Chapter

Importance and Applications of Ultrasonic Technology to Improve Food Quality

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Abstract

Nutritional value and quality of food products are very important for a healthy life of human beings. Various modern thermal and nonthermal application technologies such as pulsed light, pulsed electric field, high and low hydrostatic pressure, microwave, and ohmic heating have been used to improve food products characteristics. In recent years, ultrasonic applications have been used for food processing. The ultrasonic is defined as sound waves with a frequency exceeding the human hearing limit. Based on the frequency range of ultrasonic waves, it can be used in many industrial applications including the processing of food. Applications of high-power ultrasonic with low frequency aim to improve the quality of food products. Low-power ultrasonic with high-frequency applications are used for nondestructive quality evaluation of physicochemical properties of food. The most important advantages of ultrasonic technologies are the low cost of food processing, low power consumption, simplicity compared to other technologies, suitability for the treatment of solid and liquid food, and environmental safeness and friendliness, thus becoming a promising technology for monitoring and improving quality of food products. The main objective of this chapter is to provide an overview of the principal and recent applications of ultrasonic waves to improve food product quality.

Keywords: ultrasonic applications, ultrasonic frequency, high-intensity, low-intensity, cavitation, ultrasonic equipment, food quality

1. Introduction

Improving the nutritional values and stability of quality is a very important parameter in food product quality assurance for a healthy life of human beings. Consumers are looking for fresh and good characteristics in their food with nutrient content and high sensorial quality. Now, consumers are more aware of the processing techniques used in the processing of their food, and they prefer natural products free of additives and chemicals. Therefore, there is a need for alternative technologies for food processing. Recently, various modern thermal and nonthermal technologies such as pulsed light, pulsed electric field, high and low hydrostatic pressure, microwave, ohmic heating, freezing, pasteurizing, ionizing radiation, etc. have been used to improve the physicochemical characteristics, extend the shelf life of food products, and control food quality by inactivating microorganisms at sublethal or ambient temperatures. One of the nonthermal technologies that can be used also is the application of ultrasonic (high-power and low-power ultrasonic with low and high frequency); especially it has shown a negligible effect on the nutrient value of food products [1, 2]. Applications of ultrasonic technology for food processing aim to offer consumers high-quality foods. The ultrasonic is considered to be a promising and emerging technology that can be used in food processing technology and many industrial applications by regulating frequency [3]. According to sound wave ranges used, the ultrasonic can be divided into low-power high-frequency ultrasonic and high-power low-frequency ultrasonic [4]. Low-power ultrasonic with high frequency is used for nondestructive quality evaluation of physicochemical characteristics of fruit, vegetables, and food products during processing or storage. The high-power ultrasonic with low frequency is used to improve the physicochemical properties of food products and in food processing such as humidification, hydrothermal treatments, extraction, drying, freezing, and inactivation of microorganisms of food products [3]. The ultrasonic technology has been also used in the industry of food products to develop many reliable and effective processing applications of food. The most common applications of ultrasonic in the industry of food include extraction of intracellular and material cell destruction. Depending on the ultrasonic intensity, the ultrasonic is used for the deactivation or activation of enzymes, homogenization and mixing, dispersion, stabilization, crystallization and dissolution, emulsification, hydrogenation, preservation, ripening, meat tenderization, oxidation, as a solid-liquid extraction adjuvant to accelerate and to improve the extraction, and atomization and degassing of food processing [5]. The objectives of ultrasonic research are to analyze and study the phenomena of undesirable and desirable degradation resulting from the applications of ultrasonic wave treatments in foods. The processing using ultrasonic may impact the chemical composition texture of foods [6].

Generally, ultrasonic applications are environmentally friendly and offer an advantage in the selectivity, yield, and productivity, with enhanced quality, reduced physical and chemical hazards, and short processing time. Before the commercialization of some food products such as vegetables and fruit, oils and fat, cocoa-sugar and coffee, meal and flours, dairy, and meat which are complex mixtures of proteins, sugars, lipids, vitamins, aromas, fibers, antioxidants, pigments, and mineral and organic compounds have to be processed and preserved using ultrasonic applications for food meals and to extraction of food ingredients [7]. The main purpose of this chapter is to provide an overview of the basic principles and current applications of low-intensity and high-intensity ultrasonic waves as a modern nonthermal technique for food product processing technology to improve its quality.

