

A recent review of ultrasound applications on juice

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Abstract. Ultrasound has been introduced in processing value-added food as a novel technology for years to serve multiple purposes including emulsification, drying, crystallization, and so on. It can be employed in a variety of foods like juice, dairy, lipids, meat, eggs, and so on. This literature review aims to summarize the recent research progress on ultrasound application in juice processing. It provides basic ultrasonication mechanisms, changes in juice physicochemical properties (including the general juice attributes, rheology behavior, and aroma profile), sonication-induced microorganism inactivation, and employing sonication combined with other technologies. Furthermore, introduces the concept of hurdle technology and its effectiveness when dealing with juice production.

Keywords: ultrasound, juice, physicochemical properties.

1. Introduction

Ultrasound (US), a novel green non-thermal technology applied in food processing, is defined as a soundwave with a frequency above the human hearing threshold [1]. Based on sound power, sound intensity, or sound energy density applied, sonication is divided into two categories: low energy US with frequency higher than 100kHz and intensity below 1 W/cm² for analytical applications since it cannot change the physicochemical properties of food matrix; while high power ultrasound (HPU) is characterized by frequency and power density ranging from 20-500kHz and 10-1000W/cm² respectively [2]. Figure 1 illustrates that there are two types of lab apparatus: an ultrasonic cleaning bath and a probe system, which are all composed of three essential parts: an electrical power generator, a transducer, and an emitter[3].

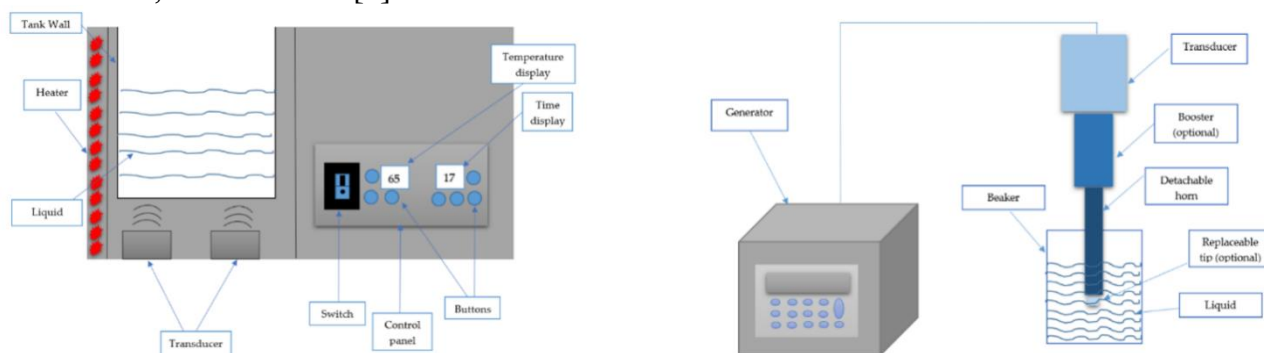


Figure 1. consists of the ultrasound bath and probe [3]

Cavitation occurs when an ultrasound wave passes through a medium. The sound wave presses and stretches the molecular, changes its space and then the “weak spot” is generated during the negative pressure cycle where the liquid is pulled apart. Once the pressure is large enough to exceed the maximum force that molecules require to hold the liquid intact, the liquid breaks down to form voids, also known as “cavitation”. As a result of cavitation, microbubbles are induced, low-power ultrasound creates “stable cavitation”, while the HPU generates “transition cavitation” [4]. As can be seen in Figure 2, transition bubbles experienced expansion under the compression cycle, which ultimately collapsed to release a variety of physic forces (such as shear force, and microjet), extremely high localized temperature with estimates of 4500-5000K, and free radicals [2].

