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Application of ultrasound pretreatment for improving the quality of pasteurized pickled cucumber

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Abstract
Ultrasound, as an emerging non-thermal technology, offers a promising approach to enhance the physicochemical quality of pickled cucumbers while preserving their sensory attributes and nutritional value. In this study, the effects of ultrasonic pretreatment on the physicochemical, textural, microbial, and sensory properties of pasteurized pickled cucumbers were investigated at 40 kHz and 150 W for 5, 10, and 15 minutes. Ultrasonic treatment did not significantly affect pH (3.84-3.88) or titratable acidity (0.53-0.55 %), indicating the preservation of overall acidity. NaCl content decreased significantly with increased sonication time, reaching from 2.75 % to 2.46 % after 15 min ($p<0.05$). Color analysis revealed that moderate sonication (5 min) improved outer and inner lightness up to 59.65 and 55.10, respectively, while maintaining green hues and minimizing browning, whereas prolonged exposure (15 min) slightly reduced color quality. Textural evaluations showed significant enhancement in hardness, firmness, and chewiness for sonicated samples, with puncture hardness increasing from 5.51 N (control) to 7.26 N and cutting hardness from 20.50 N to 25.93 N. Microbial tests confirmed all samples were free from bacterial and mold growth, indicating microbiological safety. Sensory evaluation revealed that 5-10 min of sonication significantly enhanced color, flavor, texture, crispiness, and overall acceptance, whereas 15 min led to decreased sensory quality. Considering performance and energy efficiency, a 5-minute ultrasonic pretreatment was identified as the optimal condition to enhance the quality of pasteurized pickled cucumbers.

Keywords: Acidity, Physicochemical properties, Sensory evaluation, Texture

Introduction
Cucumber (*Cucumis sativus* L.) is a member of the *Cucurbitaceae* family, which also includes melons and squashes. It is believed to have originated in India and other parts of Asia, although historical evidence indicates that ancient Egyptians, as well as Greeks, and Romans were among the first to cultivate it [1]. According to FAO data (2018), China, Turkey, Russia, and Iran are the world's leading producers, with annual productions of 67.6, 1.9, 1.6, and 0.65 million tons, respectively [2]. Cucumbers are consumed both fresh and processed, with pickled cucumbers being among the most widely consumed preserved vegetables worldwide. Pickles vary in flavor,

from salty and sour to sweet, and can be produced through either fermentation or direct acidification. However, like other vegetable-based pickled products, they are vulnerable to microbial spoilage, particularly yeasts and molds [3, 4].

Traditionally, cucumber pickling was achieved through natural fermentation using vinegar, salt, and spices without heat application. Recent advances in food processing have enabled the production of "pasteurized pickled cucumbers," where fresh cucumbers are mixed with vinegar, brine, and seasonings and subsequently pasteurized to improve microbial safety and shelf life. The effectiveness of this preservation method depends largely on the correct use of acids, salt concentration, and pasteurization conditions [4, 5]. Heat treatment, first introduced as a standard process in the 1940s, involves raising the internal temperature of the product to 74°C for about 15 min followed by rapid cooling [6]. While this ensures microbial stability, it can negatively affect color, texture, and crispness, as most vegetables are highly heat-sensitive [7].

Organic acids are widely used in canned and pickled foods due to their multiple functional roles: imparting sourness, modifying flavor and aroma, lowering pH, preventing microbial growth, catalyzing sucrose inversion, aiding gel formation, and stabilizing or clarifying fruit juices [8-10]. These acids are carboxylic compounds containing one or more carboxyl groups and can be classified as mono-, di-, or tricarboxylic acids based on their molecular structure. Monocarboxylic acids such as acetic acid are volatile liquids with a strong, pungent taste [11, 12]. In food processing, natural organic acids from fruits and vegetables contribute to product acidity, and additional acidification is often achieved by adding compatible acids to maintain desirable sensory and physicochemical properties [8-10].

Ultrasound processing is an emerging non-thermal technology that aims to minimize processing time while maximizing product quality and microbial safety [13]. High-intensity ultrasound (20–100 kHz, 10–1000 W/cm²) induces acoustic cavitation—the formation and collapse of microscopic bubbles—which generates localized high temperature and pressure, leading to enhanced mass transfer, enzyme inactivation, and microbial cell disruption. This technique has been successfully applied to preserve the color, flavor, and nutritional quality of fruits and vegetables [13-15].

