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ULTRASSOM: TECNOLOGIA EMERGENTE PARA CONSERVAÇÃO DE ALIMENTOS

ULTRASOUND: EMERGING TECHNOLOGY FOR FOOD PRESERVATION

ULTRASONIDO: TECNOLOGÍA EMERGENTE PARA LA CONSERVACIÓN DE ALIMENTOS

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REVISTA DESAFIOS ISSN: 2359-3652

ABSTRACT:

The increase in consumer demand for safe products without chemical additives that preserve their sensorial and nutritional characteristics makes the food industry pay attention and search for innovative food preservation technologies. Among the highlighted emerging technologies for food processing and preservation, ultrasound is a non-thermal technology that uses physical and chemical phenomena to rupture cells and denature enzymes, offering foods with greater productivity, yield, and selectivity, besides preserving their sensory and nutritional characteristics. Therefore, this study aimed to provide information about the ultrasound process and its applications in the food industry compared to other conservation methods. The results demonstrated that the preservation method using ultrasound devices offers the main advantages over conventional food preservation methods: simplicity, portability, low cost, reduced reaction time, and increased yield in mild conditions, in addition to maintaining sensorial characteristics and nutritional profile of foods subjected to this technology.

KEYWORDS: *New technology, innovation, food control, safety food, ultrasonic technology.*

RESUMO:

O aumento da demanda dos consumidores por produtos seguros, sem aditivos químicos, que preservem suas características sensoriais e nutricionais, faz com que a indústria alimentícia esteja atenta e busque tecnologias inovadoras de preservação de alimentos. Dentre as tecnologias emergentes de destaque para processamento e preservação de alimentos, o ultrassom é uma tecnologia não térmica que utiliza fenômenos físicos e químicos para romper células e desnaturar enzimas, oferecendo alimentos com maior produtividade, rendimento e seletividade, além de preservar suas características sensoriais e nutricionais. Portanto, este estudo teve como objetivo fornecer informações sobre o processo de ultrassom e suas aplicações na indústria alimentícia em comparação a outros métodos de conservação. Os resultados demonstraram que o método de preservação utilizando aparelhos de ultrassom oferece as principais vantagens sobre os métodos convencionais de preservação de alimentos: simplicidade, portabilidade, baixo custo, tempo de reação reduzido e aumento do rendimento em condições amenas, além de manter as características sensoriais e o perfil nutricional dos alimentos submetidos a esta tecnologia.

PALAVRAS-CHAVES: *Novas tecnologias, inovação, controle de alimentos, segurança alimentar, tecnologia ultrassônica.*

RESUMEN:

El aumento de la demanda de los consumidores por productos seguros y sin aditivos químicos que preserven sus características sensoriales y nutricionales hace que la industria alimentaria preste atención y busque tecnologías innovadoras de conservación de alimentos. Entre las tecnologías emergentes destacadas para el procesamiento y conservación de alimentos, el ultrasonido es una tecnología no térmica que utiliza fenómenos físicos y químicos para romper células y desnaturalizar enzimas, ofreciendo alimentos con mayor productividad, rendimiento y selectividad,

REVISTA DESAFIOS ISSN: 2359-3652

además de preservar sus características sensoriales y nutricionales. Por lo tanto, este estudio tuvo como objetivo proporcionar información sobre el proceso de ultrasonido y sus aplicaciones en la industria alimentaria en comparación con otros métodos de conservación. Los resultados demostraron que el método de conservación mediante dispositivos de ultrasonido ofrece las principales ventajas sobre los métodos convencionales de conservación de alimentos: simplicidad, portabilidad, bajo costo, tiempo de reacción reducido y mayor rendimiento en condiciones suaves, además de mantener las características sensoriales y el perfil nutricional de los alimentos sometidos a esta tecnología.

PALABRAS CLAVE: *Nueva tecnología, innovación, control de alimentos, seguridad alimentaria, tecnología ultrasónica.*

REVISTA DESAFIOS ISSN: 2359-3652

INTRODUCTION

Food preservation promotes the containment and/or elimination of spoilage and/or pathogenic microorganisms that can cause harm to consumers (PAHO, 2019). Also, food preservation processes promote the total or partial inactivation of microorganisms and enzymes capable of altering the food or the modification/elimination of one or more factors essential for their multiplication so that the food does not become conducive to microbial development. Understanding the factors that affect microbial growth is essential to selecting the most appropriate preservation methods to apply to various types of food (PAHO, 2019).

