**Futuristic trends of ultrasound technology in dairy and food industry**

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**Introduction**

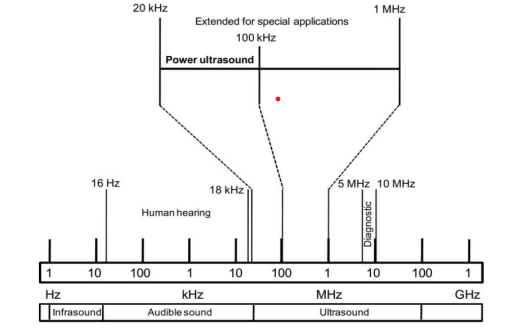
The food industry is constantly searching for the novel methods that can not only produce food products that are better in quality and safe from microorganisms, but also produce such products with appealing organoleptic characteristics while using the cost effective and energy saving methods. The most of the principle in the traditional food processing methods is mainly use heat energy to diminish the growth of microorganisms and inhibit foodborne pathogens which makes the food safe for the human consumption [1]. These thermal treatments are time-consuming and expensive to perform, using a lot of external resources while having a low production efficiency [2]. Microbiologically safe food products can be produced by using the traditionally, heat treatments like pasteurization, sterilization, canning etc. However, some volatile substances like vitamins, antioxidants, and polyphenols along with sensorial characteristics are affected due to high heat treatments [3]. For many food products that provide a risk of bacterial or viral intoxication, heat processing may not be the best option. When exposed to heat treatment, these thermally sensitive food products may experience physical, chemical, and microbiological changes that affect their flavour, appearance, and texture. This has led to the requirement for research and development into maximizing the use of already existing technologies as well as the birth of creative and efficient alternative technologies [4]. In the last few years, utilization of some new emerging technologies like high pressure processing, electric pulsed fields, ultraviolet light, light pulses, ultrasonication and irradiation being tested in food industry. Ultrasound technology is an emerging food processing technology that helps food processing preservation shifting away from conventional thermal technologies due to their detrimental effects on food quality, composition, and sensory attributes. In recent times ultrasound technology came up as one of the popular non-thermal methods which is being used for foods processing. Ultrasonic technology is being used in the food-processing for the cleaning/disinfecting of factory surfaces, but many of its uses is still being researched [5]. As a non-thermal technology, power ultrasound is attracting considerable interest in the food industry. By means of mechanical vibrations of high enough intensity, power ultrasound can produce changes in food either by disrupting its structure or promoting certain chemical reactions [6]. Ultrasound is a cyclic sound waves having the frequency greater than 20 kHz. It is relatively simple, inexpensive, power saving and thus considered as an emerging technology for developments of food products [7]. The benefits of ultrasound versus heat treatment include minimizing flavour loss, improving uniformity, and consuming significantly less energy [8]. There is growing interest amongst consumers in foods that are minimally preserved and processed. Food processors are currently placing a lot of attention on the creation of cutting-edge technologies for minimally processed foods. Conventional heating techniques for pasteurizing or sterilizing food impair the nutritional value and organoleptic quality of the food in addition to killing or reducing germs.

**History of ultrasound**

Although sound waves have been investigated for hundreds of years for a variety of purposes, the development of ultrasound began in 1790 with the discovery of echo sounding used by bats. In nature, bats and dolphins assault their prey with low-intensity ultrasonic waves, while some marine species employ high-intensity ultrasound waves to hypnotize their prey before capturing them [9]. The Curie brothers' research on the piezoelectric effect—the electric potential that a material generates in response to a change in temperature—led to the most notable innovation in the field of ultrasound technology [10]. They also studied the properties of the crystal structure to demonstrate a piezoelectric effect, a scientific basis of the first transducer. Low-intensity ultrasound techniques have been used to define food for 60 years, but it has only recently been determined how effective they are. Since the first practical use of piezoelectricity for sonar in 1917, this industry has developed significantly [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]. In Glasgow, ultrasound was first utilized for clinical purposes in 1956. Applications for ultrasound had been developed before World War II for a variety of technologies, including surface cleaning processes. The use of ultrasound in cleaning and plastic welding was well established in the 1960s. In spite of its many uses and rapid advancement, ultrasound technology is still regarded as a relatively new development in the food sector. For food preservation, microbial inactivation, food drying, and enzyme inactivation, this technology has only recently been used by the food industry. There will be a lot newer opportunities coming up in the future because of the high demand of the low- and high-frequency uses of ultrasound [13]. Major advances have been made in last 5 years turning this laboratory-based prototype technology into fully operational commercial processes. 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.