Several studies have confirmed the beneficial effects of ultrasound treatment on the physicochemical and microbiological quality of fresh produce. Alexandre et al. [15] found that ultrasound effectively preserved anthocyanins and ascorbic acid in strawberries compared with chemical sanitizers. Chen et al. [16] demonstrated that ultrasonic treatment delayed phenolic and anthocyanin degradation in litchi fruit during storage. Similarly, Wang et al. [17] reported that ultrasound enhanced total phenolic, flavonoid, and ascorbic acid contents in cherry tomatoes, while Zhang et al. [18] showed that the combination of ultrasound with zinc acetate maintained higher levels of bioactive compounds in cauliflower. In cucumbers, ultrasonic pretreatment has been shown to suppress microbial growth, reduce weight loss, and preserve firmness during storage [19, 20].

Ultrasound technology offers distinct advantages such as low cost, environmental compatibility, and non-toxicity. Its cavitation effect disrupts microbial cell structures, leading to inactivation without compromising the sensory or nutritional quality of foods [14]. Therefore, applying ultrasonic pretreatment in cucumber pickling could provide a promising approach for producing low-salt, microbiologically safe, and high-quality pasteurized pickles. Accordingly, based on our comprehensive review of the literature, no study to date has systematically investigated the effects of ultrasonic pretreatment on pasteurized pickled cucumbers with such breadth and depth of physicochemical, textural, microbial, and sensory evaluations, and the present work represents

the first comprehensive report in this field. Therefore, this study aimed to investigate the effect of ultrasound pretreatment (0, 5, 10, 15 min at 40 kHz, 150 W) on physicochemical, color, textural, microbial, and sensory quality attributes of pasteurized pickled cucumbers.

Materials and Methods

2.1. Preparation of raw materials

Fresh field cucumbers (*Cucumis sativus* L., 2n Royal seed, Seminis Co., USA) were purchased from local farmers in Bahar County (Hamedan Province, Iran). Cucumbers were graded based on shape, size, firmness, appearance, aroma, ripeness, and color. After washing to remove dirt and impurities, the cucumbers were combined with fresh aromatic herbs, including garlic, tarragon, dill, and chili peppers, all sourced locally.

Refined, non-iodized edible salt (Zohreh, Iran) was dissolved in distilled water to prepare a 5 % (w/w) brine solution, which was later added to the jars. Distilled vinegar (5 % acetic acid, Kimball, Iran) was purchased commercially and used as the acidifying agent. The filling solution used for canning the pickled cucumbers contained salt and acetic acid, with a total acidity of 0.8 % [3].

2.2. Application of ultrasonic pretreatment

Cucumber samples were subjected to ultrasonic pretreatment using a bath sonicator (vCLEAN1-L6, Becker, Iran) operating at 40 kHz and 150 W for 0, 5, 10, and 15 min.

2.3. Preparing pickled cucumber

Treated cucumbers, along with equal quantities of aromatic herbs, were placed in glass jars. The hot brine (90°C) containing vinegar was poured into the jars while maintaining adequate headspace to ensure vacuum formation during cooling. The jars were sealed and pasteurized in a hot water bath at 74°C for 15 min, then cooled gradually using cold water. The temperature of the brine and cucumber samples was continuously monitored and controlled using a digital thermometer. The samples were stored at ambient temperature (20°C) for 14 days before further analysis (Figure 1).

Figure 1

2.4. pH measurement

The pH of pickled cucumbers was measured at 25°C using a digital pH meter (Metrohm 827, Switzerland), previously calibrated with standard buffers (pH 4 and 7) [5].

2.5. Determination of titratable acidity

Titratable acidity of pickled cucumbers was measured by titrating diluted samples with 0.1 N NaOH (Merck, Germany) using phenolphthalein as an indicator [5].

2.6. Determination of salt content

Salt concentration was determined by the Mohr method. Five grams of sample were diluted to 100 mL, filtered, and titrated with 0.1 N silver nitrate using 1 mL of 5 % potassium chromate as an indicator. Results were expressed as % NaCl [5, 21].

2.7. Determination of ash content

Samples were dried in an oven and incinerated in a muffle furnace (Pars Azma, Iran) at 600 °C for 6 hours. The obtained ash was cooled in a desiccator and weighed [22].

2.8. Color measurement

Color indices of the inner and outer pickled cucumbers surfaces were determined using the image processing method. Images were captured in RGB format and analyzed using ImageJ software (Version 1.42e, USA). The L*, a*, and b* values represented lightness, redness/greenness, and yellowness/blueness, respectively [23].

