015)

Bio active extraction

Ultra sound assisted extraction is an effective method for the extraction of some active components like anthocynins, polyphenols, and tartaric acid from plant materials (Zou et al. 2011; Falleh et al. 2012; Ghafoor et al. 2009) Ultrasound extraction of phenolic compounds doesn’t damage the major compounds present in the sample (Liu et at. 2013; Falleh et al. 2012;Wang et al. 2007). Three components whichanthocynins, phenols, tannins were compared in grapes which states that the yields is similar or higher but the frequency 40kHz time taken for extraction is very less in ultrasound extraction (Carrera et al. 2012). Ultrasound extraction is found to be very useful for full utilization of mulberry, which also indicated that the ultrasound assisted extraction is a powerful tool for the extraction of important phytochemicals from plant materials (Zou et al. 2011). In animal bio active compound extraction much studies where not conducted but chitin extraction studies from prawn shells, showed that the chitin yield decreased during sonication, this loss is due to depolymerization of extracted chitin in the wash water. Subsequently, the degree of acetylation of chitin was unaffected by sonication, but the degree of acetylation of chitosans produced from sonication chitin decreased (Kjartansson et al. 2006)

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On dry matter extraction by using intensity in the range of 6.8–11.2 W/cm^2 the yield was more compare to the classical extraction method (Kobus 2006)

Fahmi et al.(2011) reported that with the frequency of 35 kHz the protein content of soymilk after treating with ultrasound has been increased and there was no significant change in viscosity.

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Valuable compounds from winter melon seeds havebeen extracted by ultrasound assisted extraction. This allowed the extraction at lower temperature and the extracts obtained posses higher quality compared to conventional solvent extraction (Bimakret al. 2012).

Ultrasound has the unique capacity to extract and simultaneously encapsulate extracted substance with a wallmaterial (Vilkhu et al.2008). All these results suggested that ultrasound assisted extraction is more effective than conventional extraction method.

3.5 Meat Tenderization

Meat palatability depends on qualities like aroma, flavour, appearance, tenderness and juiciness. Meat tenderness is one of the most important eating quality parameters (Gonzalez et al.2001; Nowak 2011). After the slaughtering of the animal the homeostasis of the body losses, this leads to the proteolysis of the animal muscles by endogenous proteases enzymes giving rise to tenderization (Ouali 1990; Koohmaraie 1996; Koohmaraie 1994; Penny, 1980; Dransfield 1992; Asghar and Bhatti 1987; Mane et al.2014). Anaged animal will give tough meat which is due to higher collagen present in the muscle fiber (Smith et al.1991), which leads to reduced acceptance by consumer. To overcome this problem changing pre- and post-slaughter conditions through the use of physical methods, as electrical stimulation (Geesink et al. 2001, Hwang et al.2003)and tenderstretch (pelvic suspension) (Fisher et al. 2000; Sorheimet al.2001) in prerigor stage of meat. While considering post-rigor meat mechanical tenderization methods like blade tenderization, grinding high pressure technology (1000–8000 bars) and Hydrodyne process (Hayward et al.1980; CheftelandCulioli 1997; Solomon et al.1997), Chemical methods like injection of a brine containing sodium chloride, calcium chloride, polyphosphates and acids. (Lansdell et al.1995; Perez et al.1998; Perezet al. 2003) and biochemical methods like activity of exogenous (eg., bromine, fisin, papain) or endogenous enzyme during aging (Koohmaraie 1994; Nagmawy and Aswad 1988; Varnam and Sutherland 1995; Gerelt et al.2000) are also being used for tenderization. The tenderization of meat depends on length of sarcomere (Hostetler et al.1972), the intramuscular connective tissue (Greaser and Fritz 1995) and proteolytic effect of the muscle (Whipple et al. 1990; Shakelfordet al.1991). Traditionally weak acid method using

Comment [H18]: Missing in references vinegar, lemon juice, salt and enzymatic preparation are used for improving the tenderness of the meat providing optimum pH to action of enzymes.

The use of ultrasound in meat industry stared early as 1950's on beef tenderization but there was not any effect found on pH by ultrasound (Stadniket al.2008). Lyng et al. (1997) reported that the tenderization effect on meat by ultrasound is due to lysosomal rupture and disruption of myofibrillar protein. The reasons of lysosomal rupture are stable cavitation and collapse cavitation which is principle of ultrasonic process *(*Aminet al. 2014).

Numerous studies have confirmed the effectiveness of ultrasound in enhancing meat tenderness and reducing aging time, all while maintaining the highest quality standards. By utilizing Warner-Bratzler shear force analysis, ultrasound ensures that muscle fibers are perfectly tenderized. With HIU (High-Intensity Ultrasound) at its core, our device delivers outstanding results, as evidenced by a significant reduction in shear force after sonication.