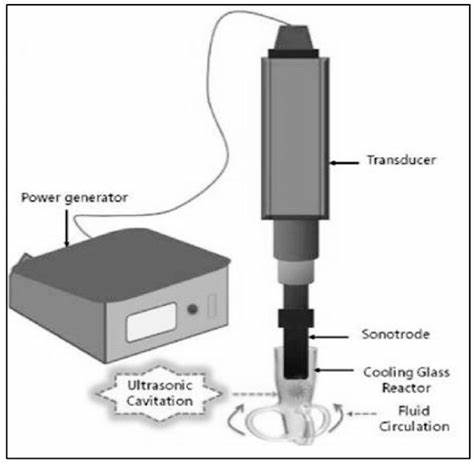
**Generation of ultrasound**

Ultrasound processing is defined as propagation of the sound waves, mechanical vibrations, with a frequency ranging from 20 kHz to 10 MHz through solids, liquids, or gases. Which is above the upper limit of human hearing, normal human hearing lies between the ranges of 20 Hz to 20 kHz.

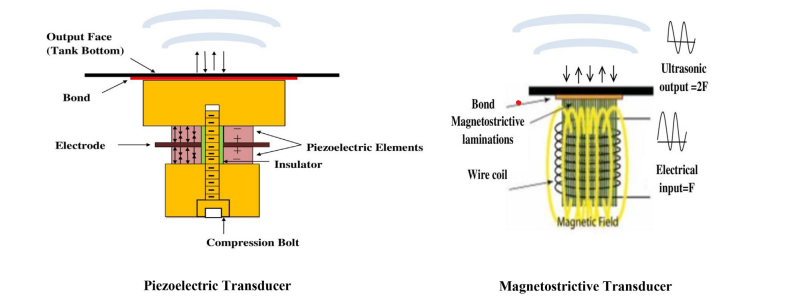


**Fig: Infrasound (1 Hz-16 Hz), human hearing (16 Hz-18 kHz), power ultrasound (20 kHz-100 kHz), extended for special applications (20 kHz-1 MHz) and diagnostic ultrasound (5 MHz-10 MHz)** [14]

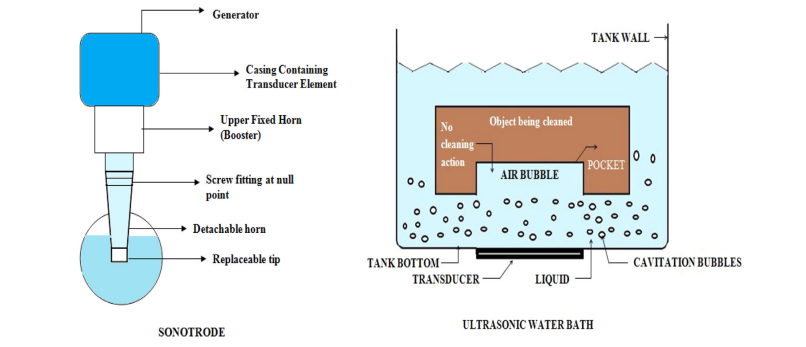
There are mainly three components which are being used in the ultrasonic processing system: 1) The electrical power generator, 2) The transducer (which are mainly of three type viz. fluid-driven, magnetostrictive and piezoelectric), and 3) The emitter(s). The electrical power generator is mainly used to provide the energy for the system, which is in most of the cases is an electrical current, except “liquid whistle,” which uses mainly the mechanical energy in the process of ultrasound wave generation. The second component is the transducer which is a core element in any kind of the ultrasonic system. The transducer converts mechanical energy or electrical energy into sound energy by using the mechanical vibrations at ultrasonic frequencies.