2.9. Texture analysis

Textural properties, including hardness, cohesiveness, springiness, and chewiness, were determined using a texture analyzer (STM-5, Santam, Iran) [24].
Puncture test: Performed with a cylindrical probe (2.5 mm diameter) at 1 mm/s.
Cutting test: Conducted using a blade probe at 1 mm/s.
TPA test: Conducted with a 49 mm cylindrical probe and 6 kg load cell at 1 mm/s to 50 % deformation.

2.10. Microbiological analysis

Microbial quality was evaluated through total viable count (TVC) and yeast/mold enumeration. PCA (Plate Count Agar) was used for total bacterial count and YGC medium (Yeast Glucose Chloramphenicol) for yeast and mold growth. Samples were serially diluted (10^{-3} to 10^{-4}). For microbial analysis, the pour plate method was used for bacterial enumeration and the spread plate method for yeast and mold counts. In the pour plate technique, 1 mL of the sample solution was inoculated, whereas in the spread plate method, 0.1 mL was surface-inoculated onto the medium. Plates were incubated at 37°C for 48 h (bacteria) and at 25°C for 10 days (yeasts/molds) [25].

2.11. Sensory evaluation

After 14 days of storage, sensory properties including color, flavor, aroma, texture, crispness, and overall acceptance were evaluated by 18 trained panelists using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Before the sensory test, panelists were trained through a brief orientation session, during which the evaluation attributes and scoring method were explained. This training aimed to ensure a common understanding of the sensory descriptors and improve the reliability of the results. The panelists were instructed on the use of the hedonic scale and on how to minimize bias during evaluation. Samples were coded randomly and presented at room temperature [26, 27].

2.12. Statistical analysis

The study followed a completely randomized design with three replicates (N = 3). Data were analyzed using one-way ANOVA and Duncan's multiple range test at a 95 % confidence level ($p < 0.05$) with SPSS software (Version 21). Graphs were generated using Microsoft Excel (2016).

3. Results and Discussion

3.1. pH

According to Table 1, the pH of pasteurized pickled cucumbers remained almost stable across all sonication treatments, ranging from 3.84 to 3.88, with no statistically significant differences ($p > 0.05$). This indicates that ultrasonic pretreatment at 40 kHz and 150 W did not alter the overall acidity of the product. The stability of pH may be due to the short exposure time, preventing

major acid-base interactions. According to the findings reported by Rosario et al. [28], the application of ultrasonic treatment, either alone or in combination with sodium hypochlorite for 5 min, did not cause any significant change in the pH of fresh-cut yellow melon compared with the untreated control.

Table 1

3.2. Titratable acidity

As shown in Table 1, titratable acidity exhibited a slight but non-significant decrease with increasing sonication time (from 0.55 % to 0.53 %). This suggests that cavitation effects generated by ultrasound did not significantly degrade or neutralize the organic acids (mainly acetic acid). Similar observations have been reported in other vegetables, where mild ultrasound had little impact on acid content due to its limited thermal effect. According to the results reported by Rosario et al. [28], the application of ultrasonic treatment, either alone or in combination with sodium hypochlorite for 5 min, did not produce any significant difference in the titratable acidity of fresh-cut melon compared with the untreated sample. This finding is in agreement with the results of the present study, where different sonication times showed no significant effect on the titratable acidity of pasteurized pickled cucumbers.

3.3. NaCl content

The NaCl content showed a clear downward trend with increasing sonication duration (Table 1). A significant reduction ($p < 0.05$) was observed from 2.75 % in the control to 2.46 % after 15 min of sonication. This reduction can be attributed to the denser and more compact tissue structure resulting from ultrasonic cavitation, which likely limited the diffusion of salt ions into the cucumber tissue during brining.

3.4. Ash content

As presented in Table 1, ash content followed a similar trend to salt, decreasing significantly from 2.76 % to 2.46 % after 15 min of ultrasound treatment ($p < 0.05$). Since the majority of mineral residues in pickled cucumbers originate from sodium chloride and other dissolved ions, the reduced mineral (ash) content in treated samples can be directly linked to their lower salt absorption. Furthermore, the enhanced firmness and lower porosity of the tissue after ultrasound treatment may have restricted ion exchange between the brine and the cucumber matrix, resulting in a reduced accumulation of inorganic solids after processing.

3.5. Color parameters

According to Table 2, ultrasonic pretreatment significantly influenced the color attributes (L^*, a^*, and b^*) of pasteurized pickled cucumbers, both on the outer surface and in the inner section.

