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Original Research

Seawater's contribution to hair damage: the interactions with bleaching and dyeing processes

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Abstract

Introduction: Hair is frequently subjected to physical and chemical treatments, such as bleaching and dyeing, which can cause significant structural damage. Environmental factors, like seawater, may further affect hair quality, but their combined impact with chemical treatments remains underexplored. This study investigates the effects of artificial seawater exposure on hair that has undergone bleaching and dyeing, focusing on parameters such as combing resistance, shine, color, and protein loss.

Methodology: We hypothesized that seawater would exacerbate damage caused by chemical treatments. To evaluate this hypothesis, hair tresses were subjected to bleaching and blonde dyeing processes, followed by immersion in artificial seawater. Various analyses, including combability tests, colorimetric analysis, shine assessment, and protein loss quantification, were conducted.

Results and Conclusion: The results demonstrated that both bleaching and dyeing treatments significantly damaged the hair, as indicated by increased combing resistance, color changes, reduced shine, and protein loss. Immersion in seawater increased combing resistance in chemically treated hair but did not lead to additional protein loss. The most substantial damage was observed in the lightest dyed hair, particularly in terms of shine reduction and protein loss, highlighting the oxidative effects of these treatments. This study underscores the importance of protecting hair from both chemical treatments and environmental stressors like seawater. To minimize damage, it is recommended to rinse hair with fresh water after seawater exposure and use conditioning products, such as leave-in treatments or masks, to restore hair health and shine.

Keywords: Hair; Damage; Environmental stressors; Conditioning; Seawater.

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1. Introduction

Hair fibers are complex structures primarily composed of the cuticle and cortex, both of which consist of keratin, a resilient protein. The cortex, which is rich in sulfur-containing amino acids, provides mechanical strength and elasticity, while melanin granules embedded within this region are responsible for hair color and photoprotection. The cuticle, a layer of overlapping cells, acts as a protective barrier against external damage. Together, these structural components ensure the integrity and appearance of healthy hair, making it an important aspect of human identity and self-esteem [1].

Despite its robust structure, hair is vulnerable to a range of factors that can alter its healthy properties. Chemical treatments such as bleaching and dyeing are among the most common practices that weaken the hair fiber. Bleaching (discoloration) involves the degradation of melanin in the cortex by hydrogen peroxide, leading to color loss, while dyeing introduces synthetic pigments that alter hair color. Both processes can disrupt the structural integrity of the fiber, leaving it more prone to damage, brittleness, and breakage [2,3].

Additionally, factors such as UV radiation [4], pollution, hair straightening procedures [5,6] and exposure to harsh environments can exacerbate this damage.

However, the specific effects of exposure to seawater on hair that has undergone bleaching (discoloration) and dyeing are not yet fully understood. Natural seawater, with its complex ionic composition, has been known to influence hair properties, but limited studies have explored the impact of artificial seawater, particularly on chemically treated hair.

The objective of this study is to evaluate the potential changes in hair fiber characteristics caused by exposure to artificial seawater, focusing on hair that has undergone bleaching (discoloration) and dyeing. By analyzing the physical and structural changes, this study aims to provide insights into how artificial seawater may affect the integrity and appearance of chemically treated hair.

2. Methodology

2.1 Preparation of the hair locks

Fifteen straight, dark brown, virgin human hair tresses, each 15 cm in length and weighing 3.0 g, were initially washed according to a standardized procedure. The hair was rinsed with warm water for 30 seconds. Following this, a 10% w/w sodium lauryl ether sulfate solution was applied at a 1:1 ratio (mass of hair to mass of solution), and a one-minute massage was performed to ensure thorough cleaning [7]. Afterward, the hair was rinsed with warm water and allowed to air-dry at room temperature (23.0°C). The tresses were then divided into five groups, as detailed in Table 1.

Table 1. Treatment samples of hair tresses and their corresponding nomenclature used in the experiments.

