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Ultrasonic treatment: A cohort review on bioactive compounds, allergens and physico-chemical properties of food

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ABSTRACT

Implementation of ultrasonic for the extraction of bioactive compounds and retention of physico-chemical properties is an important technology. This technology applies physical and chemical phenomena for the extraction of compounds. Ultrasonic assisted extraction causes less damaging effect on quality properties of food as compared to the conventional extraction technique. The present review article focuses on the degradation of various bioactive compounds as a result of ultra-sonication which include vitamins, carotenoids and phenolic compounds. This review article also discusses the influence of ultrasonic extraction on the physico-chemical properties of extracted food products. In addition, the paper explores the effect of ultrasonication on food allergenicity through changes in solubility, hydrophobicity, molecular weight as well as conformational changes of the allergens, a direct result of increase in temperature and pressure during cavitation process.

1. Introduction

Post pandemic, there has been an enhanced consumer interest and attention towards healthy and nutritious food products. People are looking for food ingredients which not only provide nutrients but also enhance their wellbeing. In this regard, bioactive compounds, nutraceuticals and functional foods have captured widespread attention (Chemat et al., 2017). Several bioactive compound such aspolyphenolics, flavones, vitamins and essential oils have been incorporated as supplements and ingredients by food manufacturers. These bioactive compounds play important roles as novel therapeutic agents and show significant medicinal effects such as anti-inflammatory, antimicrobial, antioxidant, anticancer and defending effects against various chronic diseases (Crozier et al., 2006). While trying to obtain maximum benefits from the bioactives, there is an ongoing struggle to minimize ill effects of certain molecules such as allergens. Traditional thermal extraction processing such as soxhlet extraction, water distillation extraction, steam distillation extraction has been used to extract bioactive compounds from plants. Several drawbacks are associated with thermal extraction for example, loss of nutrients, time consuming, and requirement of bulk quantity of chemicals as well as high energy consumption and adverse environmental impact. Thermal processing also causes changes in various physical and chemical parameters. Some research also proved that the thermal processing decreases the bioavailability of some bioactive compounds (Sun et al., 2016). To overcome these drawbacks, novel extraction techniques are being explored for extraction as well as food processing which include ultrasound-assisted, microwave-assisted and supercritical extraction systems (Dogan et al., 2019). These novel technologies have enhanced the extraction of bioactive compounds while reducing adverse effects associated with traditional technologies.

Over the past three decades, ultrasonic treatment has been deemed feasible "green" technology for extraction in chemistry, food and pharmaceutical industries. Green extraction aims to reduce solvent, energy, wastes and environmental pollution while obtaining highest yield of product (Wei et al., 2015). Ultrasonic treatment is extensively employed in food industry for various applications for example, extraction, tenderization and preservation. Full extraction with higher purity of the final product can be achieved by ultrasonication in a few minutes with high reproducibility, decreasing the usage of solvent and removing the post-processing steps involved in waste water treatment (Chemat et al., 2017). Ultrasonic treatment has a potential to fulfill FDA requirement of

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5 log reduction of microorganisms in beverages (Salleh-Mack and Roberts, 2007). However, there are some adverse effects of ultrasonic treatment on bioactive compounds. For example, Tiwari et al. (2008) reported the reduction of anthocyanin content in strawberry juice by 3.2%. An interesting group of molecules that has been studied in relation to ultrasonic treatment is allergens. Allergens are generally proteinaceous compounds that elicit exaggerated immune response in the form of food allergies. Since ultrasonic treatment can change the native confirmation of proteins (Ma et al., 2018) it can alter the resulting allergenic potential of compounds making it relatively safe for consumption in target consumer groups. Ultrasonication also has different effects on the physico-chemical properties of food products. Therefore, this review explores the other side of the coin with focus on degradation of bioactive compounds as well as allergens through ultrasonic treatment. The present review article clarifies the mechanism of ultrasonication and its effect on degradation of various bioactive compounds including vitamins, carotenoids and phenolic compounds along with any other limitations if any.

