Application of Thermosonication for the Processing of Fruit Juices

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Abstract

The increasing demand for superior quality and freshness in fruit juices, free from additives and preservatives, has led to the adoption of ultrasound technology in juice processing. Thermosonication emerges as an innovative and viable alternative to traditional heat treatment processes. This technique shows promise in elevating the quality and safety standards of fruit juices, offering enhanced energy efficiency compared to conventional thermal methods. Moreover, it surpasses the effectiveness, safety, and reliability of using ultrasound technology alone in achieving the desired destruction of food-borne pathogens. This article delves into the impact of combined ultrasound-heat application on the quality and safety aspects of fruit juices.

Introduction

Fruits, being highly perishable, necessitate processing into juices for a consistent year-round supply. Ensuring the utmost quality of juice is essential to meet consumer preferences, and considerations for juice safety play a crucial role in extending shelf life. Fruit juices, being thermally sensitive, are susceptible to chemical, physical, and microbiological alterations. The chosen processing methods can significantly influence both the quality and safety of fruit juices. In the present scenario, non-thermal food processing technologies offer a viable solution to cater to the demand for natural and healthful fruit juice beverages, minimizing any adverse impact on their inherent nutritional and organoleptic properties. The traditional method of processing fruit juices relies heavily on thermal procedures, leading to the loss of certain nutritional compounds like flavonoids and carotenoids. The efficiency of this conventional process typically ranges between 60 to 80% of fruit juice yield, with a noticeable decline when using older fruits. The adoption of ultrasound as an alternative technology for processing fruit juices has garnered considerable attention. This approach offers advantages such as reduced processing time, lower energy consumption, increased efficiency, and enhancements in the shelf life and quality of fruit juices. These improvements stem from the unique property of the instantaneous transfer of acoustic energy into the fruit juices. The application of ultrasonic treatment enables the penetration of fruit cell walls, facilitating the release of cell contents trapped in the fruit tissues. While thermal preservation methods like pasteurization and sterilization are commonly employed to eliminate microorganisms and deactivate enzymes in fruit juices, the high temperatures exceeding 80 °C during these treatments may lead to undesired alterations in various properties of the juices, encompassing physical, chemical, biological, and organoleptic aspects such as nutrients, color, and flavor. In contrast, thermosonication technology, which combines moderate heat within the range of 37 to 75°C with ultrasound treatment, emerges as a potential alternative processing technique capable of enhancing the inactivation of enzymes and microbial activity. The integration of low-frequency ultrasound with mild heat is anticipated to decrease both processing temperature and time by 16% and 55%, respectively. This reduction aims to mitigate adverse impacts on the quality of fruit juices, rendering the overall processing more economically viable. In comparison to conventional thermal processing, thermosonication achieves equivalent lethality values at a lower processing temperature. The inactivation of enzymes and microbes during thermosonication treatment results from the combined effects of heat and cavitation— the phenomenon involving the formation, growth, and explosion of bubbles in a liquid. Cavitation disrupts cell membranes and induces the production of free radicals through temperature and pressure changes. This article provides a comprehensive overview of current knowledge and applications of ultrasound, both independently and in thermosonication treatment, for the processing of fruit juices. It includes a detailed discussion on the effects of thermosonication treatment on preserving juice quality, encompassing parameters such as juice yield, ascorbic acid content, color, and the destruction of enzymes and contaminants in fruit juices

Basic principles of ultrasound

Ultrasound is sound wave transmitted with frequency higher than audible frequency of 20 kHz. The ultrasound equipment usually has frequencies from 20 kHz to 10 MHz. The application of ultrasound in food industry consists of low and high energy ultrasound. The low energy ultrasound has intensities of less than 1 Wcm^{-2} and frequencies of more than 100 kHz. It can be used in non-destructive analytical measurements and monitoring of composition and physicochemical properties of food during processing and storage for quality control purposes. High energy ultrasound, which is also known as power ultrasound has intensities higher than 1 Wcm^{-2} and frequency range of 20 to 100 kHz. The power ultrasound is useful in invasive applications, which gives impact to physical, chemical, and biological properties of foods in processing, preservation, and safety such as milk homogenisation, juice yield enhancement and microbial inactivation. There are two different ultrasonication techniques, which are submergence in an ultrasonic bath or direct application to the fruit juices using a probe sonicator.