In fact, recent research demonstrated that a mere 30 minutes of HIU treatment at 500 W led to a remarkable 26.2% decrease in chicken gizzard muscle fiber diameter and a 27.1% reduction in shear forces. This breakthrough technology conclusively proves that sonication can elevate the tenderness of chicken gizzards to new heights (Du et al., 2021).

Some of the studies shown that there is no effect of ultrasound on the pH (Dolatowski et al. 2000; Stadnik et al. 2008) whereas some of them stated that there is significant change in the pH after treatment (Got et al. 1999; Jayasooriya et al. 2007). This can be concluded as, the tenderization of meat increases due to collagen fragmentation which is confirmed in the microstructure examination of meat (Nishihara and Doty 1958),if the treatment is done at lower intensity there is no pH change observed (Got et al. 1999) but when it comes to higher intensity there is increase in pH.Dolatowski et al. (2000) and Stadnik et al. (2008) stated that the water holding capacity of the treated meat increases after the treatment. Though there are many studies done on ultrasonic meat tenderization the research is still needed and an ongoing project "Non-Invasive high power ultrasound (HPU) processing method for meat tenderization" coordinated in Spain shows the same.

3.6 Marination

Marination is the process of adding liquids into the meat prior to cooking process. Process of marination is dependent on the ingredient used in the solution which are mostly salt and phosphate (Young and Smith 2004). According to the Young and Smith (2004) around 50 % of the poultry meat is marinated this improves color, texture, flavour, juiciness along with saleable yield which increases the profit of seller. Conventionally the process can be accomplished by immersion, injection and vacuum tumbling (Alvarado and McKee 2007) but together sharing the disadvantage of higher process time in addition to irregular distribution is observed due to damage in the meat structure(Leal-Ramos et al.2011). So the industrial interest is to find the process which retain quality attributes and complete the process within shorter time interval. Ultrasound is a promising technology for meat processing; many applications like meat tenderization, microbial inactivation can be accomplished by ultrasound. In a study conducted by Cárcel et al. (2007) subjected pork lion sample immersed in brine solution for 45 min interval three conditions namely unstirred, mechanically stirred and power ultrasound and found that the brine absorption is more in power ultrasound treatment, but also noticed that the ultrasound intensity must be higher than $64W/cm^2$ (20kHz) which means the quantity of salt accumulated in meat is influenced by ultrasound intensity. Studies by Jayasooriyaet al. (2007) and Muletet al. (2003) also showed the improved rate of brine absorption in meat marination due to power ultrasound treatment. Considering the injection process, if previously injected meat is subjected to even low power ultrasound, positive results were observed (Jorgensen et al. 2008), while opposite of these found if the meat is not previously injected (Smith 2011).Siro et al. (2009) using vacuum tumbling and ultrasound at 20 kHz showed that ultrasonic treatment and tumbling gives favorable microstructure and textural changes and improved diffusion of salt and water-binding.

Leal-Ramos et al.(2011) have studied the marination rate in Halal and Non-Halal chicken and found that the water uptake in Halal chicken is higher at the beginning (94% in 15 min.) of the ultrasound process but as process continues the water uptake decreases (22%in 30 min.) with respect to the processing time, Contradictorily Non-Halal chicken shows the increasing rate of water uptake with respect to time (56% in 15 min. and 63%in 30 min.). This may be because in the Halal type of slaughtering, the animal is hanged inverted for nearly complete bleeding, which may facilitate the initial water uptake.

3.7 Drying

Ultrasound does not lead the product to being heated as a consequences ultrasound drying is been used for the heat sensitive material. Ultrasound drying has a direct contact with the food material. Drying of food material in ultrasound drying is by forced-air drying assisted. Where high intensity ultrasonic vibrations as rapid series of alternative contractions and expansions which produce a kind of sponge effect to extract the inside moisture. These alternating series creates microscopic channels which will make the moisture removal easier. Pressure variations at liquid/gas interfaces increase the surface moisture evaporation rate. Ultrasonic energy which produces oscillating velocities and micro streaming at the interfaces which may increases the mass transfer and diffusion boundary layer (Gallego-Jua ´rez et al. 1999). High-intensity acoustic waves also may produce cavitation of water molecules inside the solid matrix, which will remove strongly attached moisture (Mulet et al. 2003).

Ultrasound as pre-treatment: Pre-treatment is used to reduce the initial water content or to modify the fruit tissue structure to reduce the total drying, in a similar way to a sponge when it is squeezed and released repeatedly (sponge effect). Ultrasound pre-treatment consists in immersing fruit pieces in water or in an osmotic solution and to subject the fruit and solution to ultrasonic waves (at frequencies ranging from 18 to 40 kHz) for a period of time (usually less than 60 min). Ultrasound pre-treatment on several fruits: banana, papaya, melon, strawberry, sapota, malay apples, star fruit and pineapples. Ultrasound showed higher influence on fruits with high water content (pineapples, melons, malay apples) and high content of fibers and phenolic cells (sapotas). Low influence was observed in very porous fruits (strawberries) and on dense fruits with strong cell attachment (papaya). The ultrasound pre-treatment was able to reduce drying time by 20% and to reduce drying costs up to 30%. (Fernandes et al. 2008).The main difficulty in dehydration by air-borne ultrasonic radiation is the low penetration of the acoustic energy in the food material due to the mismatch between acoustic impedances. Therefore, in order to increase the ultrasonic effect on food dehydration a new procedure was developed and tested in which the ultrasonic vibration was applied in direct contact with the food samples and together with a static pressure(Gallego-Juarez et al.2007)which is shown in the fig no.4

