Journal of Food Safety and Hygiene

Journal homepage: http://jfsh.tums.ac.ir

Review

Ultrasound as a modern preservation technique in food safety: a review

Ebrahim Molaee-Aghaee[1], Ali Salehi[1*], Leila Karami[2], Nooshin Zomorodiyan[3]

[1]*Division of Food Safety and Hygiene, Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.*
[2]*Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran.*
[3]*Department of Organic Chemistry, College of Chemistry, University of Science and Technology, Tehran, Iran.*

ARTICLE INFO

Article history:
Received 14 Sep. 2021
Received in revised form 17 Dec. 2021
Accepted 25 Dec. 2021

Keywords:
Ultrasound;
Food industry;
Meat product;
Dairy product;
Fruits;
Vegetables

ABSTRACT

Ultrasonic methods are increasingly being used in the food industry for both food analysis and food modification. Ultrasound technology is relatively inexpensive, simple and cost-effective in terms of energy and time and is a non-destructive technique compared to other conventional technologies. The ultrasonic spectrum based on frequency and intensity is divided into two types, including low frequency (less than 100 kHz)-high-power (more than 1 W/cm^2) ultrasound and high frequency (more than100 kHz) low-power (less than 1 W/cm^2) ultrasound. The effect of ultrasound on various materials is caused by the formation, growth, and collapse of bubbles, which is referred to as cavitation. The ultrasonic spectrum based on frequency and intensity is divided into two types, including low frequency (less than 100 kHz)-high-power (more than 1 W/cm^2) ultrasound and high frequency (more than 100 kHz) low-power (less than 1 W/cm^2) ultrasound. Ultrasound applications in the food industry are very diverse. This review summarizes the major popular applications of low and high-power ultrasound in food science and technology.

Citation: Molaee-Aghaee E, Salehi A, Karami L, Zomorodiyan N. **Ultrasound as a modern preservation technique in food safety: a review.** J food safe & hyg 2021; 7(4): 180-190

1. Introduction

Nowadays, with the development of international trade such as the export and import of various foods, special attention has been paid to modern food preservation techniques. One of the most important and useful modern food preservation techniques is the ultrasonic method.

* Corresponding author. Tel.: +989141806511
E-mail address: salehia15@gmail.com

Ultrasound is a type of energy produced by longitudinal mechanical waves whose frequencies is greater than 20 kHz, and is above the human hearing limit (1). Ultrasound is a modern technology that is known for its reliable and cost-effective use, as well as its high performance, nonpolluting and environmental friendliness (2).

This technology is used to benefit food processing, such as increased mass transfer, food preservation and packaging, thermal treatment assistance, texture modulation and food analysis in the food industry (3). Ultrasound technology is relatively inexpensive, simple and cost-effective in terms of energy and time compared to other conventional technologies (4). As a result, this technology is recognized in the food industry as a viable and non-destructive process (5).

The ultrasonic spectrum can be divided into two types based on frequency and intensity: low frequency-high-power (LF-HP) ultrasound and high frequency-low-power (HF-LP) ultrasound (6).

The energy and frequency of HF-LP ultrasounds are <1 W/cm^2 and >100 kHz respectively (7). Low-power ultrasound does not typically induce major and severe physical or chemical changes, and it is used for non-destructive and noninvasive food analyses, as well as monitoring and control of food diversity during processing and manufacturing to ensure high food quality and safety (8). This technique has also been used in medicine, pharmaceuticals, and cosmetics. Unlike traditional analytical techniques, low-power ultrasound measurements are quick, automated, and simple to use in both laboratories and production lines (9). HF-LP ultrasound together with nuclear magnetic resonance spectroscopy (NMR) are currently the foremost popular, practical and widely used nondestructive analytical methods today (10).

Modifying the physicochemical properties and improving the consistency of various food systems during processing are typical applications of the LF-HP ultrasound with a frequency of 20–100 kHz and a power of more than 1 W/cm^2 (7,11). High-power ultrasound is able to produce changes in the material and structure. It is used in a wide range of food industry processes such as surface cleaning and decontamination, microbial and enzymatic inactivation, degassing, defoaming, and improvement of mass transfer (12). The most popular applications for low-power and high-power ultrasound are mentioned in table 1.