Hair sample	Group nomenclature
Virgin	*Control*
Bleached	*Bleached*
Bleached/ Permanent dyed with color 8.0	*T1*
Bleached/ Permanent dyed with dye 10.0	*T2*
Bleached/ Permanent dyed with dye 12.0	*T3*

Legend: Bleached= discolored hair without permanent dye

2.2 Bleaching (discoloration) and permanent coloration process

The bleaching (discoloration) process was performed by applying a mixture of 20.0 g of bleaching powder and 30.0 g of hydrogen peroxide (30 vol.) to the hair tress for 40 minutes. Afterward, the tresses were washed according to the previously described procedure.

Next, nine bleached (discolored hair without permanent dye) tresses were divided into three groups (Table 1) and treated with commercial hair dyes at blonde levels 8.0, 10.0, and 12.0, resulting in Medium Blonde (level 8.0, T1), Blonde (level 10.0, T2), and Ultra-Blonde (level 12.0, T3). The qualitative composition of the commercial permanent dye included: *water; cetearyl alcohol; propylene glycol; deceth-3; laureth-12; ammonium hydroxide; oleth-30; hexadimethrine chloride; lauric acid; glycol distearate; polyquaternium-22; ethanolamine; silica dimethyl silylate; CI 77891/ titanium dioxide, m-aminophenol, ascorbic acid, sodium metabisulfite; hydroxybenzomorpholine; dimethicone; proline, p-phenylenediamine; carbomer, threonine; resorcinol; EDTA; parfum.*

2.3 Preparation of artificial sea water

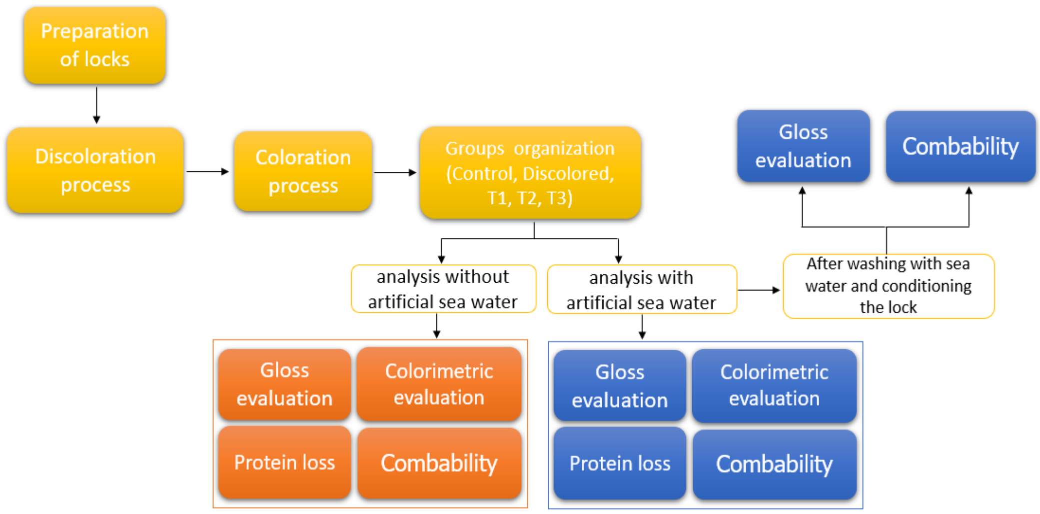
The artificial seawater was prepared using a mixture of pre-made salts (Blue Treasure Reef Sea Salt®), containing 9560 mg/L Na^+, 1350 mg/L Mg^{2+}, 380 mg/L K^+, 400 mg/L Ca^{2+}, 10.5 mg/L Sr^{2+}, 0.12 mg/L Rb^{2+}, 0.2 mg/L Fe, 0.15 mg/L Li^+, 17,600 mg/L Cl^-, 2430 mg/L SO_4^{2-}, 20 mg/L Br^-, and a pH of 8.15, dissolved in distilled water and prepared in a 2.5 L aquarium.