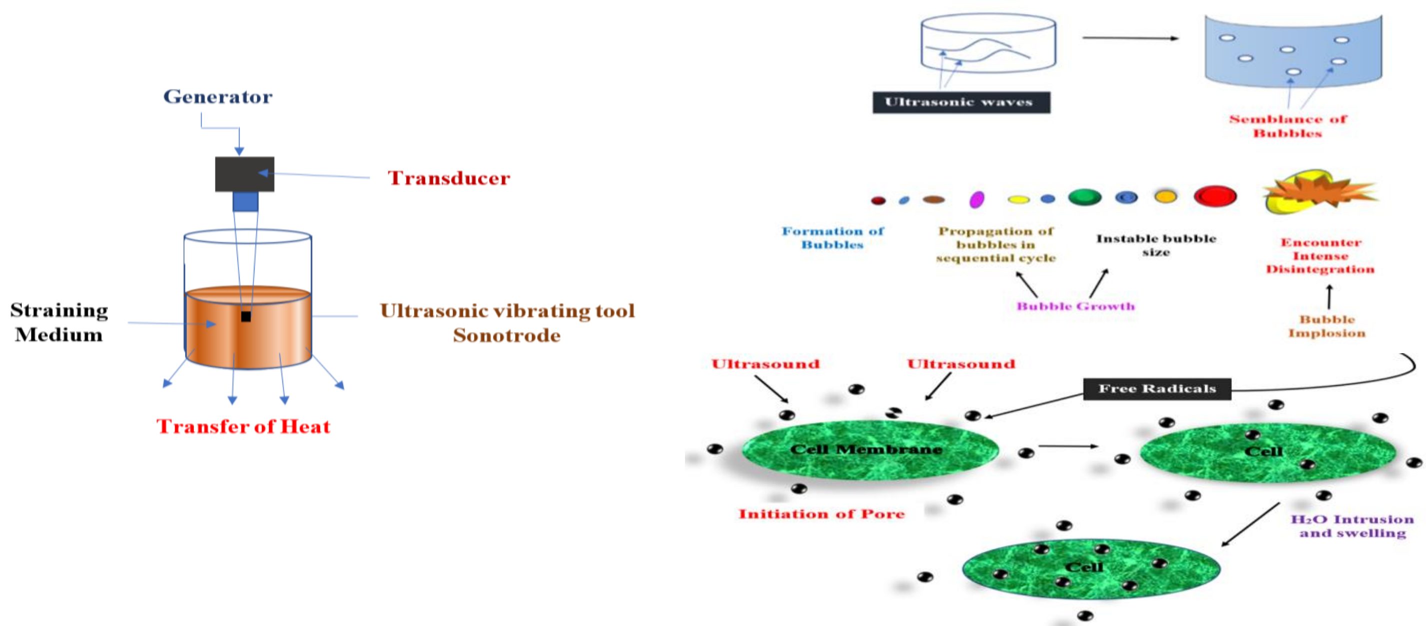

Fig. 1 Schematic view of thermosonication process. (Adapted from Das et al., 2023)

Gas bubbles are produced in liquid media by ultrasonic waves prior to acoustic cavitation phenomenon, which is the interaction between ultrasonic waves, liquid and dissolved gas when ultrasound passes through a liquid medium. Pressure changes around the dissolved gas nuclei leads to oscillations, where the dissolved gas and solvent vapour disperse in and out of the oscillating bubbles. The quantity of gas and vapour that enters the bubbles during this expansion period is beyond the quantity that diffuses out of the bubbles during the compression stage of bubbles oscillations. The bubbles then grow in successive cycles to an unstable size, burst in the compression phase and release very high heat and pressure around the collapsing bubbles to break the compounds in the liquid and give localised sterilisation effect. At this point, particle dispersion and cell disruption occur.

Thermosonication treatment in fruit juice production

The quality of fruit juice is frequently compromised by enzymatic reactions and microbial actions, leading to issues like enzymatic browning and microbial growth in apple juice. Utilizing ultrasound processing for juice treatment has been documented to have minimal adverse effects on crucial quality attributes such as vitamin C content, color, cloud stability, and viscosity. The application of thermosonication treatment offers a method to deactivate enzymes and eliminate microorganisms at lower temperatures and shorter durations, resulting in reduced losses of ascorbic acid, total phenolics, flavonoids, and flavonols. Here are some of the effects of thermosonication treatment on fruit juice quality:

Microbial Inactivation: Thermosonication helps in the reduction of microorganisms (bacteria, yeast, and molds) in fruit juices. The combination of heat and ultrasound disrupts cell membranes and structures, leading to the inactivation of microorganisms. This can extend the shelf life of the juice by reducing the risk of spoilage and improving safety.

Enzyme Inactivation: Enzymes responsible for the deterioration of fruit juices can be inactivated by thermosonication. This helps to preserve the color, flavor, and nutritional content of the juice by preventing enzymatic browning and other undesirable reactions.

Improved Extraction of Bioactive Compounds: Thermosonication can enhance the extraction of bioactive compounds, such as antioxidants, from fruits. The mechanical effects of ultrasound can break down cell walls, releasing more compounds into the juice. This can contribute to the health benefits of the juice.