The effect of ultrasound on various materials is caused by the formation, growth, and collapse of bubbles, which is referred to as cavitation (13). Principally, Cavitation phenomenon occurs when the size of the micro-bubbles in liquids increases due to the high and low pressure cycles produced by ultrasound waves (14). A vast amount of energy is released as the size of the micro-bubbles expands and gradually collapses. In general, the basis of the cavitation phenomenon is the disintegration of microscopic air bubbles due to the absorption of ultrasonic energy (15). As a result, the cavitation process causes two major effects, which are referred to as physical and chemical effects (16). Physical effects mostly occur at frequencies of 20 to 40 kHz. Since the energy released in this frequency range is higher, the bubble's size is larger and the number of cavitation spots would be low (16, 17). The size of the bubble would be smaller at frequencies above 80 kHz due to the less energy released, so the number of spots is higher, and the predominant effects are mainly chemical (18). Hence, various physical and chemical effects are generated based on the ultrasound intensity and frequency. Because of the asymmetry of the bubble-burst cavity, high-velocity liquid micro-jets are produced near of solid boundary (19). Liquid jets induce intense adiabatic contraction of gases and vapors within bubbles by causing strong vibrations on the surface of the solids, which causes very high temperatures inside the bubbles (20). When ultrasonic waves strike a material, these waves apply a force that, if perpendicular to the surface, passes through the environment in the form of a pressure wave, and if it is parallel to the surface, it creates an incision wave (21). These waves allow the areas to compact and expand. Gas bubbles are formed in the environment as a result of pressure fluctuations in these areas. Inside the bubbles, a condensation state occurs when they are compressed. Vibration waves are generated by the collision of condensed molecules. Both of these compressive and thermal changes gradually lead to tissue degradation and cell membrane thinning over time (22,23).

The pulse-echo technique is the most commonly used ultrasonic technique. The pulse-echo technique is widely used in ultrasonic inspections for thickness measurement and defect sizing, and it includes identifying indication echoes when the signal is reflected from a discontinuity in a test material structure (24,25). Most ultrasound measurement systems include the following components: Cell Measurement, Signal Generator, Transducer and oscilloscope. The signal generator produces an electrical pulse with a specific frequency and oscillation, then, the transducer converts the electrical pulse into an ultrasonic pulse. This pulse passes through the sample in the Cell Measurement and after colliding with the inner wall of the Cell, it is reflected and returns to the transducer, where it is detected (Fig.1) (26,27).

Table 1. The most popular applications of low-power and high-power ultrasound in the food industry

Type of ultrasound	**Applications**	
High frequency-low-power	Meat products	
	Fruits, vegetables and Fruit juice	
	Milk and dairy products	
	Cereal products	
	Fat and emulsion products	
	Honey	
	Food proteins	
	Aerated foods	Ice cream
		Whipped cream
		Confectionary
		Desserts.
		Bread dough
	Food gels	
	Ultrasonic monitoring of food freezing	
low frequency-high-power	Emulsion formation	
	Food preservation	Microbial and enzyme inactivation
		Microbial decontamination and surface cleaning
	Mass transfer	Extraction
		Drying and dehydration
		Drying and dehydration
	Energy transfer	Heating
		Freezing
		Thawing
	Foaming and degassing capacity	
	Filtration	
	Texture modification	
	Food cutting	