2. Overview of sound waves

The sound wave type is determined by its frequency. **Figure 1** shows the sound spectrum which displays the various frequencies present in a sound. “Infrasound” indicates a sound wave below the human hearing range. This frequency of sound is used by submarine sonar devices and whales. The frequency of the sound for the human hearing ranges from 20Hz to 20 kHz [8, 9]. The sound signal arises from many sources, e.g., the air turbulence or gases, passage through fluids, and by the impact of solid against another solid similar or non-similar. Because the sound is a natural phenomenon of waves, it may contain only one frequency as a sine wave with pure steady state (**Figure 2**) or contain complex frequencies such as the noise generated by many sound sources, e.g., machines and engines. The frequency of sound (f) is sound pressure times number. The sound frequency also may be identified by the frequency of angular (ω) expressed in radians per second as shown in Eq. (1). The period (T) is the time amount for a cycle of the single [10]:

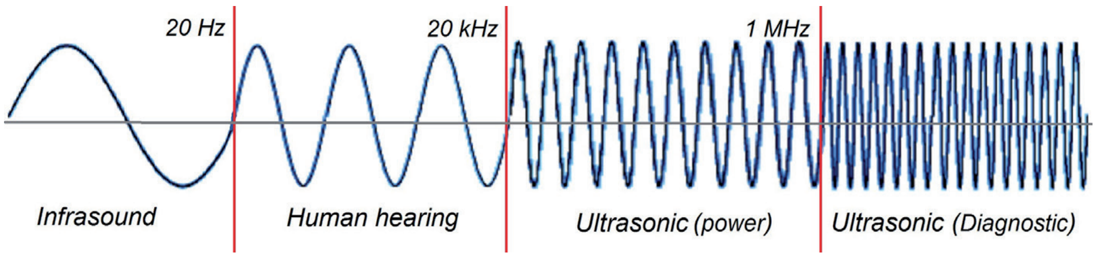

Figure 1.
Sound spectrum.

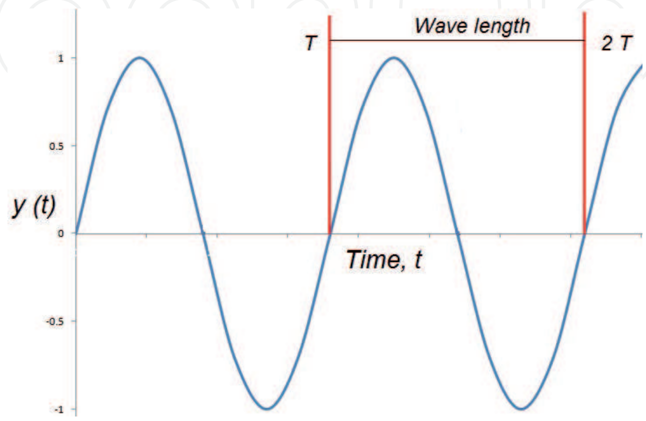

Figure 2.
The pure steady-state sine wave pulses.

$$\omega = 2\pi f = \frac{2\pi}{T} \quad (1)$$

Actually, the amplitude of the sound wave is strongly affected by the particles near the source of the sound waves, and on the contrary, the deeper particles are in the treated medium, the lower the sound wave amplitude. This reduction in sound wave amplitude at the deep is due to the attenuation produced by the treated medium. As a result, the sound amplitude versus wavelength distance is actually an exponentially sinusoid degenerate (**Figure 3**). The wavelength ((λ) is the distance between peaks of successive amplitude) is related to frequency (f) through the traveling wave velocity (c) as shown in Eq. (2) [11]:

$$\lambda = \frac{c}{f} \quad (2)$$

Ultrasonic is a wave of sound with a frequency greater than the human hearing limit. Ultrasonic is considered an energy form generated by a longitudinal mechanical

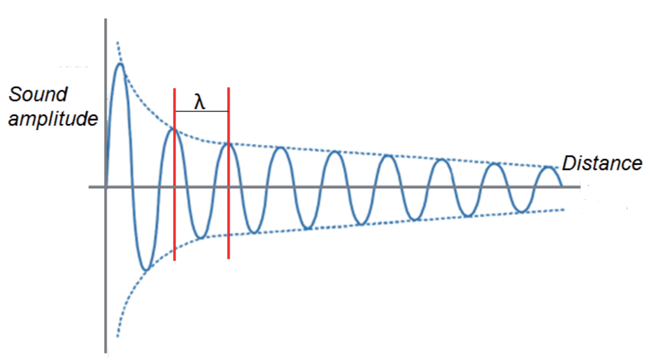

Figure 3.
Sinusoidal ultrasound wave.

