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Ultrasound application as a new green technology for preservation of table eggs: A review

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ABSTRACT

In recent years, there has been a significant increase in research demonstrating the new and diverse uses of non-thermal food processing technologies, including more efficient mixing and blending processes, faster energy and mass transfer, lower temperature and selective extraction, reduced thermal and concentration gradients, reduced equipment size, faster response to extraction control, faster start-up, increased production, and a reduction in the number of steps in preparation and processing.

Applications of ultrasound technology have indicated that this technology has a promising and significant future in the food industry and preservation, and there is a wide scope for its use due to the higher purity of final products and the elimination of undesirable sensory qualities, as well as the fact that this technology consumes only a fraction of the time and energy required compared to traditional processing and preservation methods and techniques. Therefore, ultrasound is considered a non-thermal processing and preservation technology that has the potential to be a suitable alternative to thermal food processing technologies. Ultrasound is a form of energy generated by sound waves at various frequencies too high to be detected by the human ear, i.e., frequencies above 16 kHz. Ultrasound technology has gained wider applications in food industry and enhancing the extraction of valuable compounds from vegetables and food products.

Keywords: Ultrasound technology, Table eggs, Preservation, Bacterial inactivation.

Introduction

Table eggs are eggs produced for human consumption and this type is produced by birds called domestic birds, and these eggs are characterized by being an important food for humans as an important protein source in human nutrition and one of the most important protein sources because it contains all the essential amino acids needed by the human body, and the percentage of protein survival in the body is equal to 100% (Al-Obaidi and Al-Shadeedi, 2022). In addition, table eggs, specifically egg yolks, provide all the essential fatty acids and fat soluble vitamins, and also provides with water, except for vitamin C, a large number of mineral elements, and is characterized by its low energy content, low calories and being a low-cost source of animal protein, and eggs are one of the most consumed foods around the world due to their multifunctional properties such as ease of preparation and delicious taste, in addition to that it is included in many recipes and food industries for all ages, because it contains All the essential amino acids needed by the human body. (Mehas and Rodger's, 1994; Obi and Igbokwe, 2007; Layman and Rodriguez, 2009; Al-Obaidi et al., 2019). All foods are destroyed with the increase in storage and preservation and need preservation methods to increase the duration of their consumption and eggs are perishable food because they contain a high percentage of moisture, protein and amino acids as an important source for the growth of microorganisms (Al-Shadeed, 2023).

Fresh eggs do not contain large numbers of microorganisms, but soon the egg begins to become contaminated after contact with the outer surroundings of the halls of domestic birds and during the transport and circulation of eggs, where the number of microorganisms begins to increase on the surface of the outer shell of the eggs. Fresh eggs contain three layers of protection, namely the outer epidermis layer or the so-called outer waxy layer, then the calcareous shell, and then comes the inner membrane of the shell, which is an outer and inner membrane. Each of these layers has an important and effective role in protecting the egg and reducing or hindering the entry of microorganisms (Morsi et al., 2015; Al-Shadeedi, 2023; Salman et al., 2023).

There is no ideal method to store eggs that prevent them from spoilage or corruption, and the methods of storing eggs are not all ideal and all of them do not prevent their spoilage or damage over time, but we always try to store eggs to reduce the deterioration of their quality and always try to find the best means to prolong the storage period, it is necessary that the fresh egg reaches the consumer with high quality while extending the shelf life using effective new processing techniques, and eggs are transported from production fields to refrigerated wholesale warehouses before It reaches the consumer using cardboard trays with a capacity of 30 eggs, placed inside cardboard boxes with a total capacity of 12 layers of cardboard and marketed in this way to retail stores. The egg intended for storage must be clean and free from external defects, as these eggs are more resistant to microbiology and storage conditions (Izat et al., 1986; Dev, et al., 2008; Shenga et al., 2010; Al-Shadeedi, 2018; Oliviera et al., 2022).