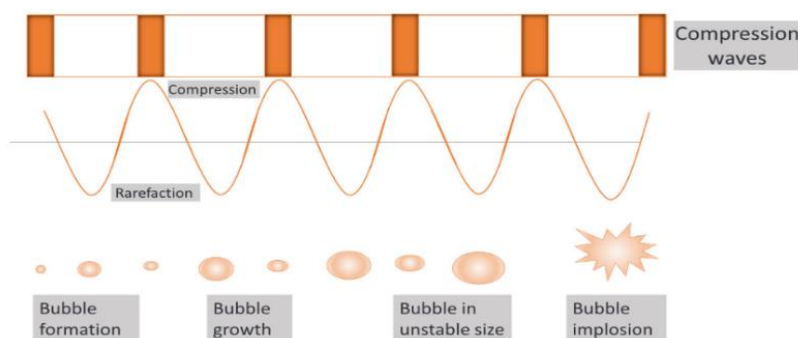


Figure 2. illustrates microbubble expansion and collapse within the cavitation process [1]

2. The influence of ultrasound on juice properties changes and microbe inactivation

2.1. Juice Physicochemical Property

2.1.1 General juice properties

To provide better quality juice with less segmentation after a period of storage, cloud retention and or turbidity is measured in the lab. Those attributes relate to cellulose particles, hemicelluloses, protein, lipids, pectin, and other compound interactions with serum. Owing to the acoustic energy is expected to reduce particle size and distribute them uniformly, the US alters both particle and serum properties which enhances particle-particle and particle-serum interaction [5]. The experiment conducted on kiwi juice in Table 1 reveals that the sonication treatment increased cloudiness value significantly as a result of cell deterioration while decreasing the turbidity of the supernatant after days of separation as a result of large particles being broken down by cavitation [6].

Humans benefit from fruit and vegetable juices, due to their containing a great amount of bioactive compounds (BACs) (such as carotenoids, anthocyanins, ascorbic acid, phenolics, flavonoids, and so on). Research believes that apart from specific experiment conditions that sonication degraded the BACs values in juice, generally, the US increased the total BACs and total antioxidant capacity value to improve the accessibility for consumption. They propose that cavitation breaks the cell integrity and allows intracellular compounds to be released [7].

Besides, almost all kinds of sonication related to juice experiments argue the US can help to stabilize other values like pH, total soluble content, and color, which are regarded as crucial for juice quality determination. pH plays a vital role in the product safety management process because acidic or alkaline conditions inhibit or promote microbial growth and affect the taste of juice [6]. In terms of total soluble content (TSS) is mainly determined by reducing and non-reducing sugars, with minor contributions from organic and amino acids and other soluble proteins [3], It is therefore considered an essential criterion for determining fruit flavor and ripeness, which dominates the responsibility for final juice products variation. When sample juices undergo light to mild treatment conditions, the L index value slightly increased to brighten the juice with ultrasound applied while the a and b index remained steady. However, as more harsh treatments were applied, there are significant changes were observed in the rise in a value and drop in L value, which means that the juice color became darker and brown. Researchers believe that localized heat induces Maillard reaction which contributes to darkening the juice's appearance [8]. The market prefers brighter juice than others since it indicates the freshness of the juice. Because of that, endogeneity enzymes including PME, polyphenoloxidases, and peroxidases required to be eliminated during manufacturing procedures to extend the shelf life. Ultrasound treatment in unwanted enzyme inactivation outperforms the conventional treatment, especially when combined with other methods like heating [9].

2.1.2 Rheology Behavior

The rheology behavior particularly influences the consumer's choice. Thick juices have a richer mouth feel and higher nutrition quality to some extent, while thin juices have a clear and more consistent appearance with less sedimentation. Due to the particle size, total soluble solids, pulps, and many other compositions that exist in the juice matrix, the flow behavior heavily relies on them and the coexisting forces among them. The pseudoplastic behavior also known as non-Newtonian shear thinning behavior was observed both in lily juice and Annona Crassiflora juice. As a consequence of the physical force such as shock wave, microjet, etc., generated by microbubbles collapsed during the cavitation process, they both exhibited a significant increase in small particle size, cloudy value, and total soluble solids [10][11]. Rising values in small particles were confirmed by the microscope examination, which presented the ultrasound altered the tissue structure and crushed particles into smaller ones. Apart from that, zeta potential is a key parameter to evaluate the charge states on the particle surface, which indicates the potential stability of the colloidal suspension in the system [12]. Researchers found that the pH and zeta potential in lily juice remained stable throughout the whole time. Others suggest that the unchanged pH might contribute to the stable zeta potential [13], as shown in Table 1.