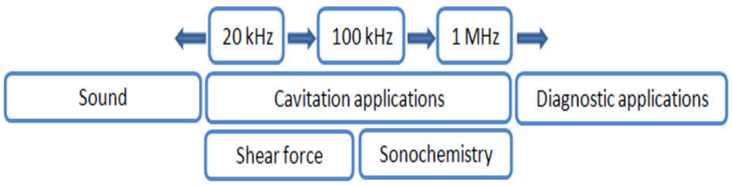

Figure 4.
Ultrasonic frequencies classification.

wave with one-dimensional propagation and frequency of vibration above 20,000 cycles per second (20 kHz) as shown in **Figure 4**. Ultrasonic waves can be categorized according to its frequency into two categories that are: (1) Low-frequency category which has frequency ranging from 20 to 1000 kHz. The applications of this category are used at high-power intensities in industrial applications, ultrasonic therapy, sonochemistry, and nanotechnology. (2) High-frequency category which has a frequency above 1 MHz and is being used at low-power intensities for nondestructive quality evaluation, imaging, and diagnostic applications [6, 12].

Use of ultrasonic application provides a good way to reach higher rates for the chemical and physicochemical process, shorter processing times and pathways of reaction. Interaction mechanisms between the product material and ultrasonic waves vary as a function of the input power of the ultrasonic. The pulse of ultrasonic speed depends on the acoustic properties of the medium of treated material. The speed of sound propagation in solid materials is higher than the sound propagation speed in liquids and greater in liquids than in gases [9].

3. Ultrasonic equipment

The main equipment of ultrasonic consists of a transducer, electrical power generator, and sound emitter devices. The emitter's function is to physically send the waves of ultrasonic to the medium. There are two types of ultrasonic systems used in the industry of food products: one using the bath as a traditional method and other using the horn as the sound emitter. The horn-based system is utilized in many applications from ultrasonic application in food processing and cleaning of plant surfaces for the process of food to application of ultrasonic for welding of metals [11].

3.1 Ultrasonic transducers

The transducer is the most important part of ultrasonic systems; the role of the transducer in the system is to generate the actual ultrasonic waves by converting the mechanical or electrical energy into sound energy at ultrasonic frequencies by vibrating mechanically. The ultrasonic transducer contacts to an electrical generator with 20 kHz frequency to transform electrical energy into ultrasonic energy by mechanical vibration at the same frequency (20 k cycles per second) [13]. The most applicable methods of ultrasound generation are carried out using ultrasonic transducers depending on the principle of the electrostrictive transformer. The principle of the methods is based on ferroelectric materials' elastic deformation within a high-frequency electrical field which results in molecules' polarized mutual attraction in the field. Then, the high-frequency alternating current is transmitted via two electrodes to ferroelectric material. After generating mechanical oscillation, the waves of sound are transmitted to the amplifier to generate the ultrasound [14].

The ultrasonic transducer is an electronic device that generates and receives the waves of sound. The transducer basically functions as a converter of energy, where it converts a form of acoustical energy into other energy forms (e.g., mechanical, electrical, or thermal energy). In addition, the transducer is reversible in either direction to convert electrical or mechanical energy to sound energy or vice versa. The most high-intensity ultrasonic generators are essentially magnetostrictive devices crystal oscillators in use. The categories of ultrasonic transducers fall into the following [10]:

1. Crystal oscillators are work through the effect of piezoelectric (reversible).

2. Magnetostrictive equipment are works based on the phenomenon of magnetostriction (reversible also).

3. Mechanical transducers that operate as generators and receivers.

4. Electromagnetic transducers are work based on the principle of the audio loudspeaker (but only work in the lower frequencies range of ultrasonic).

5. Other different types are thermal, optical, and chemical transducers.

6. Ultrahigh transducers that operate in the frequency range at megahertz or gigahertz.

Generally, the main transducers used in the most ultrasonic application can be summarized into three types: piezoelectric, magnetostrictive, and liquid-driven. The piezoelectric and magnetostrictive transducers convert magnetic and electrical energy into ultrasonic energy. The liquid-driven transducers depend on mechanical energy to generate ultrasonic energy [15].

