Postharvest Inactivation of Yeast and Mold in Red Onion (Allium cepa L.) using Ultrasound Treatment

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Abstract: *Red onions (Allium cepa* L.*) are valued for their flavor, nutrients, and antioxidants but are prone to microbial contamination, causing spoilage and economic loss. Traditional chemical methods pose health and environmental concerns, increasing interest in non-thermal alternatives like ultrasound for microbial decontamination. This study investigated ultrasound treatment at 600 watts using frequencies of 20, 28, 40, 68, and 80 kHz for 5, 10 and 15 minutes. The most effective treatment, 80 kHz for 15 minutes achieved a 96.05% microbial reduction. Using Response Surface Methodology (RSM), optimal conditions were identified as 25.5 kHz for 6.47 minutes, reducing microbial counts to 12,028.9 CFU/g. ANOVA showed exposure time had a significant on microbial inactivation, while frequency had a lesser effect. These findings suggest ultrasound treatment can enhance red onion shelf life and reduce post-harvest losses. Further studies are recommended for large-scale application.*

Keywords: Red onions, non-thermal technology, ultrasound treatment, microbial inactivation, Response Surface Methodology

1. INTRODUCTION

Red onions (Allium cepa L.) are a widely consumed vegetable known for their rich nutritional profile and health benefits. However, they are highly prone to contamination by yeast and molds, resulting in spoilage and potential health hazards for consumers [1]. Thermal techniques such as pasteurization, scalding, or/and drying, ensuring microbial safety and/ or enzyme deactivation. Although thermal treatments are the most cost-effective tools, they could also reduce bioactive compounds, nutrients, and even sensory attributes[2].These drawbacks emphasize the need for alternative, safer, and more sustainable postharvest treatments.

Moreover, the challenges in maintaining the quality and safety of red onions are further compounded by fluctuations in local production and growing reliance on imported supplies. The red onion production graph shows notable variations over time, while importation data highlights an increasing dependence on foreign onions particularly in 2019, when import volumes peaked at 225,790 metric tons. This trend suggests that domestic production may be insufficient to meet consumer demand, resulting in higher importation levels despite occasional peaks in local output. These market dynamics further emphasize the importance of enhancing the postharvest handling and storage of red onions to minimize spoilage and reduce dependency on imports[3].

The preservation of food quality and safety is a critical concern in the food industry. Among various preservation methods, ultrasonic treatment has emerged as a promising non-thermal technology due to its ability to inactivate microorganisms without compromising the nutritional and sensory attributes of food products. Ultrasonic treatment utilizes high-frequency sound waves to induce cavitation, which generates localized high temperatures and pressures, leading to the disruption of microbial cells.

Recent studies have demonstrated the efficacy of ultrasonic treatment in inactivating a wide range of microorganisms, including bacteria, yeast, and molds, in various food matrices[4]. However, the effectiveness of ultrasonic treatment can be influenced by several factors, including the frequency of the ultrasound waves and the duration of exposure. In addition to microbial inactivation, ultrasound treatment has a beneficial effect on aged bell pepper seeds with good effects on seed quality[5]. Multi-frequency ultrasonic treatment, which involves the simultaneous use of different frequencies, has shown potential in enhancing microbial inactivation due to the synergistic effects of cavitation at multiple frequencies[6].

This study aims to investigate the effect of different frequencies and exposure times of ultrasonic treatment on the inactivation of yeast and molds in red onions. By optimizing the ultrasonic treatment parameters, this research seeks to enhance the microbial safety and shelf life of red onions, thereby contributing to improved food quality and safety.

2. MATERIALS AND METHODS

2.1 Sampling Design

This study progressed through six distinct phases, each requiring specific materials and instruments. Figure 1 illustrates the procedural approach. The process began with fabrication, followed by sample preparation, where red onion samples were collected for treatment. In the sonication phase, samples were exposed to ultrasound at different frequencies (20, 28, 40, 68, and 80 kHz) and durations (5, 10, and 15 minutes), including a control group with no treatment. Microbial analysis was then conducted to determine microbial load after treatment. Next, statistical analysis using ANOVA assessed the significance of frequency and exposure time on microbial reduction. Finally, optimization using Response Surface Methodology (RSM) identified the best conditions for maximum microbial reduction.

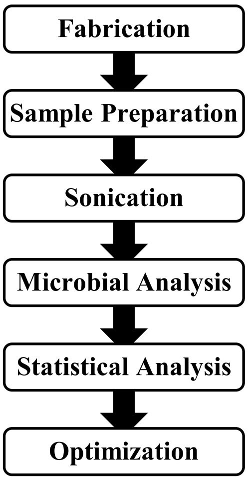

Fig. 1.Methodological Framework

2.2 Fabrication

The ultrasonic bath used in this study was carefully designed to ensure effective microbial decontamination of red onions. Figure 2 and Table 1 show the specifications of the designed bath.