2.4 Exposure of hair tresses to seawater

The control group, along with the bleached (discolored hair without permanent dye) and dyed hair groups (T1, T2, and T3), were immersed in artificial seawater for 3 hours per day over four consecutive days in an aquarium. After each immersion, the tresses were rinsed with warm water and allowed to air-dry at room temperature (23.0°C). This procedure was established for the current study, as there is no standardized method in the scientific literature for exposing hair to seawater.

After four days of exposure to artificial seawater, the five groups were rinsed with warm water and washed with a 10.0% w/w sodium lauryl ether sulfate solution. Once the artificial seawater was removed, a conditioner was applied, and the tresses were air-dried at room temperature (23.0°C) in preparation for repeated combing and shine tests. The sequence of analyses is illustrated in Figure 1. The hair conditioner consisted of a 10%w/v Cetyltrimethylammonium chloride solution in water.

Figure 1. Sequence of the experimental procedure.



2.5 Combability evaluation

Dry combability was assessed using a Diastron® MTT 175. Initially, each tress was gently combed three times with a plastic comb to avoid damaging the equipment and to remove any tangles. Three measurements were taken for each tress, and the average total work (in Joules) was recorded. The tresses were evaluated both before and after immersion in seawater, as well as following the application of the conditioner formulation [8].

2.6 Colorimetric Analysis

The color of the hair fibers was evaluated using a Chroma Meter CR-400 (Minolta®), which provided color parameters based on three vectors: ΔL* (luminosity difference, with positive values indicating lighter shades and negative values indicating darker ones), Δa* (color tone on the red-green axis, where positive values indicate more red and negative values indicate more green), and Δb* (color difference on the yellow-blue axis, with positive values indicating more yellow and negative values indicating more blue). All parameters were summarized in the total color difference, ΔE* [5].

2.7 Shine (Luster)

The shine was evaluated by the Luster and were conducted using the SAMBA Hair® (Bossa Nova Technologie). Three hair tresses from each group were placed on a cylindrical support, with two measurements taken per tress. The evaluation was performed using two parallel images (specular and diffuse), and the luster parameter was calculated using the SAMBA Hair® 2.0 software.

2.8 Protein Loss

Exactly 100 mg of hair was placed in tubes with 15.0 mL of distilled water (in triplicate) and subjected to an ultrasonic bath at 42°C for 60 minutes to extract soluble proteins from the hair fibers. An aliquot of 0.4 mL of the supernatant was transferred to tubes containing 4.0 mL of working solution (WS), which was incubated in a water bath at 50°C for 30 minutes. After cooling to 23.0 ± 2.0°C, the absorbance of the samples was measured at 562 nm [9]. Protein loss was expressed in albumin equivalents, based on an analytical curve constructed with a standard albumin reference.

The WS was prepared by mixing reagent A and reagent B in a 100:2 ratio. Reagent A = 1% w/v deionized aqueous solution of the sodium salt bicinchoninic (BCA.Na_2) + 2% w/v of sodium carbonate hydrate ($Na_2CO_3.H_2O$) + 0.16% of sodium tartrate (Na_2 tartrate) + 0.4% of sodium hydroxide (NaOH) + 0.95% w/v of sodium bicarbonate ($NaHCO_3$) at pH 11.25. Reagent B = 4% of copper sulfate ($CuSO_4.5H_2O$) in deionized water.