3.2 Electrical generator

The electrical generators are used to supply the ultrasonic systems with the required electrical energy to drive the transducer. Generally, the electrical generator produces a suitable power rating for the ultrasound system and allows the power to be set only indirectly through current (I) and voltage (V) settings. The current represents the electron charge traversing an area over some time interval and measured in amp, the voltage represents the stored energy in the electrons and measured in volt, and the electrical power is the output of current and voltage. Electrical generators that are designed and operate in the low frequency ranged from 10 to 40 kHz

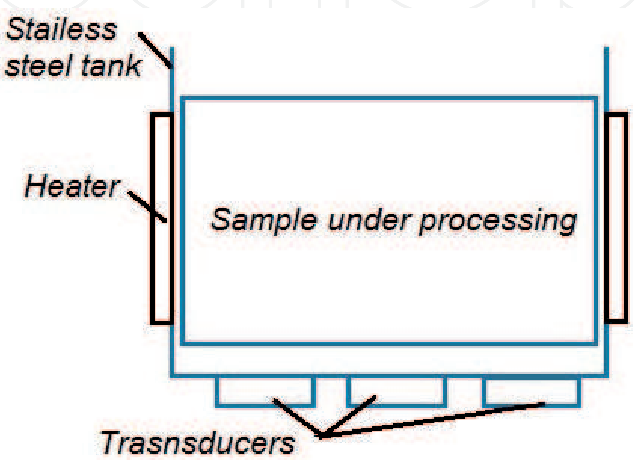

Figure 5.
Ultrasonic bath.

for ultrasonic generally focusing on industrial therapeutic applications, welding, cleaning, and disinfecting applications [11, 13].

3.3 Emitter (reactor)

The function of the emitter (reactor) is to radiate the waves of ultrasonic which are produced by the transducer into the treated medium. In addition, the role of the emitter may also be to amplify the ultrasonic vibrations when radiating them in some ultrasonic system. The main types of emitters are horns and baths; the horns often require a sonotrode to attach with the horn tip. The baths (**Figure 5**) usually consist of a stainless steel tank fixed with its base one or more transducers. The stainless steel tank holds a liquid case sample, and the transducers radiate ultrasonic directly into the sample [15].

4. Applications of power ultrasonic in food processing

Although the ultrasonic has been used in the twentieth century, most of the new and improved ultrasonic applications has reached practically only in the past few years. Ultrasonic applications can be classified into two categories as high intensity and low intensity. High-intensity applications deliberately affect the contents of the propagation medium. Uses of high intensities include liquid atomization, material machining, medical surgery and therapy, material cleaning, plastics and metals welding, biological cell disruption, and material homogenization. Low-intensity applications carry the objective of transmitting energy through a medium in order to convey information through the treated medium or to obtain information about the medium. Uses of low intensities include nondestructive testing, medical diagnosis, elastic property measurements of materials and agricultural products, and acoustical holography. Nowadays, ultrasonic application technology has extremely affected the meat industry, with a controlling role in the classification of the product quality. It is being used to measure the fat layer thickness in live animals, and it is also utilized to predict carcass traits as a livestock management part, and it has been used to improve homogenized milk quality. In addition, the ultrasonic application technology is utilized in the pest control that includes the expulsion or killing of insects [10, 11]. The potential uses of ultrasonic applications technology for improving the nutritional and quality aspects of food have been highlighted by Ashokkumar [16]. The ultrasonic application technology offers a huge potential to bioprocessing industries and foods. Developing custom-made and new equipment is an issue to be addressed by food technologists, physicists, and engineers [16].

In addition, ultrasonic applications have been used for food processing as an important alternative processing method of conventional thermal. Ultrasonication process can preserve and pasteurize food products by inactivation of microorganisms and many enzymes at normal conditions of temperature to guarantee the safety and stability of foods for improving food quality. The changes in ultrasonic physical properties, such as attenuation and scattering caused by treated food product materials, have been also used in applications of food quality assurance [17]. The potential applications of ultrasonic are not only affected by the medium (gas, liquid, solid, or supercritical) but also the treatments variables (flow regime, temperature, ultrasonic intensity, etc.) and the structure of product which could affect the magnitude of the changes induced by ultrasonic processing [18]. Ultrasound can be divided into different frequency ranges. Most ultrasonic applications in the food processing technology involved nondestructive measurements which referred especially to the assessment of product quality; such applications use low power less than 1 W/cm^2

and high-frequency ultrasonic of 100 kHz to 1 MHz. Low-intensity ultrasonic is commonly applied as an analytical method to provide information on the food product's physicochemical properties such as acidity, ripeness, firmness, content of sugar, etc. The high power levels used (typically in the range 10–1000 W/cm^2) with low frequency (16–100 kHz) are used to make physical or chemical changes in the food to improve its properties [11, 19].