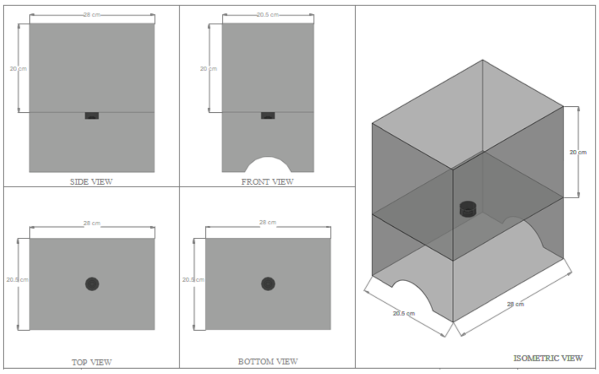

Fig. 2. An Ultrasonic Bath Designed and Fabricated for Red Onions

Table 1. Designed Ultrasonic Bath

Parameter	cm
Length	28
Width	20.5
Height	20
Floor Area (cm^2)	574
Capacity (L)	11.48
Power (W)	600
Power Density (W/cm^2)	1.0452

2.3 Sample Preparation

The study began by collecting onion samples from Reyes Market in Brgy Bula, General Santos City. These onions had been stored under cold conditions for five months prior to treatment. Medium-sized onions (3.5–5 cm in diameter), following the classification set by PNS/BAFPS 14:2004, were specifically selected. After collection, the onions were inspected, and any defective samples were discarded to ensure only quality samples were used. The initial weight of the selected onions was measured, and randomization was performed to assign the samples for each test.

2.4 Sonication

An experimental set of three onion samples was immersed in distilled water and subjected to ultrasonic waves for 5, 10, and 15 minutes at varying frequencies of 20 kHz, 28 kHz, 40 kHz, 68 kHz, and 80 kHz. The water-to-fruit ratio was maintained at 4:1 (weight basis), consistent with previous experiments. This ratio was chosen because prior studies have shown that at this liquid medium-to-fruit ratio, the dilution of the osmotic solution is negligible, and the increase in soluble solids content observed during ultrasound pre-treatment is minimal (less than 2.0 g/L) [7]. Additionally, the transducer will not operate if the generator fails to provide the required frequency for the transducer.

2.5 Experimental Set-up

The study utilized a fabricated stainless steel cleaning bath with dimensions of 20 cm in height, 20.5 cm in width, and 28 cm in length.

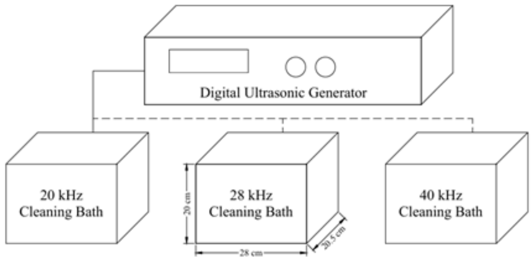

Fig. 3. Experimental Setup (low-frequency)

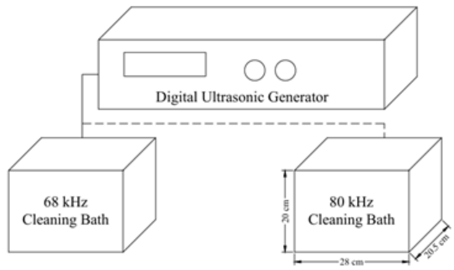

Fig. 4. Experimental Setup (high-frequency)

Five cleaning baths were set up, each equipped with different ultrasonic transducers operating at 20 kHz, 28 kHz, 40 kHz, 68 kHz, and 80 kHz, respectively. A digital ultrasonic generator, capable of producing frequencies ranging from 17 kHz to 52 kHz when connected to the appropriate transducers, was used for the lower frequencies. Another digital ultrasonic generator, designed for higher frequencies (68 kHz and 80 kHz), was utilized, capable of producing frequencies from up to 85 kHz. The distilled water in the cleaning baths was maintained at ambient temperature. To generate the desired frequency, the ultrasonic generator was connected to the corresponding cleaning bath with the appropriate frequency transducer. This process was repeated for all target frequencies and the specified study duration.

