



## Ultrasound Applications in Fruit and Vegetable Processing

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**Abstract:** Thermal treatments are the most traditional and widespread methods used for food processing and preservation. However, these treatments in terms of time and high temperature can cause changes in flavour, taste, colour, texture, nutritional value and sensorial properties of foods. Considering consumer demand for fresh and natural food products, non-thermal food preservation techniques have been gained wide interest. An interesting alternative means of preserving of foods and avoiding the adverse effects of thermal treatments could be provided by the ultrasound applications.

Ultrasound consists of sound waves with high frequencies which is near the upper limit of human hearing range. Nowadays, applications of ultrasound and its effects on food components have attracted considerable relevance among researches due to its promising effects in food processing and preservation. It has been realized that ultrasound applications have much offer to the food industry such as drying, microbial inactivation, enzyme inactivation, filtration, freezing, extraction, production of emulsions and etc. In this review, the principles of ultrasound system is explained and the effects of ultrasound applications in fruit and vegetables processing are outlined.

**Keywords:** Fruit, non-thermal processes, ultrasound, vegetable.

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## Meyve ve Sebzelerin İşlenmesinde Ultrases Uygulamaları

**Öz:** Isıl işlemler gıdaların işlenmesinde ve muhafazasında kullanılan en geleneksel ve yaygın yöntemlerdir. Bununla birlikte, bu uygulamalar yüksek sıcaklık ve uzun süre gerektirmesi bakımından gıdaların lezzet, tat, renk, tekstür besin değeri ve duyuşal özelliklerinde değışikliklere neden olabilmektedir. Tüketicilerin taze ve doğal gıda ürünlerine olan talebi göz önüne alındığında, ısıl olmayan muhafaza teknikleri geniş ilgi görmektedir. Ultrases uygulamaları, ısıl işlemlerin olumsuz etkilerinden kaçınmanın ve gıdaların muhafazasının ilginç bir alternatif yoludur.

Ultrases, insan işitme aralığının üst sınırına yakın, yüksek frekanslı ses dalgalarından oluşur. Son zamanlarda, ultrases uygulamaları ve gıda bileşenleri üzerindeki etkileri, gıda işleme ve muhafazasındaki gelecek vadeden etkileri nedeniyle araştırmalar arasında hayli ilgi çekmektedir. Ultrases uygulamalarının, gıda endüstrisine kurutma, enzim inaktivasyonu, filtrasyon, dondurma, ekstraksiyon, mikrobiyal inaktivasyon, emülsiyon üretimi gibi pek çok alanda önem arz ettiği anlaşılmaktadır. Bu derlemede ultrases sisteminin prensipleri açıklanmış ve ultrases uygulamalarının meyve ve sebze işlemedeki etkileri özetlenmiştir.

**Anahtar Kelimeler:** Isıl olmayan işlemler, meyve, sebze, ultrases.

### Introduction

Ultrasound is a process which carried out under pressure of waves with a frequency of 20000 Hz or more. The acoustic wave is one of the mechanical waves, and waves propagation carry out with a material medium. Usually, waves are classified using the human audible frequency as a reference. On the other hand, low-energy ultrasounds are defined through frequencies of more than 100000 Hz at densities under  $1 \text{ W cm}^{-2}$ . High-energy ultrasonics are defined by densities upper than  $1 \text{ W cm}^{-2}$  at frequencies between 20000 Hz and 500000 Hz. The ultrasound waves demonstrate several alterations in their properties (speed, abatement, frequency spectrum) during propagation owing to a medium. Ultrasound is a novel technique that can be utilized for the diminishing of processing period, preservation of quality, and providing of food safety. Moreover, ultrasound implementation can be preferred for the control of fresh fruit and vegetable qualities, cheese ripening, cooking oils, bread and cereal products, bulk and emulsified fat-based food products, food gels, and frozen foods. In addition, ultrasound implementation improves the hygiene standards of food manufacturing. Cavitation formed during ultrasound treatment can decrease the implementation times and limit the usage of chemical substances, in this way it can improve cleaning processes. Ultrasound method has low cost and its implementation is simple, therefore it is preferred as an alternative technology in the food industry (Arvanitoyannis et al., 2017). Furthermore, ultrasound has many advantages to provide for the food industry such as inactivation of microorganisms and enzymes, drying, freezing, osmotic dehydration, extraction, filtration, homogenization and etc., including the efficiency enhancement of several processes in foods (Rastogi, 2011).

The influences of ultrasonic pretreatment before drying of various fruits and vegetables were comprehensively researched. Generally, the usage of ultrasound is enhanced influential diffusivity of water in fruits and vegetables, so drying time is shortened (Dehghannya et al., 2015).