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3.8 Pasteurization and sterilization

The process of pasteurization and sterilization are conventionally described as the destruction of microbes either pathogenic or complete by application of heat. The processes are highly adopted in the industries though there are some of the drawbacks like the amount of nutrient loss, development of undesirable flavors and deterioration of functional properties of food products due to the time temperature combinations of these. This leads to innovation of non thermal pasteurization and sterilization involving pulsed electric field inactivation, pulsed light inactivation, high pressure and ultrasonication (Povey and Mason 1998). This provided an alternative to the food processing techniques of conventional pasteurization and sterilization this gives a new concept of the processes explaining that "the destruction of microbes pathogenic or complete by either of the method". The bactericidal effect of ultrasound was first observed by Harvey and Loomis in the 1920s which inspired the scientists to apply the ultrasound in the process of microbial inactivation in food. Though the technique is known as non-thermal the cavitation will generate some amount of heat but the microbial destruction is due to implosion, shock wave formation and hot spot formation(Pagan et al. 1999).By taking this ability of ultrasonic waves into consideration many studies has been conducted to check the ability of the ultrasound on the microbial destruction. Some applications of ultrasound Pasteurizationand sterilization are given in table no.3

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Along with specific microbes food commodities are also studied to check the feasibility of the process (Herceget al. 2012)has studied the effect of ultrasound on the *Staphylococcus aureus*and*Escherichia coli* in Milk. Milk is been treated with 20 kHz power ultrasound, temperature (20,40 and 60 °C), amplitude (60, 90 and 120 mm) and treatment time (6, 9 and 12 min). The study shows that the microbial disintegration of the species in the milk shows direct proportion to the amplitude, process temperature and process time.Ha et al. conducted a study to check the resistance of the *E. coli* 87-23 specie inoculated on baby carrot to the different combinations of mano-thermo-sonication (MTS) reactor at different frequencies, as a result they found that the reduction rate of the species is significantly different at different frequencies. The ultrasound found to be an effective method of microbial inactivation but in liquids it imparts metallic flavour like coconut water which is not desirable.

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3.9 Cooking

In conventional cooking food is subjected to higher temperature which will facilitate the masstransfer to cook the food. During cooking many physicochemical changes occurs in food makingit more palatable and eases the digestibility. In foods like brown rice, beef and meat some of the disadvantages observed during conventional cooking like in brown rice the cooking time is more as it contain morefibers in bran portion (Muramatsu et al. 2006) and resist the mass transfer where as in meat and beef the low water absorption results in harder texture.To overcome this problem in brown rice many treatments like heating with immediate cooling (Tadahiko et al 1986), Pre-gelatinization (Ataullah et al1960; Freserick et al. 1963; Douglas 1976; Afif et al. 1992), Germination (Se-Soon et al. 1999; Hiromichi et al. 2003; Hidechika et al. 2004; Sang-You et al. 2007), and Enzymatic treatment (Ruiyu and Jinlin2006; Mithu et al 2008) has been studied but each treatment is having own disadvantages. So many people are interested with some other treatments to overcome the problem of time consumption. The ultrasound treatment has also been studied showing reduction in time of cooking as the ultrasounds willdepolymerize the fibers in the bran improving the mass transfer in the endosperm (Cuiet al. 2010). In Meat and Beef the ultrasound will give a softer texture to the product and improving the water absorption of the myofibrillar protein as the cavitation may results the hydrogen bondings with water. Due to higher water binding, the nutrient retained in meat which reducesleaching losses during cooking. With reference to these studies, Ultrasound can come forward as a newer, faster, and healthier method of cooking of food. Backed by scientific research, ultrasound uses ultrasound waves to cook meat, ensuring it stays moist and preserves essential nutrients. Say goodbye to dry and overcooked meals!

But that is not all. Ultrasound’s benefits extend beyond meat. Fruits and vegetables cooked with ultrasound technology retain more nutrients, have improved heat transfer rates, and offer enhanced sensory attributes. With ultrasound, it can create healthy and flavourful dishes that will impress even the most discerning palate.

