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Original Article

Impact of high intensity ultrasound on the quality and preservation period of blue shrimp (*Litopenaeus stylirostris*) muscle

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Abstract
Due to the limited shelf life of aquatic products, the use of advanced technologies to extend their freshness has become more popular recently. This study aimed to assess the impact of high-intensity ultrasound (HIU) on the quality of blue shrimp (*Litopenaeus stylirostris*) tails during 20 days of ice storage. Shrimp samples were treated at 70% amplitude for 0 (C), 30 (T1), 60 (T2), and 90 (T3) minutes. Key quality parameters were analyzed every 5-day. The initial total bacterial count (TBC) was 2.02 log CFU g^{-1}, increasing to 6.09 (C), 5.32 (T1), 5.01 (T2), and 5.34 (T3) at the end of storage, with the control samples exceeding the acceptability limit. In terms of color, the initial L* value was 52.96, increasing to 62.96, 57.69, 57.94, and 57.78 for C, T1, T2, and T3, respectively. No significant differences were observed among treatments in pH (ranging from 7.22 to 8.33), shear force (from 15.40 to 18.50 N), water-holding capacity (from 93.02 to 98.23%), TVB-N (from 24.11 to 31.61 mg $100g^{-1}$), or non-protein nitrogen (from 0.78 to 0.48%). Likewise, SDS-PAGE profiles showed no visible protein degradation. These results indicate that HIU, particularly at 60 minutes, can extend shelf life by delaying microbial growth and preserving color, without adversely affecting the physicochemical or structural properties of the muscle.

Keywords: postmortem changes; seafood quality; shelf life; ultrasound

1 | INTRODUCTION

In Mexico, a major challenge in the food sector is post-harvest loss, which accounts for approximately 37% of the country's total food production (World Bank and WRAP 2020). Aquatic products are among the most perishable, with nearly 50% of them being wasted due to their high susceptibility to deterioration (CEC 2017). Mexico is one of the leading fishing countries globally, ranking 16th in total production, with 1.95 million tons produced in 2020 (FAO 2022). Fishing plays a crucial role in providing food and creating jobs in Mexico. Around 1.1 million tons are used for industrial processes such as reduction, canning, and freezing, while approximately 600,000 tons are consumed chilled or iced, primarily for domestic consump-

tion (Anuario Estadístico de Pesca 2020). However, this sector is the most affected in the country. In Mexico, one of the main fisheries is shrimp. Due to its volume, it is positioned in third place in fishery production, only below sardines and tuna; however, due to its value the shrimp fishery is ranked first (Anuario Estadístico de Pesca 2023). It is known that fishery products are highly perishable, and high volumes can be wasted throughout the food chain (Germond *et al.* 2023). Therefore, it is necessary for our country to adopt preservation technologies, to prolong the shelf life of economically important seafood species, particularly shrimp, thereby minimizing losses and enhancing the quality of the product available to consumers.

There are currently emerging technologies that could improve or increase the shelf life of several seafoods, thus preserving their freshness. One of these methodologies is the application of high intensity ultrasound (HIU) (Albuquerque *et al.* 2021; Ugalde-Torres *et al.* 2024). This technology can delay bacterial growth and decrease endogenous enzymatic action, one of the main causes of freshness decrease, since it leads to the accumulation of metabolites leading to deterioration (Alarcón-Rojo *et al.* 2019; Ganjdoost *et al.* 2021).

A study conducted by Pedros-Garrido *et al.* (2017) found that HIU at 30 kHz had an impact on the microbiological and quality parameters of various fish species, including salmon, mackerel, pollock, and hake. The researchers noted a reduction in colony-forming units (CFU) ranging from 1.5 to 0.5 CFU g^{-1} when compared to control treatments (samples without HIU). Additionally, a significant decrease in thiobarbituric acid reactive species (TBARS) levels was observed. On the other hand, Yi-Ming *et al.* (2021) and Yang *et al.* (2022) studied mackerel and sea basal (*Lateolabrax Japonicus*), respectively, and found similar results. Given the above, this research aims to evaluate the effect of HIU application on the quality and shelf life of blue shrimp (*Litopenaeus stylirostris*) tails during ice storage.

2 | METHODOLOGY

2.1 Raw material

Shrimp (6 – 8 cm tail) were caught off the coast of Bahía Kino (28.8340°N –112.0580°W) using a monofilament fishing net. Subsequently, they were stored on ice and transferred to the University of Sonora. Once in the laboratory, shrimp were deheaded and washed with cold water (5°C).