**Fig. An ultrasonic system [15]**

Magnetostrictive and piezoelectric transducers are the two main types used for generating ultrasound. Magnetostrictive transducers function as electroacoustic transducers that generate ultrasonic waves. They operate based on the principle of magnetostriction, which describes the resulting change in length per unit length caused by magnetization upon the application of a magnetic field, provided the material used is magnetostrictive. Most commercial transducers used in ultrasound technology are predominantly piezoelectric, although there are also some that are magnetostrictive. Piezoelectric transducers function by converting cyclic electrical current into physical vibrations, while magnetostrictive devices convert varying magnetic fields into physical vibrations.

The third component in the ultrasound system is the emitter. The emitter is responsible for radiating the ultrasonic waves from the transducer into the medium, and in some cases, amplifying the waves. Emitters can be in the form baths, horns, or sonotrode. Baths are commonly used in ultrasound systems and consist of a tank that contains one or more transducers. The transducers radiate ultrasound into the sample or medium being examined. Horns can also be attached to transducers to amplify the ultrasound signal and apply it directly to the food material, such as food. Furthermore, sonotrodes can be attached to the tip of the horn to further radiate the ultrasonic wave into the sample. The shape of the horn and the inclusion of a sonotrode play a role in controlling the amount of amplification. Sonotrodes, which are used for amplification, are often made from titanium due to its lightweight nature (allowing for efficient transmission of energy) and its rigidity (ensuring durability). Common shapes for sonotrodes include knives, nozzles, or dies. It's important to note that airborne ultrasound systems do not require emitters, as they rely on the propagation of ultrasound through air rather than a liquid medium.



**Principles of ultrasound**

**Acoustic Cavitation**

The principal method through which ultrasound affects food is by acoustic cavitation. In the liquid being treated with ultrasound, this process involves the fast expansion and contraction of nano/micro bubbles of gas. Energy is created by the formation of pressure waves.

Ultrasound is a form of energy which is generated by using sound waves having frequency that is above the range of human hearing. Due to the compression and rarefaction of the medium particles, there will be a considerable amount of energy produced when sound waves travel through any product. Therefore, cavitation is the development, expansion, and collapse of bubbles that produce a concentrated amount of mechanical and chemical energy [16]. Cavitation, which happens when ultrasonic waves pass through a liquid medium, which leads the formation of gas bubbles inside the liquid [17]. When the interaction between liquid, dissolved gas, and sound waves occurs, it causes oscillations and a change in pressure around the dissolved gas nuclei. Additionally, the solvent vapour and dissolved gas diffused inside and outside of the oscillating bubbles. The bubbles will eventually expand in cycles, reach an unstable size, and rupture. High pressure and heat are released when bubbles burst, which breaks down the liquid's chemical constituents. Depending on the intensity of the delivered sound, it causes cell fragmentation, particle dispersion, and localized sterilization.

**Types of sonication**

The effectiveness of ultrasound for food preservation can be improved by combining it with other treatments. Numerous investigations have combined either pressure, temperature, or both pressure and temperature with ultrasound.

**a) Ultrasonication-** Application of ultrasound at a low temperature is known as ultrasonication. As a result, it can be applied to products that are sensitive to temperature and where nutrients like vitamin C, protein denaturation, and non-enzymatic browning may be lost. However, stable enzymes and/or bacteria that might demand a lot of energy must be killed or rendered inactive over an extended period of exposure. Depending on the ultrasonic power and period of application, there may be a temperature increase during ultrasound application, which needs to be controlled to optimize the process [18].

**b) Thermo sonication** is a combination of ultrasound and heat. Here, the product is heated to a reasonable level while also being treated to ultrasound. The ultrasonic generates a significant quantity of cavitation as a result of the added heat, which has a bigger impact on the inactivation of microorganisms than heat alone. As a result, the use of low frequency ultrasound in conjunction with gentle heat will reduce processing time and temperature by 55% and 16%, respectively, while maintaining or improving product sensory quality [19].

**c) Manosonication (MS)** is a combination technique that use both pressure and ultrasound. MS uses low temperatures, moderate pressures, and ultrasound to assist inactivation of enzymes and/or bacteria. At the same temperature, its inactivation effectiveness is greater than that of ultrasound alone[20].