3.10 Homogenization

Homogenization is the process of converting larger sized particles in mixture to the smaller size using high pressures (10-20 MPa.) at elevated temperatures of 55-70^{o}C (Tamimeand Robinson 1985.) Homogenization process is an important and necessary pretreatment in most of the food processing industries dealing with pulps, milk, ice-cream and yoghurt. As mentioned in the emulsion and pasteurization-sterilization topic of this paper the ultrasound is capable of dividing the dispersed phase into smaller size and can also kill the microbes so scientists have

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studied the simultaneous homogenization and microbial destruction (pasteurization) in industrial processing (Rieneret al.2009) as shown in fig.5. In a study conducted by Wu et al. (2000)showed the effect of ultrasound on homogenization followed by fermentation. In this the milk 150 ml was subjected to an ultrasound generator (500 W nominal powers at 20 kHz.) with a 13-mm diameter probe and power levels selected were 20, 50 and 100. In the results homogenization efficiency was examined under the microscope which shows disruption of fat globules is not because of vibrations but it is because of intense cavitation and longer exposure which will result in formation of smaller size granules. The examination of the fermentation is done by monitoring the pH which shows statistically there is significant difference between controlled and treated samples but no difference between the treated samples on comparison. The examination of water holding capacity, viscosity and syneresis also has done which shows water holding capacity and viscosity follow direct proportion, whereas syneresis follow indirect proportion. In another study conducted by Rieneret al. (2009) which is a primary study on the chemical changes took place during the ultrasonic homogenization of milk.In normally pasteurized and homogenized milk, four compounds, acetone, 2-butanone, chloroform and dimethylsulfide were found of which acetone and 2-butanone were the major compounds (Ott et al. 1999). In Ultrasound treated sample many more compounds namely 1-hexene, 1-octene, 1-nonene, 5-methyl-1,3-cyclopenatadiene, benzene, toluene, p-xylene, n-hexanal, and n-heptanal increased in concentration over the first 5 min of treatment and changed little thereafter. These compounds are synthesized due to localized temperature associated with cavitation. So, though the ultrasonic treatment is useful may rises to off flavor after processing.

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3.11 Emulsification

Emulsification is a process of mixing the immiscible liquids to form a stable mixture. Now a day's emulsion got importance as they are used as carriers to deliver the hydrophobic bioactive compounds into different food products. As compared to the conventional methods Ultrasonic emulsion provides particles with submicron size, more stability without the use of any chemical surfactant and lower energy consumption (Chendke and Fogler 1975). Due to such reasons ultrasonic emulsification is attracting interest for in-line treatment (Behrend and Schubert 2001). In the food industry, ultrasonic emulsification is attracting interest for products such as fruit juices, mayonnaise and tomato ketchup (Povey and Mason 1998) and in aroma encapsulation (Mongenot et al. 2000).

In the conventional methods agitation will divide the droplets or particles of the dispersed phase into micron sized drops or particles but ultrasound is comparable to micro-fluidization in terms of generating sub-micron dispersions in equal time interval (Jafari et al.2007), the shockwave andcavitation will divide the dispersed phase. Though the ultrasounds divide the droplets and particles in sub-micron size the stabilization of emulsion is dependent on the emulsifying agents used this is shown in fig. no. 6.

Proteins perform many functions in the food industries such as emulsification, encapsulation, improve viscosityand gelation (O'Connell and Flynn 2007).Proteins are mainly utilized for the stabilization of the emulsion as they are having both hydrophobic and hydrophilic characters in a single molecule which helps them to adsorb oil and water to form an interfacial film (Foegedingand Davis 2011; Lam and Nickerson 2013). In a study conducted by O'Sullivan et al. (2015)analyzed the effect ofultrasound on the different proteins of plant and animal origin.Treated Bovine gelatin (BG), Egg white protein (EWP), Pea proteinisolate (PPI) shows that there is significant reduction in emulsion droplet size by comparison to their untreated counterparts ~200 nm at 4 wt% where asFish gelatin (FG), Soy protein isolate (SPI), Rice protein isolate (RPI) 0.1 wt% FG yielded emulsion droplets ~5 nm with untreated sample whereas ~2 nm which is not much different.

Likewise, a study on dairy proteins (O'Sullivan et al. 2014): sodium caseinate (NaCas), whey protein isolate (WPI) and milk proteinisolate (MPI). As the solutions(0.1% wt.) were treated and shown decrease in protein size NaCas 245 ± 12 to 58 ± 4, WPI 433 ± 11 to 72 ± 9 and MPI 956 ± 48 to 256 ± 6, this is due to the ultrasonic cavitation induce higher shear on the proteins in solution. This changes the electrostatic and hydrophobic interaction of proteins (O’Brien 2007). Though ultrasound is an effective method but there are indications that the emulsification of edible oils might lead to some deterioration in quality(Chemat et al. 2004) this may be due to free radicals formed during the treatment of ultrasound which may react with the free and unsaturated fatty acids.