2.2 Ultrsound application and ice storage

Taking into account information from the literature and previous studies carried out in our laboratory, the samples were sonicated for different durations: 0 (Control, C), 30 (T1), 60 (T2), and 90 (T3) minutes, at 70% amplitude using a Branson Digital Sonifier SFX 550 (Branson Ultrasonics Corporation, Danbury, CT, USA), which operates at 20 kHz and is fitted with a 1.27-cm-diameter titanium probe. During the sonication process, the samples were kept in an ice bath to ensure that the temperature did not exceed 10°C. Afterward, the sonicated shrimp were stored on ice in a sealed cooler. To assess the effect of HIU on microbial, biochemical, and textural changes, samples were collected every 5 days (on days 0, 5, 10, 15, and 20).

2.3 pH measurements

The pH measurements were performed using the method outlined by Montoya-Camacho *et al.* (2021). A Hanna HI 90140 penetration pH meter (Hanna Instruments, Inc., USA) was used for the pH determination. The equipment was calibrated daily with commercial standard solutions.

2.4 Total volatile bases nitrogen (TVB-N)

A 5 g sample was combined with 300 mL of distilled water. Then, 2 g of magnesium oxide and 25 mL of commercial oil were added as defoaming agents. The mixture was heated to boiling and allowed to distill for 25 minutes. The distilled liquid was collected in an Erlenmeyer flask containing 15 mL of 2% boric acid, and the resulting solution was titrated with 0.05 N H_2SO_4. The Total Volatile Basic Nitrogen (TVB-N) was calculated and expressed as mg of nitrogen per 100 g of sample, following the method of Woyewoda *et al.* (1986).

2.5 Non-protein nitrogen (NPN)

For this determination, 10 g of the sample were mixed with 50 mL of 10% trichloroacetic acid (TCA). The mixture was then homogenized and centrifuged at 2000 × g at 4°C for 15 minutes using a refrigerated centrifuge (Sorvall Biofuge Stratos, Thermo Scientific, Hanau, Germany). After centrifugation, the nitrogen content in the supernatant was measured using the method described by Woyewoda *et al.* (1986).

2.6 Sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE)

Proteins were analyzed using SDS–PAGE following the method of Laemmli (1970), which involved a 12% running gel and a 4% stacking gel. Protein samples were heated at 95°C for 5 minutes, and 20 µg of protein were loaded into each lane. Electrophoresis was performed in a Mini-Protean 3 Cell system at 95 V. After the run, the gel was stained with a solution containing Coomassie Brilliant Blue R-250 (0.125% w/v), methanol (40% v/v), and acetic acid (7% v/v). The gels were then destained using a solution of methanol (50% v/v) and acetic acid (10% v/v). Images of the gel were captured and analyzed using a GS-800 densitometer (Bio-Rad Laboratory Chemicals, Hercules, CA, USA).

2.7 Shear force

Shear force measurement was conducted to assess the texture of blue shrimp muscle. This was done using a Warner-Bratzler blade attached to a Shimadzu texturometer (model: EZ TEST EZ-S, Shimadzu Corp., Japan). A standardized sample from the shrimp's fourth somite (n = 6) was used, kept at room temperature throughout the analysis, and the required force (N) to cut through the muscle was recorded. The test was performed at a speed of 20 cm min^{-1}, with the shear force applied perpendicular to the muscle fiber orientation (Canizales-Rodríguez *et al.* 2015).

2.8 Water holding capacity (WHC)

The WHC was measured following the method outlined by Cheng *et al.* (2013). To perform this, 5 g of shrimp muscle were centrifuged at 19600 × g for 30 minutes at 4°C in a refrigerated centrifuge (Sorvall Biofuge Stratos, Thermo Scientific, Hanau, Germany). The WHC was then calculated using the following formula.

$$\%WHC = 100 - [(Wi-Wf)/Wi] \times 100$$

Where, Wi = initial weight (before centrifugation); Wf: final weight (after centrifugation).

2.9 Color

Color changes in shrimp muscle were determined by tristimulus colorimetry using a Minolta CR300 colorimeter (Minolta Co., New York, NY, USA). The measurements were carried out on the surface of the muscle.

2.10 Microbiological changes

To examine the effect of HIU on microbial inhibition, the total plate count of mesophilic bacteria was assessed. Aseptic samples (10 g) of blue shrimp muscle were homogenized in 40 mL of peptone solution (1 gL^{-1}). Serial dilutions were prepared from the homogenates, and total viable count (TVC) was determined using the pour plate method with Plate Count Agar. The plates were incubated at 37 ± 2°C for 48 hours. TVC was quantified following the standard methodology (NOM 1994).