**d**) **Manothermosonication (MTS)** is a technique that combines pressure, heat, and ultrasound. The temperature and pressure that are being used here will maximize cavitation and increase the effectiveness with which enzymes and bacteria are inactivated. When compared to thermal treatments at the same temperatures, MTS treatments inactivate a number of enzymes at lower temperatures and faster times. High thermos tolerance microorganisms can be rendered inactive by MTS. According to reports, MTS inactivates thermo resistant enzymes such lipoxygenase, peroxidase, and polyphenol oxidase [21].

**Classification of ultrasound application**

The ultrasound frequencies are further classified into three ranges that are employed in food processing each offer different advantages. Large amplitude waves are employed in the 20–100 kHz region of low frequency, high power. These waves are sometimes referred to as power ultrasound since they modify the physicochemical composition and structure of food. Sonochemistry, or activation of chemical reactions and the formation of free radicals, occurs in the intermediate frequency range (100 kHz to 1 MHz). Sound travels and penetrates in sinusoidal waves at low and middle frequencies. Acoustic cavitation results from the medium's elastic response, which causes vibration.

The high frequency, low power range (1–10 MHz) of ultrasound is used for diagnostic applications in food processing. These ultrasonic waves don't alter the food they pass through, making them suitable for analytical applications such determination of   a food's structure, composition, and physical state. Examples include determining the amount of protein, water, and fat in food, altering the consistency of dough, determining the composition and purity of oil, examining the physical characteristics of batters, adulterating honey, and more.

**Applications of ultrasound technology in dairy and food industry**

**Filtration**

To improve the efficiency of the separation process, ultrasonic waves are used in combination with a traditional industrial filter. Injecting ultrasound waves into the process improves fluid flow and membrane surface. The benefit of Laminar flow is established across the filter when ultrasound is applied. The resulting turbulence combats cake formation by disperse. During filtration, solids in the extract are concentrated by adsorption on the membrane surface, therefore increasing the cake resistance and decreasing permeate flux. Ultra sonification causes significant flooding of initial. Ultrasonically assisted membrane filtration (UAMF) is a process that employs ultrasonic energy to remove particulate matter from aqueous solutions. It is mainly used after dialysis. Ultrasound, when combined with filters, enhances the life of the filter, by preventing the caking and clogging of the membrane, enabled by continuous cavitation at the surface of the filter. Ultrasound cleaning is an emerging technology and explored the use of ultrasound for cleaning applications in the industrial sector. The applications of ultrasound cleaning are increasing due to customer demand for more efficient, environmentally friendly.

**Fouling removal**

Fouling of ultrafiltration membranes is a major issue affecting the cost and efficiency of many dairy manufacturing operations. During the filtration of processed milk and its constituents, a build-up of particles occurs on the filtration membranes leading to membrane fouling, and ultimately reduced throughput in large-scale processing. The problems of fouling or concentration polarization caused by the deposition of the filtrate or filter cake on the membrane surface is a major issue in this process. These problems cause a reduction in filtration efficiency. Ultrasound significantly improved membrane cleaning efficiencies. However, it was suggested that the capital and operating costs associated with the application of ultrasound for the membrane cleaning cycle alone are unlikely to be economic. More significantly, ultrasound was effective in improving production flux values by between 40% and 70% [22]. Ultrasound was found to be effective in two ways. Firstly, the convective heat transfer coefficient was enhanced which led to a lower heating surface temperature for a constant heat energy input. This lower surface temperature resulted in reduced fouling. Secondly, even when the surface temperature was fixed, fouling was delayed when sonication was used, probably due to scouring and acoustic streaming effects at the surface.