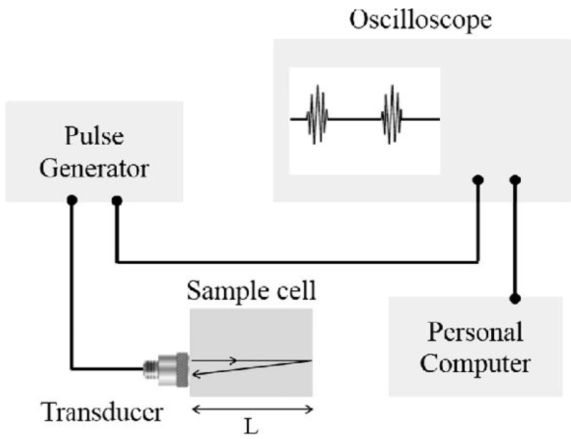

Figure 1. Schematic diagram of pulse-echo ultrasonic technique (28)

2. Meat and meat products

Parameters of pH, water holding capacity (WHC), texture, oxidative stability and sensory attributes are some of the most important consistency characteristics to consider when evaluating meat and its products (29). Since the 1950s, ultrasound has been used in the meat industry to assess the fat and muscle of live cattle (30). Nowadays, the ultrasonic method is also used in various fields of the meat industry, including animal fertility assessment, animal slaughter, quality detection and the cutability of carcasses after slaughtering (29, 31). One of the most important applications of ultrasound in the food industry is assessing the composition of adipose tissue thickness in live animals and carcasses (such as fish, goats, sheep and poultry) (32). While NMR and X-ray imaging techniques used in the meat industry are usually very costly and time-consuming. Tenderness is an essential feature of meat quality and consistency that is determined by the structural organization and integrity of the skeletal muscle and composition (33). Tenderness of meat is one of the most important factors in customer satisfaction in meat consumption and is usually achieved after slaughter in a number of ways, including the hanging of the carcass, mincing, and the use of an enzyme (34). However, these manual methods often have a negative impact on the appearance and quality of the meat. Therefore, the ultrasonic technique could be a suitable alternative to manual and conventional approaches. Ultrasonic treatment enhanced meat tenderness by preventing the formation of actin-myosin complexes through rupturing cells and releasing calcium, as well as helping to release natural enzymes in meat, such as cathepsin (35,36).

Table 2. Some examples of the latest studies on the use of ultrasound technique in meat and meat products.

Ref-year	Ultrasound condition	Type of sample and Purpose of the study	Results and observations
(37)-2021	300 W at 40 kHz at 30°C for 80 min	Ultrasound and quality of chicken breast meat	a slight adverse effect on the color and pH of chicken breast improving meat WHC by promoting water migration and distribution softened meat texture by destroying muscle fiber structure
(38)-2021	different power levels (200, 300, 400, and 500 W)	Ultrasound and emulsifying and gelling properties of chicken myofibrillar protein	Ultrasound-assisted immersion thawing (UT) reduced loss of gel strength and WHC. UT at 300 W decreased the turbidity and particle size of myofibrillar protein. Promoted the formation of a stable emulsion. UT-300 samples had less mobility and losses of immobilized and free water. UT at 300 W created the compact and homogeneous myofibrillar protein gel network.
(39)-2021	400 w, 45 kHz	Improve WHC of beef during freezing-thawing process	The WHC of beef without ultrasound was 0.69 after one freezing–thawing process. Ultrasound improved the WHC quality of beef (0.78). Ultrasound reduced hardness but improved springiness (elasticity) and pH value.
(40)-2021	Ultrasonic bath: at 33 kHz, 96 W, for 1 h. ultrasonic probe: at 20 kHz, 75 W, for 1 h.	Ultrasound and Pork loin (Longissimus dorsi) muscle quality	No changes were observed for shear force and TBARs values. Improving the hardness of meat at the end of storage. Improving colour at the end of storage. Prevention of cross contamination during meat processing. Increasing the shelf-life of the product.
(41)-2021	250 kHz 5 and 20°C	Ultrasound and textural properties of pork burger patties	Ultrasonic velocity increases exponentially with fat content at 5°C. Ultrasonic attenuation decreases exponentially with fat content at 5°C and 20°C. Noticeable correlations were found between hardness and ultrasonic velocity

Ultrasonic technique, as a low-cost, non-invasive procedure, greatly decreases the aging period and improves the organoleptic properties of meat. Over the last few decades, many pieces of research have shown that ultrasonic treatment has the ability to improve the tenderness and sensory properties of meat and its byproducts. A number of latest studies on the effect of ultrasound on the physical and chemical properties of different meat and meat products are summarized in table 2.