3.12 Fermentation

Ultrasound fermentation generally uses low frequency ≥20kHz with high intensity which will accelerate the process and yield better quality in product with less undesirable flavor. Cavitation phenomenon is the major mechanism that changes biological tissuesthereby increasing the cell membrane permeability during the fermentation process (Bommannan et al. 1992). Cell Membrane permeability is referring to the diffusion of molecule through the membrane. In cavitation phenomena ultrasound used to destroy the microorganisms inside the product by denaturing enzymes and protein inside the cell. Low frequency level of ultrasound will speed up the movement of liquid medium, increase mass transfer of substrate through cell membrane and increases reaction rates (Liu et al. 2006). The gas bubbles generate along the circulation liquid was known as micro streaming. Micro streaming will lead the flux of reagents to the cell and thus increasing the reaction rate. Jomdechaand Prateepasen(2006) reported that low frequency ultrasound fermentation with the intensities of 0.2, 0.4 and 0.8 W/cm2 which shows enhancements of the yeast growth compared to commonly used method and the quantity of fermentation products is directly depended on the fermented time. With the frequency of 20 kHz and different amplitudes it results that intensity of the ultrasound did not affect the duration of the fermentation or the decreasing rate of the pH during fermentation, while increase of the ultrasound intensity led to faster evolution of viscosity. The yogurt produced from ultrasound treated milk had higher viscosity, stronger coagulum and superior texture characteristics. For yoghurt fermentation with probiotics three Bifidobacteria strains and β-galactosidase enzyme in milk were investigated. β-galactosidase is an enzyme that hydrolyzes the glycosidic bond between a galactose and another sugar or alcohol molecule. So in ultrasound fermentation higher the power of ultrasound, more bacterial cells were killed and enzymatic activity also increases (Huang and Zhou 2009).

Comment [H37]: Low frequency mean??????

Comment [H38]: What was fermentation time

Comment [H39]: Fermentation time??

3.13 Defoaming

In many industrial processes like fermentation, syrup preparation excess of foam is the main problem. Foam is a dispersion of gas in liquid in which the distances between the individual bubbles are very small. Existing chemical antifoaming agents sometimes may contaminate the product and the requirement of agents will be huge so the cost is high.High-intensity ultrasonic waves represent a clean and efficient methodology to break foam bubbles. High-intensity ultrasonic defoamer is based on the use of the stepped-grooved-plate high power transducer for air-borne focusing ultrasound .This system has been successfully applied to control the excess of foam produced in high-speed bottling and canning lines of carbonic beverages (Gallego-Juárez et al. 2010). Acoustic influence depends on the structure of foam where large bubbles can be easily destructed by low intensity but small bubbles are more stable and require higher intensity.An ultrasonic defoaming system has been used in the frequencies of 21, 26 and 40 kHz for better performance(Gallego-Juárez et al.2010). Ultrasonic emitter is mounted on the rotation system that is electronically controlled. When the radiators begin revolving on their axis with angular velocity, the foams will be destructed since it is revolving the destruction will be in larger area as shown in fig.7

Comment [H40]: For what time

Acoustic vibrations in the volume with the diameter of 1800 mm two radiators in the form of stepped-variable disks with the diameter of 250 mm each and frequency range from 20 to 30 kHz which results in defoaming of different types of foam in industrial volume, was designed(Khmelevet al. 2012).

3.14 Cutting

Cutting of the food will give the finished structure to the food, generally the friction forces during cutting depend on the size of the contact area and increase with the penetration of the blade and due to these forces product deformation during cutting of food can occur (Schneider et al.2009). Because of the increasing demands of the food industry for an improved quality of the cutting process, which gives high accuracy and low product deformation, cutting with ultrasonic assistance as gaining the importance (Rawson 1998). Tools assisted by ultrasound are mainly applied in cutting of cheese, candy bars, bakery and confectionery products, and convenience food (Schneider et al. 2002). Zahn et al. (2006) explained the relation of excitation on cutting velocity and cutting work. They stated that cutting work is increasing with increase in cutting velocity whereas velocity decreases with magnitude of excitation. Schneider et al.(2009) studied the effect of excitation on the frictional forces, based on this study he stated that there is significant reduction in frictional forces due to ultrasonic excitation but the amplitude is not playing any role in it. The textural properties of food will affect the intensity of ultrasonic transmission, due to the transmission of the waves to surface of food some of its properties will change at the contact layer this change in the properties is due to deformation at contact point, heating due to friction and wave absorption (Schneider et al.2009). Due to these properties, different food is needed to process differently at optimum level, this motivated researchers to study different cuttings of food the measurement of cutting forces allows a

Comment [H41]: At what velocity

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Comment [H43]: What is optimum level characterization and understanding of the cutting process (Brown et al. 2005). Arnold et al. (2009) tested the ultrasonic cutting of the cheese and found that the forces required for cutting are more in the wire cutting in comparison to ultrasonic. Taking the cheese composition into account, the cutting work will also vary according to chemical composition. Where as in bakery products different products were studied subjecting to ultrasonic excitation. In these whole grain and white bread do not show any reduction in cutting work, reduction of cutting forces were less initially but higher towards end for ciabatta, Hamburger buns, and yeast dumplings, Rye bread and malted bread shows linear decrease, whereas the cutting structure is reported to be improved with respect to vibrations (Zahn et al. 2005).