2.11 Data analysis

Descriptive statistics (mean, standard deviation, and coefficient of variation), one-way analysis of variance (ANOVA), and multiple comparisons using Tukey's test were applied, with an α significance level of 0.05. For the analysis, three specimens (n = 3) were sampled on days 0, 5, 10, 15, and 20. All analytical determinations were performed in triplicate. Data analysis was conducted using Jump 5.0.1 (SAS Institute, Cary, NC, USA).

3 | RESULTS

3.1 pH

The initial and final pH in blue shrimp muscle during storage were 7.22 ± 0.15 and 8.33 ± 0.07, respectively (Figure 1a). A significant increase (p < 0.05) was observed during the first 10 days, followed by no significant changes (p > 0.05) for the remainder of the storage period. No significant differences were found between the control and ultrasound-treated samples.

3.2 Shear force

The initial value of shear force was 15.40 N, with final values of 17.27, 16.97, 14.56, and 18.50 N for C, T1, T2, and T3 treatments, respectively (Figure 1b). No significant changes were observed during storage, and no differences were also found between treatments.

3.3 Water holding capacity (WHC)

The initial WHC value was 93.02%, and final values were 96.32%, 90.20%, 98.23%, and 97.30% for C, T1, T2, and T3, respectively (Figure 1c). An increase in WHC was observed during storage, although differences among treatments were not statistically significant (p > 0.05).

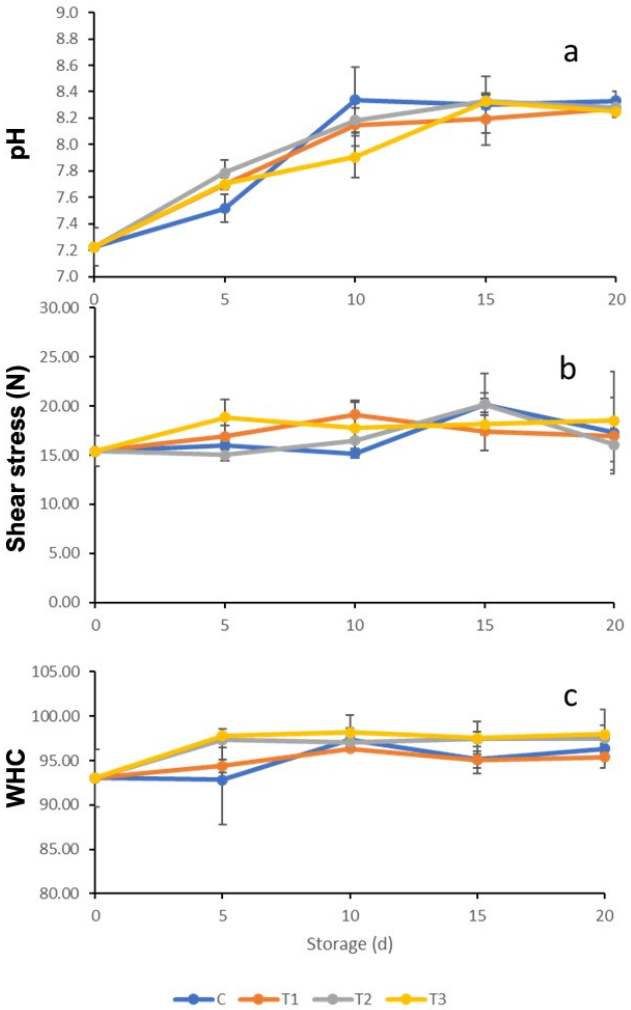

FIGURE 1 Behavior of pH (a), texture (b) and water holding capacity (c) in blue shrimp (*Litopenaeus stylirostris*) muscle during ice storage. C, control; T1, 30 min of HIU; T2, 60 min of HIU; T3, 90 min of HIU (n = 3 ± SD).

3.4 Total volatile basic nitrogen (TVB-N)

The initial value of TVB-N was 24.11 mg N $100g^{-1}$, and it increased up to 31.61 mg N $100g^{-1}$ of sample at the end of storage (Figure 2a). While, ultrasound treatments showed final values of 28.68, 28.01 and 27.05, for T1, T2 and T3, respectively. A significant increase was observed after day 15 ($p < 0.05$), but no significant differences were found among treatments.

3.5 Non-protein nitrogen (NPN)

Initial and final values of NPN were 0.78 and 0.48, respectively (Figure 2b). A significant decrease ($p < 0.05$) was observed across all treatments, but no significant differences were found between the control and treated samples.

