Ultrasound-Assisted Food Processing: A Mini Review of Mechanisms, Applications, and Challenges

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Abstract. Ultrasound technology in food processing holds promise in terms of energy efficiency, environmental impact, and sustainability compared to traditional processing methods. These conventional heat-based techniques, such as salting, smoking, and frying, are energy-intensive and time-consuming. Therefore, ultrasound as a promising technology has attracted the interest of scientists and stakeholders in the food processing field. This alternative solution utilizes ultrasound and can achieve similar results with reduced energy input. This not only reduces energy consumption but also contributes to reducing carbon footprint and greenhouse gas emissions. In addition, ultrasound processing technology enhances food safety and quality by inhibiting microbial growth and killing pathogens, leading to longer shelf life and reduced food waste. However, there are also present some limitations of ultrasound in food processing through dense and complex food matrices like protein. Current research and development efforts are expected to address these challenges and expand applications in food processing. Overall, ultrasonic technology could transform the sustainability of food processing in the future.

Keyword. Food processing, Food quality, Ultrasonication, Ultrasound applications, Ultrasound limitations

1 Introduction

Food processing involves using traditional methods, such as drying, frying, smoking, salting, or pickling to transform agricultural products and enhance their appeal, shelf-life, and safety for consumption. These traditional processing methods use heat to limit the growth of microorganisms and destroy pathogens. However, these techniques are limited since they take a long time and a lot of energy [1]. Furthermore, some foods can be impacted by losing a component throughout the traditional process, leading to changes in flavor, texture, and color [2]. As a result, research is being done to find green and innovative ways of assisted processing of food. This includes applying methods like ultrasound assisted processing.

Ultrasound involves using sound waves of high frequency and intensity to modify the physico-chemical and functional properties of food components, such as proteins, polysaccharides, and polyphenols [3]. This can be accomplished by adjusting processing parameters like temperature or pressure. Without affecting their fundamental properties, ultrasonography can also encourage interactions between various natural products. Ultrasound assisted food processing with pressure (monosonication) and thermal treatment (thermosonication), and combination of pressure and heat (Monothermosnication) can be applied to enhance food quality. This method helps to reduce microbial contamination, as well as increase shelf life and nutritional value by preserving vitamins, minerals, and other nutrients in the food [4].

In addition, ultrasound technology in food processing has important environmental implications. Compared to conventional techniques, it provides a more energy-efficient approach, reducing the carbon footprint associated with food production and preservation. This non-thermal ultrasound technique results in reducing energy consumption and less processing time. Furthermore, a research study conducted by Bhargava et al. (2020) demonstrated that ultrasound processing improves food safety and extends shelf life, reducing food waste and its associated environmental impacts [5]. Therefore, the application of ultrasound technology in food processing can contribute to a more environmentally friendly and sustainable food industry.

This review paper discusses several types of transducers used to create ultrasound, ultrasonic processing principles, and the diverse applications of ultrasonic processing in food preparation. Moreover, it also highlights the limitation of ultrasound in food processing through dense and complex food matrix like

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protein. To sum up, ultrasound technology is an emerging tool for food quality inspection and change with the potential to revolutionize food processing.

2 Generation of Ultrasound-assisted food processing: A Literature Review

The earliest use of ultrasound technology dates back to the late 19th century, when it was used by a German physicist named Christian Doppler for medical imaging [6]. Since then, its applications have expanded into many other fields including food science. Over time, researchers developed more sophisticated methods, such as using higher frequencies or amplifying sound waves in order to improve the accuracy and efficiency of results obtained from ultrasonic analysis [4]. The benefits of ultrasound technology are diverse and lucrative for the food sector and making it an emerging technology for probing and food product enhancement.

Ultrasound may be employed at both high and low power levels in food processing. High power ultrasound, which applies frequencies between 20-100 kHz, can cause cavitation in the material being processed and alter its properties through pressure, shear, and temperature changes [5, 6]. Low power ultrasound applies higher frequencies between 2-10 MHz without altering the material's physical or chemical properties. Several types of transducers, including liquid-driven, magnetostrictive, and piezoelectric transducers (Figure 1), can be applied to generate ultrasound. Liquid-driven transducers use a powerful pump to force process material within a narrow blade, causing the blade to vibrate and produce pressure waves and cavitation. Magnetostrictive transducers utilize electromagnetic devices and ferromagnetic materials that alter size whilst subjected to a magnetic field. Piezoelectric transducers convert electrical energy to acoustic energy by aligning polarized molecules within the material when subjected to an electric field (electrostriction) or mechanical force (piezoelectric effect) [7].