3.15 Depolymerization

The application of ultrasound in the practice of depolymerization is one of the oldest knownapplications reported by Schmid and Rommel,early in 1939 but as far as food industry concerned the studies were done even in 1933 (Szent-Gyorgyi 1933). The application of ultrasound to food gives rise to cavitation, during the cavitation some of the small molecules breaks and gives birth to hydroxyl radicalsboth the phenomena can cause depolymerization. Cavitation process forms the shock wave and hot spot which will break the polymer, considering hydroxyl radicals formed will act chemically on food to depolymarize its constituents (Grönrooset al.2004). Such breakdown of the complex molecules into simpler one will lead to change in different physico-chemical characteristics of the foods, the most common include solubility, viscosity, texture, (Prajapat and Gogate 2015) and in some of the cases foaming capacity, emulsifying characters and even conductivity (Jambraket al.2009). These changes are dependent on the temperature, pH (Drimalovaet al.2005) and concentration of polymers(Price et al. 1994) Some of the food application of depolymerization are given in Table 4**.**

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4.Conclusion

Preferences of the consumers have shifted towards healthy, tasty foods, which are readily available, ready to eat and easily to store. Thermal processing always leads toloss of nutritive value and sensory attributes whereas in non thermal processing, the challenge faced by food industries is providing such foods, in a form suitable for distribution and mass production so ultrasound technology is a potential technique to meet this demand. Many applications in food can be done by application of ultrasound during processing or as a pre-treatment to enhance the quality and shelf life of the products compared to conventional method.

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FIGURES

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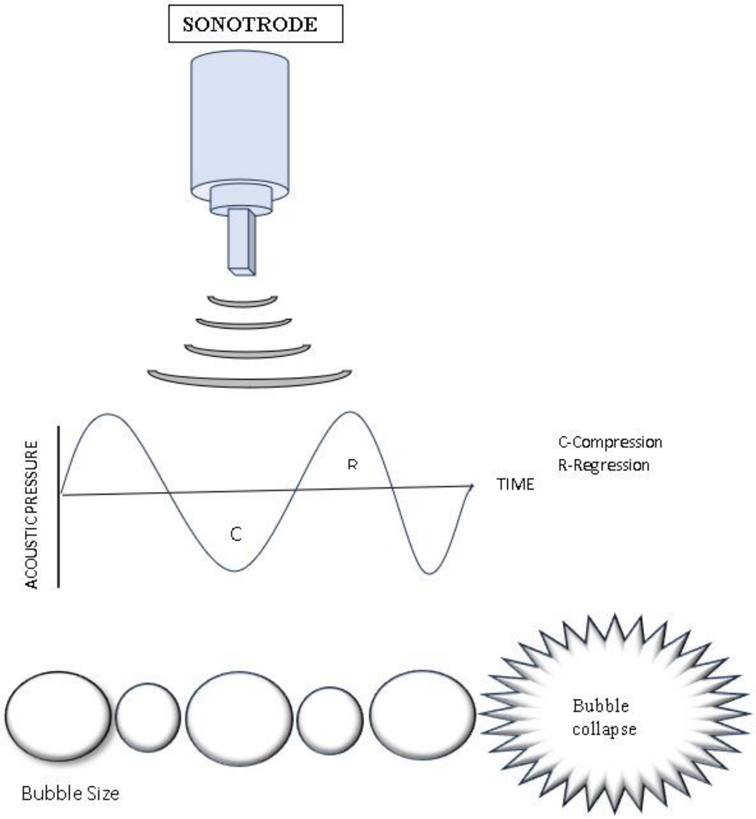