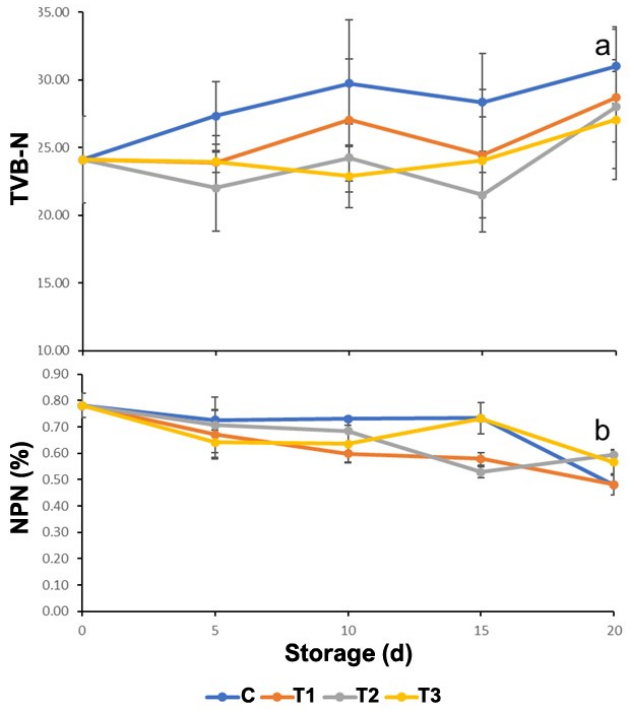

FIGURE 2 a, Behavior of Total volatile basic nitrogen (TVB-N); and b, non-protein nitrogen (NPN) in blue shrimp (*Litopenaeus stylirostris*) muscle during ice storage. C, control; T1, 30 min of HIU; T2, 60 min of HIU; T3, 90 min of HIU ($n = 3 \pm SD$).

3.6 Sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE)

Electrophoretic patterns (Figures 3a and 3b) revealed major bands corresponding to myosin heavy chain (200 kDa), actin (45 kDa), and myosin light chains (20 – 30 kDa). The band intensity of the MHC decreased with storage time.

3.7 Color

For parameter a*, an initial value of –1.85 and final values of 1.06 (C), 1.37 (T1), 0.95 (T2), and 0.58 (T3) were observed for color, with a significant increase over time ($p < 0.05$; Figure 4a) but no treatment effect ($p > 0.05$). For parameter b*, an initial value of 1.57 and final values of 5.52, 6.11, 7.22 and 5.90 were found for C, T1, T2 and T3, respectively, with significant increase over time ($p < 0.05$) and no treatment effect (Figure 4b). For parameter L*, an initial value of 52.96 was observed; while values at the end of ice storage were 62.96, 57.69, 57.94 and 57.78 for C, T1, T2, and T3, respectively (Figure 4c). Likewise, it was observed a significant effect of both storage time and ultrasound treatment ($p < 0.05$).

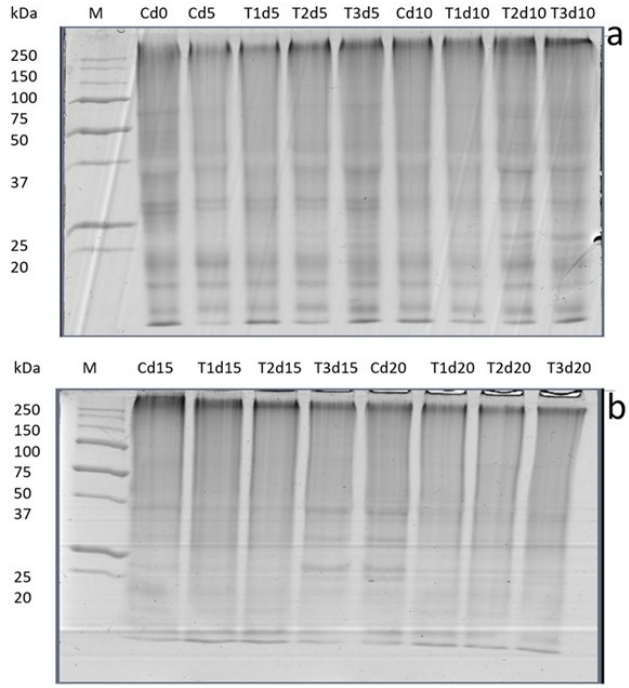

FIGURE 3 Effect of ultrasound on the electrophoretic profile of blue shrimp (*Litopenaeus stylurostris*) muscle during ice storage. (a) M, marker; Cd0, control day 0; cd5, control day 5; T1d5, day 5 of T1; T2d5, day 5 of T2; T3d5, day 5 of T3; Cd10, control day 10; T1d10, day 10 of T1; T2d10, day 10 of T2; T3d10, day 10 of T3. (b) M, marker; Cd15, control day 15; T1d15, day 15 T1; T2d15; day 15 of T2; T3d15, day 15 of T3; Cd20, control day 20; T1d20, day 20 of T1; T2d20, day 20 of T2; T3d20, day 20 of T3.