The use of ultrasound combining with hot air drying or applying as a pre-treatment was enhanced drying rate without considerable influence on the product quality. Furthermore, the application of ultrasound combining with osmotic dehydration concludes in an important water loss and solute yield at a lower solution temperature by maintaining the natural flavor, color, and heat-sensitive nutritious ingredients. Ultrasound has also important effects on the extraction process. Its mechanical influences as acoustical cavitation lead to increase penetration of the solvent in the product because of degradation of the cell walls (Rastogi, 2011). In this review, the principles of the ultrasound system were explained and summarized the effects of ultrasound as a pre-treatment in fruit and vegetable processing.

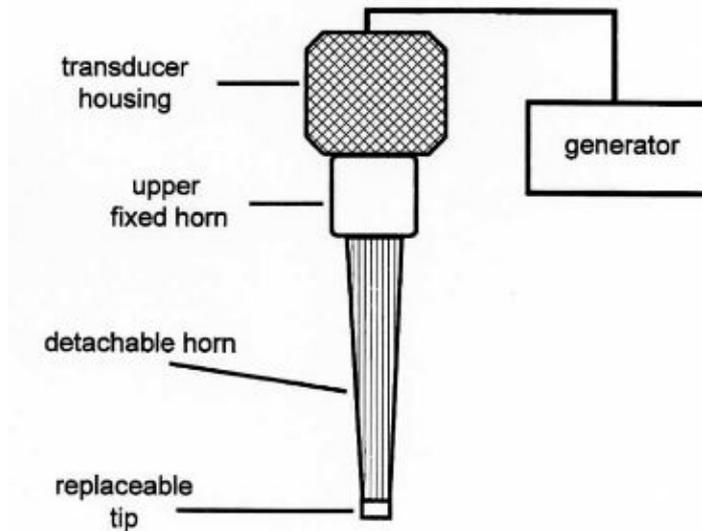
### **The System of Ultrasound**

Ultrasound, a form of energy was introduced in the 1900s and from this date using ultrasound technique within the food industry has been a theme of researches. Furthermore, low-frequency and high-energy ultrasound industry have been used since 1960 (Zbigniew et al., 2007; Earnshaw et al., 1995; Yüksel, 2013). Ultrasound could be applied to solid, liquid and gas systems for different purposes. Mechanical sound waves move in the solids, liquids, and gases with the fixed rate. The sound proceeds as longitudinal waves in gas and liquid, but in solids, it proceeds as longitudinal and transverse waves (Demirdöven and Baysal, 2012). Hearing range of the human ear varies from approximately 20 Hz to 20000 Hz. Ultrasound is described as mechanical vibration sound waves which are in the frequency above human hearing threshold (Carcel et al., 2012).

The applications of ultrasound in food industry is classified into two main classes which are high intensity ultrasound (high energy, low frequency) at frequencies between 20000 and 100000 Hz and low intensity ultrasound (low energy, high frequency) at frequencies higher than 100000 Hz and also lower than  $1 \text{ W cm}^{-2}$  intensities (McClemants, 1995; Witrowa-Rajchert et al., 2014). Low-intensity ultrasound is used for diagnostic purposes or in quality control of food and also to determine the physicochemical characteristics of foods. The sound waves are not to cause physical and chemical changes in the material (Demirdöven and Baysal, 2012; Yüksel, 2013). High intensity ultrasound is applied lower than 100000 Hz frequencies and higher than  $10 \text{ W cm}^{-2}$  energy intensity (Mason, 1998). High-intensity ultrasound has physical, chemical and biochemical effects and improves the quality of the food systems in the process.

Three different methods could be used for ultrasound applications: direct usage to the product, coupling with the device and submergence in an ultrasonic bath (Chemat et al., 2011; ŞahinErcan and Soysal, 2013). In ultrasonic baths, transducers are fixed to the underside of the tank and there is no direct contact with the sample. They have a metallic carcass with piezoelectric transducers attached to the bottom. The vibration of the transducers has transmitted the carcass then the vibration is transmitted to the liquid by the carcass. In addition to this advantage ultrasonic baths also cost lower than probe systems. However, production of the standing waves

and an irregular ultrasonic field inside the bath are disadvantages of the ultrasonic baths (Mulet et al., 2003). In contrast with ultrasonic baths, probes have the horn which is readily connected to the transducer. The horn is used to transmit or to amplify the ultrasonic signal. Probes having different sizes can be fitted to the end portion of the horn. The horn shape is utilized for increasing the amplitude gain of ultrasonic signal (Mason, 1998; Mulet et al., 2003). Figure 1 shows the schematic representation of ultrasonic probe.