2. Working principle/mechanism

In ultrasonic technique, acoustic vibrations or mechanical waves are used on the sample with frequencies from 20 kHz to 100 MHz. Ultrasonic assisted extraction (UAE) is based on the cavitation, thermal and mechanical phenomena, and is considered to be the one of the most effective techniques for the extraction of compounds of interest (Fig. 1). This combined phenomena causes' cell wall rupture, decrease in particle size as well as increment in reaction rate through mass transfer across the cell wall. Ultrasonic treatment causes mechanical impact on the cell wall. This enhances the solvent penetration into the cell. Maximum intracellular compounds thereby dissolve in solvent which is further collected and purified. Thus, ultrasonic technique can potentially accelerate the extraction of bioactive compounds (Wen et al., 2018). The extraction is carried out in gaseous or liquid solvent by the result of cavitation which builds on liquid-liquid or gas-liquid interfaces. During extraction, mechanical fragmentation of the cell wall occurs which aids in easy removal of the extract from the cell (Ilbay et al., 2013 and Dogan et al., 2019). Ultrsonication is applied for the extraction of bioactive compounds with less treatment time, reduced energy consumption, less solvent requirement and is rather simple to use as a technique (Chemat et al., 2008). This technique is one of the fastest extraction methods and very effective since the cell wall gets ruptured by the operation of ultrasonic. When the ultrasonic waves pass through the liquid, it results in compression and expansion cycles. The expansion part makes bubbles or cavities in the fluid. The processing of bubble development, growth and implosive disruption is called as cavitation (Luque-García and Luque de Castro, 2003). In the pure liquid system, the bubble retains its circular structure as the environment around the bubble is uniform. When the circular bubble ruptures near a solid surface it becomes variable in shape and generates high-speed jets of solvent against the cell walls and enhances the solvent penetration into the cell wall. This improves the interaction between solid and liquid as shown in Fig. 2. In addition, in the solid material ultrasonic wave causes swelling, hydration and expansion of the pores in the cell wall. This increases the diffusion and hence improves mass transfer (Vinatoru, 2001). However, cavitation phenomena can also introduce new reaction mechanisms with the formation of different types of free radicals. Generally, hydroxyl radicals are formed when water is used as a solvent. Sometimes highly reactive free radicals can be liberated which can alter other compounds for example proteins but also simultaneously accelerate the extraction of bioactive compounds (Wen et al., 2018).

3. Effect of ultrasonication on bioactive compounds

Bioactive compounds are often secondary metabolites which exists in plant tissues and aid the plants against external & internal stress thereby increasing their chances of survival. These are additional nutritional compounds present in food which provide positive benefits to the human health. These compounds usually degrade during conventional thermal processing and storage. However, various studies proved that ultrasonic extraction retains most of the bioactive compounds. Bioactive compounds consist of vitamins, total phenolic compounds, carotenoids and so on. Phenols are further divided into flavonoids and non-flavonoids. Flavonoids consist of anthocyanins, flavonols, flavones etc., whereas, non-flavonoids contains tannins, stilbenes and phenolic acids (Crozier et al., 2006). Specific studies have highlighted the effect of ultrasonic technology on several key bioactives as mentioned below.

3.1. Vitamins

Vitamins are essential micronutrients help in maintaining health and growth of humans. Vitamins are a group of water and fat soluble molecules which are abundantly sourced from various natural sources. These vitamins are extensively used as functional ingredients in food, drugs and cosmetics. Vitamin C, also known as ascorbic acid, is a water soluble vitamin which has proven antioxidant activity. It is thermolabile and unstable at extreme processing parameters. The degradation of vitamin C is carried out by aerobic and/or anaerobic pathways. Tiwari et al. (2008) studied the effect of ultrasonic treatment on ascorbic acid in strawberry juice. The amplitude of the sonicator probe from 40 to 100% with fixed frequency of 20 kHz and treatment time of 2–10 min was applied to the strawberry juice. It was observed that the ascorbic acid content was reduced by 11% at the highest processing conditions. This study has mentioned the reaction mechanism of degradation of ascorbic acid. The degradation may be due to the oxidation reactions supported by the free radicals produced during sonication. The mechanism is based

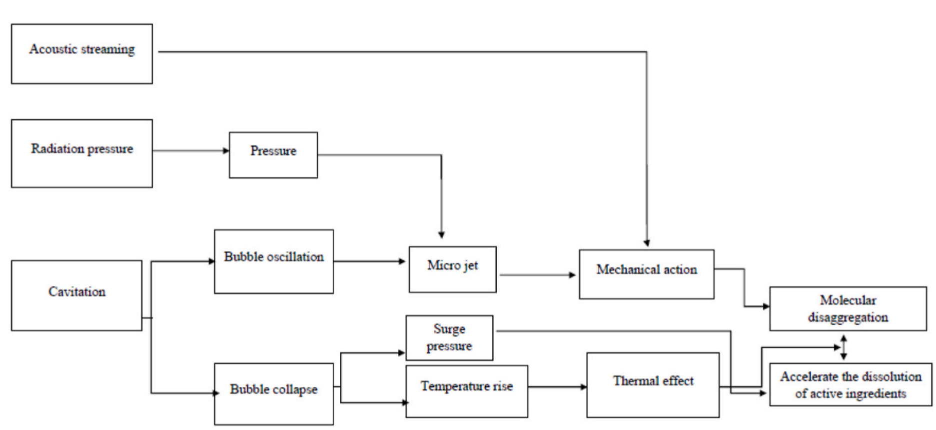

Fig. 1. Diagram of ultrasound-assisted extraction mechanism (Wen et al., 2018).