2.6 Experimental Design

The study was conducted using 16 treatments, consisting of five frequency levels (20 kHz, 28 kHz, 40 kHz, 68 kHz, and 80 kHz), various time durations (5 min, 10 min, 15 min), and untreated samples, with three replications for each treatment. The frequencies and durations used in this study were based on previous research. Randomization was performed to assign the sequence for each test. The effect of ultrasound (US) treatment (20 kHz, 28 kHz, 40 kHz, 68 kHz, and 80 kHz, 600 W) for 0, 5, 10, and 15 minutes on the microbiological quality, specifically yeast and mold counts, of red onion (*Allium cepa* L.) was evaluated.

2.7 Microbial Analysis

The red onion bulbs were placed in different separate sterile polythene bags and transported to DOST-Calumpang for analysis to determine the yeast and mold counts in the food samples. Figure 5 illustrates the flowchart outlining the procedure for determining yeast and mold counts in the food samples.

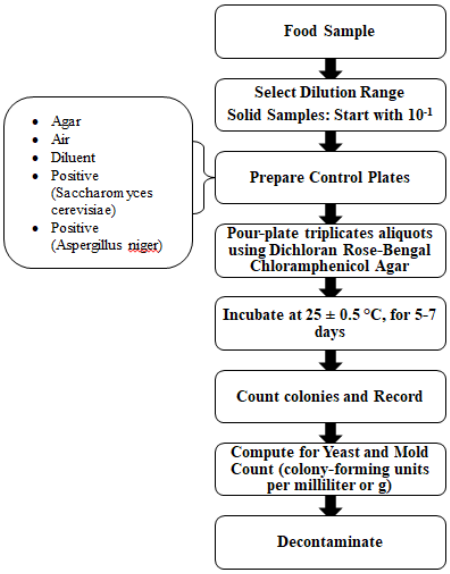

Fig. 5. Flowchart for Determination of Yeast and Mold Count in Food

2.8 Data and Statistical Analysis

After gathering the data, the effect of frequency on microbial activity was analyzed using a factorial design. The aim was to investigate how different frequencies and exposure times of onions subjected to ultrasonic technology impacted their microbial activity using Eqn 1.

$$\% \, Inactivation = \frac{\text{Initial Count} - \text{Final}}{Initial \; Count} \times 100 \qquad (1)$$

Excel, ANOVA was employed as the statistical method to determine whether the observed differences in microbial activity across various frequencies and exposure times were statistically significant. Furthermore, a correlation analysis was conducted to evaluate the relationships between exposure time, frequency, and microbial counts.

The results of these analyses provided valuable insights into the influence of ultrasonic frequency variations and exposure durations on the microbial quality of onions, highlighting significant interactions between the tested factors. These findings not only enhance the understanding of how ultrasonic technology can be optimized to control microbial activity but also offer practical applications for improving onion preservation during post-harvest handling and storage.

2.9 Optimization

Response Surface Methods are designs and models used for working with continuous treatments, particularly when the goal is to find the optimum response or describe the relationship between variables. The primary objective of Response Surface Methods is to identify the optimum response. When there is more than one response to consider, it becomes crucial to determine a compromise optimum that balances the optimization of multiple responses rather than focusing solely on one [8].

In this study, Design-Expert® Software, Version 13, developed by Stat-Ease, Inc., a company based in Minneapolis, Minnesota, USA, was utilized to design and analyze experiments for a study on using ultrasonic technology for the decontamination of red onions. The primary factors considered were time (in minutes) and frequency (in kHz), while the response variable measured was the microbial activity of the treated onions. The objective was to determine the optimal combination of time and frequency to effectively minimize microbial activity.

Initially, the experimental design was selected based on the complexity of the problem and the number of factors involved. A response surface methodology (RSM) was employed to explore the interactions between time and frequency and their effects on microbial activity. Experiments were conducted according to the design generated by the software, and the microbial activity data obtained from these experiments were input into the program for analysis.

The software performed statistical analyses, including regression modeling and analysis of variance (ANOVA), to assess the significance of the factors and their interactions. Diagnostic tools were used to evaluate the adequacy and fit of the model.

To identify the optimal ultrasonic conditions, desirability analysis was applied, with the goal of minimizing microbial activity. The software predicted the optimal combination of time and frequency. This methodical approach enabled the identification of effective ultrasonic treatment parameters for the decontamination of red onions.