**Figure 1.** Schematic representation of ultrasonic probe (Mason, 1998)

The main effect of ultrasound which must be taken into account is acoustic cavitation. During the ultrasonic operation, longitudinal waves generated as it passes through the liquid, thereby generated areas of alternative compression and expansion. These regions of pressure alteration led to occur cavitation and cavitation bubbles in the liquid (Piyasena et al., 2003; Leonelli and Mason, 2010). Cavitation could occur in two different ways which are transient and stable cavitation. In transient cavitation, the bubble size changes much more rapidly and the bubbles finally collapse with different densities. When bubbles collapse, high pressures (up to 100 MPa) and high temperatures (up to 5000 K) are temporarily produced (Mason et al., 1996; Earnshaw, 1998; Carcel et al., 2012). However, the observation of stable cavitation is commonly at high ultrasound frequencies (>200000 Hz) (Ashokkumar et al., 2010). In stable cavitation bubbles collapse less violent and thus the bubbles may grow and collapse continuously (Figure 2). The amount of released energy by cavitation depends on the kinetics and collapse of bubble's growth. This energy could be increased with the surface tension of the bubbles and lessened with a steam pressure of the liquid. Especially, hydrated foods have a high surface tension, hence medium is very effective for cavitation (Knorr et al., 2004).

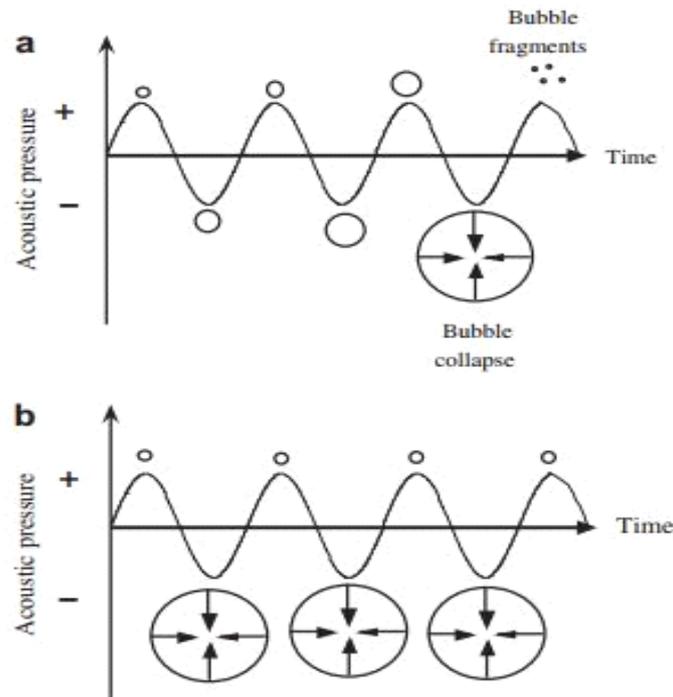


Figure 2. Transient (a) and stable (b) cavitation (Ashokkumar et al., 2010)

## Applications of Ultrasound in Fruit and Vegetable Processing

### Ultrasound Assisted Drying

Drying is the oldest and widespread method for food preservation. Conventional air-drying is widely used but it can deteriorate the quality of foods and also it is expensive and requires intensive heat (Fernandes and Rodrigues, 2007). Therefore, undesired food flavor and vitamin degradation may have occurred with air drying. Alternative methods could be used to eliminate these disadvantages (Chemat et al., 2011). Ultrasound application is one of the alternative methods which can be used in combination with or before hot air drying to reduce drying time and to increase drying rate without significantly influencing the food quality (Fuente-Blanco et al., 2006; Rastogi, 2011). The cavitation occurred in ultrasound process could be used to remove of moisture strongly attached (Fuente-Blanco et al., 2006). Also supplying with ultrasonic energy may activate the dehydration so disadvantages of air drying can be avoided (Chemat et al., 2011). Moreover, reduction in subsequent drying times and improvement in rehydration characteristics of sample are the other important properties of using ultrasound as a pretreatment of drying (Chemat et al., 2011). Many of the researches show that ultrasound assisted drying to have lots of advantages.

Nowacka et al., (2012) researched the application of ultrasound as a mass transfer improving technique before drying of apple tissue. Ultrasound treatment was carried out at a frequency of 35 kHz for 600, 1200 and 1800 seconds in an ultrasonic bath. Drying of apple cubes was performed at 70°C and the air speed of 1.5 m s<sup>-1</sup>

in the convective dryer. As a result, drying time was reduced by 31% due to ultrasound treatment. Also, ultrasound treated apples showed among 9% and 11% higher shrinkage, 6-20% lower intensity and 9-14% higher porosity than control samples.