3.8 Total bacterial count (TBC)

The initial value of TBC was 2.02 log CFU g^{-1}, and final values were 6.09 (C), 5.32 (T1), 5.01 (T2), and 5.34 (T3) (Figure 5). A significant increase ($p < 0.05$) occurred after day 10. On the other hand, the control exceeded 6 log CFU g^{-1} at the end of the storage, while all HIU-treated samples remained below this threshold.

4 | DISCUSSION

4.1 pH

The initial pH values observed in this study are consistent with those previously reported for *L. vannamei* and *P.*

longirostris (Huidobro *et al.* 2002; Peng *et al.* 2019), confirming the freshness of the shrimp samples at the beginning of storage.

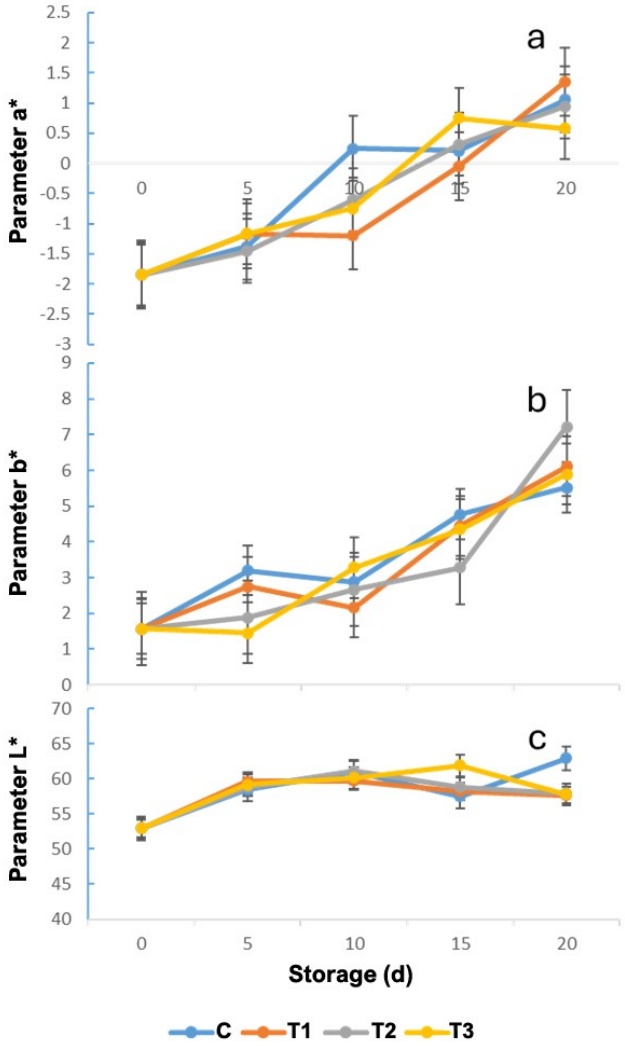

FIGURE 4 Behavior of parameter a*, b* and L* in shrimp muscle (*Litopenaeus stylirostris*) during ice storage. C, control; T1, 30 min of HIU; T2, 60 min of HIU; T3, 90 min of HIU (n = 3 ± SD).

The significant increase in pH during the first 10 days is a well-documented phenomenon in seafood preservation and has been attributed to the accumulation of alkaline compounds such as ammonia, trimethylamine, and other basic nitrogenous metabolites resulting from microbial activity and endogenous enzymatic autolysis (Díaz-Tenorio *et al.* 2007; García-Sifuentes *et al.* 2018; Mehta *et al.* 2023). After day 10, the stabilization of pH values suggests that either microbial proliferation plateaued due to substrate depletion or inhibitory conditions, such as metabolic waste accumulation, which limited further metabolite production. This plateau phase is commonly observed in fish and shellfish stored on ice and marks the transition toward spoilage. Interestingly, the application of HIU had no statistically significant effect on pH evolution throughout the storage period. The lack of pH differences between the control and treated groups may suggest that the ultrasound conditions applied (frequency, intensity, duration) were not sufficient to substantially inhibit microbial or enzymatic activity related to pH changes. Alternatively, it is possible that the microbial communities responsible for pH alteration were resistant to the HIU treatment, or that pH is not a sensitive enough parameter to detect subtle biochemical effects induced by ultrasound. In sum, while the increase in pH over time aligns with expected spoilage patterns in shrimp, the lack of response to HIU indicates the need for optimization of ultrasound parameters or complementary preservation methods if the goal is to mitigate pH-related spoilage mechanisms.