3. Milk and dairy products

In recent years, the use of ultrasound as an alternative technique for the processing dairy products has been investigated and evaluated in terms of food product physical and functional attributes, food safety, shelf life, and cost savings to food producers (2,42). Emulsification of milk products, fractionation of milk liquid and removal of fat layers, disruption of casein micelles, and production of milk with smaller particle sizes are the major applications of ultrasonic in the dairy industry (43,44).

Sonication has also been used to accelerate the ripenin g of cheese, increase lactose hydrolysis in fermented m ilk, and estimate the size and concentration of bubbles in whipped cream and yogurt (45,46). Generally, Purification, inactivation of bacteria and enzymes, and homogenization are some of the uses of this technique in the dairy industry (47). Several latest studies on the use of ultrasound on dairy products are summarized in table 3.

4. Fruits, vegetables and Fruit juice

Because of the scattering of sound from voids and pores, fruits and vegetables are extremely attenuating products (51). So, measurable ultrasound parameters such as velocity, attenuation, and resistance must be used to assess the properties of fruits and vegetables. The ultrasonic treatment has the greatest effect on fruits and vegetables due to the existence of intercellular spaces (52). Therefore, some fruits and vegetables (such as apples, bananas, cucumbers and watermelons, potatoes and squash) have very high attenuation coefficients and their ultrasonic velocity is less than the ultrasonic velocity of air (53). Many research on the impact of ultrasound on the properties of fruits and vegetables have been performed in the last decade. For instance, Mizrach in 2008, determined the various physiological and physiochemical properties of fresh fruit and vegetables in pre- and postharvest processes by Ultrasonic technology (54). Mizrach measured the various properties including firmness, mealiness, dry weight percentage, oil contents, total soluble solids, and shelf-life of fruits and vegetables. Mizrach (2004) also used an ultrasonic process to assess the maturity and sugar content of plum fruits in another study (55). Also, Seymour and coauthors have used ultrasound for microbial decontamination of fruits and vegetables (56).

Table 3. Some examples of the latest studies on the use of ultrasound technique in milk and dairy products

Ref-year	Ultrasound condition	Type of sample and Purpose of the study	Results and observations
(48)-2021	44.56 ± 3.47 W cm^{-2} 4 min	extraction of milk phospholipids from beta-serum	The extraction yield of milk phospholipids was 69.67 ± 3.45%. The recovered fraction was made of phosphatidylinositol (32%), phosphatidylethanolamine (30%), and sphingomyelin (37%).
(49)-2021	42–70 W/cm^2 for 5 min.	impact of soy lecithin in emulsification of dairy beverages	Improving the stability of ultrasound emulsions at high acoustic intensity without the use of soy lecithin. Increasing of particle size (470–500 nm). ultrasound can be used as manufacturing aid for the formulation of dairy-based emulsions
(50)-2021	amplitude = 50, and 75% time = 5, 10 and 15 min temperature = 45, 55 and 65ºC	determination of physicochemical, textural and sensory properties of yoghurt	increasing of apparent viscosity, hardness and lightness of yoghurt with increasing of time, temperature and amplitude At 75% of amplitude, the pH, syneresis and flavour decreased but acidity, adhesiveness, cohesiveness, springiness, chewiness, redness, yellowness and overall acceptance increased. Based on the physicochemical and sensorial results, sonication at 55 °C, 10 min and 75% of amplitude, effectively improved the properties of yoghurt

The ultrasonic technique has also been used to determine the concentration of various sugar species in fruit juices (42). In order to extend the shelf life of fruit juices and prevent microbial growth, typically thermal pasteurization is used. However, using high temperatures can have unfavorable biochemical and nutritional effects on final product's quality. Therefore, the ultrasound technique has the potential to be very useful as a non-destructive tool in the juice industry (57).