In another research, ultrasound assisted rehydration on rehydration capacity and water distribution of sea cucumber was investigated. Pretreatment of sea cucumber prior to drying was carried out with the temperature controlled ultrasound bath. Four ultrasound powers (0, 100, 200 and 300 W) and three frequency levels (28000, 35000 and 45000 Hz) were used. Rehydration ratio and water holding capacity enhanced when ultrasonic power increased from 100 W to 300 W and frequency levels were reduced from 45000 Hz to 28000 Hz. Ultrasound-assisted rehydration of sea cucumber had advantages such as high quality and processing efficiency (Zhang et al., 2016).

The application of ultrasound assisted drying also affects carotenoid and iron retention. For reported results by Rojas et al. (2019) it was indicated that the application of ultrasound during pre-treatments for drying (with spray drying using maltodextrin as wall material) of pumpkin and apple led to better carotenoid and iron content than conventionally dried samples.

Ultrasound and vacuum dehydration combination as a new drying method was utilized to improve the quality of carrot slices by Chen et al. (2016). Samples were transferred into a conical flask and combined with a vacuum pump at 0.02 and 0.03 MPa. Ultrasonic vacuum (USV) drying and vacuum drying at 65°C and 75°C were applied to carrot slices. The drying time decreased 41-53% due to using ultrasonic vacuum drying. The drying time of carrot slices for the USV and vacuum drying techniques at 75°C were determined to be 2.33 and 5.67 hours, respectively. The rehydration capacity, color, textural properties, retention of  $\beta$ -carotene and ascorbic acid were better preserved with this new drying technique.

Cakmak et al. (2016), applied the electropulsation (100 V, 40 s) and ultrasound (35000 Hz, half an hour) pretreatments for mushrooms. Drying experiments were carried out at 50°C with 1.5 ms<sup>-1</sup> air velocity in a tray dryer. The effect of ultrasound and electropulsation on quality properties of mushrooms was studied. As a result, it was observed that the ultrasound pretreatment significantly preserved the phenolic ingredient and color values when compared to electropulsation.

Nascimento et al. (2016), determined the effect of ultrasound treatment on drying kinetics and antioxidant capacity of passion fruit peel. They dried (1 m s<sup>-1</sup> air velocity) samples at 40, 50, 60 and 70°C without and with ultrasound implementation (21700 Hz, 30.8 kW m<sup>-3</sup>). Drying time reduced when the temperature increased and samples were treated with ultrasound. In addition, implementation of ultrasound decreased the loss of total phenolic content and preserved the antioxidant activity of samples.

The application of ultrasound (0-90  $\mu$ m wave amplitude, 10-30 min) as a pretreatment of convective drying (40-60°C) of Andean blackberry was studied by Romero and Yopez (2015). The study showed that the application of ultrasound resulted in a dehydrated product with better quality and it reduced the drying time (Romero and Yopez, 2015).

Fernandes et al. (2015), researched the influence of ultrasonic-assisted air-drying on the dehydration of apple and its effect on vitamins in the dried product. Air-drying studies of samples were performed air velocities at 1, 2, 3, and 5 m s<sup>-1</sup> and two different temperatures (45 and 60°C). Drying process was achieved with and without ultrasound in the air-drying. The ultrasound transducer was adjusted at 0.075 kW and 21000 Hz. Ultrasound application was found more effective for water diffusivity when performed at lower air velocity and lower temperatures. After the process which applied at 45 °C and 1 m s<sup>-1</sup> of air velocity, the influential water diffusivity for the ultrasound treatment was found 54 % rate higher than the conventional treatment. The implementation of ultrasound enhanced the presence of vitamins B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, and B<sub>6</sub> in the dried samples. Loss of vitamin B<sub>5</sub> and E occurred for all drying conditions. It was concluded that the drying temperature was the factor that most influenced the final value of vitamins in the samples.

Schössler et al. (2012) informed that application of convective drying with intermittent ultrasonication to apple and red bell pepper saved time about 18-27%. While Puig et al. (2012) obtained a decrease in the drying time of 49% and 72% for orange peel slabs and eggplant cylinders, respectively and Ozuna et al. (2014) determined a 55% decrease for green apple cubes.

Green bean samples were dried at 55, 65, and 75°C using varied techniques: oven, vacuum, and USV drying (the combination of ultrasound and vacuum methods). The green beans samples sonicated at frequency of 40000 Hz in the ultrasonic bath and were provided 1 W cm<sup>-2</sup> power intensity. As a result, the drying times were found as 4.5-8 h for oven drying and 3-5 h for vacuum drying. This study indicated that USV provided a higher drying rate in comparison with only vacuum drying application under the same processing situations. In addition, USV can be more beneficial drying technique than vacuum and oven drying. Application of ultrasound combined with vacuum methods could be preferred due to providing the advantages such as decreased drying time, enhanced drying rate values and preservation of bioactive components. Due to these advantages, it was suggested that USV drying could be used for drying of other fruits and vegetables (Tekin et al., 2017).