2.9 Statistical analysis

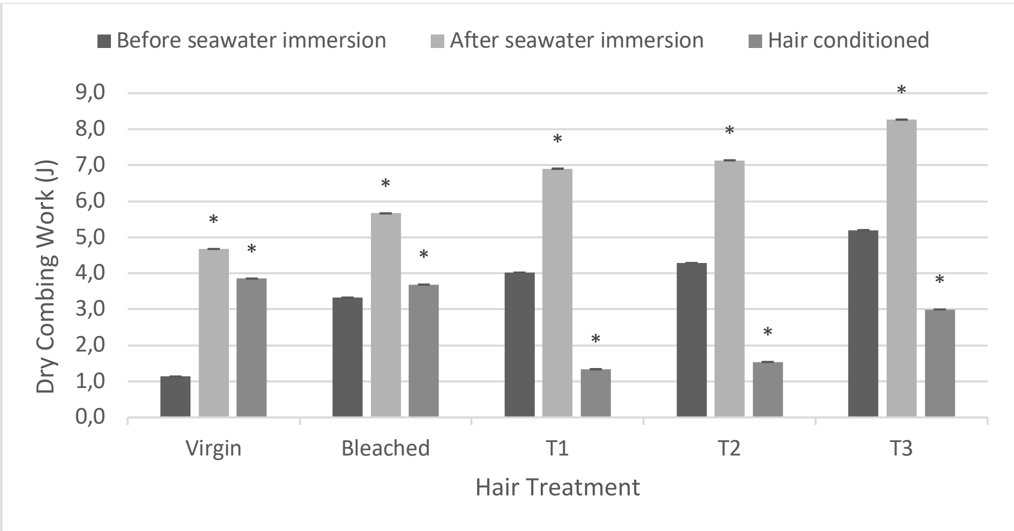
Data were statistically analyzed using analysis of variance (ANOVA), followed by Tukey's post-hoc test. A p-value of ≤ 0.05 was considered statistically significant.

3. Results and discussion

3.1 Combability test

Both the bleaching and dyeing processes led to an increase statistically significative ($p \leq 0.05$; ANOVA/Tukey test) in total combing work compared to virgin hair, confirming considerable damage to the hair fibers (Figure 2). Additionally, the lighter the dye color, the greater the extent of damage. This resulted in increased combing resistance, due to cuticle misalignment and increased roughness.

Figure 2. Total work combability of hair tresses.



Legend: Virgin (hair without chemical treatment); Bleached (discolored hair without permanent dye); T1 (blonde 8.0); T2 (blonde 10.0) and T3 (ultra-blonde 12.0). *$p< 0.05$ (n=3)

Immersion in artificial seawater significantly increased the combability resistance of all hair tresses, both virgin and chemically treated. Virgin hair exhibited a 312% increase in resistance compared to its pre-immersion control, while chemically treated tresses showed increases ranging from 60 to 70% relative to their respective controls. Seawater, with a salinity of approximately 3.5%10, introduces non-evaporative salts that tend to deposit on the hair surface, even after drying in the sun. These hygroscopic salts attract and retain moisture, drawing water away from the hair fibers, which diminishes shine and negatively affects the hair's sensory qualities. This effect is illustrated in Figure 3, which compares the appearance of blonde dyed hair (T3) before and after immersion in artificial seawater.

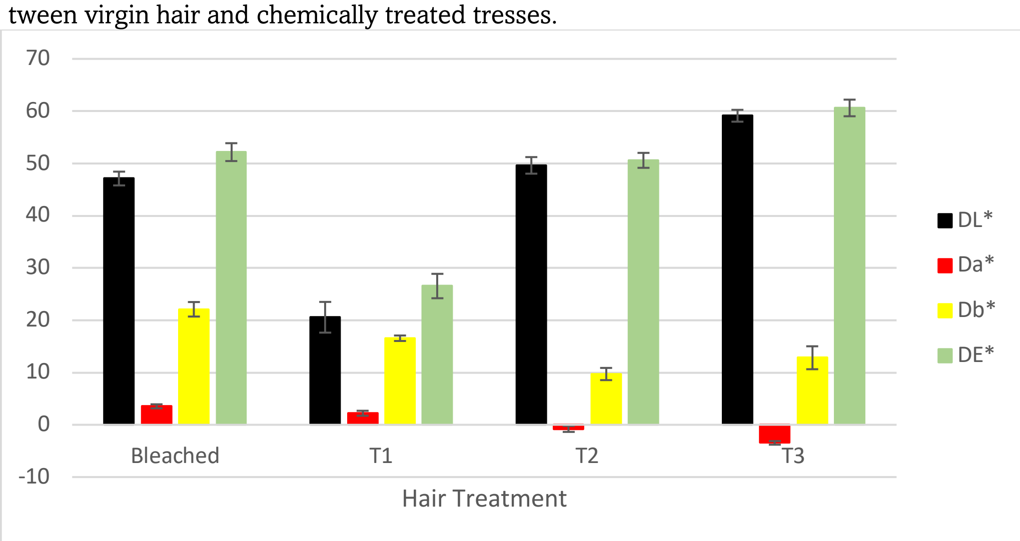
Hair conditioners function by reducing the coefficient of friction and neutralizing the negative charges on the hair fiber surface [11]. Following immersion in seawater, a noticeable reduction in the force required to comb the hair was observed in all tresses, indicating the conditioner's effectiveness in improving combability, even after seawater exposure.