Deactivating or inactivating microorganisms is one of the most important factors in the use of egg and food preservation technologies. Conventional heat pasteurization is one of the most common technologies currently used to inactivate microorganisms in food products. Sterilization technologies are also used for liquid and solid foods, as are drying, freezing, bleaching, and irradiation. Heat treatment inactivates or kills microorganisms and some germs, but it is incapable of inactivating or killing heat-resistant organisms. However, if processing involves increasing the temperature and exposure time to kill heat-resistant organisms, the food will lose important nutrients. The amount of processing, time, and temperature are proportional to the amount of nutrient loss, the development of undesirable flavors, and the deterioration of the functional properties of food products. Therefore, to replace these traditional methods of food preservation, ultrasound has emerged as a green technology that destroys harmful microorganisms without affecting beneficial ones, while preserving the sensory qualities of food products. Powerful ultrasound has multiple functions, including reducing spoilage and pathogenic microorganisms, removing other harmful substances, and ultimately preserving food products for a longer period. In fact, microorganisms are directly destroyed or removed by cavitation, which is generally a combination of the following effects (Ravikumar et al., 2017; Yüceer and Caner, 2020; Nagy et al., 2022; Ozlem and Yilmaz, 2023).

The aim of this study is to investigate the ultrasound technology and the efficacy of use it in preservation of table eggs.

Ultrasound Technology: In recent years, there has been a significant increase in research demonstrating the new and diverse uses of non-thermal food processing technologies, including more efficient mixing and blending processes, faster energy and mass transfer, lower temperature and selective extraction, reduced thermal and concentration gradients, reduced equipment size, faster response to extraction control, faster start-up, increased production, and a reduction in the number of steps in preparation and processing (Feng and Yang, 2005; Chemat and Khan, 2011).

Numerous recent surveys and applications of ultrasound technology have indicated that this technology has a promising and significant future in the food industry and preservation, and there is a wide scope for its use due to the higher purity of final products and the elimination of undesirable sensory qualities, as well as the fact that this technology consumes only a fraction of the time and energy required compared to traditional processing and preservation methods and techniques (Chemat and Khan, 2011). Therefore, ultrasound is considered a non-thermal processing and preservation technology that has the potential to be a suitable alternative to thermal food processing technologies (Rastogi, 2011). Ultrasound is a form of energy generated by sound waves at various frequencies too high to be detected by the human ear, i.e., frequencies above 16 kHz (Jayasooriya et al., 2004). Ultrasound technology has gained wider applications in almost all fields, including ultrasound therapy for medical scanning, metal processing, nanotechnology, non-destructive testing, industrial welding, surface cleaning, environmental decontamination applications, and the food industry. Ultrasound is also used as a processing aid in mixing materials, creating or destroying foam, agglomerating and sediment airborne powders, improving the efficiency of filtration, drying, and extraction techniques in solids, and enhancing the extraction of valuable compounds from vegetables and food products (Rastogi, 2011; Majid et al., 2015).