3. RESULTS AND DISCUSSION

3.1 Fabrication

The ultrasonic system was designed with a stainless steel tank to ensure durability and resistance to corrosion. One ultrasonic transducer were mounted at the bottom of the tank. An ultrasonic generator was incorporated to allow adjustments in high-intensity ultrasound, ranging from 17 kHz to 85 kHz, with a power output of 600 watts. The fabricated ultrasonic technology had a power density of 1.0452 W/cm², enabling the inactivation of microorganisms and enhancing the physical, chemical, and biochemical properties of foods due to its disruptive efficiency. The power density was calculated using the formula: $Power \; Density = \frac{Power}{Area}$. This contributed to improved food quality and better control of food properties, making the system highly effective for food processing applications.

3.2 Reduction of yeasts and molds on Red Onion

The reduction of yeast and molds was assessed across various treatments and ultrasonic frequencies, as shown in Figure 6. The untreated sample had the highest average microbial count of 754,000 CFU/g, serving as the baseline. All ultrasonic treatments significantly reduced yeast and mold counts, with higher frequencies and longer durations generally showing greater reductions.

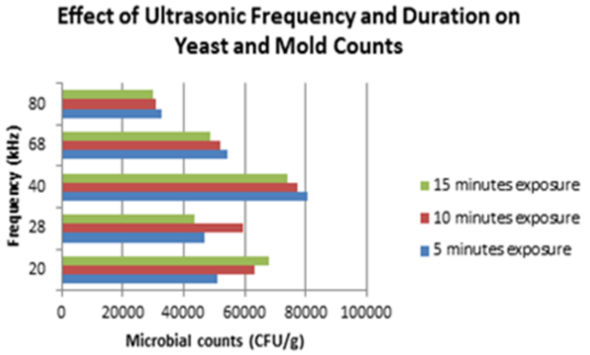

Fig. 6. Effect of Ultrasonic Frequency and Duration on Yeast and Mold Counts

At 20 kHz, the microbial counts decreased as the duration increased, from 50,800 CFU/g at 5 minutes to 68,033.33 CFU/g at 15 minutes. However, the reductions were less compared to higher frequencies. Treatments at 28 kHz showed better reductions, with the lowest count observed at 15 minutes (43,566.67 CFU/g). Similarly, the 40 kHz treatments followed the same trend but yielded slightly higher average counts compared to 28 kHz, with the lowest being 73,800 CFU/g at 15 minutes.

The most significant reductions were observed at 80 kHz. The microbial counts decreased progressively from 32,633.33 CFU/g at 5 minutes to 29,800 CFU/g at 15 minutes, indicating that higher frequencies coupled with longer exposure times are most effective in reducing yeast and mold counts.

Thus, the results demonstrate that the effectiveness of ultrasonic treatment increases with both frequency and duration, with 80 kHz for 15 minutes achieving the greatest reduction in yeast and mold populations.

3.3 Dose-Response Relationship Analysis

A dose-response relationship describes how the magnitude of a biological or chemical effect changes with varying levels of exposure, commonly visualized using a dose-response curve, where the x-axis represents the dose and the y-axis represents the observed effect [9].

In this study, a dose-response relationship was evaluated to determine the effect of treatment frequency and exposure time on microbial counts. The dose was computed as the product of frequency and time, and its relationship with microbial counts was analyzed using a linear regression model. As illustrated in Figure 8, the scatter plot reveals a negative linear trend, indicating that microbial counts generally decrease with increasing dose.

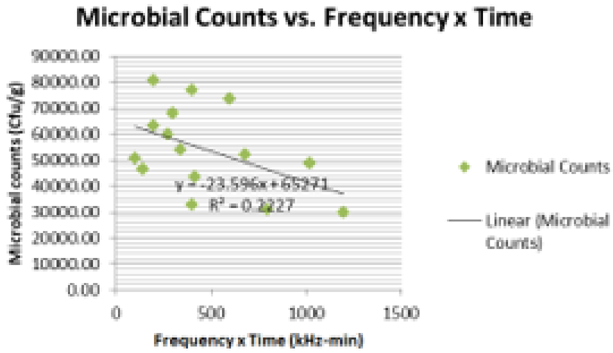

Figure 8. Efficacy of ultrasound treatment as a function frequency and time

The resulting regression equation is $y = -23.596x + 65271$. Where y represents microbial counts and x denotes dose. This equation suggests that for every unit increase in dose, the microbial count decreases by approximately 23.6 units. The y-intercept of 65,271 represents the estimated microbial count in the absence of treatment. However, the coefficient of determination ($R^2 = 0.2227$) indicates a relatively weak correlation, with only 22.27% of the variation in microbial counts explained by changes in dosage. This suggests that while dosage plays a role in microbial reduction, other factors may also influence the observed results.