Table 2

Outer surface:

The lightness (L^*) of the outer surface increased significantly after 5 and 10 min of sonication from 49.63 to 59.65 and 58.94, respectively, indicating that moderate ultrasound exposure enhanced surface brightness. This improvement may be due to cavitation-induced removal of surface pigments and air bubbles, leading to better light reflection. However, after 15 min, the lightness decreased (51.08), suggesting potential pigment degradation or tissue softening caused by prolonged treatment. The redness (a^*) value decreased progressively with sonication time, from 2.09 in the control to -3.18 at 10 min, implying a reduction in brownish or reddish tones. This reduction can be interpreted as a prevention of non-enzymatic browning reactions due to

mild sonication and limited oxygen exposure. For yellowness (b^*), the values decreased from 39.41 to 34.48, reflecting a minor shift in pigment composition. Ultrasound may have partially affected carotenoid pigments, which are sensitive to both mechanical stress and localized heat produced by cavitation. Birmpa et al. [29] reported that ultrasonic treatment for 10 minutes at a power level of 30 W/L effectively preserved the color of fresh-cut lettuce and strawberries, while also noting that the highest net color change occurred at the longest treatment durations. Similarly, in the present study (Table 2), ultrasonic pretreatment contributed to maintaining the color quality of pasteurized pickled cucumbers, particularly in terms of lightness and overall color stability, compared with the untreated control samples.

Inner section:

A similar trend was observed in the inner tissue. The lightness values improved up to 10 min (54.93) compared to the control (52.32), suggesting enhanced translucency and color uniformity. Meanwhile, redness values became less negative (-5.66 to -4.59), indicating a shift toward more natural green tones. In addition, the yellowness of the inner tissue decreased significantly after 5 min of sonication from 41.18 to 32.94.

These results indicate that ultrasound treatment up to 10 min can preserve or even enhance the desirable bright-green appearance of cucumbers, which is an important sensory quality for consumers. Overexposure, however, may cause pigment loss and slight color fading due to chlorophyll degradation. Overall, the findings from Table 2 demonstrate that moderate sonication (5-10 min) improved color brightness and freshness, while excessive treatment (15 min) slightly deteriorated chromatic quality, highlighting the importance of optimizing sonication time. Zhang et al. [19] observed that during the storage of fresh-cut cucumbers, lightness decreased, while redness and yellowness values increased; however, applying ultrasound treatment in combination with sodium hypochlorite effectively reduced the intensity of these color changes and helped preserve the visual quality of the product. Similarly, Fan et al. [20] reported that ultrasonic treatment maintained the green color of fresh-cut cucumbers during storage by inhibiting the activity of browning-related enzymes and slowing chlorophyll degradation. These findings support the present study's results (Table 2), indicating that ultrasonic pretreatment can help preserve the natural color and freshness of cucumbers by limiting enzymatic browning and pigment breakdown.

3.6. Textural properties

As illustrated in Figure 2, ultrasonic pretreatment had a noticeable impact on the texture hardness of pasteurized pickled cucumbers, evaluated by both puncture test (a) and cutting test (b). In the puncture test (Figure 2a), which measures the resistance of cucumber tissue to localized deformation, hardness significantly increased after ultrasonic treatment compared to the control ($p < 0.05$). The hardness rose from 5.51 N in the untreated samples to about 6.60-7.26 N after 5-15 min of sonication. The highest improvement was observed after 5 minutes of treatment, and no significant differences were found among the 5-, 10-, and 15-minute treatment groups ($p > 0.05$). This enhancement in firmness can be attributed to the cavitation effects produced by ultrasound, which may promote cross-linking within the cell wall, leading to stronger and more compact tissue structures.

Figure 2

Similarly, in the cutting test (Figure 2b), which reflects the overall integrity and resistance of the cucumber to cutting stress, ultrasonic treatment resulted in a significant increase in hardness. The

control sample showed the lowest cutting hardness (around 20.50 N), while all sonicated samples exhibited higher values (approximately 25.13–5.93 N). As in the puncture test, no significant differences were observed among the sonicated groups (5, 10, and 15 min). This suggests that most structural reinforcement occurs within the first few min of sonication, beyond which further exposure does not substantially enhance textural strength.