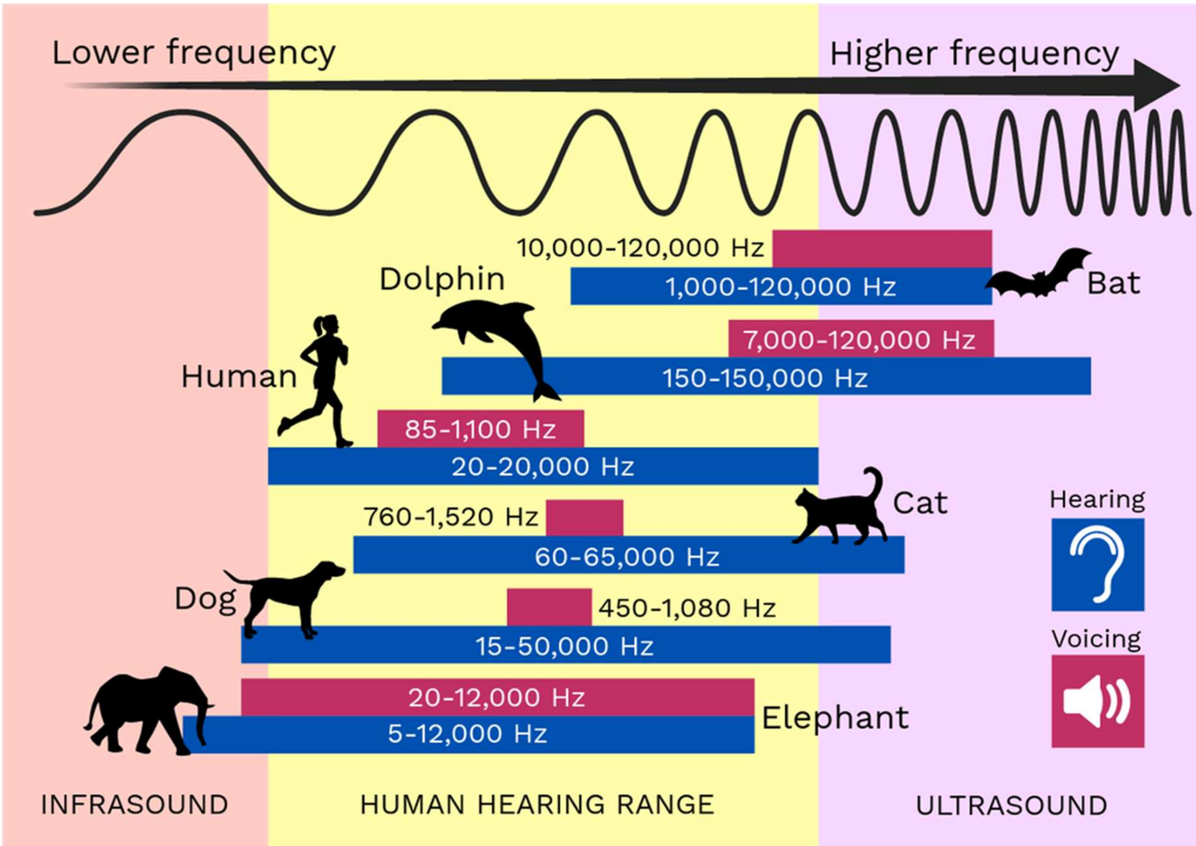

Figure (1): Frequency ranges of sound indicating infrasound (1 Hz-16 Hz), human hearing (16 Hz-18 kHz), power ultrasound (20 kHz-100 kHz), extended for special applications (20 kHz-1 MHz) and diagnostic ultrasound (5 MHz-10 MHz) (From www.animalia-life.club).

History of Ultrasound: Sound waves have been studied for many different reasons for hundreds of years, but the development of ultrasound began in 1790 with the discovery of the echolocation used by bats in nature. Dolphins and bats use low-intensity ultrasound waves to attack prey, while some marine animals use high-intensity ultrasound waves to locate their victims before hunting them (McClements, 1995). The most notable breakthrough came from the Curie brothers with their study of the piezoelectric effect, the electrical potential generated by a material in response to a change in temperature (Borisov and Gynkina, 1973). They also studied the properties of crystal structures to demonstrate the piezoelectric effect, the scientific basis for the first transducer. Low-intensity ultrasound methods were used to characterize foods 60 years ago, but the potential of this method has only recently been evaluated. Since the first real application of piezoelectric sonar in 1917, there has been significant development in the industry (Shankar and Pagel, 2011).