Among the existing preservation technologies, freezing and refrigeration can maintain, to some extent, food quality, as they do not destroy microorganisms but merely slow their development. Therefore, any disruption in the cold chain can induce the growth of undesirable microorganisms. Another existing preservation technology involves thermal processing, which destroys microorganisms and enzymes, resulting in more stable and safer products. However, this process can alter the food sensory characteristics and nutritional value (Brazil Food Trends, 2020).

The increasing consumer demand for safe products that preserve these characteristics prompts the food industry to remain attentive and seek new food preservation techniques. Additionally, trends related to sustainability and the increased use of renewable resources lead to the search for technologies known as "green" in the food sector (Hassoun et al., 2022a). Among these new technologies, two major groups are electromagnetic technology (microwave, radio frequency, infrared, and ohmic heating) and non-thermal technologies (electric pulse, pulsed light, irradiation, high hydrostatic pressure, ultrasound, and active packaging), with different applications in the industry (Brazil Food Trends, 2020; Hassoun et al., 2022b).

These emerging technologies can preserve and maintain food quality and freshness and modify the food's technological and functional properties. Besides the added value to products in processing, new technologies can influence consumer perception regarding quality or safety, which usually varies according to their profiles (Brazil Food Trends, 2020).

REVISTA DESAFIOS ISSN: 2359-3652

Among the emerging technologies for food processing and preservation, Ultrasound (US) stands out as a non-thermal technology that uses physical and chemical phenomena to break cells and denature enzymes, offering foods with greater productivity, yield, and selectivity, as well as better processing time, better quality, lower chemical and physical risks, and does not harm the environment (Verruck & Prudencio, 2018).

In this context, this study aimed to review data on the application of ultrasound in the food industry and to evaluate the advantages and limitations of its applications compared to other existing food preservation methods.

METHODOLOGY

This review was conducted through a systematic search in scientific databases (Scopus, Web of Science, and PubMed) in January 2024, using the following descriptors: “Ultrasound”, “Food preservation”, “Non-thermal technologies”, “Emerging technologies”, “Ultrasonic technology”, “Food industry”. The inclusion criteria were: original articles and reviews published between 2019 and 2024, focusing on ultrasound applications in the food industry compared to conventional methods. Studies unrelated to food or those that did not address quality parameters (sensory, nutritional, or microbiological) were excluded. The highlighted results were compiled for analysis, comparison, and performance of this study. The initial search yielded 250 articles. After screening by title, abstract, and compliance with the criteria, 45 articles were selected for full analysis and data extraction. The final selection prioritized studies demonstrating the advantages of ultrasound, such as efficiency, cost-effectiveness, and preservation of food attributes. The high exclusion rate resulted from our stringent criteria, which mandated direct comparisons between ultrasound and conventional methods, as well as comprehensive reporting of quality parameters.