As shown in Table 3, ultrasonic treatment significantly affected the textural attributes of pasteurized pickled cucumbers, including firmness, cohesiveness, springiness, and chewiness ($p < 0.05$). Firmness increased notably from 30.47 N in the control to 37.86 N after 5 min of sonication, suggesting that moderate ultrasound improved tissue compactness. However, at 15 min, firmness decreased to 34.69 N, implying that excessive cavitation disrupted structural integrity. Zhang et al. [19] reported that the application of ultrasonic treatment increased the firmness of fresh-cut cucumber samples after 8 days of storage. In other words, this technique can inhibit the activity of cell wall-degrading enzymes, thereby helping to maintain the hardness and structural integrity of fruits and vegetables during storage.

Cohesiveness showed slight increases at 5–10 min but declined after prolonged exposure. This indicates that moderate ultrasound promotes internal elasticity and reduces tissue collapse, while over-treatment may weaken pectin structures. Springiness (elastic recovery) of the pasteurized pickled cucumbers responded non-linearly to ultrasonic pretreatment (Table 3). While moderate sonication (5–10 min) significantly decreased springiness compared with the control ($p < 0.05$), extended exposure (15 min) led to an increase in springiness. Chewiness followed a similar pattern, peaking at 5 min (1.87 N) before decreasing at 15 min (1.38 N).

Overall, the results from Figure 2 and Table 3 indicate that ultrasonic pretreatment, particularly at moderate durations (5–10 min), effectively enhances the hardness, crispness, and structural integrity of pasteurized pickled cucumbers. These improvements are likely due to ultrasound-induced reinforcement of cell wall components, reduced enzymatic softening, and improved intercellular cohesion. However, prolonged sonication offers no further benefits and may even cause tissue softening through excessive cell wall disruption and pectin solubilization.

Table 3

3.7. Microbial test results

As shown in Figure 3, no microbial growth was observed on either the PCA or YGC media, indicating that all pasteurized pickled cucumber samples were microbiologically safe. The absence of bacterial and mold colonies across all treatments confirms the effectiveness of pasteurization in combination with ultrasonic pretreatment in ensuring microbial stability and product safety during storage. These results demonstrate that ultrasound application did not compromise microbial quality and that all samples met acceptable hygiene and safety standards.

Figure 3

3.8. Sensory attributes

As presented in Table 4, ultrasonic pretreatment significantly influenced several sensory properties of pasteurized pickled cucumbers, including color, flavor, texture, crispiness, and overall acceptance ($p < 0.05$). The visual characteristics of the cucumbers were notably affected by sonication time. The 5- and 10-minute treatments received the highest scores for appearance color (8.22 and 7.94, respectively), significantly higher than the untreated (7.33) and 15-minute samples (7.33). A similar pattern was observed for interior color, where moderate sonication (5–10 min) preserved the inner green hue better than prolonged treatment. This enhancement can be attributed to the mild cavitation effects of ultrasound, which may inactivate oxidative enzymes such as polyphenol oxidase and peroxidase, thereby reducing pigment degradation. However,

excessive exposure (15 min) might have induced slight pigment disruption or tissue damage, leading to reduced color scores.

Table 4

Regarding appearance acceptance, samples treated for 5 and 10 min achieved the highest panel scores (~8.0), suggesting improved visual appeal and uniformity. Similarly, odor acceptance was significantly reduced at 15 min (7.22) compared with the control (8.00), likely due to minor volatile loss or the formation of off-odors from prolonged cavitation. Shorter sonication times (5–10 min) maintained desirable aroma characteristics without generating undesirable odors.

Flavor scores followed a similar trend, with the 5- and 10-minute treatments (8.28 and 7.89) receiving the highest evaluations, while the longest sonication (15 min) resulted in a significant decline (7.50). This indicates that moderate ultrasonic exposure can enhance flavor perception, possibly through improved diffusion of salt and acid into the cucumber tissue, leading to more balanced taste profiles. In contrast, extended sonication may alter volatile composition or texture perception, negatively impacting flavor.

Crispiness and texture were among the most positively influenced parameters. The 10-minute sonicated samples showed the highest crispiness (8.44) and texture acceptance (8.28), significantly higher than both the control and the 15-minute treatment ($p < 0.05$). This improvement is likely related to ultrasound-induced microstructural reinforcement, as observed in the texture hardness data. The phenomenon suggests that moderate ultrasound can enhance cell–cell adhesion and maintain firmness during pasteurization, resulting in a more desirable crunchy texture.