Fig 1: acoustic cavitation generated by ultrasound devices

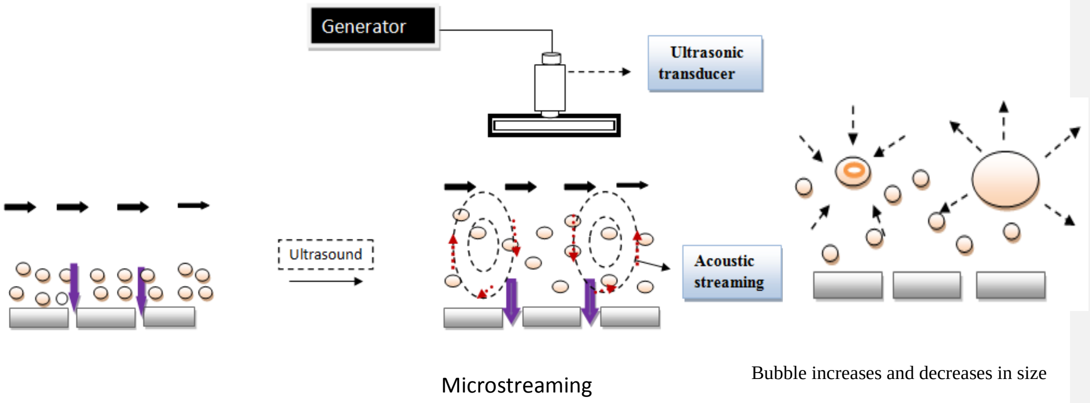

Fig.2. Mechanisms for particle removal/detachment with ultrasonic cleaning

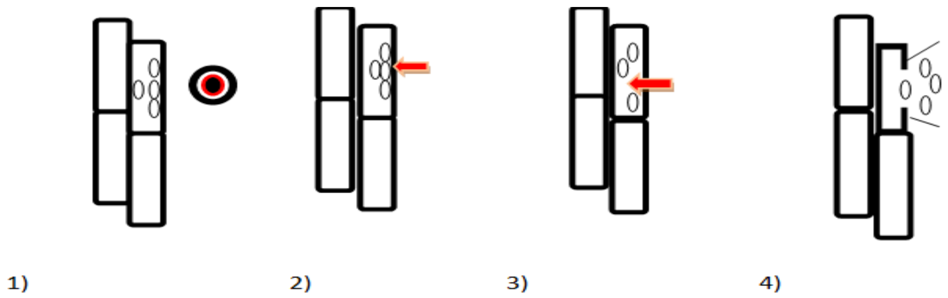

Fig. 3 Mechanism of ultrasound extraction

1) Due to cavitation phenomenon this bubble will collapse 2) Micro-jet directed to the matrix 3) Micro jet penetrate to matrix and destroy the cell wall 4) Ingredient is been extracted

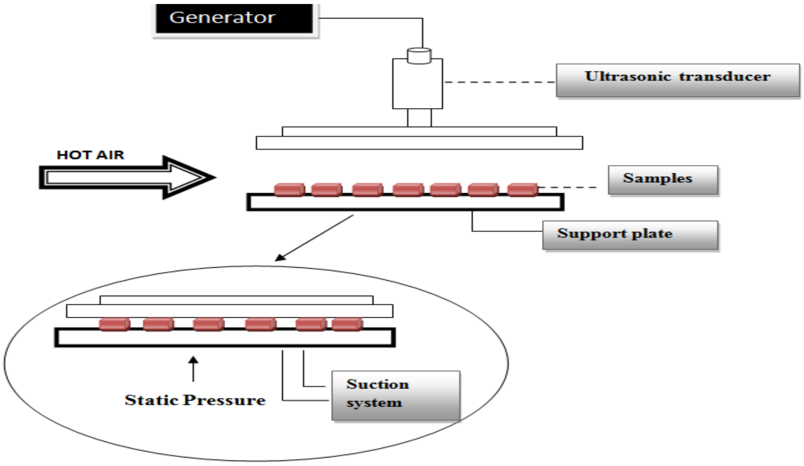

Fig.4 Ultrasound drying

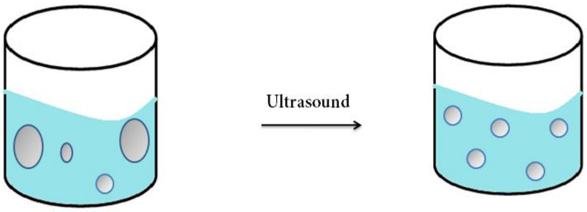

Fig .5 Droplet size distributions

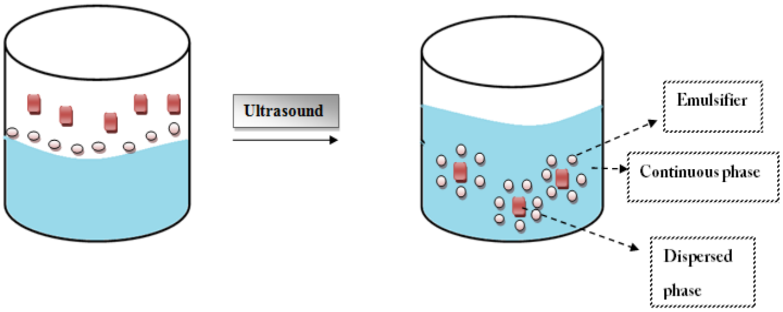

Fig .6 Dispersion of immisible solvents

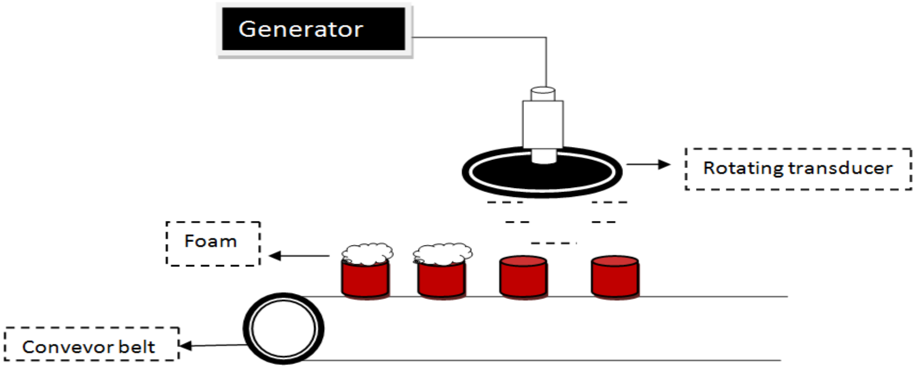

Fig. 7Defoaming by ultrasonic transducer

Comment [H60]: Correct conveyor belt

TABLES

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Table.1 Applications of ultrasound in food filtration