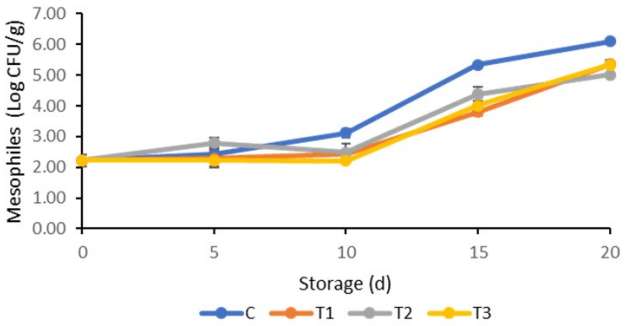

FIGURE 5 Behavior of mesophiles in blue shrimp (*Litopenaeus stylirostris*) muscle during ice storage. C, control; T1, 30 min of HIU; T2, 60 min of HIU; T3, 90 min of HIU.

4.2 Shear force

Texture is one of the most important quality parameters in seafood, often used as an indicator of freshness and structural integrity. In this study, the shear force values of *L. stylirostris* muscle remained relatively stable throughout the 20-day ice storage period, with a slight increasing trend, although the differences were not statistically significant. The lack of significant softening during ice storage contrasts with several previous studies that report texture degradation as a consequence of proteolytic activity and muscle fiber weakening (Fu *et al.* 2014; Canizales-Rodríguez *et al.* 2015). However, the observed stability in shear force in this study may be influenced by specific intrinsic factors such as shrimp size, muscle composition, or lower enzymatic activity. The specimens used here (average length ~8 cm) were notably smaller than those used in other studies (>20 cm), which may affect the extent and rate of proteolysis. Additionally, the absence of significant differences between control and HIU-treated samples indicates that high-intensity ultrasound, under the tested conditions, did not negatively impact muscle structure. While HIU has been reported to disrupt tissue integrity due to cavitation effects, such outcomes are strongly dependent on frequency, amplitude, and treatment duration (Lee *et al.* 2023). In our study, the

mild HIU parameters applied may have preserved the muscle matrix without inducing structural damage. Overall, the maintenance of shear force throughout storage suggests that the product retained acceptable textural characteristics, and that HIU treatment does not compromise this attribute, which is essential for consumer acceptability.

4.3 Water holding capacity (WHC)

WHC is a crucial quality attribute in seafood products, closely related to texture, juiciness, and overall acceptability. In our study, WHC values of *L. stylirostris* muscle showed no statistically significant differences ($p \geq 0.05$) among the control and HIU-treated groups throughout the 20-day ice storage period. This stability in WHC suggests that the muscle matrix maintained its structural integrity during storage, despite the potential for protein denaturation or degradation under the storage conditions. These findings differ from previous reports where a significant decline in WHC was associated with the disruption of myofibrillar proteins and the weakening of muscle fibers over time (Fu *et al.* 2014; Canizales-Rodríguez *et al.* 2015). Moreover, the use of HIU under the conditions tested (amplitude, frequency, and duration) did not lead to any noticeable improvement or deterioration in WHC, indicating that the treatment was not intense enough to cause structural modifications in the muscle protein network. Previous studies have shown that HIU can increase WHC by modifying protein conformation and improving water entrapment (Mehta *et al.* 2023), but these effects are highly dependent on the specific ultrasound parameters and the characteristics of the treated tissue. Therefore, the absence of significant changes in WHC across treatments suggests that neither ice storage nor HIU treatment, under the present experimental conditions, compromised the product's water-retaining ability, an important feature for consumer perception and yield during processing.