Overall sensory acceptance followed the same general pattern, peaking at 5 min (8.06) and 10 min (8.50) of sonication, which were significantly higher than the untreated (7.53) and the overexposed (15-minute, 7.28) samples. These results confirm that ultrasonic pretreatment for short to moderate durations improves sensory quality by enhancing color retention, flavor balance, and crispness, whereas prolonged exposure tends to degrade sensory perception.

In summary, Table 4 demonstrates that a 5–10 minute ultrasonic pretreatment provides the most desirable balance of sensory properties, producing pickled cucumbers with improved color, flavor, and texture while avoiding the negative effects associated with excessive sonication time.

4. Conclusion

Ultrasonic pretreatment at 40 kHz and 150 W effectively improved the quality of pasteurized pickled cucumbers by enhancing textural and sensory attributes without compromising pH, titratable acidity, or microbial safety. Moderate sonication (5 min) significantly increased hardness, firmness, and chewiness, with puncture hardness rising from 5.51 N to 7.26 N and cutting hardness from 20.50 N to 25.93 N, indicating improved structural integrity and resistance to mechanical stress. Color parameters were also positively affected, as lightness increased on both outer and inner tissues, while undesirable browning was minimized, preserving the bright green appearance important for consumer acceptance. NaCl and ash contents decreased with prolonged sonication, reflecting restricted ion diffusion due to ultrasound-induced tissue compaction, whereas pH and titratable acidity remained stable. Sensory evaluation highlighted that short to moderate ultrasound exposure (5–10 min) enhanced appearance, flavor, texture, and overall acceptance, while extended treatment (15 min) caused slight pigment loss, minor flavor deterioration, and decreased crispness. Microbial analysis confirmed that ultrasound did not compromise safety, as no bacterial or fungal growth was observed. Considering the balance between quality improvement and energy efficiency, a 5-minute sonication treatment was

identified as optimal, providing significant enhancement in color, texture, and sensory properties while minimizing processing time and energy consumption.

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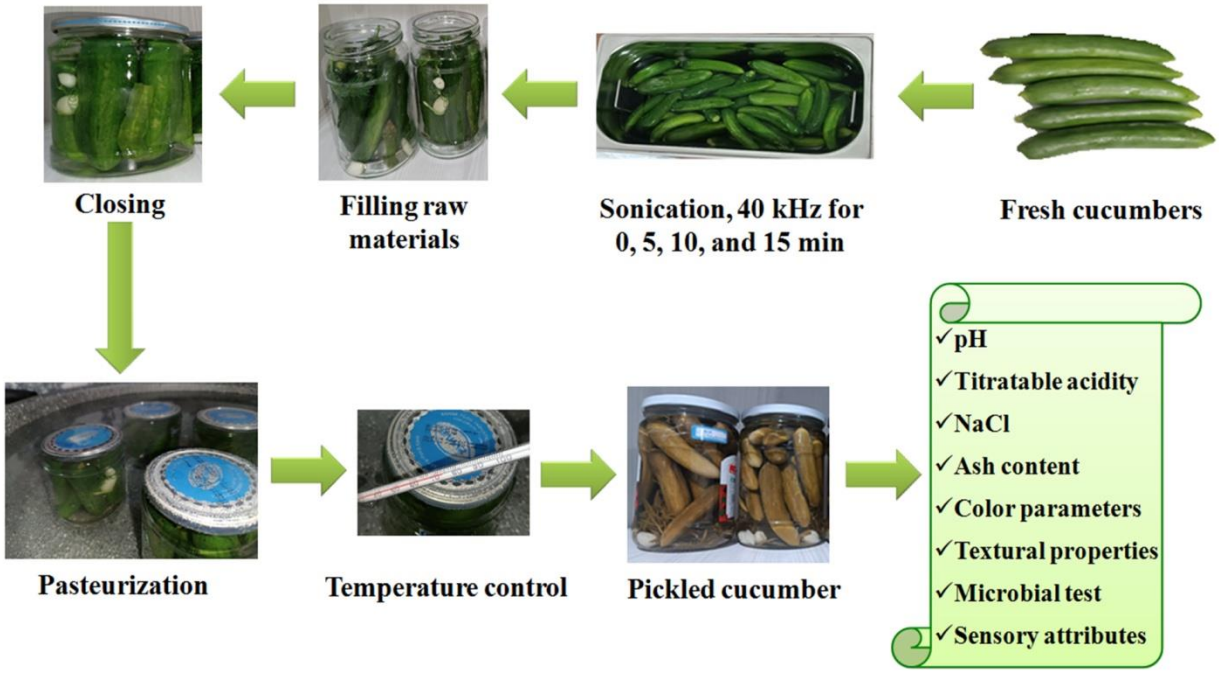

