Food Research 7 (4) : 365 - 370 (August 2023)
Journal homepage: https://www.myfoodresearch.com

FOOD RESEARCH

Ultrasound as an innovative way to modify food structure and opportunities in food industry

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Article history:
Received: 4 December 2021
Received in revised form: 22 January 2022
Accepted: 25 January 2022
Available Online: 31 August 2023

Keywords:
Ultrasound,
Protein modification,
Polysaccharides modification,
Emulsion modification,
Ultrasonication in food applications

DOI:
https://doi.org/10.26656/fr.2017.7(4).975

Abstract

This review illustrated the recent ultrasound applications in different food systems derived from a number of food sources including dairy, animal, cereal, and fruit. Aside from an overview of the physiochemical effects of sonication on food structure modification on protein, polysaccharides and emulsions, which contribute to the changes in the key functionality of these major components in the food system, the benefits of ultrasound modification on protein, polysaccharides and emulsions are also summarized. In the food industry, ultrasonication is recognised as an emerging green technology with great application potential. Power ultrasound, a high-power low-frequency ultrasound, is of significant interest as it possesses wide usage within numerous sectors, particularly food processing. The potential benefits and limitations of ultrasound are evaluated, and it is concluded ultrasound in food applications is a high-potential topic of research. Further study is necessary to be conducted to widen the application and efficiency of this technology in other industrial sectors.

1. Introduction

Consumer markets demand food products with nutritional characteristics comparable to those found naturally, and these food products need to maintain freshness in storage and distribution prior to consumption. This can be achieved by processing technologies that shorten processing times and extend product shelf life whilst maintaining significant nutritional quality and sensory characteristics. In the food industry, there is increasing interest in emerging green technologies such as ultrasound with huge application potential.

Current food applications of ultrasound are primarily for quality enhancement and process control. There are various examples of ultrasound application in mass transfer, emulsification, crystallization, foam production as well as homogenization and inactivation of microorganisms (Unver, 2016) and enzymes. The review aimed to illustrate the recent ultrasound applications derived from a number of food sources including dairy, animal, cereal, and fruit and summarises the benefits of ultrasound modification on protein, polysaccharides and emulsions in the food industry.

2. Fundamental of ultrasound

Ultrasound is an acoustic wave above human auditory perception, usually referring to a frequency greater than 16 kHz. Based on the wave frequency, ultrasound is classified into two categories: high frequency (100 kHz - 1 MHz) with low intensity (<1 Wcm^2) and low frequency (20 - 100 kHz) with high intensity (10 - 1000 Wcm^2). In food physicochemical properties, high-frequency ultrasounds are commonly used for analytical evaluation, and low-frequency ultrasounds are for modification (Chemat *et al.*, 2011).

2.1 Acoustics cavitation and its effects

Power ultrasound generates different effects when passing through the material (Ozuna *et al.*, 2015). These effects are described by various mechanisms where acoustic cavitation plays a pivotal role. The cavitation is generated by localised pressure differentials occurring over a few microseconds due to the quick formation and collapse of gas bubbles (Pandit *et al.,* 2021). These cavitation effects involve either physical or chemical mechanisms. The mechanical effect is deterioration due to cavitation bubble collapse. The chemical effect is the formation of free radicals.

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eISSN: 2550-2166 /
Published by Rynnye Lyan Resources

2.2 Effects of ultrasound on food

Ultrasonic cavitation causes temperature rise where the bubble collapses due to localised intense hydrodynamic shear forces (O'Brien, 2007; O'Donnell *et al.*, 2010). The functionality of proteins can be altered by increasing molecular weight known as aggregation, by reducing molecular weight known as proteolysis. Without requiring the presence of additives or extreme thermal treatments, power ultrasound simplifies processing by offering the possibility of protein structure modification. Table 1 summarizes the different studies on the effects of ultrasound on food structure.

2.2.1 Effects on protein

Generally, high protein systems do not reconstitute easily (O'Sullivan *et al.*, 2017). When a high-protein dairy powder is added to water, there are five phases starting with wetting, swelling, sinking, dispersion and finally dissolution (Crowley *et al.,* 2016). Power ultrasound affects protein rehydration during dispersion and dissolution, the release of constituent molecules by a complete breakdown of granular structure (Vos *et al.*, 2016). Ultrasonication improves dairy protein powders' dissolution and solubilization rates as compared to conventional dissolution methodologies such as high-pressure homogenization, and/or low and high-shear mixing (Chandrapala *et al.*, 2014).