Ultrasound was first used for clinical purposes in 1956 in Glasgow. Before World War II, ultrasound applications were developed for a range of techniques, including surface cleaning procedures. By the early 1960s, ultrasound technology was well established and used in cleaning and plastic welding (Mason, 2003). Despite its diverse applications and significant development, ultrasound is still considered a new technology in the food industry. This is because the food industry has only recently begun to use this technology for food preservation, microbial inactivation, food drying, and enzyme inactivation. The continued demand for low- and high-frequency ultrasound applications will bring further new opportunities in the future (Jose et al., 2014). Significant progress has been made over the past five years in transforming this prototype laboratory technology into fully operational commercial operations throughout Europe and the United States. Applications in which high-power ultrasound can be used range from existing processes that have been improved by retrofitting high-power ultrasound technology, to the development of processes that were not yet possible using conventional energy sources (Ravikumar et al., 2017).

Types of Ultrasounds: Ultrasound can be used for food preservation in conjunction with other processors to increase the efficiency of the technology. Numerous studies have been conducted combining ultrasound with either pressure, temperature, or pressure and temperature. Accordingly, the types of ultrasounds used can be divided into:

Ultrasonication (US): This is the application of ultrasound at low temperatures. Therefore, it can be used for heat-sensitive products where there is concern about nutrient loss, such as vitamin C, protein denaturation, non-enzymatic browning, etc. However, it requires a prolonged exposure period to kill/inactivate stable enzymes and/or microorganisms, which may require high energy requirements. During ultrasound application, a temperature rise may occur depending on the power of the ultrasound and the application time, and this requires control to optimize the process (Zheng and Sun, 2006).

Thermosonication (TS): This is a combination of ultrasound and heat. Here, the product is exposed to ultrasound along with moderate heat. As a result of the additional heat, ultrasound produces a high amount of cavitation, which in turn has a greater effect on inactivating microorganisms than heat alone. Therefore, combining low-frequency ultrasound with moderate heat can reduce processing time by 55% and processing temperature by 16%, while reducing product sensory quality (Abdullah and Chin, 2014).

Ultrasound with Pressure (Manosonication or MS): This is a combined method in which ultrasound and pressure are applied together. Ultrasound helps inactivate enzymes and/or microorganisms by combining ultrasound with moderate pressures at low temperatures. Its inactivation efficiency is higher than that of ultrasound alone at the same temperature (Dolatowski et al., 2007).

Ultrasound with Thermal Pressure (Manothermosonication or MTS):
This is a combined method of heat, ultrasound, and pressure. Here, the applied temperature and pressure maximize cavitation and provide greater efficiency in inactivating enzymes and microorganisms. Thermal ultrasound treatments inactivate many enzymes at lower temperatures and/or in a shorter time than heat treatments at the same temperatures. Microorganisms with high heat tolerance can be inactivated by thermal ultrasound. Heat-resistant enzymes, such as lipoxygenase, peroxidase, and polyvinyl oxidase, have been reported to be inactivated by thermal ultrasound (Ercan and Soysal, 2013).

Ultrasound Principle: The basic principle by which ultrasound works is cavitation. Ultrasound is a form of energy generated by sound waves at a frequency inaudible to the human ear. When sound waves propagate through any product, a high amount of energy is generated due to the compression and rarefaction of the medium's molecules. Cavitation is the formation, growth, and collapse of bubbles that generate localized mechanical and chemical energy (Gogate and Kabadi, 2009). When ultrasound waves pass through a liquid medium, gas bubbles form within the liquid due to cavitation (Kentish and Ashokkumar, 2011). This is the interaction between sound waves, the liquid, and the dissolved gas. It changes the pressure around the dissolved gas nuclei, causing oscillations. Furthermore, the dissolved gas and solvent vapor diffuse into and around the oscillating bubbles. The bubbles then expand in successive cycles to an unstable size and then rupture. The bursting of bubbles releases extremely high pressure and heat around the collapsing bubbles which breaks down compounds in the liquid, causing particles to disperse, cells to break down and provide a local sterilization or pasteurization effect depending on the intensity of the sound applied (Abdullah and Chin, 2014).