Figure 1- Schematic of ultrasonic pretreatment, pasteurization, and quality evaluation of pickled cucumbers

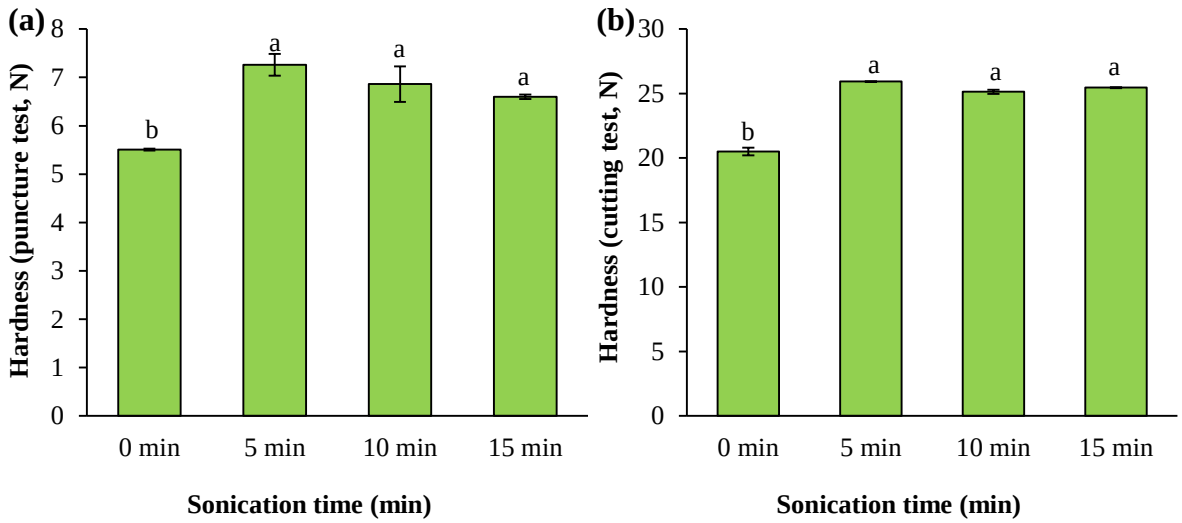

Figure 2- Effect of ultrasonic pretreatment on the texture hardness of pasteurized pickled cucumbers: (a) puncture test and (b) cutting test.

Data are presented as mean ± standard deviation (N = 3). Different letters above the columns indicate statistically significant differences ($p < 0.05$).

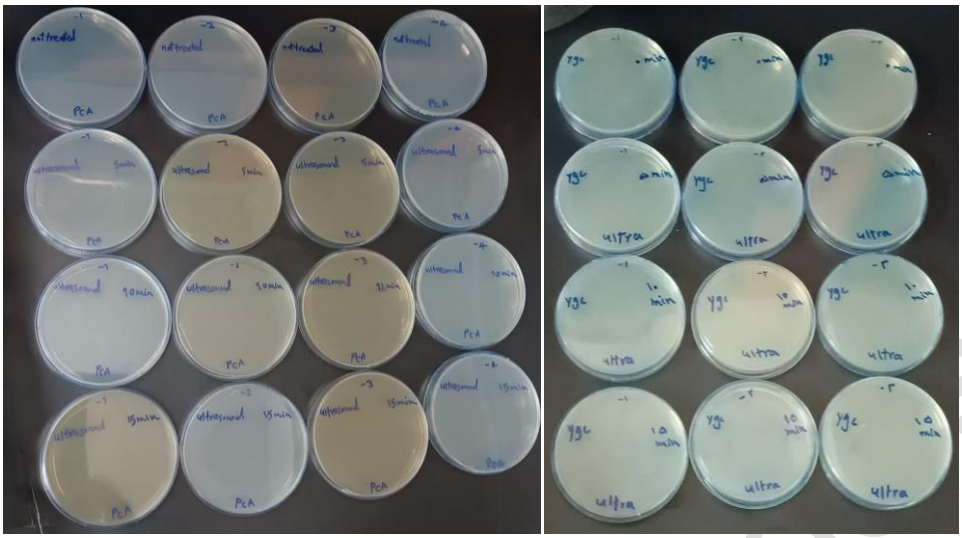

Figure 3- Effect of ultrasonic pretreatment on bacterial growth (PCA medium, left) and mold growth (YGC medium, right) on microbial culture plates after incubation