DISCUSSION

Definition and Mechanism of Action of Ultrasound

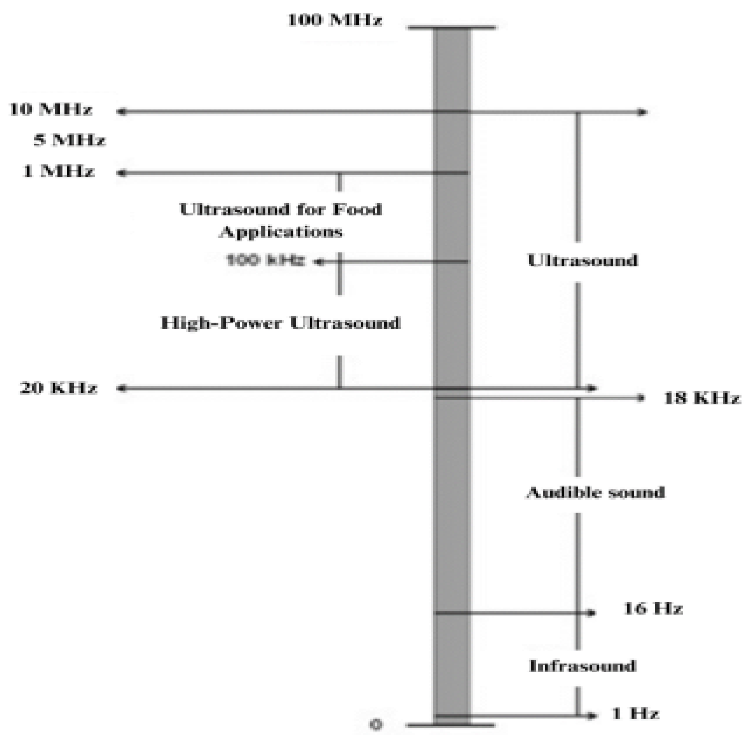
Sound waves are defined as infrasound, audible sound, and ultrasound (US). Infrasound is the lowest frequency classification in the acoustic spectrum, with a frequency range of less than 20 Hz. The audible sound is what humans can hear and has a frequency range between approximately 20 Hz and 20 kHz (Figure 1). US

REVISTA DESAFIOS ISSN: 2359-3652

encompasses the frequency range starting from 20 kHz. High-frequency ultrasounds, greater than 2 MHz, are used for imaging. On the other hand, low-frequency ultrasonic waves (between 20 and 100 kHz) have higher power and can alter the media exposed to this radiation, as they can produce agitation, cavitation in the liquid medium, microflows, microjets, and heating (Rosa, 2022), which can be employed to achieve technological effects in food (Figure 1).

US is defined as sound waves with a frequency range varying from 20 kHz to 10 MHz, longitudinal, and mechanical in nature, requiring an elastic medium to propagate. It occurs by alternation between cycles of compression and rarefaction (and subsequent collapse) of particles in the medium through which it is propagating, causing variations in the medium pressure and allowing the energy transfer from the movement of particles. This effect is the cavitation phenomenon (Mendoza et al., 2022).

Figure 1. Frequency range of sound waves



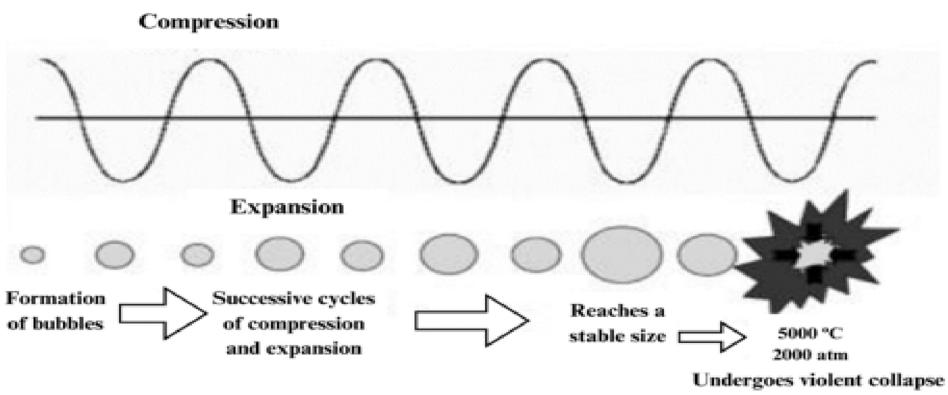
Source: adapted from Verruck & Prudencio (2018).

Thus, cavitation is a physical phenomenon: it occurs when a liquid is subjected, in an intense ultrasonic field, to the action of waves with high rarefaction and compression speeds generated by ultrasound, culminating in the formation and activity of

REVISTA DESAFIOS ISSN: 2359-3652

numerous bubbles (or cavities) within the liquid (Figure 2). These bubbles are formed during the compression phase, and upon being subjected to intense pressure, they implode and release energy (Mendoza et al., 2022). It is one of the US action ways on microorganisms (Silva, 2017).