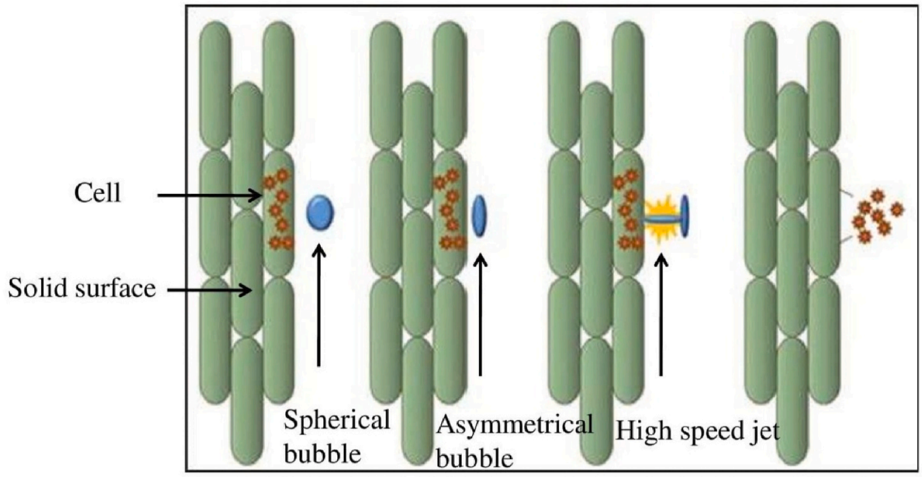

Fig. 2. Disruption of cavitation bubble and discharge of plant extract (Vardanega et al., 2014).

on the thermolysis and combustion that occurs within the cavitation bubbles, which is considered to be the primary path for the degradation. It can also be due to the interactions between free radicals and ascorbic acid causing the development of oxidation products on the bubble surface. Another study on orange juice also proved the degradation of ascorbic acid in orange juice during ultrasound processing (Valdramidiset al., 2010). A 1500W ultrasonic processor was used for the sonication of orange juice. The prepared samples were treated at fixed frequency of 20 kHz, amplitude from 24.4 to 61.01m, temperature from 5 to 30 °C and time from 0 to 10min. Treatment time has a significant effect on the decrease of ascorbic acid in orange juice. First order degradation kinetics was observed for ascorbic acid. The highest decrease in ascorbic acid content was found at 61.01m amplitude and at 30 °C temperature. Decrease in ascorbic acid led to final content being 15% of the original amounts found in fresh orange juice. In this study it was concluded that the rise in temperature and amplitude produced higher degradation of ascorbic acid.

The water-soluble vitamin B12, also known as cobalamin is also sensitive to degradation during various processing conditions such as heat, UV, oxygen and pH. The heat extraction of cyanocobalamin was compared with ultrasonic-assisted extraction and the subsequent stability of cyanocobalamin was assessed by Chandra-Hioeet al. (2020). In this study no degradation was seen during ultrasonic bath extraction treatment. This might be due to the low intensity of ultrasonication used for the extraction i.e. <1 W/cm^2. Whereas, degradation of cyanocobalamin was observed in heat extraction treatment. Industrial processing has significant impact on the degradation of α tocopherol form of vitamin E. α tocopherol is very sensitive and can be readily oxidized during processing (Gawrysiak-Witulska et al., 2009). The influence of ultrasonic processing in both bath and probe type system on the degradation kinetics of vitamin E in avocado puree was studied by Fernandes et al. (2016). Ultrasonic power-densities from 55 to 5000 W/L were used at 23 and 40 °C. Ultrasonic treatment causes the degradation of vitamin E in avocado puree and this effect is more significant in probe ultrasound with power densities from 1000 to 5000 W/L. Tocopherol was reduced by 79% at a power density of 5000 W/L during the initial steps of processing. Whereas, no major loss of tocopherol in avocado puree was found in bath ultrasound at 23 °C. The degradation of tocopherol may be due to the act of tocopherol in maintaining the levels of H_2O_2 concentration and other oxidizing agents in the cell.

3.2. Carotenoids

Carotenoids represents an essential category of natural pigments in fresh produce. Carotenoids are classified into two groups which include carotenes and xanthophylls. α-, β-carotene, lycopene are the examples of carotenoids. Whereas, the lutein and zeaxanthinare the examples for xanthophylls (Ayelén Vélez et al., 2017). Various studies have proved the relation between high carotenoid intake and reduced chances of chronic degenerative diseases for example cancer and cardiovascular disease (Kritchevsky, 1999) thereby establishing it as an essential bioactive group to be studied. Kumcuogluet al. (2014) found a progressive increase in extraction yield of lycopene from tomato paste processing waste in both ultrasound assisted extraction and conventional organic solvent extraction treatment. In this study, it was noticed that there was initial sudden rise in the lycopene yield with increase in time in both the extraction methods. This may be because of the high lycopene concentration gradient between the solvent and the cell during the initial time of the extraction process. Further, the values of lycopene yield for 30 and 40 min for conventional organic solvent extraction matched those to the yield at 20 and 30 min for ultrasound assisted extraction method. During extraction with ultrasonic treatment, cavitation and thermal effects has a significant effect on the extraction yield. As the intensity of power increased, additional energy was moved for cavitation. This phenomenon causes the increases in lycopene yield. When the ultrasonic intensities are lower, the thermal effect is negligible because heat generated from ultrasonic may get entirely diffused. Whereas, with the increase in ultrasonic intensity, the cavitation effect reduces while there is an increase in the thermal effect. Similarly, Yilmaz et al. (2017) have done a comparative study between ultrasound-assisted extraction and conventional organic solvent extraction methods for the lycopene and β-carotene extraction from tomato-processing wastes. These authors also found the similar results for both the extraction methods. Ultrasound-assisted extraction required shorter time for extraction in comparison to conventional organic solvent extraction method. Highest lycopene and β-carotene yield was achieved at 90W ultrasonic power for 30 and 15 min, respectively. Lycopene concentration increased with the increase in time for the ultrasonic power of 50, 65, 90W. However, β-carotene concentration reduced at 90W. This may be due to the sensitivity variation of lycopene and β-carotene in thermal treatments. Lycopene was more resistant to thermal degradation in comparison with the other carotenoids for example, α-carotene and β-carotene. Li et al. (2013) found the amount of carotenoids extracted with ultrasonic treatment was equal to the amount obtained in conventional solvent extraction method. In this experiment, carotenoids were extracted from fresh carrot using ultrasonic-assisted extraction and solvent extraction. Sunflower oil was used instead of organic solvent while performing ultrasonic-assisted extraction. The maximum yield of β-carotene using ultrasonic-assisted extraction i.e.