Table 1. Ultrasound application on juice

Type of Juice	Experiment condition	Key finds of food matrix	Key findings of microorganism inactivation	Reference
Pumpkin juices	Frequency: 25kHz	No significant change in color, sugar, and organic acid content.	<i>Staphylococcus aureus</i> : Conventional pasteurization contributes to microbe reduction significantly. The ultrasound treatment showed promising effectiveness in microbe inactivation in more harsh experiment conditions.	[7]
	Temperature: 20°C, Time: 0, 5, 10, 20 min, Power: 0, 100, 200, 300, 400w	Carotenoid and total antioxidant capacity increased along with the ultrasound power rise. Microstructure: processes 200w distorted the shape and broke down the cell wall. No significant change in sensory property.		
Pineapple juice	Sonication amplitude: 50% (100w) and 70% (140w), Time: 5, 10, 15 min.	Color: pasteurization leads to visible color change, while only prolonged sonication treatment caused a "slightly noticeable change". No significant changes in pH, total soluble content, and titratable acid for both sonication and heat treatment. The severe ascorbic acid reduction is strongly linked with rising temperatures, while the sonication.	Although Aerobic bacteria reduced to 1.25 log CFU/mL. Under the same condition, the destruction of yeast and mold only reached 42% and 50% respectively.	[8]
	Comparing with pasteurization: 70, 80 and 90°C; Duration: 1min.	A significant increase in clarity, non-enzyme browning index shows alone with US treatment duration. The deterioration of the carotenoid was observed at 140w, 15 min; which stands in contrast to other sonicated samples. The content value of phenolic, flavonoid, and DPPH improved under sonication.		
Cashew Apple Juice	Ultrasound Power Density: 2500, 3750, and 5000 W/L. Temperature: Maintained at 25 °C. Processing Time: 10 minutes.	Sonication treatment results in aromatic hydrocarbons decreased like styrene. And convert the free fatty acids and long-chain esters into short-chain esters, aldehydes, and alcohols.		[14]
Lily juice	Ultrasound power density: 0, 152, 304, 456, 608, and 760 W. Frequency: 25 kHz	Pseudoplastic behavior was observed. Small particles, cloudy value, and total soluble solids increased significantly, while the sedimentation components and centrifugal sedimentation rate decreased.		[10]

Annona Crassiflora juice	Time: 10 minutes (2s on, 2s off)	pH and zeta potential remained stable. However, at higher power levels, color change has been seen that dropped in L value with a rose in a value.	[11]
	Frequency: 20 kHz.	Low amplitude power released more bioactive compounds, like Total phenolic compounds, Total carotenoids, and Ascorbic acid without degradation.	
	Ultrasound power: 400W (Amplitude: Ranged from 20% to 100% of total power)	Total color difference and turbidity increased significantly with increasing the sonication density and duration.	
	Time: 2 to 10 minutes.	Large particles crushed into small ones examined by microscope.	

2.1.3 Aroma Profile

The aroma profile of fruit juices is an essential aspect that contributes to consumers' overall sensory appeal. The aroma of fruit juice often comes from the mixture of multiple volatile compounds like esters, fatty acids alcohols, and so on [15]. The research conducted on cashew apple juice volatile compounds changing with sonication[14] shows that the content of free fatty acids and long-chain esters dropped significantly under ultrasound treatment by 90% and 73% respectively, while the short-chain esters increased by 27%. Free radicals generated by cavitation attack the internal carbon-carbon bonds of free fatty acids and esters [16], which induces internal scission reactions. Overall, the ultrasound has a positive impact on the aroma profile of cashew juice. The experiment also presents the decrease in aromatic hydrocarbons, which is an off-flavor compound. This phenomenon can be observed within all power densities.