These findings are consistent with and supported by previous studies that examined the impact of chemical disinfectants on microbial survival. In particular, a related study investigated the dose-effect relationship between the log survival rate of Total Coliforms (TCs) and the concentration-time product of free residual chlorine. The regression analysis yielded the equation $y = -0.0575x + 3.0416$ with an R^2 value of 0.5184, indicating a moderate correlation between chlorine exposure and the reduction in microbial survival. The negative slope confirms an inverse relationship: as chlorine exposure increases, the survival rate of Total coliforms decreases [10].

3.4 Effect of ultrasound treatment on the microbial quality of red onion

The ultrasound treatment applied to red onion samples at various frequencies and durations had a significant impact on microbial quality, as shown by the reduction in microbial counts (CFU/g) and corresponding microbial inactivation percentages using equation 1. Figure 8 shows the microbial inactivation of red onion using ultrasonic technology.

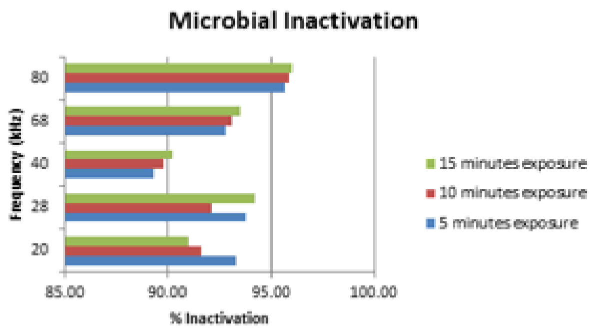

Fig. 8. Microbial inactivation of each treatment

The untreated onions had a baseline microbial load of 754,000 CFU/g. After applying ultrasound at 20 kHz for

5 minutes, microbial counts dropped to 50,800 CFU/g, representing a 93.26% reduction. However, extending the treatment to 10 and 15 minutes slightly reduced the destruction rates to 91.59% and 90.98%, indicating diminishing returns with prolonged exposure at this frequency.
The treatment at 28 kHz was more effective, reducing microbial counts to 46,733 CFU/g after 5 minutes with a 93.80% reduction. Longer durations of 10 and 15 minutes further increased the reduction rates to 92.09% and 94.22%, respectively, indicating that higher frequencies enhance microbial control. Conversely, the 40 kHz treatment showed less effectiveness, with destruction rates between 89.32% and 90.21% across different exposure times, suggesting that this frequency did not generate as much microbial inactivation as others.
The 68 kHz frequency yielded consistent results, with a 92.82% destruction rate after 5 minutes and improved reductions with longer treatments. However, the most effective treatment was observed at 80 kHz, which reduced microbial counts to 32,633 CFU/g after 5 minutes, achieving a 95.67% reduction. This frequency showed the highest efficiency, with destruction rates of 95.90% and 96.05% at 10 and 15 minutes, respectively, making it the most optimal for microbial inactivation.
These findings align with various studies on ultrasound's microbial inactivation effects. It is reported that ultrasonication effectively reduced the viable cell counts of Escherichia coli, Pseudomonas fluorescens, and Listeria monocytogenes. A complete reduction (100%) in E. coli was achieved after 10.0 minutes of treatment, while Pseudomonas fluorescens was completely inactivated (100%) after 6.0 minutes. In contrast, Listeria monocytogenes showed a 99% reduction in viable cell counts after 10.0 minutes of ultrasonication[11]. Additionally, Ultrasound washing at a fixed frequency of 40 kHz applied to Chinese cabbage achieved a reduction of over 3 log CFU/g in E. coli counts, enhanced total phenolic content by approximately 20%, and increased reducing power activity by more than 32% [12].

3.5 Assessing the Effects of Frequency, Time, and their Interaction on the Response Variable using ANOVA

The ANOVA evaluates the decontamination of microbial activity using ultrasonic technology, with time (A) and frequency (B) as factors as shown in Table 2. The cubic model, developed using Response Surface Methodology (RSM), is statistically significant overall, with a p-value of less than 0.0001 and an F-value of 351.58, indicating it effectively explains an amount of variability in microbial activity. Among the factors, time (A) has a significant effect on the response, as indicated by its p-value of 0.0163. In contrast, frequency (B) does not show a statistically significant impact, with a p-value of 0.3153. Similarly, the interaction between time and frequency (AB) is not significant ($p = 0.3173$).