Generally, the ultrasonic applications are separated into two categories: the first category is low-intensity ultrasonic (called nondestructive or high-frequency ultrasound), and the second category is high-intensity ultrasonic (called low-frequency or power ultrasound) [20].

4.1 Applications of low-intensity ultrasonic

Low-intensity high-frequency ultrasonic is a nondestructive technique which is applied for detection purposes and provides information about the physicochemical characteristics of food products such as structure, firmness, composition, flow rate, physical state, etc. [21]. The action of ultrasonic waves is dependent on the input power. So the low-power ultrasonic is considered a noninvasive nondestructive method, and it is a useful technique for characterizing the physicochemical properties of food products, determining the food components type and contents, and measuring the emulsions droplet size. Irradiation of food products by low-power ultrasonic did not create any physical changes, at variance the high-power ultrasonic created the changes [9]. It is also used as a processing method in the industry of food to describe the components of food products, often in line with quality assurance. The nondestructive test basically is done by sending waves of ultrasonic through the medium without causing any permanent electrical, chemical, or physical changes in the food products. This is due to the use of too low ultrasonic intensity (<1 W/cm^2), so there is no change in the foods by using this [11, 20, 21].

When ultrasonic waves pass through the medium, the particles in the medium oscillate mechanically in response to the low-intensity (low-energy) ultrasound. After that, the particles exposed to the waves of ultrasonic simply return to their position of equilibrium when the ultrasonic source is stopped. The distance to the location of reflection can be calculated by measuring the attenuation coefficient and frequency properties of ultrasonic to evaluate the physicochemical properties and to allow detection of compositional changes in the food products [11, 21]. In using low-intensity ultrasonic to characterize vegetable and fruit properties, there must be a relationship between the property to be measured and any measurable parameter of ultrasonic (e.g., impedance, attenuation, or velocity). The particular parameter that often influences the properties of ultrasonic in vegetables and fruits is the presence of intercellular air spaces that causes a resonant phenomenon over ultrasonic frequencies in a wide range. The appropriate frequency which transmits normally through vegetables and fruits is above 1 MHz at low intensity to avoid the damage in plant tissue [22].

On the other hand, there are other indirect applications for high-frequency ultrasonic in food processing area such as applications of ultrasonic in humidifiers or misting devices which are used in humidification or hydration of fresh fruit and vegetables or humidification systems of meat in the cold storage rooms for improving the quality of the product and decreasing the weight loss during the storage period. The operating principle of ultrasonic humidifiers depends on converting the electrical energy into periodically mechanical vibration by piezoelectric transducers and horn, which vibrates at high frequencies. The piezoelectric transducers are placed at the bottom of the water in order to produce high-frequency waves that propagate upward into the water. Then the ultrasonic wave rarefaction cycle causes cavitation; in addition, the water over the piezoelectric transducer will produce a wavy layer. If the ultrasonic waves have enough energy that can overcome the water surface tension, then droplets will be generated from the water top surface. When the vibrating surface amplitude is increased to a level that the ultrasonic waves collapse and are unstable, the droplets will be ejected away from the water surface into a mist. The droplet's size is dependent on the frequency of vibration and water depth above the piezoelectric transducers [23, 24].

The diameter of the atomized droplets is calculated based on the properties of the ultrasonic generator by Eq. (3) [25–27]:

$$D_d = \alpha_g \sqrt[3]{8\pi \times \sigma_s/\rho_s \times f^2} \tag{3}$$

where D_d represents the droplet diameter, f is ultrasonic frequency, ρ is a liquid density, σ is a surface tension, and α_g is a dimensionless constant ($\alpha_g \approx 0.4$).

Generally, low-intensity ultrasonic applications can invaluably improve quality control in food production and monitor the changes that occur during humidification, emulsifying, freezing, or drying of food products. Some food manufacturers use nondestructive ultrasonic applications to locate foreign particles such as organic residues, bacterial infections, or glass in solid and liquid food products during and even after food packaging [28]. Low-intensity ultrasonic has been used successfully at ultrasonic wave frequency of 150 kHz as a noninvasive and nondestructive means of evaluating the commercial poultry egg quality at different conditions of storage using the velocity ultrasound phase within the material of eggs to recognize the differences between the aged and fresh eggs [29].