**Brining/pickling**

Traditional brining has been used as a very traditional process in the preservation and manufacturing of foods. The drawbacks of traditional brining such as low efficiency and slow preservation of food can be overcome by the application of ultrasound. Ultrasonication also acts as a method in that: it is said to be able to produce pickled food products with a lesser amount of sodium chloride in comparison to presently available commercial pickles [23]. Sanchez et. al. (2000) found that the equilibrium of salt concentration in cheese treated with ultrasound cannot be attained at the initial stage of ripening as compared to conventional ripening [24]. Though, cheese brined with ultrasonic assistance depicted a low water diffusivity that explained the low drying rate. It is observed that the rate of mass transfer was enhanced significantly by applying ultrasound when reaching a threshold magnitude of intensity. Faster brining processes enable the control of bloating, structural damage, and enzymatic softening of brined foods. The higher rate of salt gain on the application of ultrasound reduces the gain of sodium chloride in the brine solution, thereby, reducing the requirement of desalting as a post-processing operation.

**Drying**

It can be seen that the application of ultrasound in the drying process accelerate the rate of drying of fruit, vegetables, meat, and fish. That helps to reduce drying time and enhance the rate of heat and mass transfer to preserve the quality of food. Ultrasonication has proven to be an effective alternative to the conventional drying process. The removal of water is facilitated by the phenomenon of “sponge effect”, improving the water diffusion from the interior to the surface of the product [25]. New micro channels are formed due to intracellular and extracellular cavitation of water. Also, ultrasound generates air turbulence at the air product interface, to remove the moisture from the surface. Research on the application of ultrasound in drying shows a reduction in drying time by about 20–30% at the low velocity of the air and reduced temperatures [26]. In addition to convective drying, ultrasound is also applicable for freeze-drying [27] and vacuum drying [28] to enhance the rate of drying over conventional methods. Cruz et. al. (2016) mentioned that pre dehydration using ultrasound before the process of convective drying of plums and grapes enhances the rate of drying and drying kinetics and also enhances the quality of the products [29]. Ultrasonication reduces drying time by increasing energy efficiency and increasing the moisture diffusivity. The application of ultrasound increased the rate of drying; however, the results may vary in some cases. In general, ultrasound treatment reduces water activity, enhances product color, and decreases the loss of nutrients: flavonoid content, antioxidant activity [30].

**Foaming**

The foam of proteins will be greater when done under ultrasound. This is because ultrasound causes more homogeneous mixing of the liquid’s components, and therefore increases the overall volume or aeration. Sheng et. al. (2018) reported a significant improvement in egg white’s foaming capacity after treatment with ultrasound at 360 W with a minor reduction of foam stability [31]. The foaming properties were influenced by variations in protein structure. Conversely, an increase in capacity and foam stability after probe sonication was observed in soy protein; however, there was no noticeable improvement in the emulsification and foaming properties, after ultrasonic bath treatment at 500 kHz. It was also found that the functional properties of serum proteins, when treated with ultrasound at 20 kHz, affected their foaming capacity and solubility due to exposure to increased temperatures, as a result of sonication [32]. The foam stability and the foam capacity of the proteins of wheat gluten when they were sonicated gradually increased with the increase in the power of treatment [33].

**Defoaming**

The implicit use of sound energy for defoaming has been known for several decades but without real artificial perpetration. High- intensity ultrasonic swells offer a seductive system of froth breaking since they avoid the need for high air inflow, help chemical impurity and can be used in a contained terrain, i.e. under sterile conditions. This makes it particularly appropriate for implantation in the food and pharmaceutical industries [34]. A system for ultrasonic defoaming been developed grounded on a new type of focused ultrasonic creator. This new system has been successfully applied to control the excess of froth produced in high-speed bottling and canning lines of carbonic potables. For the perfect defoaming effect, it is not only important to overcome on the acoustic intensity but also a minimum treatment time is required [35].

**Degassing/Deaeration**

The generally used styles for the process of degassing of liquid are by reducing the pressure or by boiling while acoustics treatment can perform this function with minimal temperature change. Upon operation of ultrasound the gas bubble vibrates fleetly due to which they come near to each other and grow to an effectively larger size which enables them to elevate through the liquid, against gravitational forces, to reach the surface [36]. This technique can be applied in the degassing of carbonic beverages in the food industry like in the case of beer before bottling, also called defobbing [37]. In the manufacturing of carbonic beverages, the major purpose is the relegation of gas from the face of the liquid, avoiding any organoleptic damage to the product by oxygen or bacteria. This process includes the coupling of a transducer to the external side of a bottle, which results in degassing. In comparison to mechanical agitation, the aural system reduces the count of bottles broken and beverages overflow.