Reduced Processing Time: Compared to traditional heat treatments, thermosonication often requires shorter processing times. This can help in preserving the sensory attributes of the juice, such as color and flavor, as well as minimizing the impact on heat-sensitive nutrients.

Texture and Viscosity: The application of ultrasound in thermosonication may affect the texture and viscosity of fruit juices. It can break down cell structures and improve the homogeneity of the juice, leading to a smoother texture.

Improved Heat Transfer: Ultrasound facilitates heat transfer within the product, ensuring more uniform heating. This can result in more consistent product quality and reduce the risk of localized overcooking or undercooking.

Energy Efficiency: Thermosonication can be more energy-efficient compared to conventional heat treatments, as it often allows for lower temperatures and shorter processing times.

Minimal Impact on Nutrient Content: In some cases, thermosonication has been shown to have a lesser impact on the nutrient content of fruit juices compared to traditional thermal processing methods. It's important to note that the specific effects of thermosonication can vary depending on factors such as the type of fruit, initial juice quality, process parameters (temperature, ultrasound frequency, intensity), and treatment duration. Research in this field is ongoing, and advancements in technology and processing techniques may continue to refine the understanding of the effects of thermosonication on fruit juice quality.

Thermosonication treatment has been investigated for its potential to enhance the safety of fruit juices by reducing microbial contamination. The combination of heat and ultrasound in thermosonication can lead to several safety-related effects:

Pathogen Reduction: Thermosonication can be effective in reducing pathogenic microorganisms in fruit juices. The treatment targets a broad spectrum of microorganisms, including potential pathogens, which contributes to the overall safety of the product.

Spoilage Microorganisms: The inactivation of spoilage microorganisms by thermosonication helps prevent deterioration of the juice quality and ensures that consumers are not exposed to potentially harmful or undesirable microbial metabolites.

Reduced Reliance on Chemical Preservatives: The microbial inactivation achieved through thermosonication may reduce the reliance on chemical preservatives in fruit juices. This is beneficial for consumers who may prefer products with fewer additives.

Improved Homogeneity: Thermosonication can contribute to improved homogeneity of the juice by breaking down cell structures and ensuring more uniform heat distribution. This helps in achieving consistent microbial inactivation throughout the product, reducing the risk of localized areas with insufficient treatment. The combination of heat and ultrasound ensures that all portions of the liquid volume receive similar treatment. This consistency is crucial for achieving a homogeneous product, as it reduces the likelihood of localized overprocessing or underprocessing, which could affect the overall quality of the juice.

Minimized Risk of Cross-Contamination: The uniform application of thermosonication treatment helps minimize the risk of cross-contamination by ensuring that all parts of the juice receive adequate microbial inactivation. This is particularly relevant in large-scale processing where ensuring uniform treatment can be challenging. Thermosonication minimizes the risk of cross-contamination in food processing, including the treatment of fruit juices, through several mechanisms that ensure uniform and thorough microbial inactivation such as uniform treatment, enhanced penetration, reduced temperature variability, prevention of cold spots, consistent microbial inactivation, and improved homogeneity.

Conclusions

The concurrent use of ultrasound and mild heat in the fruit juice processing industry holds significant promise, offering multiple advantages in preserving juice quality and ensuring safe processing. Ultrasound-induced cavitation plays a crucial role in reducing juice yield, ascorbic acid content, and color loss, while simultaneously enhancing enzyme inactivation and microbial destruction. This approach allows for shorter processing times, categorizing it as a form of minimal processing, aiming to retain freshness and promote health benefits.

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Table 1: Effect of thermosonication on quality attributes of fruit juices

Sl No.	Quality attributes	Effect of thermosonication treatment	Findings
1	Colour of juice	Promotes juice lightness	Highest retention of carotenoid from carrot juice 97.33% (Jabbar et al., 2015) Significant retention of anthocyanin from blueberry juice 94.12% (Wu et al., 2021)
2	Vitamin C content	Removes dissolved oxygen during cavitation to produce less degradation of ascorbic acid	Significant amount of vitamin C was retained in blood fruit and apple juice (about 96%) (Sashikumar al., 2019; Abid et al., 2014).
3	Juice yield	Increases juice production capacity	Juice yield of Blueberry and Mango was found to be higher of 82.3% (Wu et al., 2021). (Holtung et al., 2017).
4	Inactivation of enzymes	Improves juice rheological properties by inactivation of pectin methylesterase (PME) and polygalacturonase (PG).	PPO and POD inactivation in apple juice were 93.85% and 91%, respectively (Abid et al., 2014). PME inactivation in tomato juice were more than 98.5% (Liao et al., 2018). PME and PG in Chironji juice was almost inactivated and 90% inactivated, respectively (Pradhan et al., 2020).
5		Preserves juice colour by inactivation of polyphenoloxidase (PPO) and peroxidase (POD).	

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