A number of latest studies on the ultrasound applications on various properties of Fruits, Vegetables and Fruit juice are summarized in table 4.

5. Advantages and limitations of Ultrasonic method

Ultrasound is adaptable, portable, and has a high depth of penetration. High sensitivity and the ability to find very small defects. It has no negative impacts on food and is a non-destructive technique and rapid compared to conventional techniques such as thermal methods. Furthermore, it is readily adaptable for online measurements, which would be helpful for tracking food processing operations (10,62).

One of the main limitations of ultrasonic technique is that the presence of gas micro-bubbles in a sample would attenuates ultrasound to the point that an ultrasonic wave cannot be pervaded through the sample. In addition, it requires highly trained operators as well as the careful attention of experienced technicians (63).

Table 4. Some examples of the latest studies on the use of ultrasound techniques in Fruits, Vegetables and Fruit juice

Ref-year	Ultrasound condition	Type of sample and Purpose of the study	Results and observations
(58)-2021	630 W 40 kHz 10 min	the ultrasonic coupling purslane extract on the browning resistance of fresh-cut potato	The optimal ultrasonic time was obtained 10 min. The mixture of ultrasound and 0.02% purslane extract had a better anti-browning effect. The ultrasound method reduced the cell membrane damage. Ultrasonic reduced anti-browning minimum effective concentration of purslane extract.
(59)-2020	12, 18 and 25 kW m3 40ºC	drying of fruits and vegetables	The use of ultrasonic waves changed the microstructure of materials both on the surface and inside them. The ultrasonic wave reduced the thickness of boundary layer.
(60)-2020	50 W, 240 W, and 300 W 25ºC 45 kHz 30 min	freeze-drying of carrot slices	The ultrasound treatment reduced drying time significantly ($p<0.05$). At ultrasonic power of 150 W, 240 W, and 300 W, the drying time was reduced by 20.7%, 23.7%, and 22.6%, respectively. The determination of b-carotene content was significantly higher ($p < 0.05$) at 300 W.
(61)-2020	100, 200, 300 and 400W 20 kHz 5, 10, 15, 20 and 30 min 25, 35, 45, 55 and 65ºC	Inactivation of polyphenol oxidase in quince	The polyphenol oxidase activity was reduced to 35% at the intensity of 400 W for 20 min. The ultrasound technique inactivated the enzyme. High-intensity ultrasonic treatment caused protein aggregation, distortion of tertiary structure, and α-helix degradation in the PPO enzyme.

6. Conclusion

Ultrasound is an advanced technique in the field of food science and technology. Ultrasound's tunable frequency broadened its applications in food analysis, processing, and quality control. The ultrasonic spectrum based on frequency and intensity is divided into two types, including low frequency-high-power (LF-HP) ultrasound and high frequency-low-power (HF-LP) ultrasound. The application of HF-LP ultrasound provides a non-invasive, inexpensive and simple method for assessing the food composition, physical and chemical properties and detecting contamination in a variety of foods, including fish, eggs, poultry, dairy foods, and so on. The LF-HP ultrasound modifies the physicochemical properties and increases the consistency of different food systems during processing by mechanical, chemical and biochemical effects. Over the decades, researchers have investigated the impact of ultrasound on the different properties of foods. This procedure has helped to minimize cost, save energy and improve food product quality.

Conflict of interest
Authors declare no conflict of interest.

Acknowledgment
Authors are thankful for the support of Tehran University of Medical Sciences.

References

1. Kasmawan IGA, Sutapa GN. Yuliara IM. Treatment of 40 KHz continuous ultrasound towards blood cells of mice (Mus Musculus L). Int J Life Sci 2018; 2: 66-74.

2. Awad T, Moharram H, Shaltout O, et al. Applications of ultrasound in analysis, processing and quality control of food: a review. Food Res Int 2012; 48: 410-27.