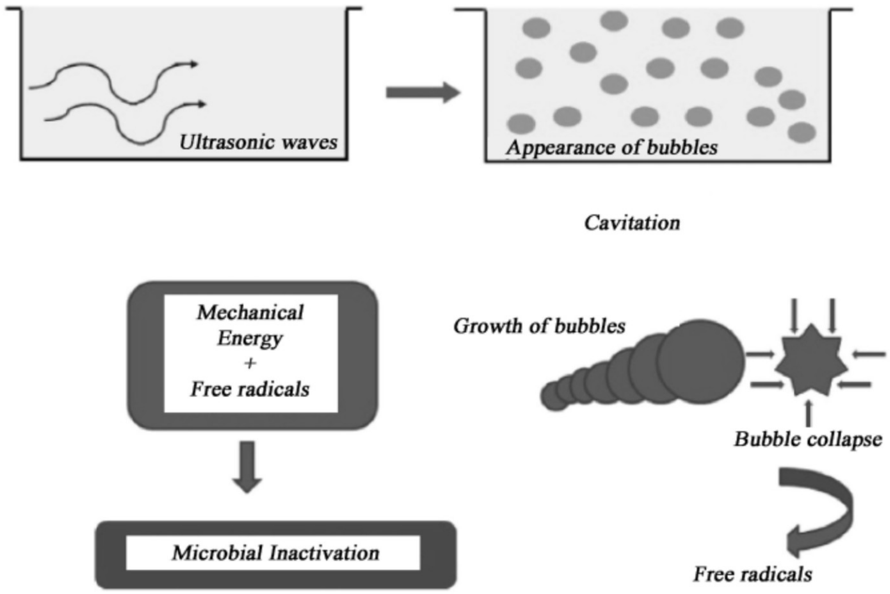

Figure (2): Ultrasonic waves and its mechanism (the cavitation phenomenon) (Jose et al., 2014).

Ultrasonic Preservation of Solid, Semi-Solid, and Liquid Foods: When ultrasound is applied to a solid-liquid system, it produces a series of effects that can affect the internal and external resistance to mass transfer between the solid and liquid (Mulet, 1994). In solid foods, when ultrasound is allowed to pass through, the product dries at a higher rate at a lower solution temperature. It also protects the product from hardening, non-enzymatic browning, and deterioration, while preserving the natural flavor, color, and heat-sensitive nutritional components. This is due to the increased permeability of the cell wall due to the formation of microscopic channels that facilitate the transfer of water to the outside and solutes to the inside. Therefore, microscopic jets striking the surface of the solid food can inject liquid into the solid and affect the mass transfer between the solid and liquid. In solids, ultrasound produces a series of rapid compressions and expansions of the material, comparable to a sponge being repeatedly squeezed and released (Floros and Liang, 1994). This effect, known as the "sponge effect," facilitates fluid flow out of samples (Gallego-Juarez et al., 1999). On the other hand, compressions and expansions of the material can create microchannels suitable for fluid movement (Muralidhara et al., 1985). The described effects can affect both internal and external resistance to mass or heat transfer and are the reason behind the application of high-intensity ultrasound to improve certain transfer processes. In heat transfer processes, high-intensity ultrasound can be used to improve the convective heat transfer coefficient in a manner similar to mechanical stirring (Carcel et al., 2007: Bhargava et al., 2020).

Application of Ultrasound in the Food Industry: Deactivating or inactivating microorganisms is one of the most important factors in the use of food processing and preservation technologies. Conventional heat pasteurization is one of the most common technologies currently used to inactivate microorganisms in food products. Sterilization technologies are also used for liquid and solid foods, as are drying, freezing, bleaching, and irradiation. Heat treatment inactivates or kills microorganisms and some germs, but it is incapable of inactivating or killing heat-resistant organisms. However, if processing involves increasing the temperature and exposure time to kill heat-resistant organisms, the food will lose important nutrients. The amount of processing, time, and temperature are proportional to the amount of nutrient loss, the development of undesirable flavors, and the deterioration of the functional properties of food products. Therefore, to replace these traditional methods of food preservation, ultrasound has emerged as a green technology that destroys harmful microorganisms without affecting beneficial ones, while preserving the sensory qualities of food products. Powerful ultrasound has multiple functions, including reducing spoilage and pathogenic microorganisms, removing other harmful substances, and ultimately preserving food products for a longer period. In fact, microorganisms are directly destroyed or removed by cavitation, which is generally a combination of the following effects (Ravikumar et al., 2017):

Mechanical effects: These include turbulence, pressure, rarefaction, and shear.