Over 60 years have passed since low-intensity ultrasound was first used to analyze and describe food items, but only recently have researchers started to fully understand its capabilities. In the past, ultrasound was largely employed for non-destructive testing of food quality and making physical and mechanical changes to food items. It was employed, for example, to destroy cell walls and let intracellular materials to be released [8]. Recently, ultrasound has been integrated into various stages of food processing, such as blanching, drying, extraction, freezing, etc., to improve efficiency [9]. Although these technologies demand an initial investment, they can ultimately increase product quality while lowering expenses.

3 Ultrasonic Assisted Food Processing: Food properties modification

Ultrasonic has several principles to improve food processing including acoustic cavitation, mechanical effects, vibration, and agitation [5]. To increase emulsion homogeneity and stability, researchers utilized an ultrasonic agitator. The ultrasonic agitator caused localized high-intensity mixing, which resulted in smaller droplet sizes and improved emulsion stability [10]. Another important principle is a vibration that's useful for delicate and sticky food items like cheese, pastries, and cakes since it lessens the growth of bacteria on the product surface and helps to prevent sticking [5]. Table 1 illustrates other ultrasound principles with instances of how they are applied, including uniform heat, cavitation, and diffusion.

Ultrasound waves are passed through the food product, and the way the waves travel through the product can provide information about its physical and chemical properties, to assess the quality of food products [11]. Jiménez et al. (2017) developed an ultrasound-based monitoring system to measure the properties of raw milk during curdling and found that the ultrasound measurements of temperature and viscosity were highly correlated with traditional methods. The researchers concluded that ultrasound has potential for use in optimizing the curdling process and enhancing dairy products quality [12]. Furthermore, utilizing ultrasound in the meat industry can improve the meat tissue's water dynamics and tenderness. In addition, it

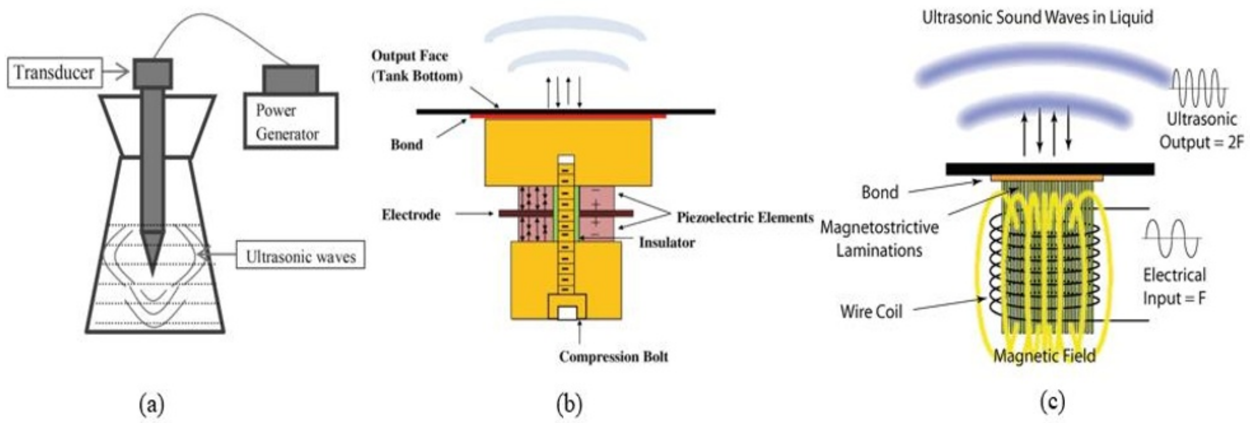

Fig. 1. Several types of transducers used in ultrasonic generation: (a) Ultrasonic probe [8] (b) Piezoelectric transducers (c) Magnetostrictive transducers [5]

can also increase the meat's water holding capacity and enhance its color [13]. These processes create novel methodologies that exceed the potential of traditional techniques in food processing.

Ultrasound technology can also be employed to lessen microbial contamination in food processing. The usage of high-intensity ultrasound can reduce the harmful microorganisms and enzymes present in dairy products. To emphasize, the findings of subjecting ultrasound in dairy products show increased probiotic viability, reduced lactose content, and higher oligosaccharides concentration [14]. Hence, further investigation is required before ultrasound can be scaled up to industrial levels to identify the best application parameters for each type of food. The pros of ultrasound application in food processing include improved physical, and chemical properties, reduced spoilage by microorganisms, and enhanced. However, it can be expensive to implement, as specialized equipment and instrumentation are required [12, 15].