3. Tao Y, Sun DW. Enhancement of food processes by ultrasound: a review. Critic Rev Food Sci Nutr 2015; 55: 570-94.

4. Soria AC, Villamiel M. Effect of ultrasound on the technological properties and bioactivity of food: a review. Trend Food Sci Tech 2010; 21: 323-31.

5. Taskhiri MS, Hafezi MH, Harle R, et al. Ultrasonic and thermal testing to non-destructively identify internal defects in plantation eucalypts. Comput Elect Agri 2020; 173: 105396.

6. Kuang Y, Jin Y, Cochran S, et al. Resonance tracking and vibration stablilization for high power ultrasonic transducers. Ultrason 2014; 54: 187-94.

7. Astráin-Redín L, Raso J, Condón S, et al. Application of High-Power Ultrasound in the Food Industry. Sonochem React Intech Open, 2019. doi: 10.5772/intechopen.90444

8. Nipornram S, Tochampa W, Rattanatraiwong P, et al. Optimization of low power ultrasound-assisted extraction of phenolic compounds from mandarin (Citrus reticulata Blanco cv. Sainampueng) peel. Food Chem 2018; 241: 338-45.

9. Andueza D, Mourot BP, Hocquette JF, et al. Phenotyping of animals and their meat: applications of low-power ultrasounds, near-infrared spectroscopy, Raman spectroscopy, and hyperspectral imaging. Lawrie´ s Meat Sci 2017: 501-19.

10. Majid I, Nayik GA, Nanda V. Ultrasonication and food .technology: a review. Cogent Food Agri 2015; 1: 1071022

11. Mamvura TA, Iyuke SE, Paterson AE. Energy changes during use of high-power ultrasound on food grade surfaces. South Afric J Chem Eng 2018; 25: 62-73.

12. Turantaş F, Kılıç GB, Kılıç B. Ultrasound in the meat industry: General applications and decontamination efficiency. Int J Food Microb 2015; 198: 59-69.

13. Hinman JJ, Suslick KS. Nanostructured materials synthesis using ultrasound. Sonochem 2017: 59-94. doi.org/10.1007/978-3-319-54271-3_3.

14. Roohi R, Abedi E, Hashemi SMB, et al. Ultrasound-assisted bleaching: Mathematical and 3D computational fluid dynamics simulation of ultrasound parameters on microbubble formation and cavitation structures. Innovative Food Sci Emerg Technol 2019; 55: 66-79.

15. Hu A, Jiao S, Zheng J, et al. Ultrasonic frequency effect on corn starch and its cavitation. LWT-Food Sci Technol 2015; 60: 941-47.

16. Yusof NSM, Babgi B, Alghamdi Y, et al. Physical and chemical effects of acoustic cavitation in selected ultrasonic cleaning applications. Ultrason Sonochem 2016; 29: 568-76.

17. Fu X, Belwal T, Cravotto G, et al. Sono-physical and sono-chemical effects of ultrasound: Primary applications in extraction and freezing operations and influence on food components. Ultrason Sonochem 2020; 60: 104726.

18. Kentish S, Ashokkumar M. The physical and chemical effects of ultrasound. Ultrasound technologies for food and bioprocessing: Springer, 2011.

19. Marhamati M, Kheirati Kakhaki Z, Rezaei M. Advance in ultrasound-assisted extraction of edible oils: a Review. J Nutr Fast Health 2020; 8: 220-30.