Table 2. ANOVA for Evaluating the Effect of Time and Frequency on Microbial Activity Using a Cubic Model

Source	Sum of Squares	df	F-value	p-value
Model	4.62E+11	9	351.58	< 0.0001
A-A	1.60E+09	1	10.93	0.0163
B-B	1.75E+08	1	1.2	0.3153
AB	1.74E+08	1	1.19	0.3173
A^2	1.34E+11	1	91.53	< 0.0001
B^2	2.72E+08	1	1.87	0.221
A^2B	3.56E+07	1	0.25	0.6349
AB^2	9.68E+07	1	0.6626	0.4467
A^3	1.20E+11	1	81.92	< 0.0001
B^3	4.96E+07	1	0.3393	0.5814
Residual	8.76E+08	6		
Cor Total	4.63E+11	15		

In the cubic model, the influence of time on microbial activity is strong, especially when considering higher-order effects. The quadratic term for time (A^2) shows a significant nonlinear relationship ($p < 0.0001$), meaning that microbial activity changes in a curved pattern over time. The cubic term for time (A^3) is also significant ($p < 0.0001$), indicating even more complex time-related effects on the decontamination process. In contrast, the quadratic and cubic terms for frequency (B^2 and B^3), as well as their interactions, do not have a significant effect, as their p-values are greater than 0.05.
Using Response Surface Methodology (RSM) with the cubic model provides a detailed understanding of how the variables interact, helping to find the best conditions for microbial decontamination. The small amount of unexplained variation compared to the total variation confirms that the cubic model fits the data well, showing that RSM is a reliable tool for studying these relationships.

3.6 Correlation Analysis of Exposure Time, Frequency, and Microbial Counts

Understanding the relationship between different factors is important for improving treatment processes, especially for reducing microbes. In this study, the focus was on how exposure time and frequency (kHz) affect microbial counts (CFU/g), which measure the amount of yeast and molds. A correlation matrix was used to find out how strongly these factors are connected and how they influence each other. The goal was to see if increasing exposure time or frequency could help reduce microbial counts.

Table 3. Correlation Analysis between Exposure Time, Frequency, and Microbial Count

	Time	Frequency (kHz)	Counts (CFU/g)
Time	1		
Frequency (kHz)	0.1385	1	
Counts (CFU/g)	-0.5167	-0.4995	1

The results showed that exposure time and microbial counts had a negative correlation of -0.5167. This means that as exposure time increased, the microbial counts decreased, and the connection between them was moderately strong. Similarly, frequency and microbial counts had a negative correlation of -0.4995, meaning that as frequency increased, microbial counts also tended to decrease.

In simple terms, both longer exposure times and higher frequencies helped lower the number of microbes, although the effect wasn't perfect. These findings suggest that adjusting these factors could be a useful way to reduce microbial levels and improve treatment processes.

3.7 Optimization of Ultrasound Parameters for Postharvest Inactivation of Yeast and Mold

The effect of ultrasound treatment parameters namely time and frequency on the reduction of yeast and mold counts was evaluated using a Response Surface Methodology (RSM) approach. The resulting contour plot visually represents the interaction between these variables and their combined influence on microbial inactivation efficacy as shown in Figure 9.

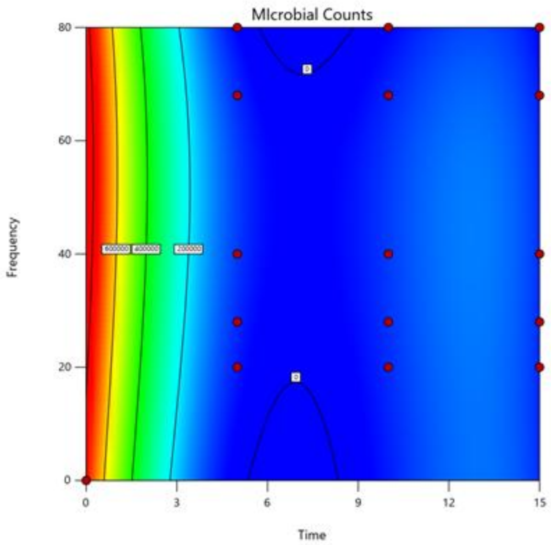

Fig. 9. Contour Plot of Microbial Counts as a Function of Ultrasound Time and Frequency

The color gradient, ranging from red to blue, indicates varying microbial counts, with red representing higher counts and blue representing lower counts.

A steep gradient in microbial reduction is seen as time increases, with microbial counts reducing significantly as we move rightward along the x-axis (time). Even at lower frequencies, prolonged time contributes significantly to inactivation.

The prediction and control of microbial growth are essential in ensuring the safety and quality of food products especially in red onions. An optimization process was performed using Response Surface Methodology in Design-Expert software to minimize microbial activity during the ultrasonic decontamination of onions. The constraints table outlines the defined ranges for the factors: time was set between 0 and 15 minutes, frequency between 0 and 80 kHz, and microbial activity between 29,800 and 754,000 CFU/g, to minimize microbial counts. Each parameter was given equal importance, indicating that all were critical to the optimization process. Figure shows a predictive modeling to estimate microbial counts as a function of time and frequency.