Figure 3. Appearance of bleached hair tress (T3): (A) after immersion in artificial seawater; (B) before immersion in artificial seawater.

3.2 Colorimetric Analysis

The colorimetric analysis revealed a significant change in the melanin content of the hair fiber after the bleaching process, as expected, primarily observed by the increase in the luminosity parameter (L*) (Figure 4). Hydrogen peroxide, commonly used in bleaching treatments, works by oxidizing the melanin in the hair. This process breaks down and dissolves the melanin, leading to the removal of color. The degree of lightening achieved depends on factors such as the concentration of hydrogen peroxide, the duration of its application, and the natural color of the hair 12. However, traces of melanin remained, resulting in an orange undertone in the hair 13. Following the application of hair dye in shades 8.0, 10.0, and 12.0, an increase in the L* parameter was observed, indicating further lightening of the strands. These alterations led to a noticeable increase in overall color variation (ΔE*).

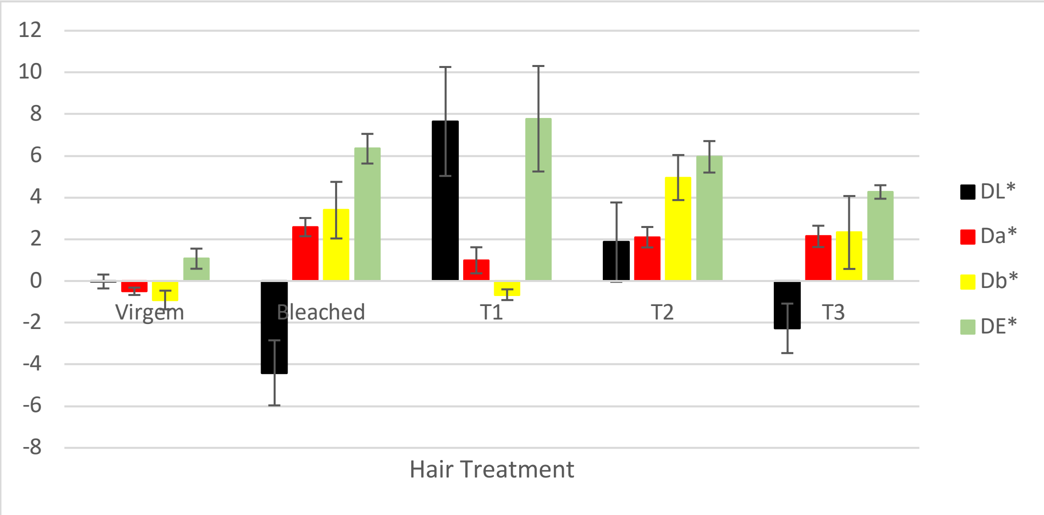
Figure 4. Variation in hair color after the bleaching and dyeing processes – comparison between virgin hair and chemically treated tresses.



Legend: Bleached (discolored hair without permanent dye); T1 (blonde 8.0); T2 (blonde 10.0) and T3 (ultra-blonde 12.0).

After immersion in artificial seawater, the virgin hair showed the smallest color variation (DE* = 1.07 ± 0.48), while T1 exhibited the highest variation compared to its color before exposure to seawater, showing that the lightest the hair, lower is the perception of color change (Figure 5).

Figure 5. Variation in hair color after immersion in seawater.