Ultrasound treatment of plant protein systems could potentially benefit powder dissolutions, as ultrasonication can result in smaller aggregate plant protein size in an aqueous solution (Cao *et al.*, 2021). Ultrasonication of proteins is linked to structural changes, resulting in physicochemical changes. These lead to benefits such as lower bulk viscosity and superior emulsion stability.

2.2.2 Effects on polysaccharides

Polysaccharides have a broad range of properties based on the structure which refers to monosaccharide composition and linkages type between units. Ultrasound degradation considerably reduced viscosity and increased solubility in starch (Cheng *et al.*, 2010). The crystalline structure of corn starch granules remained unchanged under ultrasonication (Huang *et al.*, 2007). In water, sonication also resulted in substantial porosity increment (Sujka, 2017). Modified pectin showed superior functional properties and bioactivities after modification. Ultrasound was investigated to degrade and modify biopolymers with high efficiency and low cost. Modification factors are temperature, ultrasound frequency, power intensity, as well as duration (Almagro *et al.*, 2017).

2.2.3 Effects on emulsion

Power ultrasound is useful in forming nano-sized droplets. Prolonging the residence time reduces droplet size, eventually to a minimum size per formulation. Higher acoustic power reduces the time taken to attain minimal droplet size (Leong *et al.*, 2009).

Power ultrasound is commonly used for emulsion formation from either coarse pre-emulsions or discrete continuous and dispersed phases. The formulation and emulsification processing conditions are deciding factors affecting the resultant emulsion microstructure. Prolonging the contact time can minimize the droplet size, providing sufficient residence time and coverage (Lau *et al.*, 2022). Increasing treatment time decreases

Table 1. Effects of ultrasonication on food structures.

Authors	Food Structure	Study Findings
Chandrapala *et al*. (2010)	Protein (Higher protein aggregation)	Sonication changed protein properties (structural and thermal) of reconstituted whey protein concentrate (WPC) solutions.
Jambrak *et al*. (2007)	Protein (Better solubility and foaming ability)	Ultrasound can cause protein molecules hydrolysis or degradation via hydrodynamic forces, due to the cavitation effect produced under high pressure.
Ren *et al*. (2017)	Protein (Higher enzymolysis efficiency)	Ultrasound was used to pre-treat protein prior to proteolysis to improve enzymolysis efficiency, improved ACE inhibitory activity of zein hydrolysates.
Cui *et al*. (2018)	Polysaccharide (Better extraction efficiency)	Ultrasound favoured extraction of polysaccharides from *V. volvacea* affected molecular weight range, ratio, and compositions of polysaccharides.
Lin *et al*. (2018)	Polysaccharide (Better extraction efficiency)	Ultrasound-assisted extract scavenged more OH radical and Fe ion, which could improve the efficiency of ZSS polysaccharide extraction.
Zhou and Ma (2006)	Polysaccharide (Increased degradation)	Higher ultrasonic power and temperature led to a faster degradation rate of *Porphyra yezoensis* (PYPS) solution and decreased pH value.
Jafari *et al.* (2006)	Emulsion (Oil droplet size reduction)	Emulsion droplet size decreased with longer sonication time. Optimal conditions were necessary for emulsion.
Kaltsa *et al*. (2014)	Emulsion (Better stability, lower viscosity)	Higher amplitude produced stabler emulsions. Smaller oil droplet size and thinner. The rate of change was more by changing amplitude than sonication time.
Li and Xiang (2019)	Emulsion (Better stability and shelf life)	Ultrasound lowered average droplet size, emulsion viscosity, and narrowed emulsion distribution range, demonstrating better food shelf life.

https://doi.org/10.26656/fr.2017.7(4).975

emulsion droplet size in batch-processing methodologies (O'Sullivan *et al.*, 2016). A slower flow rate which prolongs the emulsion's residence time for continuous processing reduces emulsion droplet size (O'Sullivan *et al.*, 2016). Nano-sized (~200 nm) emulsion droplets were achieved.

Emulsifiers are added to improve product stability and extend shelf life. Stable emulsions are of critical importance. High-pressure homogenization, due to its high efficiency, is a conventional approach to emulsification. Both homogenization and ultrasonication are effective in lowering the viscosity, average droplet size and narrowing the distribution range (Li *et al.*, 2019). However, high-pressure homogenisation led to aggregation in the emulsion while by ultrasound treatment the emulsion was stable for one month of storage. Ultrasonication used to prepare emulsion has the potential to demonstrate better food shelf-life (Li and Xiang, 2019).