**Depolymerization**

One of the oldest applications of ultrasound is in the degradation of polymers [38]. The depolymerization process occurs through the effects of cavitation and can involve two possible mechanisms: mechanical declination of the polymer from collapsed cavitation bubble and chemical declination as a result of the chemical response between the polymer and high energy molecules similar as hydroxyl revolutionaries produced from cavitation phenomena [39]. Ultrasound depolymerization is actively used to depolymerize Starch. Exposure to ultrasound at a low power causes a temporary reduction in viscosities of polymeric liquids but high ultrasound power results in depolymerization and a permanent change in rheology which are useful in food processing [40]. Recent studies have focused on polymer degradation by ultrasonic treatment, including organic substances (nitrobenzene, polyethylene, dyes, aniline) which would slowly develop into a biopolymer (starch, protein, carrageenan) [41]. Exposure to ultrasound also finds great potential in the conversion of raw materials of biomass such as the polymeric carbohydrates to beneficial low weight molecules [42, 43].

**Cutting**

Ultrasound has improved the overall processing of food by improving the cutting process. Acoustic equipment represents a new way of cutting or cutting a variety of food products during production, minimizing product waste and reducing maintenance costs. Ultrasonic cutting uses a knife blade connected to an ultrasonic source and connected through a shaft [44]. Tools used for cutting come in a variety of shapes, and each shape can be thought of as an ultrasonic horn that is part of an overall ultrasonic resonant system. Cutting with superimposed ultrasonic vibrations directly competes with conventional techniques such as knives and saws and high-speed waterjet cutting. Ultrasonic cutting requires little energy [45]. The characteristics of ultrasonic cutting depend on the condition and type of food, that is, thawing or freezing. Cutting fragile and foreign foods such as pastries, cakes and other baked goods, cheeses and sticky products is one of the most popular applications. Vibration prevents product from sticking to the blade and reduces microbial growth on the product surface. In other words, ultrasonic vibrations allow for “self-cleaning” of the blades. The repeatability and precision of cuts reduces losses due to cracks and crumbs compared to cuts, and improves weight standardization and part dimensions. [46].

**Sterilization/pasteurization**

Thermal sterilization and pasteurization are conventional techniques commonly used to inactivate enzymes and microorganisms in food. Thermal sterilization leads to significant loss of nutrients, development of off-flavours and loss of functional properties of food. Due to the cavitation effect, ultrasound helps eliminate these negative effects of Thermal sterilization. [47]. Ultrasound assisted pasteurization has found to be very effective against E. coli, Listeria monocytogenes and Pseudomonas fluorescens with no ill effect on casein or total protein content of the milk pasteurized [48]. The killing of microbes is due to cell membrane thinning, free radical production, and localized heating. Ultrasound alone or in combination with temperature and pressure is effective in inactivating enzymes such as polyphenol oxidase, peroxidase, lipoxyginase and pectin methylesterase, stopping the degradation of vegetables, fruit juices and dairy products. known to be relevant [49].

**Extraction**

Extraction is a key process step to effectively separate and produce various oils, bioactive compounds and molecules from their matrices. Soxhlet extraction, heating to reflux, and maceration are the most commonly used conventional extraction techniques that require large amounts of solvent. labor intensive, energy intensive, cost intensive [50]. Ultrasound-assisted extraction is an effective alternative that overcomes the drawbacks of traditional technologies with enhanced yields [51]. Ultrasonic implosion and cavitation disrupt cell walls and improve mass transfer from solid to liquid phases. In addition, the application of ultrasound creates microchannels within the tissue, enhancing solvent penetration into solid matrices and increasing mass transfer [52]. Thus, Ultrasonic extraction contributes to efficient recovery of compounds with reduced time, energy and solvent requirements, bringing the additional benefits of cold extraction to temperature sensitive foods. Ultrasound-assisted extraction is usually performed in continuous wave mode, while pulsed mode techniques are used for long-term extraction. It is generally preferred for the extraction of bioactive compounds due to its versatility, ease of use, industrial applications, and low solvent usage and retention of bioactivity [53]. Recently the ultrasonic assisted extraction has been extensively employed for the extraction of bioactive compounds from food and food wastes.