Low-intensity ultrasonic applications are considered one of the efficient tools for nondestructive quality evaluation of fresh fruits and vegetables. These applications are characterized as a reliable and fast technique for correlating fruit and vegetable properties and specific indices of quality with the different growth stages, after maturation, during storage, and after storage to be ready for marketing and consumption while ensuring its quality. Commercial application of ultrasonic applications will be useful to consumers and growers due to the public demand for high-quality and uniform agricultural products [30]. High-frequency ultrasonic technique using a contact transducer of 100 kHz as a nondestructive tool to determine fruit quality of navel oranges was applied successfully after fruit harvesting with a high accuracy level. Water content and density of the fruit can be determined accurately regardless of the other physical properties such as maturity, size, and the peel uniformity by isolating the results section which relates straight to the fruit acoustic properties. There is a high level of correlation between orange firmness and the reflected energy quantity of ultrasonic. Using ultrasonic technique, substandard individual fruit can be identified and sorted to be discarded at any harvest time and during processing or in a storage room. On the contrary, the methods of traditional destructive can be applied only on a limited sample of fruit after harvesting [31]. The measurements of the ultrasonic velocity (high-frequency) and attenuation which was conducted at 25 MHz on samples of mango juice showed a big variability with a maturity of fruit at picking and after picking at ripening stage in relation to texture of fruit, the content of total soluble solids (TSS), and changes in biochemical composition [32]. Many research has been done on nondestructive applications of ultrasonic technologies in food processing, but further future research is needed in this area in order to develop new automated ultrasonic equipment.

4.2 Applications of high-intensity ultrasonic

Applications of high-intensity ultrasonic or power ultrasonic are used to change the physical or chemical properties of food products as well as to promote the reactions of chemicals, produce emulsions, inhibit enzymes, disrupt cells, crystallization processes modification, etc. [21]. The use of high-intensity low-frequency ultrasonic waves generating sonotrodes was initially proposed for cleaning, emulsification, and bacterial lysing. The high-intensity ultrasonic wave (high-power) equipment using sonotrodes operating was further developed for processes of chemicals (up to 6 kW). In recent, ultrasonic systems are developed to generate high mega-sonic frequencies of ultrasound (400 kHz) with a high power level (>100 W). Therefore, the high-intensity ultrasonic wave is suitable for many applications in food products [33].

The high-intensity ultrasonic fundamental effect on the fluid material is for effective hydrostatic pressure on the medium and the imposition of acoustic pressure. The acoustic pressure (P_a) is a sine wave dependent on the ultrasonic frequency (f), time (t), and the wave pressure amplitude at the maximum ($P_{a\text{-}max}$) [Eq. (4)]. The maximum wave pressure is proportional to the transducer power input [34]:

$$P_a = P_{a\ max} \sin(2\pi f t) \tag{4}$$

The application of high-intensity ultrasonic (high power level = 75 W) was developed and tested to assist in convective heat transfer during food drying. The application of ultrasonic is based on the ultrasonic energy transmission through airborne contacts and solid contact series between the ultrasonic transducer and the tray of the food product as a vibration surface of ultrasonic transmitting. The slices of apple were dried using this method without compromising the quality of the product. The results indicated that using the ultrasonic application during apple drying led to the following: processing time was accelerated, consumption energy was reduced, production throughput was increased, and the quality of the product was not affected by ultrasonic processing. The results also indicated that the ultrasonic treatments led to improve the convective drying process efficiency when using high-power ultrasonic at low temperature. These results are very useful at the need to dehydrate heat-sensitive products effectively or to decrease food drying time in order to preserve the physicochemical and nutritional properties of food products [35]. Pasteurization of many food products by an ultrasonic application at 50°C has a preserving potential on the food quality in terms of color, flavor, and physicochemical properties compared to the techniques of conventional pasteurization at high temperatures [36]. The propagation of ultrasonic in a medium causes chemical and physical impacts, and these impacts have been used to improve the efficiency of the operations of various food processing technologies, and it has been also used as diagnostic technology in food quality control. The high-intensity ultrasonic application was applied to control ice crystal's size distribution in low-temperature processes and related applications such as thawing, freezing, freeze-drying, and freeze concentration. It has been led to improve the freezing process efficiency, accelerate the freezing rate, and ensure frozen food quality [37].