2.2. Ultrasound microorganism inactivation

Moreover, sonication as an alternative to sterilizing a variety of juices has also been conducted. A study on three types of pumpkin juice presents that the sterilization of *Staphylococcus aureus* is promising compared with non-sonication treatment, meanwhile, the microorganisms' inactivation efficiency highly relies upon the US duration [7]. As a consequence of the cavitation phenomenon, bacteria's membranes were disrupted for multiple reasons: localized temperature impaired cell integrity; physical forces caused cell wall vibration which weakened the overall structure to induce the micro-tears on the surface; and the free radicals oxidized amino acids, proteins, lipids to inhibit the corresponding to specific functions; free radicals, furthermore, could attack the nucleic acids and other substances inside the cell [17]. It might be due to the high power that was adopted in this experiment, the author's opinion contradicts others'. Most researchers believe employing the US alone can not effectively inactivate microbes in a liquid food matrix, and if overly intensified US is applied, adverse effects will compromise the sensory attributes of juice noticeably. Less energy density of US applied on pineapple juice shows that nevertheless, the aerobic bacteria reduced to 1.25 log CFU/mL, yet, under the same treatment, the destruction of *yeast* and *mold* only reached 42% and 50% respectively[8]. Some other researchers are investigating the performance of bacteria inactivation when it's done by combining technologies. For instance: ultrasound with pasteurization demonstrated that in kiwi juice, 6 Log reduction of *L. innocua* under 3 minutes [6]. Despite that no desirable data on *Paecilomyces variotii mold* (highly resistant to sonication) reduction was observed in orange juice, the best result was obtained at 1.7 log reduction in the spore population after US-T (ultrasound-assisted thermal) treatment at 90 °C for 10 minutes [18].

3. Application of ultrasound combined with other technology

Even though employing ultrasonication in juice manufacturing is promising, yet US is far from perfect. Apart from the poor microorganism inactivation performance mentioned above, adverse effects caused by prolonged treatment time or over-intensive US power compromise the overall quality of juice. Therefore, research on combining ultrasound with other technologies has become more popular. As in Table 2 the study focused on muskmelon and sugarcane blend juice undergoing microwave and thermo-sonication treatment indicated that nutrition values increased not only in bioactive compounds and antioxidant activity; but also in retention after 90 days of storage, which outperformed the untreated samples [9]. The combination approach allows microwave and thermos-sonication to complement each other's drawbacks. More specifically, a mild thermos-sonication parameter was adopted because microwave treatment followed by, which in turn enhanced the BACs and antioxidant activity value.

Table 2 Combination of ultrasound with other technologies

Type of Juice	Type of technology combine	Experiment condition	Main Results on Sterilization	Main results on food matrix physicochemical change	Reference
Kiwi juice 20ml	Thermosonication.	Frequency: 20KHz Pulsation: 10s on and 5s off	5-log-cycle reduction in <i>L. innocua</i> , and within 3 min achieved 6-log reduction.	Opposed to cloud value, no significant change in pH, TCD (difference), Soluble solid content, total phenolics, and chlorophylls value. The lightness increased in both treatments. Retained essential minerals (K, P, Mg, Ca).	[6]
	Comparing with Pasteurization	Ultrasound power: 80% amplitude Temperature: 45, 50, 55°C Ultrasound power: 5W/mL			
Orange juice 50mL	Comparing: US, TS (thermos-sonication), and US-T (ultrasound-assisted thermal)	US: conduct at room temperature with intervals (5, 10, 20, 30, and 40 min)	<i>Paecilomyces variotii</i> mold spores show undesirable reduction under sonication treatment alone (<0.5 log). Nonsignificant log reductions were found under TS and US-T treatment when they were at the same temperature.		[18]
		TS: temperature (55, 65, and 75°C) with intervals (5, 10, 20, 30, and 40 min) US-T: Ultrasonication duration is 10 min			
Strawberry juice 200mL	Pulsed Electric Field (PEF) followed by High-Power Ultrasound (HPU) compared with untreated juice	Water Bath: 10 min at 52, 72, and 92°C PEF Parameters:		Bioactive compounds showed no significant total phenols and hydroxycinnamic acid remained stable regardless of treatment duration, while the flavonoids and condensed	[19]
		Frequency: 100 Hz Voltage: 30KVcm-1 Pulse width: 1 us			