334.75 mg/L was achieved in 20 min whereas, solvent extraction required 1 h for obtaining the similar quantity of β -carotene of 321.36 mg/L. These researchers have not obtained carotenoid degradation with ultrasonic treatment using sunflower oil. Chuyen et al. (2018) observed gradual increase in carotenoid concentration with extraction time at three different ultrasonic powers. Lutein has therapeutic property for the prevention of human eye degenerative diseases. Song et al. (2015) studied the stability of all-trans lutein under the influence of ultrasonic treatment. It was observed that the ultrasonic treatment causes isomerization of lutein to its isomers. The degradation patterns changed at different temperatures. First-order degradation kinetics of all-trans lutein was seen at 20 °C. Whereas, second-order kinetics was observed at 30–50 °C. The gradual reduction in retention rate of all-trans lutein occurred with the increment in ultrasonic frequency and power. Whereas, the retention rate of all-trans lutein enhanced with the increase in temperature.

3.3. Phenolic compounds

Phenolic compounds are the main bioactive components of various fruits and vegetables because of their influence on the sensorial properties and nutritional qualities of food positive effect on health (Dogan et al., 2019). They are further categorized into different groups such as phenolic acids, flavonoids, tannins etc. Anthocyanin is a primary group of water soluble phenolic compounds and provides color to the fruits (Gan et al., 2018). Anthocyanins have been proved to be effective in preventing diseases such as cancer, coronary heart diseases and other metabolic disorders. Anthocyanins are very unstable and degrade instantly during extraction, processing and storage (Fennema and Tannenbaum, 1996). During ultrasonic extraction, cavitation causes severe physical changes inside the bubbles. This leads to various events such as destruction of bubbles, degassing, formation of free radicals etc. This further results in changes in temperature, pressure and physical interaction between solid and liquid interfaces which induces the degradation of anthocyanins (Gomes et al., 2017). Setyaningsih et al. (2016) worked on stability of 40 phenolic compounds from the various groups such as cinnamic acids, catechins, stilbenes, flavonols, benzoic aldehydes under ultrasonic assisted extraction. The effect of treatment temperature from 10 to 70 °C for 20 min on the stability of 40 phenolic compounds was studied. Interestingly, it was observed that many of the phenolic compounds were stable at extraction temperature of 70 °C. Whereas, a few phenolic compounds started degradation at 50 °C. Therefore, to achieve more than 90% recoveries, it was suggested to perform ultrasonic extraction treatment at temperature between 10 and 50 °C for nearly all phenolic compounds except gallic acid and kaempferol. 12 and 16% degradations of gallic acid and rutin was found at starting temperature of 60 °C for UAE. However, phenolic compounds such as *p*-coumaric, o-coumaric and resveratrol indicated 11, 12 and 21% degradation at 70 °C under UAE.

Antioxidants delay or prevent oxidation of macromolecules such as lipids, proteins and DNA under oxidizing conditions. Various researches have confirmed that the oxidative stress is related to several diseases such as diabetes, neurological disorders, cancer as well as cardiovascular disorders (Vilkhuet al., 2008). Antioxidant activity of bayberry juice was recorded as percent DPPH inhibition and the initial value was 193.19 mg TE/100 ml (Cao et al., 2019). Low ultrasonic intensity of 90.41 and 180.82 W/cm^2 did not cause significant changes in DPPH inhibition values. Whereas, significant reduction in antioxidant activity was observed after 6–10 min treatment time at intensity of 271.23, 361.64, and 452.05 W/cm^2. While using ultrasonic treatment, low intensity with less treatment time had no significant effect on antioxidant activity. Hence in the conclusion of this study, it was seen that with the higher ultrasonic intensity and time, the antioxidant activity gradually reduced for bayberry juice. Also, Sun et al. (2016) examined that the increase in sonication power from 200 to 500 W and processing time from 0 to 60 min, led to significant decrease in the antioxidant capacity of pelargonidin-3-glucoside. In comparison with control sample, the maximum reduction in antioxidant activity was found to be 74.77% and 72.74%, at 500W for 60 min as analyzed by the FRAP and DPPH procedure, respectively.