High-intensity ultrasonic is being applied as an efficient preservation tool in fields of food processing for fruits and vegetables, honey, cereal products, proteins, gels, enzymes, cereal technology, dairy technology, water treatment, microbial inactivation, etc. [38]. In a previous study, the researchers have studied the effects of high-intensity ultrasonic at different levels of power ultrasound of 0, 200, 400, and 600 W as nonthermal processing on microbial inactivation (aerobic mesophilic, molds, yeasts, and coliforms), microstructure (particle size distribution and optical microscopy), rheology, color, and kinetic stability of the inulin-enriched whey beverage. The result obtained by applying ultrasonic power of 600 W was comparable to applying a high temperature of 75°C at short treatment time of 15 s concerning the total microbial inactivation. In addition, the high-intensity ultrasonic was better than the high-temperature short-time ultrasonic in improving kinetic stability of beverage, decreasing consistency and viscosity, avoiding phase separation, disrupting fruit and milk cells, and decreasing particle size. Therefore, nonthermal processing by high-intensity ultrasonic seems to be a promising technology for the production of probiotic dairy beverages. However, further future studies concerning the ultrasonic application effect on nutritional properties of this product must be evaluated before marketing [39]. Sterilization and improved emulsification can be conducted at lower temperatures than conventional treatments at high temperatures using high-intensity ultrasonic to produce a stable food product by retaining the useful bioactive ingredients and preventing spoilage of treated food. Applications of high-intensity ultrasonic in the fractionation of fat, dairy beverages production, and disruption of casein offer the potential of decreased treatment times; properties of the possible product have more advantages than those produced through conventional thermal techniques. Therefore, using ultrasonic applications in this area will lead to economic savings to producers in terms of producing value-added products and processing times and temperature. The consumers were satisfied with ultrasonic application studies for processing of food products to improve the quality of final products in terms of flavor, color, texture, and other physicochemical characteristics [40].

High-intensity ultrasonic treatment is a good process to inactivate enzymes and microorganisms at combined pressure and heat treatments as a hurdle technology. This combination is a successful application in lower temperatures for the inactivation process which provides a good solution for food product producers to secure fresh-like foods [41]. The impact of power ultrasound on the fruit and vegetable quality during drying and pre-treatment has been assessed. The indicators of fruit quality such as the losses of leaching, rehydration capacity, shrinkage of fruit, and the final product's organoleptic characteristics have been also evaluated. The result showed that enzyme inactivation and leaching losses during blanching using high-intensity high-power ultrasonic at low temperature are similar to the result found using conventional treatments, but there is a significant reduction in the ultrasonic treatment time. Ultrasonic application in the drying of strawberries and carrots produces a highly significant reduction in the time of processing while providing high-quality final products. The final products' quality was equivalent or superior to final products obtained in convective dryer prototype under similar conditions, was higher than marketed products, and was similar to the produced products by freeze-drying [42]. The impact of low-frequency high-power ultrasound (40 kHz, 130 W) on bean in terms of kinetics of hydration and cooking times was studied. Treatment of bean samples by ultrasonic waves for 30 min at 30°C 30 min occurs a significant increase in the effective diffusivity up to 45 times and reduces the time which obtains the equilibrium moisture content by 58.8% and the reduction percentage in cooking time reached 43% [43].

Generally, high-power ultrasonic has become an efficient technique for some commercial applications, such as homogenization, emulsification, crystallization, extraction, dewatering, low-temperature pasteurization, deforming, degassing, viscosity alteration, reduction of particle size, and inactivation or activation of enzymes. In addition, due to the need for inactivation of enzymes and microorganisms without destroying food nutrients, the high-power ultrasound applications are the best processing methods as a nonthermal alternative method to thermal processing treatments for food product preservation. This is due to continuous development and improvement in the design and manufacturing of ultrasonic equipment, but high-power ultrasonic for food processing like most innovative technologies in this field is not an effective technique for large-scale commercial application. Therefore, there is a need to conduct research on high-power ultrasonic for it to become an efficient large-scale commercial technology for processing food products [36, 44].

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5. Applications of cavitation

The cavitation phenomenon (liquid rupture) is easily observed in water boiling, turbines, hydrofoils, and in seawater in the proximity of a rotating propeller of the ship. It happens in those liquid regions that are subject to rapidly vacillating pressures with high amplitude. Cavitations also happen in a liquid exposed to high-energy ultrasonic, considering that the sound travels through a small volume of fluid or water. During the negative half of the pressure cycle, the liquid is exposed to tensile stress, and during the positive half of the pressure cycle, the liquid is exposed to compression stress. Therefore, the bubbles entrapped in the liquid will extend and retract alternatively. When the amplitude of pressure is sufficiently large and the bubble initial radius is minimal than the critical value, R0 is given using the following equation [10]:

$$R_o = 1/\omega\sqrt{3\gamma\left(\left(P_o + \frac{2T_{st}}{R_o}\right)/\rho\right)} \tag{5}$$

where ω is a signal angular frequency, P_o is the hydrostatic pressure in a liquid, γ is a principal specific heat ratio of the gas in a bubble, T_{ts} is a surface tension at the bubble surface, and ρ is the intensity of liquid.