More recent study, utilized ultrasound pretreatment before hot air and microwave drying of garlic slices cause to increase in drying rate by 19.30 % (hot air) and 13.82 % (microwave) when compared with controls. It was also concluded that rehydration rates increased after both of the treatments (Bozkir et al., 2019).

From all the results, using ultrasound as a pretreatment of drying process has great advantages such as; decrement in drying time, higher drying rate and rehydration capacity, preservation of phenolic and vitamin content, antioxidant capacity, color values and textural properties of the treated samples.

### **Ultrasound Assisted Osmotic Dehydration**

In general, the ultrasound assisted osmotic dehydration includes the immersion of fruits and vegetables in a hypertonic solution in which ultrasound is performed. Ultrasound technique when combined with high sugar concentration expedites the rate of water draw off from the texture and may considerably decrease the osmotic dehydration time. The advantage of this technique is that there is no heating applied, thus deterioration of the product is reduced. Moreover, it creates faster and complete degassing, starting several reactions by composing

free radicals, enhances polymerization, and depolymerization effects besides that also increasing rate of propagation (Silva and Stojanovic, 2007).

Nowacka et al. (2014) informed that ultrasound application at frequency of 35000 Hz for 30 min to the kiwi samples led to 45% mass gain when compared with control. However, Xin et al. (2014) found that the utilization of ultrasound affected osmotic dehydration time of broccoli samples as 90 min. At the same time, L-ascorbic acid content in ultrasound treated samples was more preserved than un-dehydrated frozen samples. Furthermore, enhanced color retention and firmness of samples obtained during storage at -25°C for 6 months.

The ultrasound assisted osmotic dehydration was applied to cranberry samples by Shamaei et al. (2011). In addition, ultrasound treatment at low (35000 Hz) and high frequencies (130000 Hz) were compared. The findings demonstrated that the usage of acoustic waves at lower frequency was much preferred because of lower color loses and higher firmness of the end product. On the other hand, the high frequency had induced structural deterioration, whereas, the implementation of mild conditions had composed a less micro channel. Furthermore, Oliveira et al. (2010) examined the ultrasound assisted dehydration process of Malay apple. In that study, the samples were dipped in the lower temperature osmotic solution and applied ultrasound treatment. The rate of solid material and water loss in ultrasound implemented samples were concluded higher than control samples. It was also observed that the natural color, flavor and nutritious ingredients of the product were preserved during the treatment.

Garcia-Noguera et al. (2010) indicated that ultrasound assisted osmotic dehydration cause an incensement in water diffusivity and reduction in drying time of strawberries. Strawberries were dunked in distilled water and two osmotic solutions (25 and 50% w/w sucrose in water) and were treated with sonication using two ultrasonic baths (25000 and 40000 Hz, 30°C). The maximal water loss value (4.8%) was observed in the 50% sucrose solution concentration.

Fernandes and Rodrigues (2008) indicated that soluble solid decreases (usually sugar) in ultrasound-assisted osmotic dehydration for various fruits. Furthermore, depending on the ~~diversity in the~~ results acquired from various fruits, more researches on the influence of ultrasound on osmotic dehydration are required (Amami et al., 2017).

### **Ultrasound Assisted Freezing**

Freezing as a means of preservation of food has been used in the modern food industry for hundreds of years. It can be depicted as ice crystallization process from water. Several treatments such as freeze concentration and freeze drying, and the quality of frozen foods are influenced by the size and shape of crystals. In addition, these properties have great importance in final products because of changing the sensorial characteristics in the frozen condition (Arvanitoyannis et al., 2017). Conventional freezing methods have disadvantages such as non-uniform crystal formation, deterioration of food material structure and loss in sensorial characteristics of food. Thus, some innovative technologies like ultrasound have given rise to use. Ultrasound assisted freezing as a novel

technique leads to occur a much smaller ice crystals in food materials and so cell damage is decreased (Lakshmisha et al., 2008; Zhang et al., 2019).

Li and Sun (2002) examined the combination of freezing and ultrasound immersion which applied to the potato samples. It was determined that ultrasound power, exposure time, and freezing phase were effective on freezing. For stronger sonication was required to increase the ultrasound power or exposure time. However, these parameters should be chosen by considering the thermal impact of ultrasound. This study was carried out at ultrasonic power of 15.85 W for 2 min, and greatly enhancement in freezing rate was obtained. Implementation of ultrasound to the phase change period while freezing process greatly increased the freezing rate.