In another study, UAE was compared with solvent extraction for the potential recovery of phenolic compounds from pumpkins and peaches (Altemimi et al., 2016). Optimal extraction of total phenolics from pumpkins was achieved using UAE at a temperature of 41.45 °C, power of 44.60% with a treatment time of 25.67min. Whereas, for peaches the optimum conditions for the extraction of total phenolics was at temperature of 41.53 °C, power of 43.99% and time of 27.86 min. A comparative study has been conducted on the extraction of phenolic compounds with conventional and ultrasound-assisted extraction techniques from vegetable sources (Medina-Torres et al., 2017). In this study it was demonstrated that phenomenon of acoustic cavitation is responsible for the effective recovery of phenolic compounds. Further, it was concluded that the energy requirement, treatment time and temperature in UAE is comparatively less than the conventional method of soxhlet extraction. Hence, UAE is very helpful for the extraction of thermo-sensitive compounds.

4. Effect of ultrasonication on allergens

Food allergy is an adverse immune response initiated by consumption of specific foods or food additives. Most allergens are known to be water-soluble glycoproteins having masses of 10–70 kDa that show the following functionalities (1) Ability to sensitize a genetically predisposed individual by initiating formation of IgE antibodies, (2) Binding to those generated IgE antibodies, and (3) Commencing an exaggerated immune reaction post IgE binding. Most common symptoms of food allergies are gastrointestinal, respiratory, cardiovascular, and cutaneous symptoms and eventually an anaphylactic shock. Studies have reported eight major food groups, namely eggs, milk, fish, shellfish, tree nuts, peanuts, soybeans, and wheat that account for approximately 90% of all the allergic reactions (Nayak et al., 2017).

High-intensity ultrasound equipment involves mechanical waves within a frequency range of 20–100kHz (Feng et al., 2011). The high energy waves cause physical and chemical changes through formation of bubbles in food matrix via intermittent compression and rarefaction until critically sized bubbles collapse. The increase in temperature and pressure (up to 5000K and 1000atm, respectively) as a result of the collapsed cavities forms the basis for conformation change of allergens and their resulting reactivity. High-velocity gradients and shear stress resulting from sonication lead to micro-streams that have structural effects like alteration of the native protein structure, formation of new intra-/intermolecular interactions, and breakdown of the large molecules (Soria and Villamiel, 2010). Cavitation changes the allergenic proteins and influences the ability of antibodies to interact with the modified proteins, thereby reducing the chances of IgE-mediated food allergic reactions. Additionally, high agitation caused by microstreaming often disrupts Van der Waals interactions and hydrogen bonds in polypeptides, resulting in protein denaturation. Thus, researchers attributed lower allergenicity after ultrasonication processing to changes in solubility & hydrophobicity, molecular weight as well as conformational changes. Table 1 highlights the effect of sonication treatments on allergens from common food products such as milk, shrimp, crabs, peanuts and soy flour. Varying frequencies and treatment times for different food products led to differential reduction in allergenicity. In case of shrimp allergenicity was seen to reduce from 100% to 25.3% using ELISA assay, thereby highlighting the massive potential this technology has against allergens. Researchers have also explored ultrasonication assisted enzymolysis of proteins to obtain biofunctional hydrolysates and peptides (Liang et al., 2017). It has been well established that breakdown of high molecular weight proteins in to low molecular peptides is associated with lower allergenic profile and enhanced bioavailability (Arteaga et al., 2020). Hence many

Table 1
Ultrasonication as a strategy to reduce protein allergens in commonly consumed animal and plant protein sources.

Allergen	Food source	Processing treatment	Effect on biomolecule	Effect on allergenicity	Reference
Casein	Milk	25 kHz frequency, 900 W, 20 °C, 60 min	Colloidal casein with lower diameter	IgE binding capacity reduced from 1.09 to 0.93	Wang et al. (2020)
β-lactoglobulin (BLG) and α-lactalbumin (ALA) in whey protein hydrolysate	Milk	Ultrasound-Ionic Liquid pre-treatment at 300 W ultrasonic power for 15 min	Smaller molecular weight peptides increased	Antigenicity of alcalasehydrolyzed ALA & BLG decreased by 68.54% and 66.58%	Zhang et al. (2019)
Tropomyosin fraction	Shrimp	High intensity ultrasound treatments (30 Hz, 800 W) for 30–180 min	Results in low molecular weight fraction	Allergenicity reduced from 100% to 25.3% (ELISA)	Li et al. (2006)
Tropomyosin from crab crude extract (CCE)	Crab	Ultrasonication at 200 W, 30 °C for 60 min,	IgE-binding sites on allergen destroyed	ELISA inhibition reduced approximately by half-80%–40% for chymotrypsin-Ultrasonicated samples	Yu et al. (2011)
Ara h 1 and Ara h 2	Peanuts	1–5 h at 50 Hz.	Reduced solubility of Ara h1	Ultrasonication followed by trypsin and chymotrypsin digestion had the highest IC50 (31.95 lg/ml)	Li et al. (2013)
Glycinins&Conglycinin	Soy flour	Extraction with an ultrasonic dismembrator at 60 Hz, 300 W	Reduced solubility	Least amount of soy proteins detected using ELISA in sonicated samples (14 mg/ml) as compared to conventionally (28.99 mg/ml) extracted samples	Amponsah & Nayak (2016)