20. Luque-Garcıa J, De Castro ML. Ultrasound: a powerful tool for leaching. Trend Analyt Chem 2003; 22: 41-47.
21. Wu X, Joyce EM, Mason TJ. Evaluation of the mechanisms of the effect of ultrasound on Microcystis aeruginosa at different ultrasonic frequencies. Water Res 2012; 46: 2851-58.
22. Zhang P, Zhu Z, Sun DW. Using power ultrasound to accelerate food freezing processes: Effects on freezing efficiency and food microstructure. Critical Rev Food Sci Nutr 2018; 58: 2842-53.
23. Bermudez-Aguirre D. Sonochemistry of foods. Ultrasound: Advances for Food Processing and Preservation: Elsevier, 2017. 1st ed, USA.
24. Rau R, Unal O, Schweizer D, et al. Attenuation imaging with pulse-echo ultrasound based on an acoustic reflector. International Conference on Medical Image Computing and Computer-Assisted Intervention: Springer, 2019.
25. Yan J, Wright WM, O'Mahony JA, et al. A sound approach: Exploring a rapid and non-destructive ultrasonic pulse echo system for vegetable oils characterization. Food Res Int 2019; 125: 108552.
26. Øyerhamn R, Mosland EN, Storheim E, et al. Finite element modeling of ultrasound measurement systems for gas. Comparison with experiments in air. J Acous Soc Americ 2018; 144: 2613-25.
27.Al-Aufi Y, Hewakandamby B, Dimitrakis G, et al. Thin film thickness measurements in two phase annular flows using ultrasonic pulse echo techniques. Flow Measur Instrument 2019; 66: 67-78.
28.Mohammadi V, Ghasemi-Varnamkhasti M, Ebrahimi R, et al. Ultrasonic techniques for the milk production industry. Measurement. 2014; 58: 93-102.
29. Alarcon-Rojo AD, Carrillo-Lopez LM, Reyes-Villagrana R, et al. Ultrasound and meat quality: a review. Ultrason Sonochem 2019; 55: 369-82.
30. Shung KK. Diagnostic ultrasound: Past, present, and future. J Med Biol Eng 2011; 31: 371-4.
31. Tait RG. Ultrasound use for body composition and carcass quality assessment in cattle and lambs. Veterin Clin: Food Animal Prac 2016; 32: 207-18.
32. Scholz AM, Bünger L, Kongsro J, et al. Non-invasive methods for the determination of body and carcass composition in livestock: dual-energy X-ray absorptiometry, computed tomography, magnetic resonance imaging and ultrasound: invited review. Animal 2015; 9: 1250-64.
33. Morton JD, Pearson RG, Lee HYY, et al. High pressure processing improves the tenderness and quality of hot-boned beef. Meat Sci 2017; 133: 69-74.
34. Bhat ZF, Morton JD, Mason SL, et al. Applied and emerging methods for meat tenderization: A comparative perspective. Comprehen Rev Food Sci Food Safe 2018; 17: 841-59.
35. Chang HJ, Wang Q, Tang CH, et al. Effects of ultrasound treatment on connective tissue collagen and meat quality of beef semitendinosus muscle. J Food Qual 2015; 38: 256-67.
36. Saleem R, Ahmad R. Effect of low frequency ultrasonication on biochemical and structural properties of chicken actomyosin. Food Chem 2016; 205: 43-51.
37. Cao C, Xiao Z, Tong H, et al. Effect of ultrasound-assisted enzyme treatment on the quality of chicken breast meat. Food Bioprod Process 2021; 125: 193-203.
38. Zhang C, Liu H, Xia X, et al. Effect of ultrasound-assisted immersion thawing on emulsifying and gelling properties of chicken myofibrillar protein. LWT 2021; 142: 111016.