Legend: Bleached (discolored hair without permanent dye); T1 (blonde 8.0); T2 (blonde 10.0) and T3 (ultra-blonde 12.0)

3.3 Shine Assessment

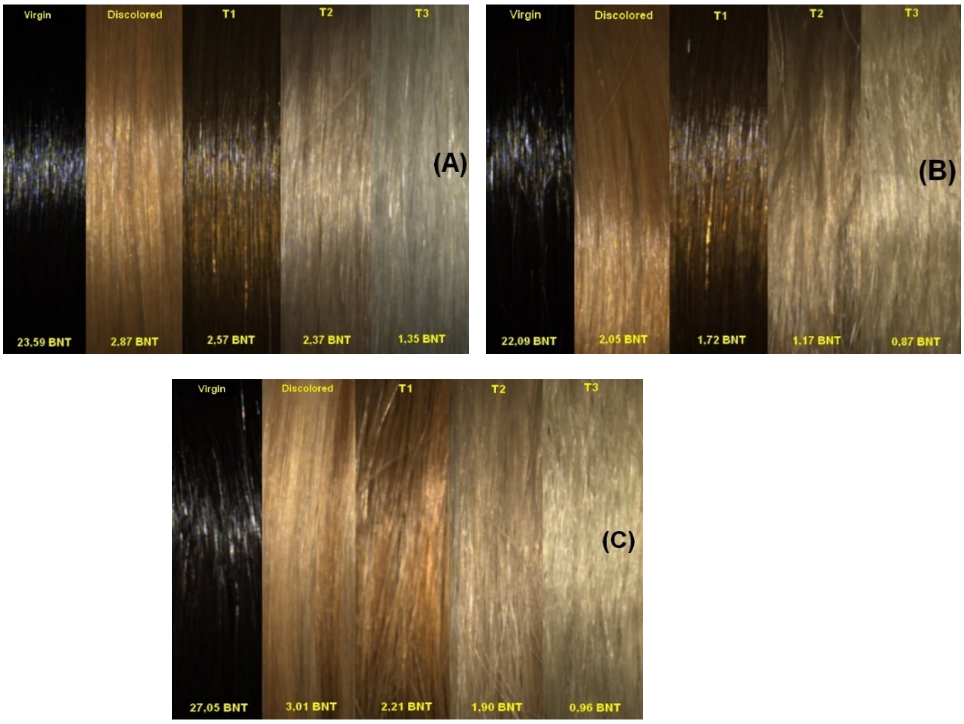
Figure 6 presents the luster analysis results obtained using SAMBA® on chemically treated hair tresses. Virgin hair, which had not undergone any chemical treatment and exhibited the darkest color prior to seawater immersion, displayed the highest luster value of 23.59 BNT. This value was significantly higher than those recorded for the bleached (2.87 BNT) and dyed groups, including T1 (2.57 BNT), T2 (2.37 BNT), and T3, the latter showing the lowest luster value at 1.35 BNT.

According to Gao et al. [14], who evaluated the gloss (luster) values of different hair colors -including white, blonde, bleached, brown, black, and red—darker hair exhibited the highest gloss (luster) values, whereas white hair showed the lowest. This finding helps explain why T3 recorded the lowest luster value in our study, as it not only had the least melanin content but also experienced the most substantial damage from the bleaching (discoloration) process.

Virgin and bleached hair exhibited post-immersion shine values that were close to their respective pre-seawater results. In contrast, the bleaching (discoloring) followed by dyeing process caused the most significant reduction in shine. As shown in Figure 6B, the values recorded after seawater immersion revealed a noticeable decrease in shine levels for tresses subjected to the dyeing process (T1, T2, and T3). Among these, T3 experienced the most substantial decline, with a shine (luster) value of 0.87 BNT - 55.10% reduction compared to its pre-immersion value of 1.35 BNT (Figure 6A).

The application of hair conditioner led to an increase in shine (luster) across all hair tresses evaluated, as expected. Notably, the effect was more pronounced in the bleached (discolored) and T2 hair treatments (Figure 6C).

Figure 6. Images of hair fibers and their corresponding Luster Values (BNT).