4.4 Total volatile basic nitrogen (TVB-N)

TVB-N is a widely accepted indicator of protein degradation and microbial spoilage in seafood products. It reflects the accumulation of volatile nitrogenous compounds such as ammonia, trimethylamine, and dimethylamine, which result from microbial and enzymatic activity during storage and their value should not exceed 30 mg of N/100 g of muscle (Woyewoda *et al.* 1986). As can be seen, shrimp has a high TVB-N content since day 0, this has already been reported by other authors for different species of shrimp from the Sea of Cortez (Fu *et al.* 2014; Canizales-Rodríguez *et al.* 2015; García-Sifuentes *et al.* 2018). Similarly, high TVB-N values have also been reported for other marine products caught in northwestern Mexico, such as sierra fish (Castillo-Yañez *et al.* 2007), jumbo squid (Marquez-Rios *et al.* 2007), cazon fish (*Mustelus lunulatus*) (Ocaño-Higuera *et al.* 2009), among others. Thus, the high initial content may be linked to environmental factors and the organisms' endogenous biochemical processes. On the other hand, TVB-N content remained unchanged during the first 15 days (below the maximum allowed limit) and then increased significantly on day 20 (above the allowed limit). This is the normal behavior of this indicator; it usually increases to higher levels than those allowed when the bacterial load has exceeded the permissible limits. Regarding the effect of HIU, the TVB-N values were below compared to control treatment; however, this behavior was not significant. According to health regulations, the control treatment would not be suitable for consumption; however, this determination should be taken with caution, since it has been documented that many marine products exceed the permitted limit in freshly caught specimens. Therefore, maximum limits must be established for each species, where microbial load determination and sensory analysis play an important role.

4.5 Non-Protein Nitrogen (NPN)

NPN compounds, such as free amino acids and small peptides, typically result from endogenous proteolytic activity during storage and are often considered indicators of protein degradation (Woyewoda *et al.* 1986). In this study, a significant decrease in NPN content was observed over the storage period across all treatments, with initial and final values of 0.78 and 0.48 mg $100g^{-1}$, respectively. However, no significant differences were found between the control and ultrasound-treated samples. This indicates that, under the used conditions in this experiment, there was no effect on endogenous or exogenous biochemistry. The decline in NPN content over time contrasts with the usual trend reported in fish and meat products, where NPN tends to increase due to proteolysis. However, reduction of NPN during storage has already been reported in other investigations, Mehta *et al.* (2023) reported initial and final values of 0.29 and 0.18, respectively, after 14 days of ice storage of white shrimp (*L. vannamei*). The reduction in NPN content suggests that amino acids could be one of the main components of NPN in shrimp muscle, and these compounds may be used by bacterial development during storage. It is important to note that both endogenous and microbial enzymes can generate ammonia by deaminating free amino acids; however, not at a detected level by smell. On the other hand, amino acid deamination could partially explain the slight increases observed in pH and TVB-N. The lack of differences between treatments indicates that HIU, as applied in this study, did not significantly alter the rate of proteolytic activity or the retention of soluble nitrogen compounds. This outcome may be due to the moderate ultrasound parameters used, which were not sufficient to disrupt muscle structure or enzyme function to a degree

that would affect NPN generation or retention.

4.6 Sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE)

The SDS-PAGE analysis was conducted to assess potential structural changes in muscle proteins as a result of ultrasound treatment during refrigerated storage. The electrophoretic profiles revealed consistent band patterns across all samples, with major bands corresponding to myofibrillar proteins such as myosin heavy chain (MHC), actin, tropomyosin, and troponin (Peng *et al.* 2019). No significant differences were observed between the control and ultrasound-treated samples throughout the storage period. These findings suggest that the ultrasound treatments employed in this study did not cause significant protein degradation or aggregation detectable by SDS-PAGE. This aligns with previous reports indicating that moderate ultrasound treatments may not produce measurable changes in the electrophoretic profile of muscle proteins unless higher intensities or prolonged exposure are applied (Zou *et al.* 2025). These results are consistent with the observed trends in texture, WHC, NPN and TVB-N, which also did not indicate extensive protein breakdown. Overall, the stability of the electrophoretic pattern across treatments supports the conclusion that HIU, at the intensities used, does not adversely affect the structural integrity of major muscle proteins in this product.