Muskmelon and sugarcane juice blend	HPU followed by PEF compared with untreated juice	Duration: 1.5, 3.0, and 4.5 min HPU Parameters: Ultrasound power: 400W Amplitude: 20-100% Pulse: 10-100% Duration: 2.5, 5, and 7.5 min Data Collection: Analysed before, immediately after treatment, and after 7 days of cold storage	tannins stability relied on both treatment durations. As for antioxidant activity: both BACs (bioactive compounds) and antioxidant activity outperformance under shorter treatment times. After 7 days of storage: hurdle technology presents a synergistic effect in preserving BACs. Prolonged both HPU and PEF treatment resulted in a decrease in BACs, phenolic compounds, flavonoids, tannins, etc., while the DPPH activity reached the peak value along with the longest PEF duration.	[20]
	Thermos-sonication with microwave	Thermos-sonication: Frequency: 20KHz Amplitude: 70% Duration: 5, 10, and 15 min Microwave: Temperature: 90°C Power: 400W Duration:120 s Storage: up to 90 days under 4±1°C	After 15 min treatment, samples increased significantly in physicochemical properties (pH, total soluble solids, and titratable acidity), bioactive compounds (total phenolic content TPC and total flavonoid content TFC), and antioxidant capacity. Hurdle technology increased TPC and TFC retention greatly after 90 days of storage.	

Apart from studying the ultrasound usages alone or combined with others on value-added food, the hurdle concept has emerged in recent years in food processing. Different from simply combining with other types of technologies, hurdle technology emphasizes the sequence of the treatment applied and the outcomes [21]. To achieve lower processing conditions than using them independently, the parameters of certain technologies have to be optimized before [22]. Experiments on strawberry juice by leveraging high-power ultrasound (HPU) and Pulsed Electric Field (PEF) reveal that HPU came first causing higher extraction yield on BACs and condensed tannins, while applied PEF first resulting in efficient energy using [19], [20]. HPU and PEF serve to enhance the accessibility of bioactive compounds in juice differently; on the one hand, HPU uses acoustic cavitation to create microbubbles that collapse and generate intense localized pressure, temperature, and radiative particles which destroy the cell membranes; on the other hand, PEF uses short bursts of high voltage to permeabilize cell membranes [23]. Higher extraction yields and greater nutrition retention obtained in the sequence of HPU came first, which could disrupt the cell integrity and release the intracellular compounds and

then stabilize by the PEF. Conversely, PEF impaired the cellular membrane structure and made it more sensitive to sonication which requires less energy and treatment time to achieve desired outcomes [24].

4. Conclusion

High-power ultrasound is an environment-friendly and promising technology employed in juice manufacturing. Nonetheless, the US applied alone outperforms the conventional heat treatment in improving accessibility and retention of multiple nutrient compounds. Recent research embarks on the hurdle of technology to allow them to complement each other's downside and unleash their potential to obtain desired outcomes under minimal treatment conditions. However, before introducing them into production, further researches need to focus on optimal parameters for specific food samples and technology adopted, unveiling the sequence effects of technology application, and conducting shelf-life estimation after treatment.

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