Figure 2. Cavitation Process by Ultrasound and Burst of Formed Bubble



Source: adapted from Silva (2017)

There are two subfamilies of US energy: A) high energy, characterized by low frequencies (20 kHz – 100 kHz) and mainly applied to fresh foods such as fruits and vegetables, as they can penetrate the food without damaging it; and B) low energy, characterized by high frequency (5 MHz–10 MHz), primarily used for medical purposes (Mendoza et al., 2022).

In foods, the US causes chemical and/or mechanical effects in processes such as filtration, fermentation, extraction, homogenization, degassing, mixing, fermentation, and crystallization. US treatment can also have effects such as defoaming, viscosity modification, particle size reduction, destruction, and modulation of cell and microorganism growth, and it can disperse aggregates, inactivate enzymes, and sterilize equipment (Li et al., 2024; Mendoza et al., 2022).

US waves are characterized as mechanical waves, meaning they require a material medium to propagate. In the food industry, two categories of ultrasound are used as High-frequency and Low-intensity (less invasive, aiming to transmit energy without modifications). Low-frequency and high-intensity ultrasounds cause more significant changes in the food, as previously described. High-intensity ultrasound generates the

REVISTA DESAFIOS ISSN: 2359-3652

cavitation process, which causes changes to the food. In this process, sound waves alternate between high and low pressure, producing gas microbubbles that float and gradually increase in size until they burst, a phenomenon called cavitation, which releases high temperatures and pressures, causing physical and chemical changes to the food. When these collapsed bubbles come into contact with biological material, such as microorganisms, it can lead to their inactivation, as cavitation causes the thinning of the cytoplasmic membrane and releases free radicals from water vapor through bubble collapse, which are harmful to microorganisms. In this context, regarding efficacy, cavitation is influenced by the frequency and intensity of the ultrasound, as well as the characteristics of the exposed food, such as sample volume, water volume, dissolved gas, temperature, pH, type of microorganisms present in the food, and their structure. Gram-positive bacteria are more resistant to the effects of ultrasound due to the thicker and more rigid protein envelope in their cell structure (Leães, 2019). Thus, the cavitation phenomenon enhances the microbiological quality of foods by reducing microbial load. It occurs through shear forces that rupture the cell envelopes of microorganisms, leading to their death.

Additionally, the occurrence of this phenomenon results in the formation of free radicals, which, being oxidizing compounds, can break DNA and inactivate enzymes of microorganisms and foods, thereby compromising the sensory qualities of foods and providing higher microbiological safety to raw materials and food products in various ways (Alvarenga, 2021).

High-power ultrasound (HPU) has been used in various foods in their processing chains due to its beneficial effects caused by the cavitation phenomenon. Researchers have found that the US can benefit from meat products through their ability to alter properties. In one study, the effect of US treatment (4.2, 11, or 19 W/cm²) for 10, 25, or 40 minutes accelerated mass transfer and protein extraction. The microjets caused by cavitation act as a microscale injection system, accelerating the diffusion of NaCl, while shock waves and pressure gradients increase protein extraction. Thus, the US is an interesting possibility for the curing process (Rosa, 2022).

Ultrasonic Processing

Currently, there are three types of ultrasonic baths: the classic ultrasonic bath, which uses only a single frequency (usually 40 kHz); the second type is a multi-frequency unit, which operates using ultrasonic transducers with different frequencies (25 and 40

REVISTA DESAFIOS ISSN: 2359-3652

kHz) simultaneously, located at the bottom and the sides, respectively. The third type is the most technologically advanced (Silva, 2020).

Ultrasonic baths occur in stainless steel tanks composed of three parts: generator, transducer, and tank. In laboratories, it is considered the most common and accessible method, with most having a capacity of up to 10 L. These baths are stainless steel tanks with multiple transducers attached to their base and/or sides (Takao, 2022; Leães, 2019).

At first, there must be liquid in the tank (usually water) to begin the process, and the treatment of the matrix can occur either in direct contact with the water or in a container placed in the tank. There are various transducers that can allow the US to operate at different frequencies. However, when in operation, all transducers must vibrate in the same phase to increase the acoustic energy produced on the surface. The generated power primarily depends on the number of transducers and the frequency of the type of transducer. An electrical signal from the generator, analog or digital, allows operation in different modes and frequencies for specific applications. The transducers are connected to an electronic device that supplies electrical energy under the necessary conditions (frequency and intensity) to stimulate them. Thus, the transducers act like a "speaker" that vibrates according to the frequency of the signal they receive. The ultrasonic energy in the bath is directly transferred to the liquid filling the tank, which then transfers this energy to the food immersed in the liquid (Li, 2024).