4.7 Color

Color is one of the key parameters influencing the quality and consumer acceptance of fishery products. It is known that during ice storage the meat color can change significantly, which could be a factor in the acceptance or rejection by the consumer. In this study, the a* values increased significantly over storage time, shifting from negative to positive, which suggests oxidative changes in pigments or heme-containing proteins. However, no significant differences were observed between the control and ultrasound-treated samples, indicating that the ultrasound treatments did not alter the trajectory of this color shift. Similarly, b* values increased significantly across all treatments, which indicates a progressive yellowing of the samples during storage. These results show that shrimp muscle took on a slightly brown coloration, which can be attributed to the action of polyphenol oxidadase enzyme. Yet again, ultrasound treatments had no significant effect on this trend, suggesting that under the conditions applied, ultrasound neither accelerated nor mitigated this discoloration pathway. Regarding the parameter L*, an initial value of 52.96 was observed; while values at the end of ice storage were 62.96, 57.69, 57.94 and 57.78 for C, T1, T2, and T3, respectively. These values were higher than those reported by Canizales-Rodríguez *et al.* (2015), who studied the color changes of blue shrimp (*L. stylirostris*) during ice storage, reporting initial and final values of 51.83 and 45.62 (15 days storage), respectively. It was possible to observe that the color of shrimp muscle changed during ice storage and the HIU application. Interestingly, the control exhibited the highest increase in L*, while ultrasound-treated samples showed comparatively lower lightness values. This suggests that ultrasound may have had a protective effect on muscle structure, possibly by reducing surface dehydration or limiting protein aggregation, thereby maintaining a more uniform appearance. Taken together, these findings indicate that storage time is the main factor influencing the color of blue shrimp muscle. These results are consistent with previous studies reporting that ultrasound can modify the microstructure of muscle foods, thereby influencing their optical properties (Jing-yu *et al.* 2017).

4.8 Total bacterial count (TBC)

TBC is commonly used to assess the number of viable microorganisms present in food, its determination is very important to define the shelf life during storage. In this research the initial mesophilic bacterial load was relatively low (2.02 log CFU g^{-1}), indicating appropriate hygienic handling at the beginning of storage. However, as expected during ice storage, microbial growth increased significantly over time. As expected, the microbial load remains almost constant during the first 10 days, to subsequently increase significantly on days 15 and 20. Mendes *et al.* (2002) reported a similar behavior. They found an initial value of 3.7 log CFU g^{-1} and a final microbial load of 6.3 log CFU g^{-1} for pink shrimp (*Parapenaeus longirostris*). Likewise, Canizales-Rodríguez *et al.* (2015) reported an initial value of 3.47 CFU g^{-1}, as well as 6.3 log CFU g^{-1} at the end of ice storage (18 days) of blue shrimp (*Litopenaeus stylirotris*). According to the Official Mexican Standard NOM-027-SSA1-1993, the maximum value allowed for mesophiles is 7 log CFU g^{-1}. In our study, this limit was not reached, so the microbiological quality remained under the Mexican sanitary standards during 20 days of ice storage. However, Montoya-Camacho *et al.* (2021) recommends as a safety measure for consumers a value below 6 log CFU g^{-1}. Therefore, the control was not an edible product, while shrimps subjected to HIU were below 6 log CFU g^{-1} and can be considered as an edible food. On the other hand, the increases observed in all treatments explain the increase in TVB-N and pH during storage. The lower microbial load in the samples subjected to HIU demonstrates its efficiency in retarding microbial development. Our results align with the findings of Haughton *et al.* (2012) and Ganjdoost *et al.* (2021), who observed a significant reduction in mesophilic colonies following the application of HIU to mushroom and chicken meat samples. This reduction in CFU g^{-1} is attributed to the generation of intracellular cavitation, where mechanical shocks disrupt the structural and functional

components of cells, leading to cell lysis (Chemat and Ashokkumar 2017). These findings support the potential application of HIU as a non-thermal preservation technology to slow down microbial proliferation and enhance the safety and quality of fish during ice storage.

CONCLUSIONS

The effect of the application of high intensity ultrasound on blue shrimp (*L. stylirostris*) tails was studied, which showed a positive effect on color and microbial development. This indicates that HIU can be used to enhance the shelf life of blue shrimp, as well as to decrease melanosis caused by the polyphenol oxidase enzyme. On the other hand, no significant changes were found in the rest of the parameters evaluated, which indicates that HIU can be used in this species without causing adverse damage to the quality of its muscle.

CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHORS' CONTRIBUTION

Conceptualization: R. Partida-Rivera and S. Ruíz-Cruz. Methodology: R. Partida Rivera, N. Montoya-Camacho and V. M. Ocaño-Higuera. Investigation: W. Torres-Arreola and R. Partida-Rivera. Writing—original draft preparation: J. C. Rodríguez-Figueroa and G. M. Suárez-Jiménez. Writing—review and editing: E. Márquez-Rios. Project administration: E. Márquez-Rios.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on a reasonable request from the corresponding author.

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