The sound pressure load (<10 Pa) exerted on the ear of human is very small, but the pressure of ultrasonic (MPa) in liquids can be high enough to create the cavitation phenomenon (can destroy the treated medium). Ultimately, the cavitations lead to free radical production and sonochemical that react chemically with media (liquid) and also lead to the destruction of microbiological cells [11]. The ultrasound passage in liquid products generates a physical effect and mechanical agitation due to acoustic cavitation [16]. The food industry has usually depended on the heating methods for enzyme and microorganism inactivation for preservation of food products. Despite thermal method actually leading to destroy some spores, kill microorganisms, and inactivate some enzymes, food may lose their organoleptic and nutritional properties during the process. On the contrary, the inactivation mechanism using the ultrasonic application depends on the generation of physical forces due to the phenomenon of cavitation [17]. Transmitted, dispersed, and reflected pulses of acoustic can be used in food product quality assurance. Using ultrasonic application for enzymatic inactivation of some food products is very important for the preservation of quality which is a requisite for secure food material stabilization. The physical and chemical forces generated by ultrasonic cavitation raise severe damage to the microorganism's cell wall, leading to microorganism inactivation. In addition, ultrasonic cavitation effects in liquid foods lead to disrupting the functional and structural components up to microorganisms cell lysis [17]. The applications of ultrasonic that are used for flaw detection in food processing for quality assurance of food products must be designed with ensuring that no cavitation possibly occurs. On the contrary, there are other applications of ultrasonic, depending on inertial cavitation to produce desirable changes in food products. These changes are produced by cavitation, such as microorganism inactivation and release of nutritional compounds and oils through the erosion of the cellular structure of the treated product cell [11]. The released energy during cavitation has a great ability to improve food products' safety by destroying the pathogenic and food spoilage microorganisms and foreign material detection in food products. Although the applications of cavitation are well applied in many different industries other than food processing, the application of cavitation in processing of dairy products and its ingredients is recently gaining much attention, and it has a large potential to become a promising method in the near future in dairy product processing area such as reduction of viscosity, homogenization, making of yogurt, cream, and cheese, waste management, microbial inactivation, food safety, etc. Power ultrasound cleaning application at low frequency generally operates between 20 and 50 kHz. The cleaning effect of ultrasound depends on cavitation. Increasing the cavitation in cleaning liquid increases the ultrasonic cleaning effect. The most important parameters affecting the cavitation are ultrasonic frequency and temperature [41, 45].

6. Conclusions

Ultrasonic applications can be considered promising and applicable as a green technology for food safety and quality assurance purposes of food products. Ultrasonic applications are divided into two categories according to its intensity and frequency: high frequency with low intensity (power ultrasound) and low frequency with high intensity (nondestructive). High-intensity applications deliberately affect the contents of the propagation medium. Uses of high intensities offer an advantage in the selectivity, yield, and productivity, with enhanced quality, reduced physical and chemical hazards, and short processing time. Before the commercialization of some food products such as vegetables and fruit, oils and fat, cocoa-sugar and coffee, meal and flours, dairy, and meat which are complex mixtures of proteins, sugars, lipids, vitamins, aromas, fibers, antioxidants, pigments, and mineral and organic compounds have to be processed and preserved using ultrasonic applications for food meals and to extraction of food ingredients. Low-intensity applications are used for nondestructive quality evaluation of food products. The physical and chemical forces generated by ultrasonic cavitation raise severe damage to the cell wall of microorganisms, leading to their inactivation. A major advantage of the ultrasonic applications in food processing is that it is perceived as benign by the consumers. On the contrary, other processing technologies such as gamma radiation, microwaves, ohmic heating, and pulsed electric field can be cautiously considered by some of the population. Generally, the sound waves are considered nontoxic, safe, and environmentally friendly; this gives the use of ultrasonic major advantage over other modern processing techniques. In addition, it is characterized by the low cost of construction, low power consumption, simplicity compared to other technologies, and suitability for solid and liquid food products. Despite conducting a lot of research on applications of ultrasonic technologies for food products, there is still a need for more future research in order to utilize this technology on a fuller industrial scale to produce high-quality and safe food products.

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Conflict of interest

The authors declare no conflict of interest.

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