hydrolysate and peptide products with higher degree of hydrolysis and resulting lower molecular weight peptides are used in sports nutrition and other functional applications.

Other novel studies have been undertaken to conjugate proteins with polysaccharide with an attempt to enhance functionality of the protein while reducing its allergenicity. One such study involves buckwheat protein isolate (BPI) conjugated with dextran through ultrasonication using 10 mm titanium tip for 80min at 70 °C and ultrasonic intensity of 544.59 W/m^2 (Xue et al., 2017). Thus ultrasonic treatment can be effectively used for processing allergen containing products and converting them to product safe for individuals with allergies and intolerances. This would no doubt increase consumer base and economic returns to the food manufacturers.

5. Effect of ultrasonication on physicochemical properties

5.1. Texture

Ultrasonication can have varied effects on the texture of a food product. The effect of ultrasound and cavitation on the changes in macromolecules can lead to changes in the hardness/toughness or tenderness/softening. The effect seen on texture is mainly due to mechanical breakdown of myofibrillar protein structures, rupture of collagen macromolecules and enhanced proteolysis or protein denaturation and myofiber fracture when meat is treated in ultrasound baths or probes (Alarcon-Rojo et al., 2019). Depending on whether toughness or tenderness is preferred end result, sonication can lead to desirable or undesirable end product. Hence optimization of sonication treatment for different food products, along with correlation studies on sensorial traits is necessary before application of this pre-treatment. One such study focussed on the effect of ultrasound on raw and boiled shrimps by treating them with power ultrasound (30 kHz, 800W) at 0 °C (treatment 1) and 50 °C (treatment 2) for 0, 2, 8, 10, and 30 min. Ultrasound treatment for 30 min lead to an increase in hardness in treatment 1, to a peak-1.5-fold higher than the control, compared to 27% increase in treatment 2 (Li et al., 2011). The increased hardness and chewiness of the product was not correlated with sensory traits but reduced allergenicity was seen for the treated sample. The increased hardness was attributed to osmosis and water loss from the tissue after sonication. A study focussed on using high-intensity ultrasound as pre-treatment for drying of pear slices studied the resultant texture characteristics of the dried pear slices. Ultrasound equipment at a frequency of 24 kHz and amplitudes of 25, 50, 75 and 100%, was utilized in this study. It was seen that the hardness of pear slices decreased [from untreated sample (104.72N), 50% of amplitude (93.461 N) to 100% amplitude (62.206 N)] with an increase in ultrasound intensity and all the process parameters had significant effect on the textural properties of pear slices (Dujmic et al., 2013).

Another study of beef steak analyzed the effects of low-frequency, high-power ultrasound (40 kHz, 1,500W) on meat quality. Beef steaks were sonicated for 10, 20, 30, 40, 50 or 60 min and it was observed that most sonicated beef samples showcased higher water-loss rates when compared to the control sample and 10 min-sample. Water-loss rate increased with duration of ultrasound treatment. The observed effect may be due to the disruption of the cellular structure and the resulting water loss in often associated with negative effect on sensory characteristics of steaks (Chang et al., 2015). As seen from the studies on texture of shrimp, pear and beef, the effect of ultrasonication varies depending on the type and composition of food matrix. While ultrasound has been effectively used for reducing microbial load and extending shelf life, its effect on texture cannot be ignored and needs detailed studying before adaptation of this technology. According to Fig. 3, it has been proved by Moghimi et al. (2018) that ultrasonic causes changes in structure of black cumin seeds. These authors proved that the power of ultrasonic wave has more influence on the oil extraction yield than irradiation time. Fig. 3 shows that the improved extraction efficiency of oil is due to the rupture of cell membrane and formation of several holes. The cavitation bubbles collapse on the external surface leads to deformation in the pressure zone. This phenomena causes degradation of cells' membrane and development of several holes.