Although progress in studying the role of power ultrasound on the solubilities of proteins and formation of nano-emulsions has been made, this is predominately done at a small scale in laboratories. To better utilise this versatile technology further work is required.

3. Applications of ultrasound in food

3.1 Applications in food industry

Ultrasonic waves are categorized into two depending on intensity and frequency. Frequencies higher than 100 kHz with low intensity are used for diagnosis. These waves are non-destructive and widely deployed in quality control and analysis, providing valuable insight into food's physical and chemical properties. Higher sound energy improves mechanical effect by promoting heat and mass transfer, better in modification application.

3.2 Effects on food structure properties

Ultrasonication can alter food structure with effects on texture and consistency. The main interest is in ultrasound in the structural modification of food products. Numerous studies have shown improvement in texture retention in low-intensity ultrasound pre-treatment. The various ultrasound effects are either physical or chemical cavitation effects. Table 2 summarises different studies on the effects of sonication in food samples.

3.3 Potential benefits and limitations of ultrasonication

Ultrasound is considered non-toxic, safe, and environmentally friendly. Cheaper running costs, simple operation and efficient power output are a few noted benefits as ultrasonication does not need complex machinery. Relative to existing conventional methods, ultrasonication provides a better yield and extraction rate. It also leads to a minimum loss in flavour with superior consistency. Ultrasonication has generated interest in applications such as processing, emulsification, extraction, preservation, homogenization and more.

The use of ultrasonication has its limitations despite its advantages. Ultrasound applications require higher energy input which makes industrialists hesitate when applied commercially. Ultrasonication leads to physical and chemical effects which may be the cause of food

Table 2. Examples of sonication applications in food.

Authors	Food Sample	Study Findings
Brilhante de San Jose *et al*. (2014)	Fruits and Vegetables	Ultrasound removed surfaces dirt and inactivated microorganisms, it can be used alone or associated with chemical sanitisers.
Bosiljkov *et al*. (2016)	Cow Milk	Probe diameters have a significant effect on physical properties and homogenization. Increased amplitude and time increase homogenization.
Cao *et al*. (2010)	Strawberries	Ultrasound showed the ability to improve the shelf-life and quality of strawberries.
Chang *et al*. (2015)	Meat (Beef)	Tenderness, juiciness and flavour are key to meat quality. High power low-frequency ultrasound had positive effects on connective tissue properties and meat texture.
Ferrante *et al*. (2007)	Orange Juice	High intensity with a combination of heat treatment and natural antimicrobials may be an option in fruit preservation.
Hosseini *et al*. (2013)	Acidified Milk Drinks	Sonication was used to homogenise nanoparticles in the mixed dispersion, these may assist fortification of acidic beverages.
Stadnik and Dolatowski (2011)	Meat (Beef)	Low-intensity ultrasound improved beef tenderization without negative effects on its proportions of Mb redox forms and CIE colour parameters.
Wu *et al*. (2000)	Yoghurt	Before inoculation, a higher ultrasound amplitude level considerably thickened viscosity enhanced the water-holding capacity and lowered syneresis.
Li and Xiang (2019)	Emulsion (Better stability and shelf life)	Ultrasound lowered average droplet size, emulsion viscosity, and narrowed emulsion distribution range, demonstrating better food shelf life.

https://doi.org/10.26656/fr.2017.7(4).975

product quality impairments by developing off-flavours, altering physical properties, and degrading components. Ultrasound also leads to changes in food compounds due to radical formation under critical temperature and pressure. These radicals (OH and H) deposited at the cavitation bubble surface stimulate radical chain reactions which degrade products and result in significant quality defects.

4. Conclusion

Environmentally friendly and efficient are two of the main benefits of using ultrasound in food. The benefits of this technology in polysaccharide modification are emphasized. Ultrasound can alter food structure. Acoustic cavitation is the key through either mechanical effect or chemical effects. To commercialize polymers modification sonochemical reactors need to be better developed. Many studies in food technology have been conducted on ultrasound technologies, but more work is required in order to create highly efficient automated ultrasound systems that will lead to labour reduction, financial and energy efficiency, and maximise safe food production.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

The research work was funded by Taylor's Flagship Research Grant (TUFR/2017/003/02).

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