Apart from the applications in food processing, ultrasound is extensively used as a pretreatment technique for lignocellulosic biomass [16]. This process employed high-intensity ultrasound to modify biomass structure and improves the accessibility of enzymes and chemicals to its contents. Ultrasound pretreatment has proven effective in improving enzymatic hydrolysis, increasing sugar release, and enhancing the efficiency of biofuel production from biomass. Moreover, it also assists in the extraction of beneficial bio-chemicals from lignocellulosic biomass, enabling their use in waste valorization and biorefinery processes [17].

4 Ultrasonic Assisted Food Processing: Limitations and Potential Prospect

Ultrasound effectiveness is limited in dense and complex food matrices such as protein-based ones, where it may struggle to penetrate deeply and reach the target region [23]. The influence of ultrasound can vary relying on the food type and whether the proteins are separated or present in the food system [24]. In addition, ultrasound may generate free radicals that can oxidize active compounds in some solid meals, altering the food matrix's properties or even making it unsafe for consumption [25]. Using ultrasound to measure food properties of complex food matrices can also present challenges such as attenuation, lower resolution with lower frequencies, and difficulty in obtaining clear results when multiple variables are changing simultaneously [26]. Thus, it is crucial to select the appropriate frequency, power, and mode of operation, while considering the type of food matrix.

Ultrasound technology has shown considerable promise in the food sector, and its uses are anticipated to expand in the future. Ultrasound, for example, is likely to be integrated with other processing technologies, such as high-pressure processing, pulsed electric fields, and thermal processing, to achieve greater efficiencies and improve food product quality and safety [27]. Furthermore, the operation of ultrasound in food processing is probably going to become more automated and miniaturized with invention of portable and handheld devices [28]. This will make it easier for food processors to apply ultrasonic technology at various phases of the food manufacturing process. Application of

Table 1. Principles of Ultrasound and its application in food processing.

Ultrasound Principle	Ultrasound Specifications	Sample Tested	Application	Observations	References
Uniform heat transfer	High-intensity ultrasound, frequency range between 20 kHz and 1 MHz, with an intensity level of up to 100 W/cm^2	Juice	Pasteurization	Inactivation of microorganisms present in juice, resulting in a 5-log microbial reduction; Shortage of pasteurization time; Reduction of negative impacts on juice organoleptic and nutritional characteristics	[18]
Diffusion	Low-intensity ultrasound, frequency range below 40 kHz	Polyphenols (plant material)	Extraction	Increase extraction yield of polyphenols; Improve phenolic extract biological activity over conventional maceration	[19]
Cavitation	High-intensity ultrasound, frequency of 20 kHz, power output of 500 W, and duty cycle of 50%	Green pepper	Drying	Reduction in drying time; Low energy consumption; Maintain product quality factors such as shrinkage and nutrient content	[20]
	High-intensity ultrasound, frequencies of 30 kHz and 20 kHz, and the power levels ranged from 150 W to 175 W	Broccoli	Freezing	Reduction in overall freezing time as well as pre-cooling, phase transition, and sub-cooling durations for broccoli; Drip loss reduction compared to normal immersion freezing	[21]
	Low-intensity ultrasound, frequency is 20 kHz	Skim milk	Emulsion	High encapsulation yield; Good shelf stability	[22]

the technology will become more targeted and precise as we learn more about how ultrasound impacts various food components, its mode of action, and its influence on the physicochemical qualities of food.

Ultrasound applications have the potential to improve food processing by successfully killing microorganisms and enzymes while maintaining food's sensory and nutritional characteristics. These technologies can complement existing traditional methods and can be combined into various unit operations like blanching, drying, and freezing to improve efficiency. Furthermore, ultrasonic technology in food processing is a sustainable alternative since it may eliminate the usage of chemical preservatives and increase product shelf life, decreasing food waste. Furthermore, the initial investment required for ultrasound equipment and the need for skilled operators could limit its adoption by small-scale food factories or those operating in low-income countries [27]. Therefore, solving this dilemma requires scientists to further explore these technologies in future research to develop safer, more efficient and economical food processing technologies.

5 Conclusions

In conclusion, advances in food processing are being driven by the continued development of ultrasonic technology. These developments improve several areas of food processing, including consistent heat distribution, extraction, emulsion stability, and bacterial control on product surfaces, by using principles including acoustic cavitation, mechanical effects, vibration, and agitation. In addition, there is a growing trend of integrating ultrasound with other technologies such as pulse electric fields, to further improve food safety and quality. As a result, the ongoing advancements in ultrasound-assisted food processing show immense potential to revolutionize the food industry, offering more sustainable and efficient processing techniques.

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