Similar studies claimed that ultrasound-assisted immersion freezing was used for processing of apples. In the study, apple cylinders were dipped in the ultrasound bath which worked at a frequency of 40000 Hz. The study was achieved at the power of 131.3 W with different times and temperatures near the initial freezing point. As a result, the implementation of ultrasound at 0°C or -1°C for 2 min in total, with half minute intervals, cause to considerable enhancement in freezing rate when compared with immersion freezing without ultrasound (Delgado et al., 2009).

Xin et al. (2014) examined influences of ultrasound application on freezing time, microstructure, firmness and drip loss of broccoli. An ultrasound assisted freezer was used to froze broccoli florets at 20000 and 30000 Hz frequencies and 125, 150, 175, 190 W different power levels. Consequently, the total freezing time required for pre-cooling, phase change and sub cooling stages of broccoli was considerably shortened by the utilization of ultrasound assisted freezing at 150 W or 175 W power level. It was also concluded that the microstructure and the firmness of broccoli texture were protected and the drip loss was greatly decreased by the implementation of ultrasound assisted freezing in comparison with the normal immersion freezing.

Briefly we can say that, ultrasound assisted freezing may shorten the freezing time, decrease the dimension of the ice crystals, better preserve the cell structure and above all advance the quality of frozen food.

### **Ultrasound Assisted Emulsification**

Emulsification is one of the earliest usage of ultrasound in food processing. Wood and Loomis (1927) reported the ultrasound emulsification application for the first time. The first patent was granted in 1944 in Switzerland. Since then, many scientists and industrialists have utilized various forms of ultrasound equipment (whistle, horn) to create emulsions (Abismail et al., 1999). It is important for the quality of many food emulsion products such as margarine, butter, ice cream, fruit juices, mayonnaise and etc. Ultrasound assisted emulsification offers following advantages when compared with conventional methods (Chemat et al., 2011):

- Supplement of a surfactant to produce and stabilize the emulsion is not necessary
- The emulsions have extremely narrow particle size.
- The emulsions are more stable
- To produce an emulsion by using ultrasonication needs less energy than conventional methods.

Abismail et al. (1999) studied to compare the oil-in-water emulsions generated by mechanical agitation at 170 W or power ultrasound at 20000 Hz, 130 W using the same model system: water/kerosene/polyethoxylated (20 EO) sorbitan monostearate. The results showed that the drop size in ultrasound treatment, was obtained much smaller than the one given by mechanical agitation under the same conditions. Furthermore, it was concluded that it made the insolated emulsions more stable. They were also determined that for a certain drop size, less surfactant was necessitated.

On the other hand, one of the researches aimed to determine the efficiency of emulsification with the ultrasonic horn at 20000 Hz. They studied the organic phase that involved the surfactant Span 80 and the acidic carrier di (2-ethylhexyl) phosphoric acid (D2EHPA) in kerosene. The interior aqueous phase occurred with divalent Cu(II)-EDTA chelated anions as the tracers. The trials were carried out as a function of emulsification time, surfactant and carrier concentrations, ultrasonic power, and the volume ratio of the internal aqueous phase to organic phase. Consequently, they have reported that mostly the process of emulsification last about 1 min. With ultrasound application, the droplet sizes of W/O emulsions (Sautermean diameter,  $d_{32}$ ) were found much smaller than those reported previously by mechanical agitation (Juang and Lin, 2004).

### **Ultrasound Assisted Extraction**

Food industry has recently been a growing interest in replacing conventional extraction processes by alternative greener and cheaper techniques. Due to many health and environmental reasons chemical extraction processes are hindered (Koubaa et al., 2018). Among the most promising techniques that could extract valuable compounds from plant matrices, the Ultrasound Assisted Extraction (hereafter - UAE) has taken great interest (Vuong et al., 2015). UAE concludes in lower extraction times and higher efficiency when compared with traditional extraction methods (Vilkhu et al., 2008). Some researchers reported that applying the UAE to a variety of plants, led to an important increase in antioxidant activity of extracts, involving olive leaves (Sahin and Samli, 2013), peach, pumpkin (Altemimi et al., 2016) and green tea (Nkhili et al., 2009). UAE has been indicated an efficient technique for extraction processing (Roselló-Soto et al., 2015). However, a few authors reported that unsuitable UAE conditions may lead to a considerable decomposition of phenolic compounds (Dahmoune et al., 2013; Babazadeh et al., 2017). The recuperation of phenolic compounds may affected by parameters such as solvent type, extraction time, extraction temperature, particle size of the sample, ultrasonic power and frequency (Chemat et al., 2017). Khan et al. (2010) reported that during the UAE application, sample grain size was an important property for yield of total phenolic compounds from orange peels. In another research it was determined that temperature was influential parameter on the extraction efficiency of phenolic acids from Citrus unshiu Marc peels (Ma et al., 2009).