Some US baths also allow high water temperatures inside them. Additionally, the water level in the bath can affect the formed acoustic field, making it convenient to work with the liquid level recommended by the manufacturers. Moreover, ultrasonic bath systems have different modes of operation, whose use varies according to the purpose of the food matrix. These are degas mode, sweep mode, and normal mode. The degas mode operates the US by alternating intervals. During operation, cavitation bubbles collect gases, pushing them to the surface, and during intervals, these bubbles are released from the surface of the liquids. This model is often used in degassing processes. In sweep mode, the generator oscillates the ultrasonic frequency within a narrow range, distributing cavitation more homogeneously and eliminating less efficient zones near the corners of the tank. This mode is suitable for cleaning operations. Finally, the normal mode operates with a fixed frequency range, providing

REVISTA DESAFIOS ISSN: 2359-3652

stability and optimized liquid flow in the tank, making it more recommended for sample preparation (Leães, 2019).

It is also worth noting that ultrasonic baths emit low power to prevent cavitation damage to the tank walls, and the power density is low due to the generally large volume of liquids in the tanks (Sanches, 2020).

Applications of Ultrasound in the Food Industry

Food properties such as composition, structure, and physical state can be evaluated by low-power (high frequency) ultrasound waves through a non-invasive, inexpensive, and simple technique that does not cause structural changes. This characterization in the industry is relevant for better process control and detecting foreign objects in the food matrix (Verruck & Prudencio, 2018).

On the other hand, high-power (low-frequency) US waves can modify food properties through cavitation, heat transfer, mass transfer, and vibration. Those waves can be used when mechanical, physical, and chemical/biochemical changes are desired, such as viscosity alteration and emulsion generation in foods, disruption of cellular structures, inactivation of microorganisms, dispersion of aggregated structures, polymerization, removal of gases in liquid foods, protein and enzyme extraction, and more (Verruck & Prudencio, 2018).

Applications	Conventional Methods	Ultrasound Principle	Advantages	Products
Filtration / Separation	Filters (semipermeable membranes)	Vibrations	Reduced time, Improved filtration	Liquids
Foam Formation Treatment	Thermal, Chemical, Electrical, Mechanical Treatments	Cavitation Phenomenon	Reduced time, Improved hygiene	Carbonated beverages, Fermented products

REVISTA DESAFIOS ISSN: 2359-3652

Table 1. Applications of Ultrasound in Food Processing.

REVISTA DESAFIOS ISSN 2359-3652

According to Table 1, the most frequent advantage of using the US in food processing is the time reduction in other processes. Considering its versatility and wide range of applications in both liquid and solid foods of animal and vegetable origin, the US can contribute to optimizing processes in any food preservation, stabilization, transformation, or quality improvement, thereby enhancing the final product quality.

Ultrasound is already applied in various unit operations in the food industry, such as filtration, freezing, thawing, brining, drying, foaming, degassing, deaeration, emulsification, cooking, cutting, sterilization, pasteurization, extraction, and rehydration. In filtration, it has been used in liquid food products like juices, increasing membrane permeability, requiring less time, and improving the filtration process (Naji et al., 2020).

In freezing/crystallization, ultrasound is used in dairy products, fruits, vegetables, and meats, improving freezing through microstructure preservation, requiring less time, and achieving small crystal sizes with improved diffusion and rapid temperature reduction (Zhu et al., 2020).

In the thawing process, the US has shown reduced thawing time, preserved color of frozen foods, inhibited lipid oxidation, improved product quality, and reduced product dehydration (Li et al., 2020).

In the brining of products like cheese, meat, and fish, the US promotes lowering water activity, extending product shelf life, requiring less sodium chloride, ensuring uniform salt distribution, and saving time (Hatloe, 1995; Sánchez et al., 2000).