**Rehydration**

Ultrasound has been used as a pretreatment for drying, dehydration as well as rehydration operations. Aksoy et. al. (2019) also reported, that ultrasound treated samples showed higher rehydration ratio for minced meat at 35°C and 25 KHz in comparison to control samples [54]. Similar results were reported for rehydration of dried carrot treated with ultrasound. Researchers have reported that application of ultrasound can lead to pore formation and develop higher internal stress [55]. Osmotically dehydrated samples that were sonicated and rehydrated showed higher rehydration rates due to the formation of microporous channels by sonication [56]. Miano et. al. (2016) suggested that the application of ultrasound improves the mung bean hydration process and reduces the time required for it [57]. They also succeeded in increasing the germination rate of the beans, which is desirable for germination without changing the starch properties.

**Homogenization and Emulsification**

Sonication of fresh milk at 20 kHz reduced fat globule size. Homogenization for 10 minutes at power level 40 was similar to conventional homogenization. Ultrasonic emulsification is primarily caused by cavitation, the collapse of air bubbles at the interface of two immiscible continuous and dispersed phases [58]. High-amplitude homogenization also improved water-holding capacity and viscosity, and reduced syneresis in yogurt made from sonicated milk [59].

**Cooking**

In conventional cooking methods, when food is exposed to high temperatures, the outside can be overcooked and the inside is undercooked, resulting in reduced product quality. Ultrasound is capable of providing improved heat transfer properties, which is an essential requirement to avoid such problems, and they are already used in cooking. [60]. A patent describes a cooking vessel in which ultrasound is applied to a hot oil to provide better and more even overall frying and it is claimed to reduce energy consumption [61].

**Demoulding**

In general, industrial cooking results in product adhesion to the cooking container or in other operations the container must separate from the mould. Currently, to solve this problem, mechanical methods such as vibrating tapping are used to remove the product. An alternative   
solution to these conventional methods is to demould food products by coupling the mould with an ultrasonic source. [62]. The industrial food product de-moulding device combines a mould and an ultrasonic source to promote the removal of the product contained in the mould by means of high-frequency relative motion between the contact surfaces of the mould and the product contained in the mould. This technique removes the surface coating and ensures that any material left in the mould can be cleaned automatically.

**Freezing and crystallization**

Freezing and crystallization are linked in that both processes involve, initial nucleation followed by crystallization [63]. Sonication is thought to improve both the nucleation rate and the crystal growth rate in saturated or supercooled environments by inducing a large number of nucleation sites in the medium during exposure to ultrasound. This may be because the foaming bubbles act as nuclei for crystal growth and/or the breakdown of particles or crystals already present in the medium, thereby increasing the number of nucleation sites. Under the influence of ultrasound, conventional cooling allows for faster and more uniform seeding, resulting in a much shorter residence time [64]. In addition, since there are a greater number of seeds, the final size of the ice crystals is smaller and so cell damage is reduced [65]. Accelerated cooling is achieved by improving heat transfer [66]. Acoustic cavitation also occurs and acts as nuclei for crystal growth or by disrupting already existing nuclei. In the case of freezing, this will lead to the formation of fine ice crystals and shorten the time from the onset of crystallization to complete ice formation, thus reducing damage to cellular structure [67].

**Chemical and physical effects of ultrasound**

During ultrasonication, hydrolysis occurs, resulting in the generation of H• and OH•. The hydroxyl radicals generated during ultrasonic treatment can be used to improve the hydroxylation level of the food matrix and thereby increase the antioxidant activity of the food [68]. The H• radicals and other secondary reducing radicals are used to generate metal nanoparticles by reducing metal ions and OH• radicals growing in bubbles oxidize organic pollutants. One of the important applications in the food industry is that superoxide species (HO2•) formed from primary radicals can form disulfide cross-links between proteins. Tiwari et al. (2009) found that vitamin C retention of ultrasound treated orange juice is higher than the other heat based treatments [69]. Some negative effects of ultrasonication have also been seen such as off flavor development. Riener et. al. (2009) showed that high ultrasonication of milk produces volatile organic compounds that may be responsible for the "rubbery" aroma of the milk [70]. The physical effects of ultrasound can be summed up as higher turbulance throughout the medium, but are strongest near system boundaries and interfaces. At low frequencies (20-100 kHz), these higher disturbances are mainly due to transient cavitation, i.e., catastrophic collapse of microbubbles around the liquid.