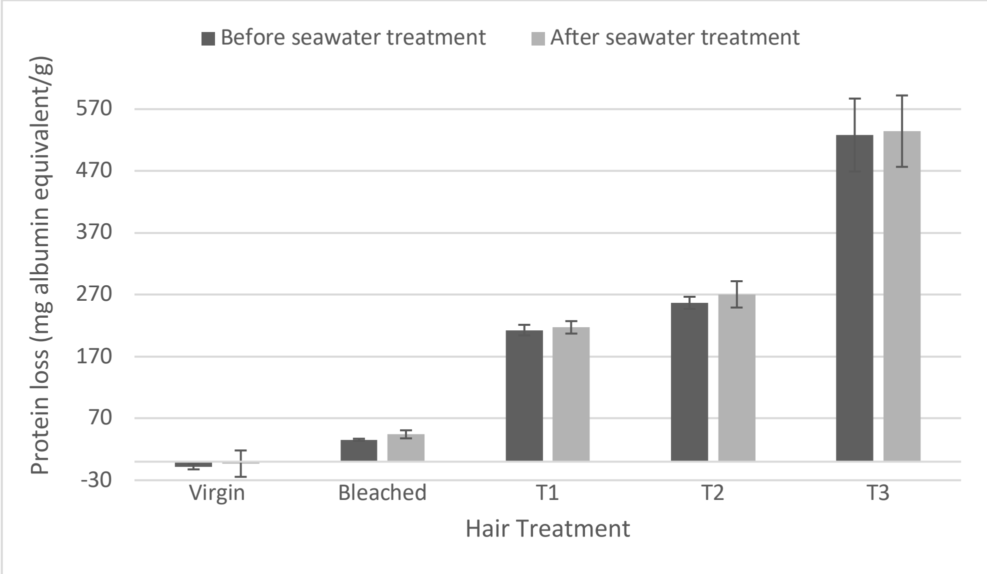
Legend: (A) Hair fibers before seawater immersion; (B) Hair fibers after seawater immersion; (C) Hair tresses after seawater immersion, followed by washing and conditioning procedures. Virgin (hair without chemical treatment); Bleached (discolored hair without permanent dye); T1 (blonde 8.0); T2 (blonde 10.0) and T3 (ultra-blonde 12.0).

3.4 Protein loss

Hair fibers exposed to physical or chemical treatments can experience damage to their structure, leading to changes in protein composition. Immersion in seawater did not result in protein loss, as shown in Figure 7. However, the combination of bleaching (discoloring) and dyeing led to significant protein loss. The lighter the dye, the greater the oxidative impact and protein loss. Consequently, the results suggest that T3 experienced the highest protein loss among the chemical treatments, indicating that the primary damage to the hair fiber was due to the combined effects of the bleaching (discoloration) and dyeing process, rather than exposure to artificial seawater.

Relating this to the other tests previously discussed, it is evident that the combination of bleaching (discoloration) and dyeing caused the most significant damage to the hair tresses used in this study, with exception of combing. This was the only test where artificial seawater induced dryness, which exacerbated the damage caused by the combined bleaching (discoloration) and dyeing process.

Figure 7. Protein loss of hair fibers before and after immersion in seawater.



Legend: Virgin (hair without chemical treatment); Bleached (discolored hair without permanent dye); T1 (blonde 8.0); T2 (blonde 10.0) and T3 (ultra-blonde 12.0). *$p < 0.05$ (n=3)

4. Conclusion

The study demonstrated that both bleaching (discoloring) and dyeing significantly damaged hair, as shown by increased combing resistance, color changes, reduced shine, and protein loss, highlighting the oxidative effects of these treatments. Immersion in artificial seawater increased combing resistance in chemically treated hair but did not cause protein loss, affecting the cuticular layer, indicating that the primary damage was due to the chemical treatments rather than seawater exposure. The findings emphasize the need to protect hair from both chemical treatments and environmental stressors like seawater. To counteract seawater's drying effects, it is recommended to rinse hair with fresh water and use conditioning products like leave-in treatments, masks, or leave-on conditioners to restore shine and health.

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Conflicts of Interest: The authors declare no conflicts of interest.

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