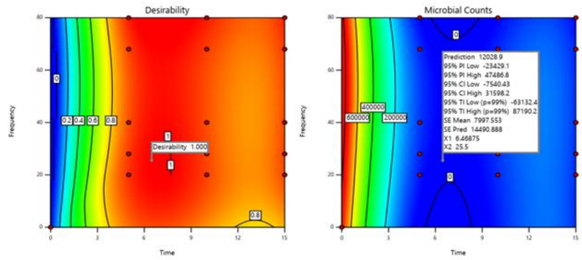

Fig. 10. Response Surface Contour Plot showing Optimized Parameters for Desirability and Microbial Reduction

The model predicted a microbial count of 12,028.9 CFU/g. However, there is a significant amount of uncertainty in this prediction. The 95% prediction interval ranged from -23,429.1 CFU/g to 47,486.8 CFU/g, indicating that the actual microbial count could vary widely. The 95% confidence interval, which reflects the possible range for the average microbial count, was narrower, from -7,540.43 CFU/g to 31,598.2 CFU/g. In addition, the 99% tolerance interval, which covers the expected range for 99% of future individual values, extended from -63,132.4 CFU/g to 87,190.2 CFU/g.

These wide intervals suggest a high level of variability in the data or the model. The standard error of the mean was 7,997.553 CFU/g, and the standard error of prediction was 14,490.888 CFU/g, both indicating the degree of expected variation from the predicted value. These values were based on the condition where the time was 6.47 minutes and the frequency was 25.5 kHz, which represent the optimized parameters identified by the model for achieving the desired microbial count. A 3D surface plot was also performed using the designed expert as shown in Figure 12. It investigates the relationship between microbial count, frequency, and time, as visualized through a 3D surface plot.

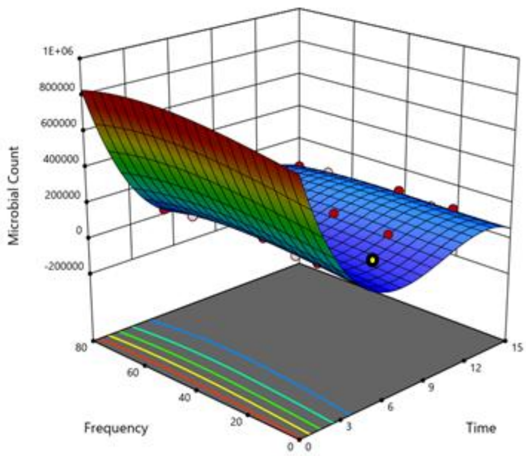

Fig. 11. 3D Plot for the optimum parameters

The 3D surface plot reveals a gradient of microbial count, with lower values (blue regions) at specific high frequencies and extended time durations, transitioning to higher counts (red regions) under less optimal conditions. The red spheres represent data points that validate the modeled surface, while the yellow sphere highlights the parameter identified as optimal.

As observed in Figure 12, higher frequencies often lead to improved microbial reduction due to the intensified cavitation effects they produce. Cavitation, which involves the formation and collapse of bubbles, creates localized high-energy zones capable of disrupting microbial cells effectively. Similarly, the duration of ultrasonic exposure significantly influences the extent of microbial reduction. Prolonged exposure times enhance the treatment's efficacy, as the sustained application of ultrasound allows for more extensive cavitation and microbial cell disruption.

3.8 Design of a Small-Scale Ultrasonic Decontamination System for Onions Using Optimized Parameters to Minimize Microbial Activity

As shown in Table 4, the proposed ultrasonic decontamination system is designed with a stainless steel tank to ensure both durability and corrosion resistance, making it suitable for repeated use in food processing environments. To maximize decontamination efficiency, the system is equipped with three ultrasonic transducers mounted at the bottom of the tank, ensuring uniform distribution of high-frequency sound waves throughout the liquid medium. These waves generate microscopic cavitation bubbles that dislodge microbial contaminants from the surface of the onions.