**Advantages and disadvantages**

Ultrasound applications offer numerous advantages in the food industry:

* 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.
* Ultrasonic treatments are flexible, adaptable, non-time consuming and do not constitute a risk to food scientist or industrialist.
* Ultrasound treated products will get minimum loss in flavour, colour and other nutritional compounds during processing.
* Ultrasound has gained huge applications in the food industry such as preservation, processing, extraction, emulsification, centrifugation homogenization, etc.
* Ultrasonication results in the production of a better-quality product at lower temperatures, with an improved rate of heat and mass transfer.
* It has been demonstrated that the technology enhances the thawing rate and improve the quality of food, reduce drying time and energy consumption, shorten the freezing time, and improve the quality of frozen food, reduce the cooking time with increased food quality, improve emulsion stability, and reduce the usage of cleaning chemicals thus prolong the service life of the filtration membrane.
* Ultrasound speeds up the filtration process, increasing the life of the filter, accelerates freezing, and results in smaller crystal size, faster drying, and thawing operations.
* With this technique, on-line measurements can be performed and are useful for monitoring food processing operations.
* It also aids in the retention of the product’s nutritional characteristics and increasing

the product shelf life.

* Low-intensity ultrasound is affordable and offer energy saving with practical uses in the food industry. Unlike most conventional food processing methods, green technologies such as ultrasound, when employed singularly or in combinations like manosonication and thermosonication conserve time, energy, solvent and water consuming.

Despite having lot of advantages, use of ultrasound waves has some disadvantages such as:

* The free radicals formed during cavitation may cause harmful effect on the consumer
* Ultrasound may cause physico-chemical effect which may be responsible for off-flavour, discoloration and degradation of components
* High initial investment and Frequency of ultrasound waves can impose resistance to mass transfer.
* Highly dependent on the sample matrix
* Highly dependent on presence of a disperse phase, which may reduce the effectiveness of the method
* Ultrasound, when applied at high intensities generates heat due to an escalation in temperature, which has detrimental effects on the organoleptic and nutritional characteristics of the food product.
* The lack of easily accessible scale-up technique and lack of proper technical knowledge are basic drawbacks.
* The absence of standardized reporting also hinders techno-economic assessment before industrial application.
* Moreover, the activated ultrasound zone is restricted to a limited zone within the ultrasound emitter vicinity.

**Future trends**

Many traditional food processing techniques are reaching their peak performance as consumer demand increases and food and environmental regulations are tightened. Research shows that ultrasound can play an important role in food technology: processing, preservation and extraction. While conventional cutting, emulsification and cleaning are often obstacles, a lack of knowledge has prevented the industry from integrating ultrasound into its processes. A recent survey and market research on possible future applications of new processing technologies (such as microwaves and ultrasounds) in the food industry revealed many companies to be hesitant to apply these new technologies. The main reason is the poor understanding of these new techniques by food professionals as well as the rationale or weight of tradition. Over the years, several studies have demonstrated the effectiveness of ultrasound in replacing and enhancing various conventional processing techniques in the food industry. However, the combination of ultrasound with other techniques produces better results regarding the overall quality of the final product and may be the subject of further research. The further development of ultrasonic application at the industrial level requires optimization of parameters and field studies to analyze the effect of acoustic treatment on bulk food production. Larger studies should also take into account the safety and harm aspects of ultrasound in humans. In addition, a huge amount of energy is required for the commercialization and industrialization of ultrasound, which is an obstacle to its application in the food industry. Therefore, ultrasonic research should be particularly focused on industrial-scale implementation. Future applications of ultrasonic technology will explore fusion with other non-thermal processes for improved results and efficiency.

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