5.2. Color

Color is one of the essential organoleptic parameters which determines the quality of food and helps in drawing the attention of consumers. With the increase in ultrasonic power, the color parameters are also affected. The study about the influence of ultrasonic on the extracted oil of black cumin seeds proved that the increase in ultrasound power increases the value of color index of the extracted oil. The reason behind the increase in color index may be due to the depletion of pigments which include chlorophylls and dissociation of phospholipids during ultrasound treatment. Zhang and Wang (2017) studied the influence of ultrasound irradiation on the absolute color as well as color density of wine during storage. The color and color density of wine treated with ultrasound was higher as compared to the non-treated control sample. It was also found that more the treatment time of ultrasound, the more rise in the value of color and color density during the storage period. This study concludes that the ultrasound irradiation enhances the color of red wine. The increase in color pigments may be due to the local spontaneous increase in temperature and pressure

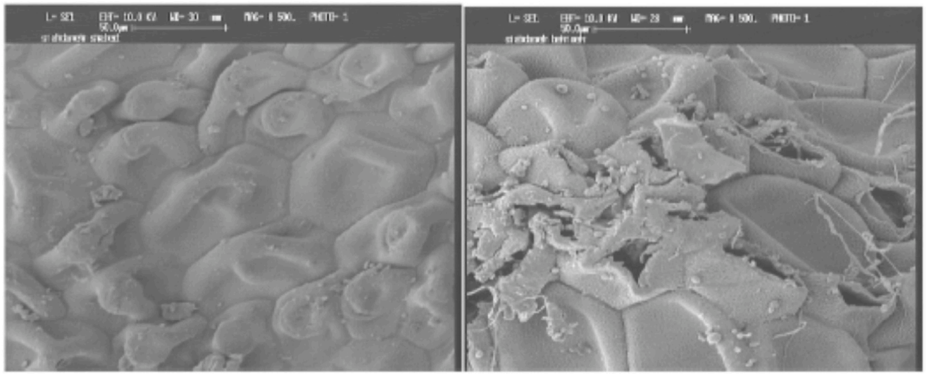

Fig. 3. SEM images of a black cumin seed structure 1) without ultrasound treatment and 2) with ultrasound treatment (Moghimi et al. (2018).

produced by the acoustic cavitation which arbitrates free radicals and chain reactions. In another study, the effect of thermos-sonication on the color of clear red pitaya juice was checked (Liao et al., 2020). In this case similar observations were made that is more the treatment time and increase in temperature more the recognizable variation in color. Reduction in L^*, a^* and b^* value of thermosonicated sample with increase in input power, temperature and treatment time was observed. Degradation of betacyanin pigment which gives red-purple colour to the pitaya juice might be responsible for the observed color loss. Influence of ultrasound on the polymeric color and color density of bayberry juice was evaluated by Cao et al. (2019). Ultrasonic treatment showed no significant effect on color density of bayberry juice. Whereas, polymeric color enhanced by 6.93–31.73% with the increase in ultrasound intensity and treatment time. Compared with control sample, an increase in the value of percent polymeric color of ultrasonic treated bayberry juice by 11.99–14.19% was also observed. The development of polymeric colormay be because of the production of chalcone which isa transitional product of anthocyanin degradation. This chalcone was not stable and would easily degrade to brown color which increases the polymeric color.

In addition, the results of the studies conducted by researchers on the influence of ultrasound on browning are not consistent. According to the investigation conducted by Sun et al. (2015), it was found that the ultrasound prevents the browning of fresh apple juice. Controlling enzymatic browning is found to be a major challenge for fresh apple juice processors. Fig. 4 demonstrates improved color and uniformity of ultrasonically treated fresh apple juice as compared to non-treated sample. The ultrasonically treated sample was more homogenous, less brown with no layers or bubbles. The browning index for fresh apple juice was found to be greater than the untreated samples at 15 °C. Jang and Moon (2011) reported that the combination treatment of ultrasonic and ascorbic acid was more effective in controlling the browning rate of fresh-cut apple. This is due to the inhibition of monophenolase, diphenolase and peroxidases enzymes. Whereas, individual ultrasonic treated fresh-cut samples showed more browning due to the constrained inactivated influence on the enzymes. In another study performed on tender coconut water the combination of ultrasound with nisin treatment decreased the enzyme activity by 50%, 30% and 35% for Polyphenol oxidase, Peroxidase and Phenylalanine ammonia lyase, respectively (Rajashriet al., 2020). This combined treatment also showed a higher browning index for tender coconut water than untreated sample. Ultrasonic treatment creates shear stress by cavitation which depolymerizes the macromolecule and produces lower molecular weight products, which may inactivate the enzymes. In this study, due to partial inactivation of browning enzymes, the residual activities of enzymes were probably responsible for the enhancement in the browning index of the ultrasonic and nisin treated tender coconut water. More studies need to be conducted at various treatment parameters to aid in complete inactivation of the implicated enzymes.

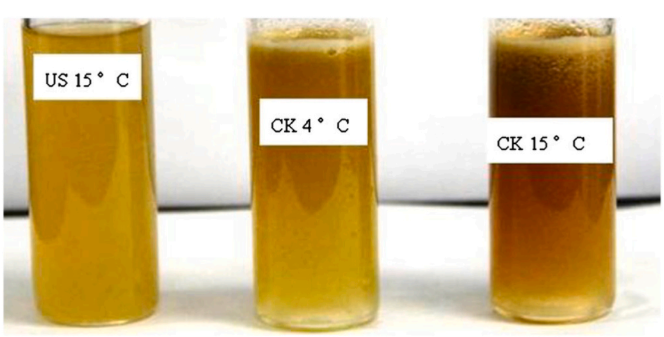

Fig. 4. Ultrasonically (US) treated fresh apple juice at 15 °C and control check (CK) at 4 and 15 °C (Sun et al., 2015).