Goldsmith et al. (2018) informed that olive pomace, a waste product of olive oil industry was involved in high concentrations of phenolic compounds. The effects of UAE on the extraction of phenolic compounds and antioxidant activity from olive pomace were studied. When applied the treatment at ultrasonic power of 250 W for 75 min at 30°C, the efficiently extraction of phenolic compounds with high antioxidant activity from olive oil

pomace was provided. Applying UAE technique led to higher extraction efficiency of water and yielded extracts with high levels of phenolic compounds. The antioxidant activity of the UAE extracts was also found higher than the control.

Papoutsis et al. (2018) determined the influence of four UAE parameters: particle size (0.14-0.28 cm), extraction time (10-60 min), extraction temperature (23-50°C) and ultrasonic power (0.15-0.25 kW) on the simultaneous recuperation of some phenolics from citrus waste using pure water as a solvent. Grain size was found to be a significant property affecting compound improvement, except for chlorogenic acid extraction. Using a particle size of 0.14 cm obtained the highest retention of p-coumaric (0.25 mg g<sup>-1</sup>) and caffeic acids (0.58 mg g<sup>-1</sup>), while for providing higher hesperidin yields, using of the particle sizes of 0.2 (6.44 mg g<sup>-1</sup>) and 0.14 cm (6.27 mg g<sup>-1</sup>) were recommended. As the extraction temperature raised from 30 to 50 °C the retention of hesperidin raised from 6.59 to 7.84 mg g<sup>-1</sup>. On the other hand, extraction time and ultrasonic power parameters did not have any important influence on the amount of phenolic compounds.

In another research, UAE, centrifugation, and ultrafiltration process were evaluated for the optimal recuperation of polyphenols. For instance, a purple sweet potato extract formed by applying UAE at a power of 840 W, at a frequency of 59000 Hz and using water as the solvent. Extract ultrafiltration was performed by using polyether sulfone (PES) for the recuperation of polyphenol, protein, and anthocyanin. Pre-treatment with the centrifugation of purple sweet potato extract at 2500 rpm over 6 min, was provided better polyphenol recuperation (29%), with satisfactory protein removal, than purple sweet potato extract filtration without centrifugation. According to the results, anthocyanin was significantly recovered (99%) from permeate (Zhu et al., 2016).

### **Ultrasound Assisted Filtration**

In today's technology, the applications of ultrasound at low frequencies take an important part for improving permeation flux in filtration processes. According to studies, the ultrasound implementation can be utilized either during the filtration to increase the permeation or as a cleaning process to enhance the cleaning yield (Kyllonen et al., 2005; Muthukumaran et al., 2006; Maskooki et al., 2015). It also composes a frictionless surface that lets the liquid or smaller particles to pass through more easily, thus improving flow and diminishing process times (Gallo et al., 2018). A further advantage is that ultrasonic cavitation in filtration improves water flow through the filter cake (Mason and Vinatoru, 2017). Nowadays, the implementations of ultrasonic waves due to degassing effects become common in various industries (Dolatowski et al., 2007; Rozenberg, 2013). It is known that the dissolved gas in the liquid can be removed by applying ultrasonic field. (Li et al., 2002; Shahraki et al., 2014;). In addition, the low frequency of ultrasound also increases the turbulence by microstreaming (Gao et al., 2012).

The influences of ultrasound with carbonated feed were analysed on ultrafiltration flux improvement and membrane hydrodynamic resistances (Shahraki et al., 2015). A cross flow ultrafiltration of cherry concentrate was carried out under ultrasound at a frequency of 37000 and 80000 Hz with carbonated feed and non-

carbonated feed, within the flat-sheet membrane module. The experiments were performed for 30 min under fixed 3 bar inlet pressure and at 20°C temperature. It was concluded that this duration was sufficient to obtain the constant value of permeate flux. Results were demonstrated that 37000 Hz of ultrasound enhanced the permeation flux higher than 80000 Hz. The lowest fouling resistance was provided for gas bubbling by carbonated feed fewer than 80000 Hz, but no considerable difference was seen among 37000 Hz and gas bubbling under 80000 Hz.

### Ultrasound Assisted Inactivation of Microorganisms and Enzymes

Microorganisms and enzymes are the main factors responsible for food deterioration. The effective inactivation of microorganisms and enzymes is a significant factor in the food industry to provide the safety and stability of food during storage and distribution. The food industry has traditionally relied on thermal treatments (pasteurization and sterilization) for the prevention of food spoilage. However, they can induce adverse effects in food products such as changes in colour, flavour, taste and texture, losses of nutrients, and deterioration of organoleptic properties of food (Piyasena et al., 2003; Arroyo and James, 2017). In recent years, ultrasound technology has been emerged as an alternative processing option to traditional thermal approaches for food preservation. Using ultrasound for inactivation of microorganisms and enzymes aim to preserve nutrients of food, prolonging shelf life of food and minimizing changes in foods natural properties (Ortuno and Bedito, 2017).