In drying, the US has shown intensified mass transfer in dehydrated products, reduced processing time, improved sensory quality, and higher drying rates due to lower resistance (Zhang and Abatzoglou, 2020).

In foam formation, such as with protein, the US has increased foam formation capacity, reduced foam stability, and water retention capacity (Yan et al., 2021; Resendiz-Vazquez et al., 2017).

REVISTA DESAFIOS ISSN: 2359-3652

In degassing/deaeration, as with carbonated beverages and aqueous solutions, the US has reduced broken bottles and beverage overflow, requiring less time (Matsuura et al., 1994).

In cooking meat or vegetable products, the US requires less time, improves nutrient retention, heat transfer rate, and organoleptic properties, and enhances product tenderization (Su et al., 2018; Sarheed et al., 2020).

In emulsification, such as mayonnaise, the US improves rheological properties and emulsion stability, requiring less time (Sarheed et al., 2020).

In cutting soft products like cheese and bread, the US offers greater precision, requires less time, and minimizes product loss (Liu et al., 2020).

In sterilization/pasteurization, as with milk and juice, the US reduces processing time, ensures efficient microbial inactivation, and requires lower temperature and energy (Baboli et al., 2020).

In extraction, whether from food or plant materials, the US increases extraction efficiency and reduces time using less solvent (Yang et al., 2017; Dzah et al., 2020).

In rehydration of foods such as dried vegetables and grains, the US reduces rehydration time (Szadzińska et al., 2017; Tian et al., 2016).

Ultrasound has been applied in the meat industry (chicken, beef, pork, rabbit), fruit and vegetable industry (fresh and minimally processed fruits, vegetables, juices, purees, refined vegetable oil), cereal industry (bakery products: bread, cookies, wafers, donuts, pancakes), dairy industry (milk, yogurt, cheese, ice cream), and emulsions (mayonnaise, dressings, creams, oil emulsions). The advantages include improved texture, enhanced water dynamics in tissues, increased water retention capacity, color enhancement, pH balance, microbial load reduction, enzyme inactivation, improved drying characteristics, purity and quality of oils, increased firmness, improved texture and color components, sensory and visual attributes of dough (texture and rheology, density, volume index), improved homogenization in dairy products, reduced fat globules, enhanced organoleptic properties and nutritional

REVISTA DESAFIOS ISSN: 2359-3652

quality, reduced cheese maturation and fermentation time, increased emulsion stability and capacity (Azam et al., 2020; Minj et al., 2020; Chávez-Martínez et al., 2020; Zhu and Li, 2019; Cui et al., 2024; Qayum et al., 2023; Wang et al., 2018; Tamang et al., 2021; Lee; Yoon, 2024; Petrauskas, 2007; Bhargava et al., 2020; Mason, 1998).

In the meat industry, the US reduces sodium during curing, providing better salt distribution in the meat and enhancing salt sensory perception even with lower total NaCl content. Fast-curing technology with an increased salt absorption rate could reduce NaCl content in brine and improve enzymatic softening and structural damage in salted foods. Several studies report that the US can accelerate and intensify sodium extraction and diffusion, reducing processing time. However, the technique has limitations (Câmara, 2021).

High time intervals, exposure, and sonication intensities can increase sensitivity, reduce the shear force of products, cause microstructural changes in tissue, or increase enzymatic activity. Nevertheless, using this technique on salts can promote sodium reduction in foods since salt crystal morphology influences solubilization and adherence to solid foods (Silva, 2020). Thus, the US can enhance the quality of salted meat products and reduce salt use and consumption, impacting dietary health recommendations.