Chemical effects: These include cavitation and the production of free radicals (H^+ and OH^-). Free radicals formed in the aqueous medium attack the chemical structure of the microorganism's cell wall, weakening the cell wall to the point of disintegration. However, these free radicals are short-lived and have no harmful effects on humans who consume these ultrasound-treated foods.

Physical effects: These include extreme temperatures and pressures in and around food products, which preserve food for longer periods (Yuting et al., 2013).

The effectiveness of ultrasound treatment depends on the type of bacteria being tested. Other factors include the amplitude of the ultrasound waves, exposure time, the size of the food being treated, the composition of the food, and the treatment temperature. Bactericidal effects of ultrasound have been observed in bacteria suspended in a culture medium (Davies-Colley et al., 1999).

Advantages of Ultrasound: Ultrasound applications offer several advantages in the food industry (Abdullah and Chin, 2014; Ravikumar et al., 2017):

(1) Ultrasound is chemical-free, safe, and environmentally friendly. Ultrasound can be combined with many thermal and non-thermal methods and is an effective means of inactivating microorganisms.

(2) The use of ultrasound in juice extraction is more efficient in enhancing juice production than other juice extraction methods.

(3) Processing time is reduced by 55% and processing temperature by 16%.

(4) Ultrasonic-treated products experience minimal loss of flavor, color, and other nutritional components during processing.

(5) Ultrasound has gained significant applications in the food industry, such as preservation, processing, extraction, emulsification, centrifugation, homogenization, and more.

Disadvantages of Ultrasound: Despite its many advantages, the use of ultrasound has some disadvantages, such as (Majid et al., 2015; Ravikumar et al., 2017):

(1) Free radicals formed during cavitation may cause adverse effects on the consumer.

(2) It is a relatively new and researched technology.

(3) Ultrasound may cause physical and chemical effects that may be responsible for undesirable flavor, color change, and ingredient deterioration.

(4) The cost or initial investment is high.

(5) The frequency of the ultrasound waves can impose resistance to mass transfer.

Using Ultrasound to Extend the Shelf Life of Table Eggs: Over the past few decades, high-power, non-destructive ultrasound technology has been an effective tool for assessing food quality. The phase velocity of the ultrasound signal transmitted through a material has been found to be related to the physical and mechanical properties of the material and can be used as a criterion for assessing food quality (Povey and Wilkinson, 1980; Abbott et al., 1997; Povey and Mason, 1998; Mizrach et al., 2004; Knorr et al., 2004; Jayasooriya et al., 2007). Ultrasound-based food quality assessment is often preferred over other techniques due to their low cost, portability, and non-destructive nature. Furthermore, low-power ultrasound signals used in non-destructive testing (NDT) do not adversely affect the physical and mechanical properties of biomaterials. Various studies have reported that "table eggs are known to be a rich source of nutrients essential for maintaining human health" (Shrimpton, 1987). Eggs are a valuable food source and have long been consumed as part of daily diets throughout the world. Assessing the freshness of poultry eggs, which is closely related to their protein, nutrient, and vitamin levels, is a crucial task in the food industry. The egg aging process depends on storage conditions such as temperature and humidity. Toussant and Latshaw (1999) indicated that the most significant physical change observed in egg material during storage is an increase in air cell volume, mainly due to the loss of water and carbon dioxide through the eggshell, as well as changes related to the aging of the egg white and yolk. Air cell volume develops immediately after egg laying by separation of the shell membranes, and the thinning of poultry egg white during storage is a well-known phenomenon. It has been reported that approximately 67% of the egg weight is related to the albumin (egg white) content (Shrimpton, 1987). Egg whites become thinner as they age due to changes in protein properties. During storage, the thick albumin gradually liquefies and becomes thinner, which is why fresh eggs broken into a dish remain high and firm, while older eggs tend to expand. The main reason for this phenomenon is changes in the lysozyme-ovomucin complex that occur due to increased pH during storage (Meszaros et al., 2006). Various methods for non-destructive egg freshness determination have been developed in the past. One such technique is the candling assay. Candling is a tedious and subjective method and is not a robust method for ensuring egg quality. In comparison, the non-destructive ultrasound-based method is an effective tool for assessing egg quality. A significant correlation has been established between the ultrasonic phase velocity and the physical and mechanical properties of the egg material. The advantages of this method prompted the authors to develop a quantitative technique for distinguishing fresh commercial eggs from old eggs (Aboonajmi et al., 2010).