5.3. Flavor

Flavor is made up of volatile (aroma) and non-volatile (taste) components. Flavor influences the sensorial quality of food as well as overall acceptance by consumer (Zhang et al., 2020). Ultrasonic treatment has significant effect on the flavor compounds. Zou et al. (2018) reported an increase in volatile flavor components such as aldehydes, ketones and alcohols in ultrasonically treated beef samples. Various studies have proved that the ultrasonictreatment provided most flavourful extracts. Teng et al. (2019) studied the effect of UAE, ultrasound-assisted drying and microencapsulation on flavors of spices. Ultrasonic reduced the drying time which helped in maintaining the flavor of spices. UAE also reduced the extraction time and lead to higher concentration of spice flavor extract, even in comparison with advanced extraction techniques such as microwave-assisted extraction. These authors also stated that flavor can be successfully retained for a longer period with the help of ultrasound-assisted microencapsulation method. In addition, UAE coupled with vacuum distillation produces high quality of flavor compound extracts from plants. This is proved by Da Porto and Decorti (2009) in the comparative research between UAE coupled with vacuum distillation and hydrodistillation for *Menthaspicata* samples. UAE production of higher flavored extract may be because of enhanced amount of oxygenated compounds (5–8 times) than hydrodistillation. Extraction yield provided by UAE was in between 0.04 and 0.13% whereas 0.01–0.02% by hydrodistillation. Zhang et al. (2020) investigated the application of ultrasonic-assisted frying to improve the flavor in meatballs. The ultrasonic-assisted frying increases the speed of free fatty acid oxidation which causes the formation of volatile flavor compounds. Also, the concentration of essential amino acid improved with the application of ultrasonication method. Similar observations were made by Zou et al. (2018) for enhancing the chemical profiles of spiced beef taste and flavor. Thus, ultrasonic can be used efficiently as a potential technique to increase the flavor profile of food products.

6. Current challenges and future perspectives

It is clear from existing literature that ultrasound technology offers several advantages such as reduction of processing time and steps involved, greater efficiency with enhanced product quality (nutritional, physicochemical & organoleptic) and improved shelf life. However it does come with some challenges. The effect of ultrasound is raw material dependent and the technology has been applied to varied plant and animal based food products such as meat, fruit and vegetables, cereals, dairy and emulsion based products (Bhargava, 2020). As seen from this review, effect of ultrasonic treatment can be positive or negative on the various biomolecules depending on the treatment parameters and the overall composition of the food under investigation. As reported, ultrasound is known to improve certain techno-functional properties while having negative effect on others. An interesting example of this would be increase in foaming capacity (techno-functional property) of food proteins that have been processed using ultrasonication. While a desirable trait for egg protein (Sheng et al., 2018) when used for its foaming applications it could reduce applicability of other proteins where foaming is undesired in the final product.

Also depending upon the unit operation this novel technique is coupled with, different end results can be expected. For example ultrasonication is often used along with filtration, freezing-thawing, dehydration, pasteurization, extraction and other existing treatments and processes. In case of ultrasonic coupled filtration, enhanced filtration is seen with reduced filtration time and prevention of membrane fouling (Kyllönen et al., 2005). Though careful optimization of ultrasound velocity needs to be undertaken to avoid any damage to the filter. Integrated use of ultrasonic treatment with other conventional or novel techniques could result in enhancement of overall quality of the processed food product. Carefully designed experimentation at pilot and industrial scale for optimization of parameters and basic research on the effect of acoustic treatment on the molecular composition of different food products needs to be undertaken. Possible adverse effect of industrial utilization of this technique needs to be studied along with energy and financial considerations.

7. Conclusion

Ultrasonic treatment used for the extraction of compounds which is free from any residual solvents, impurity or with other unwanted compounds. As conventional processing causes loses in bioactive compounds, preserving them during processing is very difficult. It could be stated that the ultrasonic treatment provides more benefits in reducing the losses and retaining the bioactive compounds compared with conventional treatments. The application of ultrasonication on expensive ingredients is an economical approach than the conventional extraction techniques, which is the need of the industry. Therefore, further studies are required on the application of ultrasonic technique for the extraction of bioactive compounds from different foods as well as on allergens. The present techniques for extraction of compounds are no consistent and used for crude extraction. Hence, more studies are required on extraction techniques for efficient production. Based on this review article, it can be possible to bring researchers from various streams such as food technology, engineering, biotechnology to provide an encouraging future for the industrial application of ultrasonic assisted extraction for bioactive compounds from various foods.

CRediT authorship contribution statement

Azza Silotry Naik: Writing – original draft, Drafting the article. **Deodatt Suryawanshi:** Writing – review & editing. **Manoj Kumar:** Writing – review & editing. **Roji Waghmare:** Conceptualization, Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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