Sl .no	Food commodity	Treatment	Effect	Reference
1	Whey filtration	50kHz	Ultrasound was effective in improving production flux values by between 40% -70%.	Muthukumaran et al. (2005)
2	Membrane technology in dairy	20kHz ,16W	Enhance the flux in ultra filtration or micro filtration processes and to improve the cleaning of fouled membranes	Shanmugan et al. (2012)
3	Surface water fouled ceramic membranes	20kHz,16W	Improved in the normalized permeate flux of surface water from 0.21 to 0.70	Gao et al. (2012)
4	Grape pomace extracts	24kHz ,400W	Filtration rate increases and extension of filter life, because clogging and caking are prevented	Liu et al. (2013)

Table 2: Application of ultrasound in drying

Sl. No.	Food commodity	Treatment	Effect	Reference
1	Blueberries	850 kHz ,and 55^0 brix syrup	The physical properties increase along with reduction in time compared to controlled sample	Stojanovic and Silva (2007)
2	Carrot	20 kHz with 2.4 and 8 mm in thick slices dried with forced-air at60 ^{0}C, 90 ^{0}C and 115 ^{0}C	As an effect of ultrasound the drying time reduced as compared to normal drying at same time.	Gallego Juarez et al. (2007)
3	Lemmon	21.8 kHz and thickness 10mm	The application of power ultrasound improved the drying rate at low air velocities in all the products	Garcıa-Perez et al. (2009)
4	Vegetable sample cut in 24 mm in diameter and 8 mm in thickness	Ultrasonic power 0 W, 25 W, 50W, 75 W and 100 W, temperature 24–26 ^{0}C and relative humidity 30–46%, static pressure was fixed at 0.06 kg/cm2	Drying occurs at low temperatures and together with vacuum, forced-air and static pressure observed less bioactive loss.	De la Fuente-Blanco et al. (2006)

Table .3 Applications of ultrasound pasteurization and sterilization

Sl. No.	Micro organisms	Treatment	Effect	Reference
1	L. *monocytogenes*	20 kHz and amplitude of 117 Am	Reduction of bacterial activity by 90%,	Pagan et al. (1999)
2	*Salmonella* spp.	160 kHz at a power of 100Wfor 10 min	4-log reduction in viable cell count	Lee et al. (1989)
3	E. *coli*	4.5 and 11.5 min	95.5% removal	Utsunomiya and Kosaka (1979)
4	B. *subtilis*	20 kHz and 150 Am at 500 kPa for 12 min	Reduction of spores between 70% and 99.9%	Sala et al.(1995)
5	Yersinia *entercolitica*	Increase in amplitude at 30^{o}C and 200 kPa from 21˚C to 150 Am	Reduced D-value exponentially from 4 to 0.37 min	Raso et al. (1998)
6	S. *cerevisiae*	20 kHz 45˚C	D-value was reduced to 22.3 min. from 739 min	Guerrero and Alzamora (1999)

Table 4 Application of depolymerization

Sl. No.	Food commodity	Treatment	Effect	Reference
1	Solution of guar gum	Ultrasound intensity (3.7, 6.3, 8.1 and 10.1 W/cm^2) time (1, 3, 5 10, 20 and 30 min) at 25 ^{0} C	The extent of Depolymerization has been analyzed in terms of the reduction in intrinsic viscosity which decreases with higher amplitude	Prajapat and Gogate (2015)
2	Beta-Lacto globulin-sodium alginate	24 kHz, times (10, 20 or 30 min) Temperatures (25 or 75 ^{0} C) and amplitudes (50 or 100%).	High intensity ultrasound could effectively decrease the intrinsic viscosity of the ALG solution with time and amplitude.	Hosseini et al. (2013)
3	Starch solution	211/631 kHz	Functionality of starch granules was significantly influenced by the length of sonication and the solution temperature.	Zuo et al. (2009)
4	Soy protein	20 kHz probe and ultrasound baths (40 and 500 kHz) system	Treatment with 20 kHz ultrasound lead to significant changes in conductivity, increased solubility for SPC, significantly changes food texture and increased emulsion activity index. Improvement in foaming and emulsifying properties of soy protein model systems after 500 kHz bath treatment.	Jambrak et al. (2009)
5	Whey protein suspensions	Low-intensity ultrasound (500 kHz) and high-intensity ultrasound (20 kHz and 40 kHz), 15 and 30 min.	40 kHz frequency had less effect on protein properties and shows better results with 15.	Jambrak et al.(2008)