Ferrante et al. (2007) examined using the combination of ultrasound and natural antimicrobials to inactivate *Listeria monocytogenes* in orange juice. The combined treatments carried out at 45°C temperature, high-intensity ultrasound (600 W, 20000 Hz, 95.2 µm wave amplitude), and the addition of various rates of vanillin (0, 1000, 1500, and 2000 ppm), citral (0, 75, and 100 ppm). The usage of mild temperature together with citral, vanillin and sonication cause to reduction in times of exposure to ultrasound to achieve a desired inactivation. Orange juices with the addition of 1000 ppm of vanillin and 100 ppm of citral were found acceptable by the panelists.

The influences of individual ultrasound (A) and combination of ultrasound with organic acids (B) to minimize or inactivate the bacteria and pathogens in organic fresh lettuce were investigated. Lettuce leaves were inoculated with *Escherichia coli* O157:H7, *S. typhimurium*, and *L. monocytogenes*. The B application (0.3-0.5-0.7-1.0 and 2.0% malic acid, lactic acid, and citric acid) was performed at a frequency of 40000 Hz, all for 5 min. When the ultrasonic treatment and 2% organic acid applied for 5 min, maximum reductions in bacterial populations as *E. coli* O157:H7 2.75 log<sub>10</sub> cfu g<sup>-1</sup>, *S. typhimurium* 3.18 log<sub>10</sub> cfu/g, and *L. monocytogenes* 2.87 log<sub>10</sub> cfu/g was obtained. It was concluded that B application provided significantly bacterial inactivation when compared with A application (Sagong et al., 2011).

The influences of ultrasound implementation in combination with commercial sanitizers for decontamination of minimally processed cherry tomatoes was evaluated by Sao Jose and Vanetti (2012). Ultrasound treatment was carried out at a frequency of 45000 Hz for 10 min in the presence of sodium dichloroisocyanurate, hydrogen peroxide, chlorine dioxide, or peracetic acid. The inactivation of natural microbiota and inoculated *Salmonella*,

situated the surface of the tomatoes, were examined. Applying of different sanitizers led to decrease in aerobic mesophilic microorganisms by 0.7-4.4 log<sub>10</sub> cfu g<sup>-1</sup>, molds and yeasts by 1.1-3.4 log<sub>10</sub> cfu g<sup>-1</sup> and *S.typhimurium* ACTT 14028 population by 3.9 log<sub>10</sub> cfu g<sup>-1</sup>. Moreover, a considerably decrement were observed in naturally present microorganisms by using the combination of ultrasound and 40 mg L<sup>-1</sup> peracetic acid.

Samani et al. (2015) evaluated the effects of microwave output power (MOP), temperature (T), ultrasound power (UP), and ultrasonic exposure time (UET) on *S. cerevisiae* inactivation in orange juice. The results showed that MOP, UP, UET, and T were the most influential parameters for decreasing *S. cerevisiae*. When compared to MOP, the UP was more efficient on *S. cerevisiae* decrement. The most appropriate conditions were obtained by 350 W MOP, 35°C T, 778.2 W UP, and 11 min of UET. The results demonstrated that *S. cerevisiae* completely inactivated when the consumption energy was 142.77 J mL<sup>-1</sup>.

It was reported that the application of ultrasound at mild temperature increased the inactivation of enzymes by 2 to 400 times that degrade product quality like pectinmethylesterase, polygalacturonase, peroxidase, polyphenoloxidase, and lipoxygenase. Furthermore, ultrasound accelerated the inactivation of partly heat-resistant enzymes such as tomato polygalacturonase and thermostable orange pectinmethylesterase at mild temperature cases. For increasing the inactivation rate, the type of enzyme, the medium in which the enzyme is suspended, and the process conditions should be taken into consideration (Terefe et al., 2015).

As a general conclusion, it can be stated that ultrasound process alone does not give influential results on microbial or enzyme inactivation enough for food preservation. The application of ultrasound in combination with other disinfection techniques (heat, pressure, antimicrobials, organic acids, commercial sanitizers) exerts a synergistic effect compared to individual treatments (Gallo et al., 2018).

## Conclusion

Ultrasound implementation can be employed to food processing methods such as drying, freezing, osmotic dehydration, rehydration, extraction, filtration, and emulsification, for enhancing process efficiency. Furthermore, inactivation of microorganisms and enzymes at low temperatures without changing organoleptic properties and nutritional value demonstrate that the ultrasound techniques have a high potential in the improvement of food processing. It is clearly seen that the ultrasound treatment is safer, more beneficial, high energy efficient, simple and an economic technique.

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