Table 1 - Effect of ultrasonic pretreatment on the pH, titratable acidity, NaCl, and ash content of pasteurized pickled cucumbers

Sonication time	pH	Titratable acidity (%)	NaCl (%)	Ash content (%)
0 min	3.88±0.05 [a]	0.55±0.02 [a]	2.75±0.05 [a]	2.76±0.01 [a]
5 min	3.85±0.04 [a]	0.54±0.01 [a]	2.63±0.04 [a]	2.72±0.06 [a]
10 min	3.85±0.02 [a]	0.53±0.04 [a]	2.63±0.05 [a]	2.74±0.18 [a]
15 min	3.84±0.05 [a]	0.53±0.02 [a]	2.46±0.08 [b]	2.46±0.33 [a]

Data are presented as mean ± standard deviation (N = 3). Different letters within each column indicate statistically significant differences ($p < 0.05$).

Table 2 - Effect of ultrasonic pretreatment on the color indexes of pasteurized pickled cucumbers

Sonication time	Outer surface			Inner section		
	Lightness	Redness	Yellowness	Lightness	Redness	Yellowness
0 min	49.63±0.58 [b]	2.09±1.16 [a]	39.41±0.33 [a]	52.32±0.07 [b]	-5.66±0.15 [b]	41.18±1.55 [a]
5 min	59.65±1.27 [a]	-2.01±0.81 [c]	36.24±1.09 [b]	55.10±0.63 [a]	-5.49±0.05 [b]	36.61±2.56 [b]
10 min	58.94±2.68 [a]	-3.18±0.54 [c]	35.88±1.24 [b]	54.93±0.82 [a]	-4.59±0.15 [a]	32.94±1.11 [b]
15 min	51.08±0.48 [b]	0.13±0.03 [b]	34.48±1.12 [b]	53.89±0.60 [a]	-4.75±0.03 [a]	41.72±1.65 [a]

Data are presented as mean ± standard deviation (N = 3). Different letters within each column indicate statistically significant differences ($p < 0.05$).

Table 3 - Effect of ultrasonic pretreatment on the textural properties of pasteurized pickled cucumbers

Sonication time	Firmness (N)	Cohesiveness	Springiness	Chewiness (N)
0 min	30.47±3.18 [b]	0.153±0.002 [b]	0.37±0.004 [a]	1.64±0.03 [a]
5 min	37.86±1.00 [a]	0.164±0.001 [a]	0.27±0.016 [c]	1.87±0.10 [a]
10 min	36.14±0.59 [a]	0.162±0.001 [a]	0.32±0.004 [b]	1.68±0.14 [a]
15 min	34.69±0.97 [a]	0.152±0.002 [b]	0.35±0.020 [ab]	1.38±0.08 [b]

Data are presented as mean ± standard deviation (N = 3). Different letters within each column indicate statistically significant differences ($p < 0.05$).

Table 4 - Effect of ultrasonic pretreatment on the sensory attributes of pasteurized pickled cucumbers

Sonication time	Appearance color	Interior color	Appearance acceptance	Odor acceptance	Flavor acceptance	Crispiness	Texture acceptance	Total acceptance
0 min	7.33±0.67 ^{b}	8.06±0.78 ^{a}	7.50±0.96 ^{bc}	8.00±0.88 ^{a}	7.89±0.81 ^{ab}	7.72±0.80 ^{b}	7.83±0.60 ^{b}	7.83±0.69 ^{b}
5 min	8.22±0.97 ^{a}	8.22±0.85 ^{a}	8.06±0.70 ^{ab}	7.78±0.92 ^{ab}	8.28±0.73 ^{a}	8.22±0.71 ^{ab}	8.50±0.76 ^{a}	8.06±0.85 ^{ab}
10 min	7.94±0.78 ^{ab}	8.17±0.69 ^{a}	8.22±0.92 ^{a}	7.61±0.76 ^{ab}	7.89±0.87 ^{ab}	8.44±0.76 ^{a}	8.28±0.73 ^{ab}	8.50±0.50 ^{a}
15 min	7.33±1.05 ^{b}	7.44±1.12 ^{b}	7.33±0.75 ^{c}	7.22±0.71 ^{b}	7.50±0.90 ^{b}	7.06±1.03 ^{c}	6.78±0.85 ^{c}	7.28±0.65 ^{c}

Data are presented as mean ± standard deviation (N = 18). Different letters within each column indicate statistically significant differences ($p < 0.05$).