39. Wang X, Dong Y, Wu R, et al. A method to improve water-holding capacity of beef during freezing-thawing process using ultrasound treatment. J Food Process Preserv 2021; 45: e15004.
40. Inguglia ES, Granato D, Kerry JP, et al. Ultrasound for Meat Processing: Effects of Salt Reduction and Storage on Meat Quality Parameters. Appl Sci 2021; 11: 117.
41. Fariñas L, Contreras M, Sanchez-Jimenez V, et al. Use of air-coupled ultrasound for the non-invasive characterization of the textural properties of pork burger patties. J Food Eng 2021; 297: 110481.
42. Paniwnyk L. Applications of ultrasound in processing of liquid foods: a review. Ultrason Sonochem 2017; 38: 794-806.
43. Leong T, Johansson L, Mawson R, et al. Ultrasonically enhanced fractionation of milk fat in a litre-scale prototype vessel. Ultrasonics Sonochem 2016; 28: 118-29.
44. Torkamani AE, Juliano P, Fagan P, et al. Effect of ultrasound-enhanced fat separation on whey powder phospholipid composition and stability. J Dairy Sci 2016; 99: 4169-77.
45. Abesinghe A, Islam N, Vidanarachchi J, et al. Effects of ultrasound on the fermentation profile of fermented milk products incorporated with lactic acid bacteria. J Int Dairy 2019; 90: 1-14.
46. Welti-Chanes J, Morales-de la Peña M, Jacobo-Velázquez DA, et al. Opportunities and challenges of ultrasound for food processing: An industry point of view. Ultrasound: Advances for Food Processing and Preservation: Elsevier, 2017. 1st ed, USA.
47. Huang G, Chen S, Dai C, et al. Effects of ultrasound on microbial growth and enzyme activity. Ultrason Sonochem 2017; 37: 144-49.
48. Rathnakumar K, Ortega-Anaya J, Jimenez-Flores R, et al. Improvements in the extraction of milk phospholipids from beta-serum using ultrasound prior to tertiary amine extraction. LWT 2021; 141: 110864.
49. Nyuydze C, Martínez-Monteagudo SI. Role of soy lecithin on emulsion stability of dairy beverages treated by ultrasound. Int J Dairy Tech 2021; 74: 84-94.
50. Kenari RE, Razavi R. Effect of sonication conditions: Time, temperature and amplitude on physicochemical, textural and sensory properties of yoghurt. Int J Dairy Tech 2021; 74: 332-43.
51. Mizrach A. Determination of avocado and mango fruit properties by ultrasonic. Ultrason 2000; 38: 717- 22.
52. Fernandes FA, Gallão MI, Rodrigues S. Effect of osmotic dehydration and ultrasound pre-treatment on cell structure: Melon dehydration. LWT-Food Sci Technol 2008; 41: 604-10.
53. Yunus R, Salleh SF, Abdullah N, et al. Effect of ultrasonic pre-treatment on low temperature acid hydrolysis of oil palm empty fruit bunch. Biores Technol 2010; 101: 9792-96.
54. Mizrach A. Ultrasonic technology for quality evaluation of fresh fruit and vegetables in pre-and postharvest processes. Postharv Biolog Technol 2008; 48: 315-30.
55. Mizrach A. Assessing plum fruit quality attributes with an ultrasonic method. Food Res Int 2004; 37: 627-31.
56. Seymour I, Burfoot D, Smith R, et al. Ultrasound decontamination of minimally processed fruits and vegetables. Int J Food Sci Tech 2002; 37: 547-57.

57. Tomadoni B, Cassani L, Viacava G, et al. Effect of ultrasound and storage time on quality attributes of strawberry juice. J Food Process Eng 2017; 40: e12533.
58. Zhu Y, Du X, Zheng J, et al. The effect of ultrasonic on reducing anti-browning minimum effective concentration of purslane extract on fresh-cut potato slices during storage. Food Chem 2021; 343: 128401.
59. Putranto A, Chen XD. Reaction engineering approach modeling of intensified drying of fruits and vegetables using microwave, ultrasonic and infrared-heating. Dry Technol. 2020; 38: 747-57.
60. Fan D, Chitrakar B, Ju R, et al. Effect of ultrasonic pretreatment on the properties of freeze-dried carrot slices by traditional and infrared freeze-drying technologies. Dry Technol 2020: 1-8.
61. Iqbal A, Murtaza A, Marszałek K, et al. Inactivation and structural changes of polyphenol oxidase in quince (Cydonia oblonga Miller) juice subjected to ultrasonic treatment. J Sci Food Agri 2020; 100: 2065-73.
62. Zheng L, Sun D-W. Innovative applications of power ultrasound during food freezing processes: a review. Trend Food Sci Technol 2006; 17: 16-23.
63. Collins JT, Boros MJ, Combs K. Ultrasound surveillance of endovascular aneurysm repair: a safe modality versus computed tomography. Annal Vascul Surg 2007; 21: 671-75.