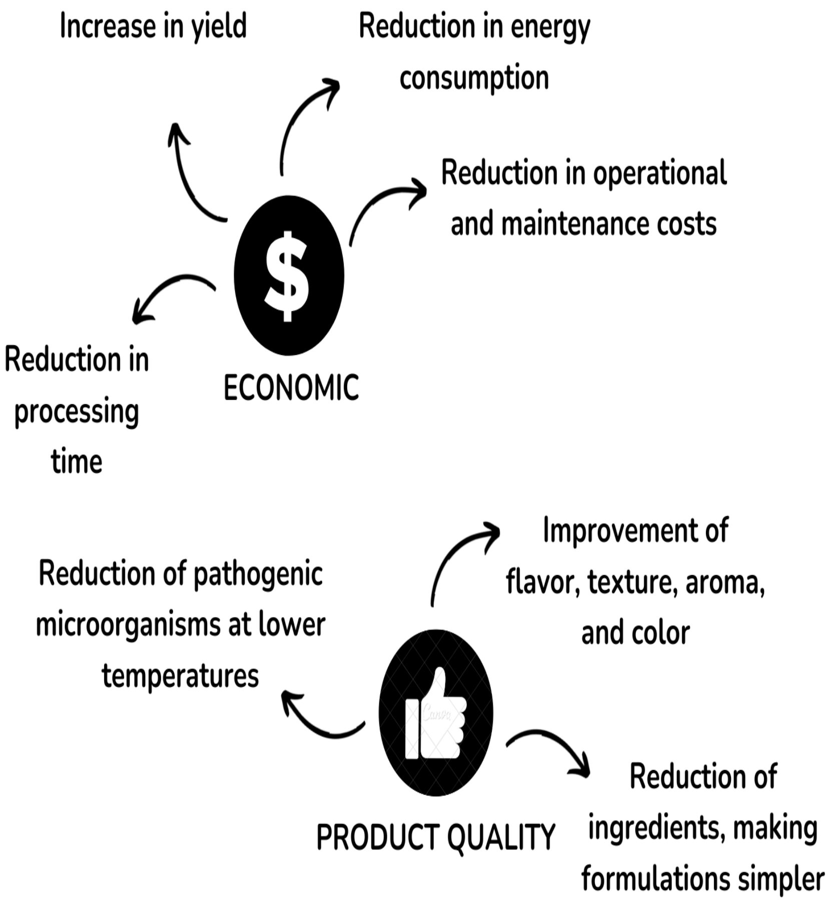
Using ultrasound in food processing ensures food preservation through enzymatic inactivation and microbial inactivation or death, without preservatives, maintaining nutritional value and sensory characteristics (texture, color, flavor, and aroma). This process reduces treatment duration and intensity and associated damage when thermal treatments are applied together. Physical alterations during ultrasound treatment in plant cells increase the availability of existing chemical compounds without degrading them while preserving product appearance. The US exterminates fungi, bacteria, and viruses faster than thermal treatment at similar temperatures. For surface hygiene of food products, the US reduces surface dirt, lowering water content and chemicals needed for cleaning reducing time and temperature in applied processes (Chen et al.,, 2020). Thus, ultrasound is considered an economical, ecological tool that enhances competitiveness in the food industry.

Limitations of Ultrasound Use in Food Processing

REVISTA DESAFIOS ISSN: 2359-3652

The cavitation process that occurs during the application of ultrasound, responsible for inactivating vegetative cells, may not be as effective for spores. Therefore, when the US is for this purpose, it is recommended to combine it with pressure treatment (manosonication), heat treatment (thermosonication), or both (manothermosonication). Additionally, the complex equipment requires a trained professional to handle it (Verruck & Prudencio, 2018). In addition, Figure 3 shows the main economic and product quality advantages of using ultrasound in the food industry.

Figure 3. Main economic and product quality advantages of using ultrasound in the food industry.



Source: Source: The authors (2024).

REVISTA DESAFIOS ISSN: 2359-3652

FINAL CONSIDERATIONS

The applications of the US energy in the food industry are vast and have shown continuous growth due to the high consumer demand for minimally processed products, without food preservatives, and with extended shelf life.

In summary, using the US in foods employs lower temperatures (non-thermal technology) by high or low-intensity mechanical vibrations with different frequency ranges. This offers a wide variety of applications, leading to the reduction of pathogenic microorganisms through enzymatic inactivation and/or microbial inactivation. These modifications increase product stability, resulting in a longer shelf life and promoting safer food for consumers.

This technology brings several benefits, such as shorter processing times, reduced processing and maintenance costs, higher yields, and preserved food's sensory characteristics and nutritional profile.

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