Table 4. Key Features and Specifications of the Ultrasonic Decontamination System

Category	Specification
Optimal Parameters	
Ultrasonic Frequency	26 kHz
Duration	7 minutes
System Dimensions	
Length, Width, Height	30 cm (11.81 in or 0.98 ft)
Total Floor Area	900 cm²
Actual Capacity	27 liters
Recommended Capacity	23 liters
Power	
Output	900 watts
Power Density	1 watt/cm^2
Design	
Material	Stainless steel tank for durability and corrosion resistance
Ultrasonic Transducers	3 ultrasonic transducers mounted at the bottom of the tank
Ultrasonic Generator	Allows adjustment of ultrasonic frequency (17 kHz to 53 kHz) and power output (600 to 900 watts)

As shown in Figure 12, a removable stainless-steel strainer is integrated into the interior of the bath to hold the onions during treatment, preventing direct contact with the transducers and helping reduce particulate contamination in the tank. A secure cover is also incorporated into the design to prevent external contaminants from entering the bath during operation and to maintain the temperature and integrity of the ultrasonic field. Additionally, the system includes a drain valve to facilitate easy disposal of used water and cleaning of the tank after each treatment cycle, thereby maintaining hygienic operation.

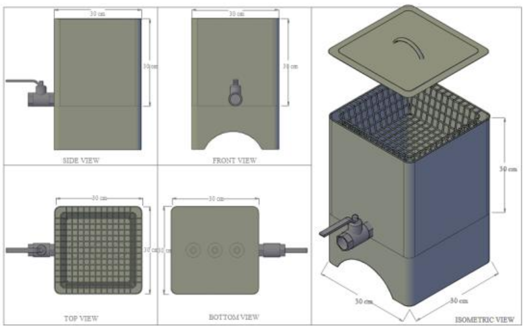

Fig. 12. Design of a Small-Scale Ultrasonic Decontamination System for Red Onions

The ultrasonic generator supports adjustable frequency (from 17 kHz to 53 kHz) and power output (ranging from 600 to 900 watts), allowing users to fine-tune the treatment according to specific produce types. The set up is shown in Figure 13. The system operates at an optimized ultrasonic frequency of 25.5 kHz and a treatment duration of 6.47 minutes, as identified in the optimization analysis. The power density of 1 W/cm² ensures sufficient acoustic energy is delivered to achieve effective microbial reduction. With a capacity of 27 liters, this system is ideal for small-scale agricultural processing and offers an effective, non-thermal method for enhancing food safety in red onions and similar produce.

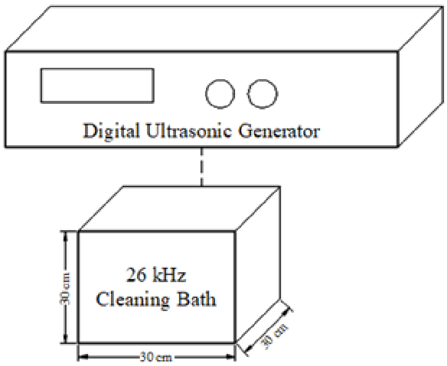

Fig. 12. Ultrasonic Generator and Ultrasonic Cleaning Bath Set-up

4. CONCLUSION

Fresh produce, like red onions, often carries harmful microbes that can affect food safety and quality. Traditional methods of decontamination, such as chemical washing, have limitations and may leave residues. Ultrasonic technology, which uses sound waves to clean surfaces, offers a promising alternative. This study investigates the use of ultrasound at different frequencies and durations to reduce microbial contamination on red onions, aiming to identify the best conditions for effective decontamination.

This study shows that ultrasonic technology is a highly effective way to reduce microbial contamination on red onions. Higher ultrasound frequencies and carefully optimized exposure times were found to be critical in achieving the best results. The most effective treatment observed was 80 kHz for 15 minutes, which reduced microbial counts by 96.05%. However, optimization using Response Surface Methodology (RSM) identified the most practical combination to be 25.5 kHz for 6.47 minutes, which reduced microbial activity to just 12,028.9 CFU/g with a perfect desirability score.

The analysis also showed that exposure time played a significant role in reducing microbes, while frequency had a lesser effect. These findings support the potential of ultrasound as a safe and efficient method for decontaminating onions and other fresh produce. A small-scale ultrasonic decontamination system was also designed based on the optimized parameters, offering a practical solution for improving food safety.

5. RECOMMENDATION

This study investigated ultrasonic treatment as a non-thermal method for reducing microbial contamination in red onions, examining the effects of different frequencies and exposure times. The results showed that ultrasound effectively lowered microbial loads, with varying success depending on the treatment settings. While promising for microbial inactivation, the study recommends further research to understand its effects on the physico-chemical qualities of produce, optimize environmental conditions, assess long-term stability, evaluate small-scale feasibility, analyze economic viability, extend findings to other foods, and use the identified optimal settings (26 kHz, 7 minutes) as a reference for future work.

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