Ultrasound applications in protein functional characterization is a broad perspective for developing food with specific properties (Martini et al., 2010). It is known that its process is related to cavitation, dynamic agitation, shear stresses, heating and turbulence (O'Donnell et al., 2010). The ultrasound technique has great application in improving protein properties. Jambrak et al. (2008) reported that the solubility and foaming capacity of whey protein hydrolysate increased after ultrasonic treatment .

Ultrasound procedures applied to the egg have been studies on determining and improving the internal quality of the egg. In a study, ultrasonic waves (frequency of 150 kHz) were used to determine the internal quality of the egg without damaging the egg shell, and it was stated that it could be used to provide information about the freshness of eggs stored for 3 weeks (Aboonajmi et al., 2010) .

According to Sert et al. (2011) in their studies where they applied 35 kHz ultrasound to eggs at different times (5,15 and 30 min), detected high specific weight, shell strength, albumen height, and Haugh unit in eggs that were subjected to ultrasound. It was stated that egg quality was significantly improved by ultrasonic treatment ($p< 0.01$). Yüceer and Caner (2014) reported that the application of 300 W and 400 W ultrasound improved the internal quality of fresh eggs during storage. It has been stated that it affects the shell strength negatively .

Aboonajmi et al. (2014) also indicated that using a non-destructive ultrasound method to develop a model for assessing the quality and freshness of table eggs, the proposed model can predict the unit of the egg, the thickness of the egg white, the air cell height, and several other egg quality parameters by calculating the ultrasonic phase velocity within the egg components. For this purpose, the effect of storage time on the ultrasonic phase velocity within poultry eggs was considered, along with the peak values of the transmitted ultrasonic signals in the time and frequency domains, as indicators of egg freshness. Tests were conducted on eggs stored for five weeks under different storage conditions. The calculated parameters were used to develop various models to predict the number of storage days for egg samples. The results showed that the amplitude of the main peaks of the ultrasonic signal in the time domain increased with the number of storage days. Furthermore, there was a significant difference between the average values of the phase velocities obtained at different times during the storage period. Comparing the results obtained for eggs stored at room temperature with those refrigerated showed that these differences were more significant for eggs stored at room temperature. Caner and Yuceer (2015) noted that ultrasonic processing is an emerging technology that could be an alternative to existing heat treatment techniques in food. Ultrasonic treatments can also be used to extend the shelf life of table eggs during storage at room temperature. The effectiveness of ultrasonic treatment at different power levels (200 W, 300 W, and 450 W) and treatment times (2 and 5 min) was evaluated to enhance the functional properties of eggs during storage at 24°C for 6 weeks. The results showed that ultrasonic treatment and treatment duration significantly improved egg quality attributes, including yolk index, egg white pH, dry matter, and functional attributes, including relative beating ability and egg white viscosity. This resulted in extended shelf life and shelf life, and improved egg quality attributes when using ultrasonic waves at 300 W and 450 W. The researchers indicated the importance of ultrasonic treatments in improving the internal quality of fresh eggs during storage, but at the same time had a negative effect on shell strength.

Yüceer and Caner (2020) noted that ultrasound is one of the fast, versatile, emerging, and promising green technologies used in the food industry in recent years, extending shelf life, including in egg processing. Chen et al. (2019) study the effects of ultrasonic treatment (180 W, 25 min) on the foaming and physicochemical properties of egg white from shell egg stored for seven periods (0, 15, 30, 45, 60, 75 and 90 d) were investigated in this study. The foaming ability significantly increased after ultrasound treatment and the highest foaming ability (99.13%) was achieved at 60 d compared to untreated egg white (29.75%). This improvement was ascribed to the increased free sulfhydryl content and surface hydrophobicity, indicating that egg white protein became easier to adsorb at the air-water interface and its structure was more flexible. However, a reduction in the foaming stability of ultrasound-treated egg white resulted from the lower absolute zeta potential. Moreover, decreasing particle size and broadening protein size distribution were obtained after ultrasonic processing. Using scanning electron microscopy, small aggregates were observed on the surface of the untreated sample after storage, while the ultrasound-treated sample had large numbers of irregular and unevenly distributed pores with different sizes. These results provide important evidence of the protein properties induced by ultrasound modification during storage, and further expand the ultrasound application in the food storage industry.

Nagy et al. (2022). Study revealed that combination of sonication and low-heat treatment was able to reduce the concentration of *E. coli* from 5-log CFU × mL^{-1} below 10 CFU × mL−*1* at 300 W, 40 kHz and 60 min of sonication in liquid egg products. The 60 min treatment was able to reduce the *E. coli* concentration below 10 CFU × mL^{-1} in the case of egg yolk regardless of the applied frequency, absorbed power or applied energy dose. The 30 min treatment of sonication and heating was able to reduce significantly the number of *E. coli* in the egg products, as well. Our results showed that sonication with mild heat treatment can be a useful technique to decrease the number of microorganisms in liquid egg products to a very low level. Near-infrared spectroscopy was used to investigate structural changes in the samples, induced by the combined treatment. Principal component analysis showed that this method can alter the C-H, C-N, $^{-}$OH and $^{-}$NH bonds in these egg products.

Ozlem and Yilmaz (2023) study to determine the effects of ultraviolet and ultrasound applications applied before storage to the quality characteristics of the eggs collected from laying hens. Eggs collected in the morning were subjected to ultraviolet and ultrasound treatments before storage and stored for 28 days in an environment of 20°C and approximately 60% humidity. The applied treatments made a significant difference between the groups in egg shell thickness ($p<0.01$), albumen weight ($p <0.01$) and yolk dry matter value ($p<0.01$). Storage time, on the other hand made significant changes between groups on weight loss, shell breaking strength, albumen and yolk quality characteristics. The interaction of applications and storage time was statistically significantly in weight and height of albumen, Haugh unit and dry matter of yolk. As a result, the effects of processes such as ultraviolet and ultrasound applied to eggs, especially on egg shell thickness, reveal the importance of application time and application amount in such studies.

Conclusion

Applications of ultrasound technology have indicated that this technology has a promising and significant future in the food industry and preservation, and there is a wide scope for its use due to the higher purity of final products and the elimination of undesirable sensory qualities, as well as the fact that this technology consumes only a fraction of the time and energy required compared to traditional processing and preservation methods and techniques. Therefore, ultrasound is considered a non-thermal processing and preservation technology that has the potential to be a suitable alternative to thermal food processing technologies. Ultrasound is a form of energy generated by sound waves at various frequencies too high to be detected by the human ear, i.e., frequencies above 16 kHz. Ultrasound technology has gained wider applications in food industry and enhancing the extraction of valuable compounds from vegetables and food products.

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